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THE FEASIBILITY OF SAND-ABSTRACTION AS A VIABLE METHOD OF GROUNDWATER ABSTRACTION

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THE FEASIBILITY OF SAND-ABSTRACTION AS A VIABLE METHOD OF GROUNDWATER ABSTRACTION

ABSTRACT

Many rural communities in arid areas of the world make extensive use of perennial water supplies retained within the sediment of a river channel. This naturally filtered water provides for their basic subsistence. A general term applied to the abstraction of water from river sediment is sand-abstraction.

Ephemeral and seasonal rivers primarily drain the dryland regions of the world. These arid regions are typically subject to extensive environmental degradation with a consequent high degree of surface erosion. As a result, many of the rivers have become sand rivers, filled with copious amounts of sediment. Most arid areas are subject to occasional rainstorms and flash floods that immediately drain to waterways and saturate the sediment within the river channel. In larger rivers a perennial supply of water is maintained within the sediment.

Despite a perceived potential for this water resource there has been little development of any small-scale technology that is suitable for use at a basic rural level. A research and study programme was instigated to assess fully, the potential of such a resource. Field research was undertaken to characterise typical sand rivers and to assess the water storage and water loss and retention factors within river sediment. A check list for identifying possible sand-abstraction sites was devised. In the process of this study the advantages of storing water in sand was fully appreciated and attention given to the development of initially less suitable sites in serious water deficit areas. Systems for efficient abstraction of water were reviewed and designs formulated for the fabrication of equipment to mechanically draw water from river sediment. A series of well-screens, well-points, infiltration galleries and caissons have been designed and initial tests have been conducted under field conditions. Simple technology handpumps that it was considered could be operated, maintained and repaired by rural communities using locally available materials have been developed in conjunction with the abstraction equipment.

In consultation with rural people an analysis was made of the technical and sociological requirements that are considered essential for the sustainability of technology suitable for use by disadvantaged rural communities. Both practical and literature research has indicated the latent possibility of this technology. Interaction has been maintained with four communities throughout the research and development period and contributions and indications received are that there is a need to develop such a water source with an upgraded technology.

The conclusion from the work undertaken is that development of the technology is worthwhile and that greater efforts should be made to promote it at a small-scale, rural level. In addition the potential to provide clean water in arid regions from such a lowtechnology application should be drawn to the attention of professional water engineers.

Keywords:

sand-abstraction, sand rivers, ephemeral rivers, well-points, handpumps, arid areas, community development

Abstract

Abstract

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Chapter 1

Overview of Study and Research

1. The Shortage of Water

1.1. A Traditional Belief

The amaNdebele people who inhabit the semi-arid area of western Zimbabwe have a symbolic belief of the origin of life. According to folklore, in the very beginning the World was dry, flat and featureless – devoid of life. God was not at all impressed, he decided to send his Son to Earth. He gave him a bow and arrow and told him that if he wanted to call God he should stamp on the ground.

At first the Son did not know what to do in this arid, barren World. He then remembered Gods instruction, to stamp on the earth. He looked around for something to stamp on and finally after much searching found a small stone – a tiny pebble. He stamped on this and immediately mighty rocks sprang up out of the ground, thus the Matopo Hills were formed. The skies darkened and a huge cloud formed overhead. The Son was frightened and took his bow and shot an arrow into the cloud. Immediately lightning flashed and torrential rain poured down and cascaded off the rocks. The Son saw that God and the water were one.

The Son then took a needle and sewed the rocks together; the thread formed the rivers that flowed between the rocks. Life started in the valleys and people came. Thus the Son saw that God was the water and the water was the people and that the people were the water and were God. (Anon).

Through this traditional belief amaNdebele people conceptualise the links between God, water and people and the interdependence of each. The dependence on water and religion, the communication with ancestral spirits, with a divine creator and with the all pervading need for water in an arid and harsh environment are omnipresent. The amaNdebele are not alone in such a belief, Redmond (2002) states that animistic religions, which are the traditional beliefs of many people of Africa accord water a supernatural life force.

1.2. Background and Outline

1.2.1. Water Sources

The absolute importance and vital need for water in a harsh environment is paramount, but in such areas, water is generally not readily available. In semi-arid and arid areas rainfall is seasonal and typically occurs as heavy storms over only a few months, consequently river flow occurs infrequently and thus river channels remain surface dry for much of the year. Surface water utilisation from perennial rivers is therefore not an option but is restricted to water harvesting in dams. Arid areas are also characteristically associated with regions of limited geological weathering where conditions are not conducive to groundwater development. Thus shallow well digging, which often constitutes a relatively easy and effective method of developing a groundwater resource, has a limited potential restricted to select areas.

Historically, for its continuity and well-being it was vital in water deficit areas for a community to find a reliable source of water. Traditionally water sources were river pools and wet-land areas, known in southern Africa as vleis and variously as marshes, dambos and soaks. These water sources were very often only seasonal supplies, which dried up as the dry season extended. However in these areas, within a river channel there was likely to be a degree of sedimentation from land surface erosion. As this alluvium increased so water saturated the sediment and was retained within the riverbed. As the water level dropped within the sediment, so people were able to excavate and follow the water down by way of an open sand-well or scoop-well excavation. Thus a reliable and perennial supply of water was maintained. The abstraction of water from river sediment in this manner has come to be known as sand-abstraction and in many seasonal river localities it is still a widely accepted and utilised technology on which many people are dependent.

Rainfall and water are a central requirement of rural people and greatly influence the activities in which they are involved. Chenje, Chivasa et al., (1996) state that African societies have a heritage of managing and living with their environment and of being effective custodians of water. Limited water supplies throughout Africa have been successfully communally managed and safeguarded for thousands of years. Traditionally the water utilised by communities was drawn from surface water supplies. From slow running water as it seeped from the vegetation and soil into the river channel after storms and from river pools and pans as rivers ceased regular flow during the dry season. As these sources dried so people were either forced to move to new sites or to excavate open, unshored wells in the riverbed. The practice of digging open wells known locally as 'isiliba' and sometimes referred to as scoop-wells are still in extensive use today

It is the contention of this study that in spite of considerable development in both well and borehole technology, there has been very little effective practical development of the sand-abstraction system to develop it as a sustainable water supply option. Study and research will be undertaken to investigate the suitability and effectiveness of sandabstraction and if shown to be appropriate, to design and fabricate a range of low-cost methods of water abstraction.

1.2.2. Water Scarcity

Recent reports indicate the prospect of increasing limitations on the availability of water for half the world's population in the coming decades, (BBC World Service News Bulletin 2002). In densely populated areas and areas of low-rainfall, poor water management principles, drought and over-abstraction frequently demonstrate that water is becoming an increasingly scarce commodity. Particularly in arid and semi-arid areas where there are extensive dry seasons and where rainfall is low and sporadic, severe limitations are to be expected in the provision of water. There is thus an urgent and pressing need to evaluate all possible sources of fresh water, to consider alternate and possibly under-utilised supplies. This study and research programme has in part been undertaken in a wish to improve the access of disadvantaged people to sustainable water supplies.

Pacey and Cullis (1986) state that the provision of reliable water supplies has been challenging society over the millennia and particularly notes the inadequacy of water in dry areas where supplies are frequently tenuous and either do not last through the dry-season or are replenished by rates of seepage so slow that abstraction rates are best calculated in litres per hour. The author has recorded rates of abstraction of 60 litres an hour and counted 53×20 litres buckets lined up for filling at that water point in Zimbabwe in the devastating drought year of 1992. The women waiting to fill their buckets also informed him that they would start to draw water as early as 02.00 hours.

Within Zimbabwe the mean distance to all sources of water has been measured by Boydell (1990) at 0.7 kms in the wet season and almost 1.0 km in the dry season. Boydell also states that the total average time spent per household to collect water in the dry season is estimated at 152 minutes. Similar, or even greater distances and times are born out by White and Simanowitz (1991) who spent several weeks analysing peoples water use and collection habits in the Tsholotsho District of Zimbabwe. In an area of adverse water supply the author has recorded water carriers walking round trip distances of 9.0 kms in the dry-season, the return trip with a weight of 20 kg carried on the head, (Hussey 1998(c)). Quite frequently people walk long distances to a pumped groundwater supply, yet may be walking within a few metres of a reliable but untapped seasonal water supply.

Figure 1.1 indicates the countries in Africa where it is projected that there will be water insufficient by 2025, (Population Action International 1993). Each country is primarily part of an arid or semi-arid region which does not have access to a river catchment system in a higher rainfall area.

Figure 1.1: Projected water deficit countries in Africa, 2025, (Population Action International 1993)



1.2.3. Viability and Sustainability of Water Supplies

Campbell and Lehr (1973) state that by tradition people settled around a secure source of water, if this source dried up or proved to be only seasonal the people would move on with their herds of cattle to more perennial supplies of water. In some areas of the world, where for reasons of climate or geology there were no permanent streams or rivers, the inhabitants of early settlements relied for their supplies on seasonal water supplies and water which occurred underground. Price (1996) states that this was often quite close to the surface and that in order to ensure a reliable water supply a household or community would typically dig a permanent well.

Hand well digging in alluvium has progressed over time to a hi-tech water drilling industry which is used extensively world-wide in many differing situations. Drilling technology and application has developed rapidly over the last few decades and now ensures the abstraction of water from deep groundwater aquifers in fine saturated sands through to abstraction of water from fissures in consolidated rock. With such a sophisticated and readily available drilling industry, groundwater abstraction has become an automatic solution to small-scale water supply requirements and as a consequence, there has been little development of any alternate solutions. The author believes that it is to the detriment of the water supply industry that similar advances have not taken place in the development of traditional water supply systems which are often deeply ingrained in a people's culture, (Hussey 2000).

Deep-water sources have been promoted all over Africa and in arid and semi-arid areas throughout the world. However, thousands of deep water supplies are presently unusable through either diminishing water-tables or over-abstraction which has caused many boreholes to dry up. Other supplies are inoperative through broken handpumps as reported by Stern (1989) and which may be in excess of 50% of the total according to reports received by Catholic Agency for Overseas Development (CAFOD), (Henson 2003). In many cases, although the equipment may conform to Village Level Operation and Maintenance (VLOM), communities have neither the technical resources nor the capacity to repair deep-water pumping equipment. Although drilling methods have provided a relatively easy way of accessing groundwater, in many instances there still remains the problem of drawing this water to the surface. Hofkes, Huisman et al. (1981) state that the selection of suitable technology remains important since other problems are compounded when techniques, methods and equipment are used that are not compatible with the conditions and situations of small communities.

In the past many governments of industrially developing countries maintained centralised systems for initial site selection, drilling, borehole pump installation and ongoing service and maintenance of pumps. The communities played no role in identifying water sources and did not have to take responsibility for maintaining pumps and thus had little identification with their water supply systems. However, as populations increased and the economies of these countries declined, so the infrastructure deteriorated and became totally inadequate to maintain water development and abstraction systems.

In an attempt to ensure the provision of water many governments introduced decentralised systems to make communities financially and technically responsible for the service and maintenance of their water supplies. Typically there was little time for full preparation of this transfer of responsibility and invariably communities either refused to accept responsibility or to pay for a previously free service. Although a decentralised infrastructure was set up with local 'pump-minders' to service and maintain pumping equipment, too often they did not have the equipment to undertake the necessary repairs. Further, because in many instances communities would not pay pump minders for maintenance work, they in turn refused to effect a service, (Gunby, Hussey et al., 1998). It is thus apparent that water sources must be acceptable to communities and be understood by end-users if they are to be sustainable. In addition training and equipment must be in place to ensure reliable and continuing water supplies, (Mthuthuki 1996).

During the period of centralised service-maintenance, development of traditional water supplies had also very largely been ignored. However, because of break-downs, drying boreholes and unpalatable brackish water, people frequently reverted to their traditional sand river abstraction systems, (Iliffe 1990), often walking past a borehole to draw water from a river. Disadvantaged rural communities continue to use sand-abstraction to good advantage whenever and wherever they have an opportunity but other than localised use, sand-abstraction appears in the main to be a little known and under utilised water supply option.

1.3. Overview of Study and Research

1.3.1. The Problem

Within disadvantaged societies it is widely acknowledged that an adequate supply of water is essential for the provision of acceptable standards health, wealth and general well-being. The need to conserve and develop supplies of water which have the potential to improve the health and well-being of disadvantaged communities is embodied in the preamble to Workshop 3; Water, Poverty Alleviation and Social Programs, of the 2002 Stockholm Conference, (Stockholm Water Symposium 2002). It states, "Poverty remains the biggest hurdle to reaching sustainable development. Its alleviation has become a prime objective of development organisations. The magnitude of poverty is staggering and so are the human sufferings. Low and irregular income is one noticeable characteristic of poverty. It is also highly correlated with high morbidity rates, premature deaths and various social ailments, like low levels of education. Together, these circumstances make it difficult for the poor to support themselves and also to take part in many activities in society. Hence, poverty is both a violation of human values as well as a lost opportunity for the development of society at large. To a great extent, the poor are also outside the realm and reach of formal security nets. The vicious circle of poverty and circumstances, which regenerate poverty, is therefore not only a concern for the poor themselves. Pervasive and mass poverty must be reduced in order to build a stable society where water and other forms of security can be enjoyed by it's members. If the absolute and relative number of poor people increases, it will be increasingly difficult to reverse the trend. Effective programmes for poverty alleviation are urgently needed and water plays obviously a key roll in this regard".

The general preamble to the 2002 Stockholm Conference also raises the issue of "Water as an Engine for Development", citing the United Nations Millennium Declaration which draws attention to the importance of water and water related activities in supporting development and eradicating poverty. The aim is to halve by 2015 the proportion of people without access to safe drinking water and who are suffering from hunger. The Declaration also emphasizes the need for a new ethic in all environmental actions associated with conservation and stewardship of water. There is a need to stop unsustainable exploitation of water resources by developing water management strategies at local, national and regional levels which will promote adequate supplies and equitable access.

The amaNdebele succinctly state, "Amanzi yeMpilo", "Water is Life". Mpilo embodies, health, life and well-being. A similar concept was expressed during an interchange of peasant farmers in Zimbabwe in 1988. When the farmers from a dryland region of Matabeleland visited an area of permanent rivers in Manicaland, their comment was, "How can they not develop"? Water is essential to all aspects of life and where it is difficult to obtain and in short supply, life is consequently arduous and demanding. Tortajada (2001) is more prolix in his definition of the problem. "Water is not only a basic human need but also is an essential component for the proper functioning of ecosystems. Human survival and environmental conservation depend on water. For physical, technological, economic, environmental and health reasons, the amount of water that is available for use at any time at any specific location is limited, particularly in arid ares. The main issue of water management in dryland areas is thus how to ensure that enough water of the right quality and quantity is available for various human and ecosystem uses, cost-effectively and reliably on a long-term basis".

The quantity and the quality of water and its effect on society is of considerable international concern. Abwao (2001) states, "Though water is the essence of all life on Earth, it is treated by many as though it were an expendable resource. More than 70 per cent of the world's population lack clean water; and an estimated 5,000 children die each day as a result of bad water". Abawo goes on to say, "Particularly disturbing is the fact that developing countries, which remain in the early phases of demographic transition (i.e. five or more children per woman), are concentrated in the zone where water is most scarce. Thus, life support is closely linked to the challenge of finding ways to successfully cope with water scarcity". In conclusion he states, "We need to adopt innovative approaches to water security for the 21st century". "Learning how to cope with creeping but predictable water-related problems such as population growth, urbanisation and industrialisation which are intensifying the pressures on the natural systems, is a key issue. It will be essential to identify and overcome institutional and other barriers to the replicability of innovative solutions from other regions".

With the continuing growth in world population and international urban growth there is an increasing global demand for water. To compound the problem of an overall increase in demand, water is not used wisely; coupled with industrial growth and improved family incomes and subsequent increases in the use of water, the sustainability of the global water supply situation is threatened. Not only is there an increase in urban water use but there is also an increase in demand for water for irrigation. As a result of increases in the demand for water, in some areas groundwater is over-abstracted with the source subsequently greatly reduced or drying up. As resources become more scarce, it is the poor and the vulnerable who are hit first and suffer the most. According to Rijsberman (2001) access to water for agriculture is being squeezed as the focus of water source development is transferred from the farming sector and diverted to urban areas, he also states that the demand for water in urban areas in developing countries will rise very strongly in the coming decades. Lovell (2000) states that a lack of water is preventing the development of household and community based activities for millions of people living in dryland areas of developing countries. Rural water supply programmes invariably concentrate on domestic water supply and sanitation and not on the provision of water that would be used for agro-economic enterprises and poverty alleviation.

Even in the 1920s, Jennings (1923), Jennings (1927) and Cole (1966) have each cited the scarcity of water over the greater part of southern Africa. Mara and Cairncross (1989) have noted the increasing scarcity of alternate waters for irrigation which has been exacerbated by an increasing urban demand for potable water supplies. Reporting on a harsh drought affecting up to 100 million people across India, Sarkar (2000) states that modern methods of water supply have failed but that the traditional methods of water harvesting are proving more successful and at a seminar in Harare in 1995, after a series of particularly severe droughts in southern Africa, Moyo and Katerere (1995) and Roos (1995) both state the extreme need to conserve water.

To compound the requirement for adequate water in southern Africa, drought is a recurring problem, Wilhite and Glantz (1987) define drought "as a deficiency of precipitation that results in water shortage for some activity (e.g. plant growth) or for some group (e.g. a farmer) and more definitively; Jacobson, Jacobson et al. (1995) states, "Drought is defined as a period of more than two years with rainfall lower than the long-term mean". Sanford (1979) states, "Drought can also be viewed as a rainfallinduced shortage to some economic good, such as grazing for livestock, that is brought about by inadequate or badly timed rainfall. On the African Water Page, Wilhite (2001) states, "From the perspective of their residents, southern African countries are subjected relatively frequently to problems posed by drought and long-term climatic variability". It is thus imperative that all possible sources of useable water are fully utilised and at the same time protected from over exploitation. Glantz (1994) refers to climatic variations from small to large which may occur seasonally or inter-annually and also on decadal and longer term time scales. He also notes that conditions which are statistically average seldom occur with precipitation in arid areas skewed to dryness. Typically a few seasons of rainfall far above average are balanced out by a larger number of below-average rainfall seasons.

1.3.2. Water Deficit

The global and regional need for water

According to Raghunath (1987), the world's total water resources are estimated at 13.7×10^{18} m³. Of this amount 97.2 percent is salt water and only 2.8 percent fresh water. Of this 2.8 percent fresh water, 2.2 percent is surface water held in icecaps, glaciers, lakes and rivers and 0.6 percent as groundwater. However, of surface water only some 0.01% is available in lakes and reservoirs and a minute 0.0001% available at any point in time in rivers and streams with small balances held as water vapour in the atmosphere and as soil moisture in the top 0.6 metres of land surface. Of the 0.6% groundwater only some 0.3% is less than 800 m deep and therefore abstractable. To compound this comparatively infinitesimal amount of available freshwater, although replenishable, Cunningham, Hubbard et al. (1992) state that vast amounts of water are continually lost through evaporation from soil and rock surfaces.

Price (1996) states that 110×10^9 m³ of water falls annually on the land areas of the earth's surface. With a present world population of over 6 billion people this represents an amount of over 18,000 m³ per person. However, it is quite apparent that this is not all available to society as it is unevenly distributed in the time, duration and the situation of precipitation. Water loss is particularly marked in hot, dry countries and although soil moisture is replenished, long, dry periods can ensue during dry seasons. People who reside in arid and semi arid zones and who are dependent on seasonal water are thus particularly vulnerable.

According to Silvester, Dupuis-Tate et al. (2001), the total amount of available fresh water in lakes, rivers and streams is calculated at 136×10^9 m³. However he goes on to state that the distribution of this water is far from even, with most of the resource

available in temperate and high-rainfall tropical countries. Drought years and successive years of inadequate rainfall considerably exacerbate the overall shortage of and access to useable water in low rainfall countries. Comparatively, there is very little productive water available in arid and semi arid countries. It is the populations of these countries which are most vulnerable to water scarcity through drought, poor water management and over-use of water. Twenty percent of the world's population lives in arid and semi-arid zones, but only has access to 2 percent of global water resources.

Pollution, overuse and mismanagement considerably contribute to deterioration in both quality and quantity of available fresh water. Silvester, Dupuis-Tate et al. (2001) state that 40 percent of the world's lakes and reservoirs suffer from pollution, that underground water reserves provide two thirds of freshwater consumed and that 60 percent of the aquifers are overused. He also states that irrigation covers some 300 million hectares and uses nearly 70 percent of the world's water, but that 50 million hectares are improperly irrigated and suffer from salinization. A pictorial illustration, figure 1.2, after M.-F Dupuis and B. Fischesser (2000) in Silvester, Dupuis-Tate et al. (2001), shows the global water cycle and water resources available for use within a sustainable balance. Figure 1.3, also by the same authors indicates the present-day pollution and contamination of global water resources, that places increasing demands on the available supplies of water.



Figure 1.2: Water Cycle, (Silvester, Dupuis-Tate et al. 2001)

According to Musabayane (1998) there is increasing disparity between water demand and water supply in the Southern Africa region. She states that water demand is of crucial concern to the countries of the region because of the increasing human population and associated demand for resources that require water, especially food. She further maintains that some states in the region are already water-stressed due to prolonged droughts or low and unreliable rainfall while others will experience water scarcity in the not too distant future. It is estimated by Population Action International (1993) that in the short term more than forty countries could suffer from an acute water deficit.

Figure 1.3: Disrupted Water Cycle, (Silvester, Dupuis-Tate et al. 2001)



1.3.3. Sources and Availability of Water

The global demand for freshwater is estimated at 4×10^9 m³ per year, which is approximately 4 percent of the total precipitation on land and 10 percent of the total annual debit of rivers. Access to a sufficient and regular supply of clean and safe water has long been a problem to society. Price (1996), states that in order to ensure an availability of water the global population has traditionally lived in close proximity to river valleys. Figure 1.4 depicts the nature of the water cycle and the processes of recharge and loss under dry-land conditions. Problems in the provision of an adequate water supply in arid and semi-arid zones are severely compounded when considering climatic vagaries and disparities in precipitation. As a result of this, vast surface water and groundwater development programmes have been promoted and instigated, sometimes to the exclusion of any other water resource. Pacey and Cullis (1986), whilst promoting the advantages of water harvesting as a solution for adequate water supply, cites Ionides (1966) who implies that attention has been inappropriately concentrated on major rivers and the construction of dams.

Raghunath (1987) infers that as groundwater constitutes the largest available global reserve of water, it is appropriate that attention should focus on the development of that resource to cater for water demand. Piché (1998) has stated that the development of groundwater supplies, particularly in the last one hundred years, has made considerably more water available to society. However with the number of people with access to adequate supplies of safe drinking water outstripping the rate at which new and improved supplies are being constructed, (Watt and Wood 1977), all possible sources of water and systems of retaining water must be evaluated and utilised, (Hussey

1998(b)). In order to ensure an adequate supply of water of an acceptable standard for all, no single supply should be pursued to the exclusion of any other, (Hussey 2000).

Figure 1.4: Dryland Cycle, (Lovell 2000)



A water resource which has significant potential and which has been considerably overlooked by both planners and engineers is alluvial river aquifers, (Hussey 1998(a)) and (Helm 1998). According to Price (1996) sands and gravels in river valleys are of particular importance. He states that unconsolidated aquifers in many parts of the world are a considerable source of groundwater and provide the bulk of the world's development aquifers. Because of their relatively recent origin, lack of compaction and cementation they include some of the most permeable natural materials.

The expertise of abstracting water from the alluvial sediment of ephemeral rivers in arid and semi-arid countries is a traditional talent that has been utilised by communities from time immemorial. In every rainy season, no matter how poor or inadequate, it is most likely that there will be sufficient rainfall and subsequent run-off for ephemeral rivers to flow. Some of this rainfall is invariably retained for many months in the deeper layers of river sediment. Jacobson, Jacobson et al. (1995) in the book Ephemeral Rivers and their Catchment, Sustaining People and Development in Western Namibia describes the complete dependence that people in arid areas have on seasonal rivers.

Although small streams do not retain water for any appreciable period, following any period of channel discharge, temporary shallow wells are often dug to abstracted water even from such impermanent supplies. As the water level in the sediment is reduced through surface evaporation, streambed seepage and down-stream transmission so the accessibility of the water is reduced until the river channel becomes completely dry. Large river basins however frequently retain a useable, perennial supply of clean water within the river channel. Smet and Wheeler (1989(b)) for instance, maintains that for centuries sub-sand-abstraction has been used in many countries as a safe and reliable means of water filtration. He refers to 'sub-sand-abstraction' and states that many

people use the simplest and most basic technology, a small temporary hole dug in a dry riverbed, to search for water.

Irrespective of the impermanence of the reserve, water is commonly abstracted from sand rivers at any time that there is water available within the sediment. When the sediment is saturated to its full depth, sand has only to be moved aside to expose a supply of perceptibly clean water. Although this is easily achieved, the author has in fact observed donkeys pawing the sediment surface to expose water to drink, efficient systems are required that will bring to the surface useable quantities of safe water. Temporary sand-wells provide 'open water', to a depth of few centimetres, which may be carefully scooped into a container. Water abstraction in this manner is slow, tedious and limited in volume. More sophisticated abstraction systems have thus been developed which incorporate screens to separate water from sediment and some type of pumping device or gravity flow to draw off water to a false-well.

There are several methods of abstracting water from river sediment; from small-scale, basic, traditional systems to large-scale mechanised schemes. The water drawn is generally clear, filtered water which can be used for all purposes, primary domestic, secondary irrigation and livestock use. This fact is acknowledged by Hewson (1970) who adds: "An interesting feature along sections of the low rainfall areas of the Shashi, Limpopo and Lower Umzingwane Rivers is sand-abstraction. Considerable quantities of good quality water are obtained from apparently dry rivers. Large pockets of water are trapped below the sand and above bed rock. The saturated sand depth is as much as 9 metres, (30 feet). Replenishment occurs when the rivers are in spate. Several thousand acres of land have been developed under irrigation in Tribal and European farming areas". Johnstone (1989) also refers to schemes on the Limpopo River, drawing irrigation water at up to 400 m³/hr from the sediment.

During the 19th century reserves of sub-surface water in alluvial aquifers contributed considerably to the opening-up of southern Africa. Hibbert (1982) recounts that expeditions of several early explorers, including Livingstone and the early missionary, Moffat, had only been saved from disaster when a supply of shallow sub-surface water had been found. Farini (1973) records the journey of Col. Schermbrüker in 1887 who, on arriving at a dry water source and desperate for the survival of his expedition, organised the digging of a pit 3 to 3.6 metres, (10 or 12 ft) deep and 1.8 metres, (6 ft) wide at a moist spot in the pan. As the digging progressed the sand became increasingly moist but at 2 o'clock in the morning when the diggers hit rock and retired to bed, the pit was dry. However when they woke at midday they found 450 mm, (18 ins) of water in the hole – enough for themselves and their trek-oxen.

Aside from traditional usage, reference to an up-graded, mechanised system of abstraction has been traced in Zimbabwe back to the 1920s (Jennings 1923), although it is possible that the technology was first developed in the south-west states of the USA where the technology has been used extensively to abstract water from saturated gravel beds rather than river sediment, (Driscoll 1986) and (University of Minnesota 1985). In Zimbabwe the system was developed and commercialised when many installations were undertaken in the 1950's. Since then many large mechanised schemes have been established. Prince (1983) describes the installation of what is probably the world's largest sand-abstraction scheme on the Save River in southeast Zimbabwe and has also designed and installed sand-abstraction schemes for primary water supply to elite safari camps in remote areas.

The technology of sand-abstraction is essentially a system of water abstraction utilising reserves of water in seasonal river channels, but need not be limited to this. Methods of abstraction allied to sand-abstraction such as streambed and riverbank intakes and well-points installed into saturated gravel beds, each have considerable potential. Maclear (1997) states that water which could be easily drawn through jetted well-points from the gravel beds of the Cape Flats in Cape Town, South Africa, could contribute significantly to Cape Town's water supplies, but laments the fact that this water is not utilised.

Land surface erosion and the subsequent siltation of riverbeds which retains run off water has long been a climatic feature of Africa. A report by McQueen (1840) refers to sand banks and islands in the Luabo River, a tributary of the Quilimane River in Mozambique. However, since the middle of the 20th century there has been considerably more siltation of ephemeral rivers in many parts of the world, notably southern and eastern Africa. Sand-rivers are now a part of the natural environment where water is stored during the water cycle. Harvey (1999) records what he calls the terrible state of ecological collapse in the Save River catchment of Zimbabwe which has taken place in the last fifty years since the eradication of tsetse fly and the introduction of livestock. As a result of this he maintains that the catchment is subject to extensive levels of erosion with annual losses of river sand calculated to be many millions of tonnes with all the previous perennial river systems destroyed. Jarrett (1974) records widespread erosion which has taken place in recent years and which threatens most parts of Africa. He makes a further point; "It may be salutary to remind ourselves that in the main soil erosion is produced as a result of man's interference with the balance of nature. Primitive methods of cultivation do not readily give rise to it, for the incomplete clearing of the vegetation cover in small patches which is typical of peasant farming in Africa does not give scope for large-scale erosion to develop". The abstraction of water must be managed, as any other water abstraction process. The process must not be seen as an ultimate or desperate attempt to utilise a scarce and dwindling resource where all other sources have failed, but rather the positive development of conditions that have been precipitated by present day socio-economic and consequent environmental factors.

1.4. The Concept – Possibilities and Potential

1.4.1. Background to the Research

The system of sand-abstraction is under-utilised and its potential is not yet met. This study and research is intended to investigate the technology and to document and provide data and insights into its operation and functionality. Through this study an understanding will be developed of the causative factors relating to the conditions where water is retained in sediment in useable quantities. The options and potential of sand-abstraction systems will be reviewed, design options considered and a range of appropriate abstraction equipment will be developed, tested and documented.

Because of losses, seepage, drainage, evaporation and evapo-transpiration, only larger seasonal rivers can be expected to retain water perennially. Depending on the various factors, where sediment is shallow or drains quickly, the retention of water may be only for a few days or may be for several months. Consequently, as well as appropriate utilisation of alluvial sand-beds, the study will consider the feasibility of sand dams and subsurface dams which reduce downstream drainage and thus assist in retaining water for longer.

1.4.2. The Development of Alternative Groundwater Resources

The process of sand-abstraction is based on the use of sand rivers. Such rivers, usually surface dry, constitute an alternative groundwater supply. The sub-surface water which is retained in the sediment of ephemeral rivers and which is suitable for sand-abstraction is best defined as a groundwater supply. According to Blyth and Freitas (1974) rainfall entering the sediment of a river system as seepage, is regarded as a groundwater component, but when the river sediment is saturated and flow commences above the sediment surface, the river run-off becomes a surface water component. Water stored naturally in the sediment of an ephemeral river remains permanently below surface level as an unconfined aquifer. Typically the resource constitutes a clean, permanent supply of water with the same parameters that apply to groundwater and groundwater abstraction and subject to the same factors that apply to water-tables, aquifers and water-lenses.

1.5. The Availability of Water in Ephemeral Rivers

According to Price (1996) an ephemeral river is a river that may only flow occasionally, perhaps only for a few hours or days in a year, or even just once in several years. Price also makes a distinction between an ephemeral and an intermittent river which does not flow year round but flows for a part of each year, usually during or after the season of most rainfall. Ephemeral rivers are sometimes erroneously known as dryseason rivers. Kamatuku (1996) refers to ephemeral rivers as seasonal rivers and also as sand rivers as many ephemeral rivers contain copious amounts of sediment. According to Nissen-Petersen (2000) sand riverbeds may also be referred to as dry riverbeds, luggas or waddis. Price (1996) states that ephemeral rivers and streams generally occur in arid and semi-arid areas where climatic conditions are generally of an extensive dry-season and where rainfall is unpredictable. Typically in such conditions rainfall comes as heavy and localised storms that produce surface flow and interflow to a stream sufficient to sustain flow in the channel for a short period of time. Where river sediment is dry, flow may cease due to infiltration into the sediment and by evaporation, however where the river sediment is already saturated flow may extend to larger channels.

1.5.1. Extent of Ephemeral Rivers

Africa has an extensive network of seasonal rivers in North Africa, throughout the Sahel and across to the Horn of Africa and East Africa into northern Tanzania. In much of southern African from southern Angola, southern Zambia and central Mozambique rivers are again seasonal. Perennial rivers occur in Central, tropical Africa, in the coastal regions of West and central Africa and the costal belt of East and Southern Africa. Apart from the coastal belts it can be assumed that the rivers in most areas with a seasonal rainfall below approximately 1,000 mm (40 ins) are ephemeral. Figure 1.5, shows the mean annual rainfall of Africa, (Suggate 1970). Ephemeral rivers occur on most continents such as the south east of North America, the Brazilian plateau (South America), Iberia, (Europe), the Middle East and India (Asia) and much of Australia

Figure 1.5: Rainfall of Africa, (Suggate 1970)



Jarrett (1974) states that the drainage pattern of Africa reflects both the climate and the structure of the continent and that this pattern varies widely from virtually nothing in the desert areas to a closely woven network of streams and rivers in the equatorial lands where rainfall is heavy and where there is no dry season. The rainfall and climate thus dictate the drainage pattern, which together with the nature of the land mass as a high internal plateau, means that many of the coastal rivers only flow down the edges of the plateau to the oceans. The pattern of river flow is shown in the accompanying map, figure 1.6, showing the major rivers of Africa, (Jarrett 1974).

At a country level, The National Master Plan for Rural Water Supply and Sanitation, Interconsult-A/S and Norway (1985) state that most rivers in Zimbabwe dry up during the dry season and that perennial rivers are confined to the extreme eastern districts of the country. In the west the Gwaai-Shangani River catchment drains 10 percent of Zimbabwe and the Save River in the east drains 11 percent (Harvey 1999), both catchments consist of seasonal rivers with extensive sedimentation.

Figure 1.6: Rivers of Africa (Jarrett 1974)



1.5.2. Characterisation of Ephemeral Rivers

Water Retention

Water is held in the sediment of surface-dry silted rivers and where the sediment is extensive can be abstracted in useful quantities for a variety of purposes. The permanence and availability of water in an ephemeral river will depend to a large extent on the storage capacity and water loss from the sediment. The significant losses are seepage, drainage and evaporation, which occur directly from the river sediment and through the transpiration of vegetation, which draws water from the river. High rates of seepage will occur in river channels with a pervious sandstone bed and will be appreciably less in river channels where the riverbed is of granite or basalt. The rate of drainage will depend on the slope and riverbed topography, for instance rock barriers will inhibit the flow and thus drainage through sediment. A long bed of coarse sediment of an even depth and width will hold significantly more water than a river channel comprising fine sediment or rocky outcrops. At a time when the water level is near the surface of the sediment, evaporation losses can be expected to be high, however evaporation losses reduce with depth and are generally considered to be minimal i.e. below 600 mm.

Both the length and the cross sectional area of the river channel constitute major factors in the water storage capacity of a riverbed aquifer. A shallow, narrow channel with limited sediment is liable to dry up much more quickly than a deep wide riverbed which continues to be replenished by the percolation of water from further up the channel. A useful riverbed aquifer will be comprised of a river channel of several kilometres and a depth and width of sediment sufficient to minimise evaporation and impound a useable volume of water as in the sand river, figure 1.7. Where sediment is coarse and therefore has a large void ratio and where the river channel aquifer has some recharge, the supply of water can be expected to be perennial. A general guideline based on Zimbabwean experience is that 20 percent of the volume of sediment can be expected to retain water, (UNEP 2000).

According to DNR Water Facts (1997) rainfall provides the major source of recharge to groundwater. As rain falls, a portion finds its way beneath the ground surface and is stored in the pores, spaces and cracks between the particles of soil, sand, gravel and rock material. Water-saturated rock or sediment is referred to as an aquifer by (Beazley 1993) and thus by that definition a silted river channel can be considered an aquifer. The United Nations Environmental Programme, (UNEP 2000) refers to freshwater augmentation in agriculture in areas where runoff is stored in surfacial aquifers such as "dry" riverbeds and states that consequently there is a great potential for sand-abstraction. During a rainy season or wet period, precipitation will occur in a part of a river catchment or throughout an entire catchment area. If the rainfall is extensive, the land surface and river surface will become saturated to the point of surface run-off so that flow will commence from the land surface into the waterways and into the river system, (Bell, Faulkner et al. 1987).

At a period of time after the cessation of precipitation, surface runoff into a river channel will cease, but flow will still occur within a river channel. If no further precipitation occurs, channel flow will reduce in volume until it ceases to flow at the surface but will then continue as sub-surface flow. During this period of sub-surface flow, water will be retained in the voids between river sediment particles. Where streams are small and the sediment shallow, water may only be retained for a matter of days, however in large rivers with deep coarse sediment water retention is quite often perennial and may last for more than a single year.

Figure 1.7: Typical sand river, Zimbabwe



Although basically the same technology is utilised to abstract water, a distinction does need to be made between systems which abstract water from the saturated sediment of surface-dry ephemeral rivers and those which abstract water from stream bed sediment in perennial riverbeds. In both instances the source of water is from river sediment, but the supply of water to the sediment of a perennial river differs from recharge to the sediment of an ephemeral river. Price (1996) for instance states that baseflow from an aquifer generally occurs year round to supplement the surface run-off flow to a perennial river, whereas flow in a seasonal river is subject only to a sudden downpour that is sufficient to produce surface flow to sustain a stream for a short time.

Water abstracted directly from a flowing perennial river is said to be surface abstraction and is more vulnerable to pollution and the vagaries of climate and weather, whereas water drawn from the sub-surface of an ephemeral riverbed is abstracted as groundwater. The faster flow of perennial rivers increases the inflow of contaminants to the point of abstraction and in some situations has been seen to be conducive to the development of a slimy, filamentous growth around well-points in the sub-surface of the riverbed sufficient to block or adversely reduce the draw-off rate of abstraction systems, (Jetten 1991) and (Clanahan 1997). Although intermittent surface flow in an ephemeral river is theoretically surface water flow, due to its impermanence it is better considered a temporary extension of a groundwater supply. Such transient water has so far not been seen to be the cause of any contamination or reduction in abstraction rates.

1.6. Feasibility of Abstracting Water from Ephemeral Rivers

Technical Options

Methods of Abstracting Water from Sand

There are several systems of sand-abstraction that have been developed over the years. Each is dependent on equipment which can be installed into the water-bearing river sediment and at all times remain in free moving water. Schemes range in size from small-scale hand operated, essentially domestic supplies, right through to large mechanised, diesel or electric powered irrigation schemes.

In a correctly designed system a graded filter zone is created around each well-point or caisson. As water is initially abstracted so silt and 'fine' sediment is drawn from the sediment which is in the immediate zone of abstraction, but larger grains of sediment are either unable to pass through the slots or are not raised by the flow of water. Smaller grains wedge against these larger grains until the passage of fines is itself restricted. The flow of water into a well-point is thus improved as the void area in the immediate abstraction zone is enlarged and blockages are minimised, (Johnson 1966), (Michael and Khepar 1989) and others. A natural screen effect within the sediment is thus developed around the point of abstraction. As the finer sediment is initially drawn into the installation, larger particles remain in closest proximity to the screen with a progressive reduction in size, down to undisturbed sediment furthest from the point of abstraction. This process of fines removal is well documented by Driscoll, Khepar and others.

There are parallels in the technology of abstracting water from alluvial river sediment and the application of groundwater abstraction technology. The use of screens is common to both sand-abstraction and borehole water abstraction technology. However, the various systems and techniques employed in the technology of sandabstraction are not an alternative to commonly used and accepted borehole technology practices. Each system has much to offer within its own environment but cannot be used in place of the other.

To abstract clean, sand-free water successfully from saturated river sediment requires either an open well or a method of placing purpose designed equipment as deep as possible into the saturated sediment. Typical installations are:-

- Traditional open sand-well system
- Single screened well-point system
 - Driven well-point
 - o Jetted well-point
 - o Dug-in well-point
 - o Augered well-point
 - o Surging and 'sand-sucking'
- Multiple screen manifold system
- Infiltration gallery system
- Caisson system

Sociological Aspects

Water development planners such as Visscher, Paramasivam et al. (1987) of the International Reference Centre for Community Water Supply and Sanitation (IRC) and Heber (1985) of Deutsches Zentrum für Entwicklungstechnologien (GTZ) and Deutsche Gesellschaft für Technische Zusammenarbeit (GATE), frequently state that for water development initiatives to be successful, communities must be involved in the decision making process as well as the siting, construction and maintenance of a scheme. In an article on the social aspects of rural water supply Lovell, Nhunhama et al., (1998) make the point that an appropriate community choice of well design and site improves domestic water supply and nutrition. The importance of community involvement and choice to ensure project success is also borne out by Mokgatle (2000). Whilst community participation is highly desirable, communities must also be in control of the technology for a water supply to be both acceptable and sustainable. Hussey (2000), Sutton (1999(a)) and Morgan (1990(a)) are each of the opinion that traditional water sources which are conceptualised and maintained by rural communities are ultimately the most accepted and sustainable supplies of water. Sandabstraction is a technology which has been instigated and developed by rural people in arid and semi-arid areas and is a 'technology of the people', as such it is 'their' technology and thus has a greater chance of acceptability and success.

Consequently, where it has the potential, sand-abstraction is part of a community's everyday life. The principle of drawing water from river sand has evolved over time and is now well established and accepted by almost anyone living in the proximity of an alluvial watercourse. Even where water abstraction from sediment cannot be perennial, people will typically use what water they can for as long as they can. These temporary practices are mentioned by Hodson (1896) who refers to impermanent sources of water as 'sip-wells'. One of the drawbacks to the greater use and promotion of sand-abstraction is that the technology has remained with the people and it has not been accepted by water programme development professionals.

In consideration of the implementation of Agenda 21 of the Earth Summit Declaration held in Rio de Janeiro in 1992, Lusiola (1994) states that traditional practices play an important and vital role at all levels of society. Lusiola maintains that community structures with a general theme of communal living and a sharing of property and resources remains strong in Africa. Consequently they state that communities have "a built in system" for the control and use of available resources, especially of water. Hakansson (1989) notes that small-scale waterworks can be managed by non-stratified societies where they are accompanied by some form of organisation. Soccal (2000) states that sustainability occurs when communities themselves are able to develop and control efficient technologies, particularly when they are simple and inexpensive. The basic technology of sand-abstraction is simple yet effective, Wegelin (1996) states that a delegation from an external support agency that was sceptical of the merits of an infiltration gallery that had been proposed by an NGO, became convinced of the likelihood of success whilst watching children playing with water in the river sand.

Although the installation of large, mechanised sand-abstraction schemes can be very expensive, particularly where heavy earth moving equipment is employed as referred to by VITA-Volunteer (1996), small-scale community based sand-abstraction systems where communities or individuals undertake installations for themselves are extremely cost effective, (Hussey 1995).

1.7. Water Quality

Chemical quality

Groundwater in areas which are suitable for sand-abstraction are frequently tainted or even badly contaminated with mineral salts. In a survey undertaken for Plan Afric for the Department for International Development (DFID), the author found water samples so contaminated with sodium, sulphur and coal residue that the groundwater could not be used even for livestock watering, (Hussey 1998(c)). In a further study conducted by the author on water resources in the Hingwe area of Bulilimamangwe District, Zimbabwe, (Gunby, Stephen Hussey et al., 1998), the Ward Councillor, Mlotshwa (1996) stated that people would by preference frequently walk beyond an operational borehole to draw 'sweet water' from the river sand that did not contain mineral salts. In a third survey, this time for the United Nations Development Programme (UNDP), in Owambo, Northern Namibia the author learned of extensive contamination of groundwater by mineral salts, (Hussey 1993).

Groundwater contamination by mineral salts is due to the leaching of soluble salts from the surface into confined or slow draining aquifers in the sub-surface. According to Beazley (1993) in humid soils these salts are washed through the aquifer but in arid and semi-arid areas where water movement is slow and restricted, mineral salts are not washed through but remain in the groundwater to form concentrations of contaminating salts. Price (1996) states that where there is an annual surplus of precipitation over evapo-transpiration, aquifers will usually have been flushed to a depth of several hundred metres or to the full depth of the aquifer by water moving from recharge areas to discharge areas. However, in arid and semi-arid areas, where for most of the year evaporation and evapo-transpiration are likely to exceed rainfall, this does not occur and the aquifer may be a zone of concentration rather than a dissolution of salts.

Water that is retained in river sediment is faster flowing than deep groundwater and thus contains a lower mineral salt content than water which accumulates salts as it moves slowly through deep groundwater aquifers. Water drawn as sand-abstraction is thus generally not contaminated with absorbed mineral salts. Due to the natural filtration effect of river sediment, sand-abstraction water typically contains only minute quantities of particulate contaminants and is considerably less polluted with bacteria contaminants than surface water.

Bacterial quality

Slow sand filters are an acknowledged method of removing bacteria and small particles from water to make it safe for drinking, (Centre for Alternate Technology 1998), (National Demonstration Water Project 1982), (Musgrove 1996), (Graham 1988, (a)) and (Hofkes, Huisman et al. 1981). Wegelin (1996) describes the basic sand bed filtration theory and indicates that saturated riverbeds function in the same manner as slow sand filtration systems. Visscher, Paramasivam et al. (1987) state that riverbed filtration systems are as equally effective as slow sand filter beds and maintains that when perforated pipes are laid to abstract water from sand or gravel riverbeds water quality may be improved to such an extent that no further treatment is required. The author has had a similar, practical experience, in a sand-abstraction installation carried out for the Salvation Army at Tshelanyemba Hospital, Matobo District, Zimbabwe. Water sampling was undertaken to establish the extent of bacterial contamination and water purification measures which would be required. Water samples were collect in sterile conditions by the doctor of the hospital Freidell (1991) and the Bulawayo Municipal Water Works undertook water quality tests. Tests showed that water drawn directly from the river sediment required no further water purification.

1.8. Purpose of Research

Sand-abstraction is a widely utilised and popular water supply option for members of low-income communities, however as stated by Helm (1998), there has been little attention accorded to the development of sustainable, low-cost technology. Limited commercial development of the technology has taken place but this has largely been a spin-off from the development of equipment, such as well-screens that are required by the deep groundwater industry and from materials and technology that is required by the construction industry. As there is an ever-increasing need for water for basic livelihood requirements, not the least in water deficit areas, ever greater volumes of water are required for domestic. livestock and irrigation use. To meet this demand there is a corresponding need for the development of alternative water supplies and sustainable use practices. As present day demands for independent wealth and security impinge on traditional societies and lifestyles and increasing pressure is placed on conforming to modern acceptable standards, so alternatives must be developed to ensure that effective systems of water management are in place for those who remain to eke a living in conditions of generally increasing hardship. Because their lifestyle is no longer deemed suitable, it is a policy of the Government of Botswana to remove the San people from the last of their ancestral lands for relocation in established settlements where education and health services may be provided. All over Africa and particularly from areas with a harsh climate and bleak outlook there is an unending migration of skills and labour to urban areas. However, those who leave seldom relinquish their traditional rights in the expectation of returning in old age, consequently increasing pressures are placed on the women, the children and the sick who remain to maintain the home and to make a livelihood with a diminished access to resources. It is against this background that water resources and abstraction technologies are required that are acceptable to and manageable by women who are expected to maintain the status quo, with little participation in any decision making. It is thus imperative that a study, research and development initiative be undertaken of proven water supply strategies, together with a concomitant development of sustainable, low-cost abstraction technology, that will be acceptable to communities and easily managed and maintained.

This study and research sets out to demonstrate the sustainability and potential of traditional water supplies and particularly that of sand-abstraction with a view to proving its worth and increasing its application. The study acknowledges the limited and frequently inadequate supplies of water which characteristically beset disadvantaged communities in impoverished areas and considers alternate sources of water which may be developed and improved to enhance viability and sustainability.

1.8.1. Overview of Activities

A research programme was engaged in order to:

- Review the extent of knowledge and use of sand-abstraction systems and regions where the technology may be applicable
- Establish the potential of sand-abstraction for use by small-scale users, with particular attention to suitability of systems and equipment for use by women
- Document relevant information
- Develop appropriate equipment
- Establish end-user perception

1.9. Hypothesis, Aims and Objectives

Hypotheses

Four fundamental assumptions were made at the outset of this study and a research programme developed for verification:

• Sand rivers constitute a viable source of groundwater. There are sufficient volumes of water retained in the sediment of ephemeral rivers for regular, ideally perennial abstraction and sustainable use by communities or families

- Sand-abstraction can be a technology utilised by rural communities. Rural people will make adequate use of a suitable, improved technology
- Sand-abstraction can be a sustainable technology. Technology can be developed that rural people are able to operate and maintain to the extent that systems remain functional and operational for prolonged periods of time
- Strategies can be developed to assist with the establishment of the technology. Guidelines can assist with site assessment, installation design and the maintenance of abstraction equipment.

Aims

It is the intention of this study to investigate whether or not the abstraction of water from alluvium in ephemeral rivers constitutes a significant water supply potential despite the fact that sand-abstraction appears to be a little known and little utilised water supply technology. Study and research will aim to establish the opportunities and assess the potential of sand-abstraction systems in order to increase the prospects of resource poor communities.

Objectives

It is the purpose of this research to review the opportunities and potential for sandabstraction and if found apposite, to provide a basis for the development of abstraction equipment and promotion of the technology. In order to conduct this investigation an examination is required of the conditions that are suitable for sand-abstraction as well as sand-abstraction technology and expertise.

1.10.Methodology – Approach & Scope of the Thesis

The study sets out to investigate the suitability of sand-abstraction through an assessment into the extent and the use made of the existing technology by rural people in western Zimbabwe. The purpose of such an enquiry is to gauge the understanding, acceptability and management of the technology and its suitability and potential for development and promotion. Community perceptions and values have been deemed important as there is little point in developing a technology application if there is little chance of the development being understood or appreciated, or if it will not meet the needs or criteria of the target group. Lovell (2000) for instance states that little attention has been paid to how communities would use water to develop their own livelihoods and to the provision of sufficient reliable groundwater in dryland areas, which he says, is due partly to the inadequacies of abstraction technology and partly due to inadequate or poorly designed water abstraction points. Consequently there are many misconceptions of supply and demand and as a water supply deteriorates, so communities invariably limit their use to domestic water in an attempt to conserve a resource. The author has had several similar experiences and is also of the opinion that few rural people fully comprehend the loss of surface water from a dam through evaporation and therefore will not use a dwindling resource for fear of wasting it. It is thus imperative for end-users to perceive correctly not only their existing use systems but possible increased use patterns as well. An improved technology will not be

utilised if there is a concern that increased use will deplete the water supply and conversely, if the limitations of a water supply are not appreciated, improved abstraction technology will only hasten depletion of resource, with possible disastrous consequences.

From the outset of the study and research, it has been considered important to involve the users of sand-abstraction in the assessment and the process of the development of the technology. The sand-abstraction installation programme of Dabane Trust has, since its inauguration in 1991, been undertaken in conjunction with rural communities and community groups in the Matabeleland Provinces of Zimbabwe. As the study and research concepts were developed and as initial questions and queries arose, an explanation of the proposed programme was taken to community meetings and authority sought from four communities to undertake practical research within their respective localities.

The study was submitted to a carefully structured format and commenced with a number of interactive community meetings with a focus on an initial understanding of sand-abstraction from a community perspective. This initiative was followed by the establishment of four research sites to collect data on river flow and water losses from the river channel. A later development was the design, fabrication and installation of equipment considered appropriate for abstraction purposes. The equipment was subjected to a series of pump tests carried out in test tanks and was then followed by infield tests under conditions of community control and use. A further series of community meetings was held to provide feedback to the communities and also to gain feedback from them on the potential and the suitability of the equipment and on the possibility for the development of sand-abstraction.

Focus Groups

Before any practical work in data collection or development of equipment was undertaken, a series of meetings were held with groups of people from four different communities in order for the study to better appreciate the methodology and social parameters associated with the construction and use of traditional sand-abstraction systems. Issues discussed were the ownership and the responsibility and management of sites, site selection, construction, use, maintenance and management. Questions were also raised with communities and any technology that they might have developed or acquired and their perception of the suitability of sand-abstraction as a source of water. Participants were also questioned on preferences and taboos associated with sand-abstraction.

Establishment of Research Sites

Authority was sought from the four communities, particularly from community leaders, to set up a research site within each community, each to be managed by two local people. Through the sites, data have been collected on water loss from the sediment during the dry season, evaporation, rainfall and the length and duration of river flow. Further data have been collected on the height to which a river rose above the sediment and the depth to which river sediment was disturbed in the channel.

Development and Testing of Equipment

With data gathered on the properties of alluvial river sediment and information collected from users, a variety of equipment suitable for local fabrication for the abstraction of water from sediment was developed. The developed equipment was first tested in tanks under controlled conditions. A motor driven progressive cavity pump was used to draw water through the various well-points at four different rates of abstraction. The well-points were then tested in field conditions at a number of rural sites.

Community meetings

The collected information of the research and the data and initial feedback from the well-points and handpumps tested under field conditions were taken back to the communities for their deliberation

1.10.1. Logical Framework Methodology

To effectively undertake this research programme a logical-framework research base was conceived:

Goal

- To investigate the potential and possibilities for development of water utilisation from sand-abstraction water supplies and if proven suitable, to provide technical documentation on the suitability of sand-abstraction systems, river potential,
- locations and suitable sites
- To investigate the possibility of developing suitable abstraction equipment for small-scale users and if proven suitable to design and fabricate appropriate abstraction systems, techniques and installation techniques
- Provided positive assessments ensue, to promote and publicise sand-abstraction as a realistic and viable groundwater source

Purpose

- To increase awareness of the potential and possibility of sand-abstraction as a feasible and sustainable, low cost technology.
- To develop and make known low-cost equipment and systems that can be acceptable to and are able to be maintained by rural communities with few tools and minimal technical skills
- To increase the possible options and access of rural dwellers to potable, uncontaminated and untainted water supplies.
- To hopefully make more low-cost water available for secondary use, livestock, irrigation and income generating activities.
- To consider an alternative viable water supply to deep water sources.
- To demonstrate that rural communities with minimal technical aptitude have more control over sand-abstraction systems than deep water supplies.

Output

• A narrative and technical research paper evaluating the suitability of sandabstraction technology as an appropriate and worthwhile technology • Designs of abstraction equipment, such as well-points and caissons that are suitable for fabrication from readily available materials and components.

1.11.Criteria for Research and Study

Efficacy of Water Abstraction from Sand

A key aspect of the research programme was to develop an understanding of the factors relating to the separation of water from sediment and the removal of water alone from that sediment. The study will evaluate the materials, equipment and pumps suitable for the abstraction of water from river systems and river sands. An important aspect is to establish the worth of the system as a viable water supply option in suitable conditions in an industrially developing country.

Appropriateness of Water Abstraction from Sand

Sand-abstraction will provide an important and viable source of water in suitable conditions and situations if the system is understood and utilised appropriately, when the technology has been suitably refined and properly publicised.

This study will demonstrate whether or not the system is a technology that is appropriate for the abstraction of water from perennial supplies during both the wet and the dry seasons and will also establish the conditions which make the system viable. It will show whether a system that has been used intuitively since time immemorial can be developed and still retain its acceptability to present day end-users.

Sustainability of Water Abstraction from Sand

The study will evaluate the ability and the capacity of rural communities to manage the various systems effectively and independently. For the system to be sustainable the study must demonstrate the sustainability of systems as it is vital that rural communities are able to operate, service and repair equipment and installations.

Development of the Sand-Abstraction Technology

The study will investigate the suitability of fabricating equipment from commonly available materials for differing local site conditions. The intention is to improve the efficiency and to reduce the cost of equipment, which may be readily manufactured in the field. It is considered particular important to develop equipment which has a potential to assist in the abstraction of water in remote, arid and semi arid areas where it is imperative that impoverished communities are able to exercise control over their own water supplies.

Although Prince (1983), indicates that large mechanised schemes have considerable potential, this current study places more importance on small-scale schemes which are sustainable at an individual or community level, (Hussey 1998(a)).

Promotion of the Sand-Abstraction Technology

Practical research data has been collected to assist in the understanding, development and furtherance of the technology as a viable water abstraction option.

The information and data that has been obtained from the arid and semiarid areas of western Zimbabwe from existing installations and from the research sites and the trials
conducted during the research period will provide the basis of a field manual. It is intended that the manual will include fabrication details and maintenance facts of abstraction equipment and is planned for widespread dissemination

1.12.Review of Literature

Systems of abstracting water from river sediment have been successfully practised for centuries, however, there has been little documentation of the technology (Helm 1998) and (Hussey 1997). Consequently much of the material for this study has originated as inherent knowledge, rather than as documentation. In practice, where there has been commercialisation and development of sand-abstraction systems, this has been achieved at an entrepreneurial or individual company level and the research and knowledge has continued to remain undocumented, (Ndhlovu 1999) and (Cooke 1987). However, the concept of sand-abstraction at a commercial level has been proven and several companies have developed equipment which enables the mechanical abstraction of water from river sediment, (Driscoll 1986), (Boode 1994), (Soloflo 1997), (SWS Filtration 1997). Nevertheless there still remains remarkably little published documentation and very little statistical information.

The British Geological Survey, Wellfield Consulting Services, Gaborone, the Rural Industries Innovation Centre (RIIC), Kanye and the Department of Water Affairs, Gaborone, amongst others, have undertaken extensive studies on sand rivers in Botswana. However many of these reports have not been publicised nor widely circulated and have largely remained as 'in-house' documents. This is particularly surprising when considering the water storage and use potential of these sand rivers.

Much useful background material has been found in a number of books, surveys and reports specific to southern Africa. Several of the African Hunting Reprint series by the Books of Zimbabwe Publishing Company have given much insight into the lives of some of the early settlers and their dependence on alternate water supplies – before the advent of groundwater exploration. Two publications from The Desert Research Foundation Namibia, relating to the characteristics of arid and semi-arid areas of Namibia have been particularly useful. The Ephemeral River Systems and their Resources, (Jacobson, Jacobson et al. 1995) and Oshanas, Sustaining People, Environment and Development in Central Owambo, Namibia, (Cunningham, Hubbard et al. 1992) have both provided a wealth of information into rivers in dryland areas. Sally Sutton has undertaken an extensive research programme in western Zambia into the potential of traditional water supplies and has reported favourably on both the sustainability and the success which has been achieved in upgrading these sources to a 'safe' status, (Sutton 1999(a)), (Mbewe and Sutton 1999) and (Nyundu and Sutton 2001).

1.13. Summary

Water is a resource that is distributed unevenly throughout the World and is subject to excessive and disproportionate use. Many areas, particularly arid and semi-arid areas are now water deficit, where demand exceeds the possibility of supply. In many of these dryland areas aquifers often have a limited potential or are deep and difficult to access. Typically there are few opportunities in dryland areas for extensive water conservation such as surface dams and due to high average temperatures water loss is likely to be severe from open surface water, particularly in comparison to temperate areas.

Within most rural dryland areas there are few dams that have water treatment plants and hence little use is made of open surface dam water for domestic use. Due to the general potable condition of groundwater extensive use is however often made of this resource. But, in spite of modern handpump technology to Village Level Operation and Maintenance, (VLOM) specifications there are still many inoperative handpumps and thus an inadequacy of water supply in disadvantaged areas. Particularly in drought years, groundwater aquifers may also be severely depleted and unable to sustain the local community. Sustainable water abstraction systems, which are acceptable to and manageable by rural communities, are thus still required to augment existing water supplies. New and imaginative initiatives require identification and development.

Ephemeral rivers are typical within arid and semiarid areas and contain large volumes of unconsolidated sediment that retains water in the pore space. In extensive river aquifers the water resource is typically perennial, lasting throughout a dry season. Water so retained within sand riverbeds has been utilised traditionally by arid-land dwellers and has been an established and accepted expertise, probably throughout the aeon of time.

The author contends that sand river aquifers constitute a considerable water resource with an extensive potential and proposes a study to ascertain the appropriateness of the utilisation of sand river aquifers to provide water to resource poor communities. Research, design and development is also proposed to develop equipment in support of an appropriate low-cost, sustainable abstraction technology suitable for operation and maintenance by low income communities in remote areas. The possible of localised assembly and even the fabrication of abstraction equipment, such as well-points and handpumps will also be propounded at that level.

The criteria and methodologies of study are set out and research has been conducted in association with representatives of various communities where field research sites were be established. Assuming a satisfactory conclusion to the study, research and equipment development programme, it is intended that efforts will be made to incorporate the assessment and knowledge gained into a manual and to seek to disseminate the information not only within established sand-abstraction areas, but also where there is a likelihood for potential establishment and development.

Chapter 2 <u>Context and Perspective</u>

2. Explanation of Sand-Abstraction

2.1. Terminology

Sand-abstraction is commonly understood as the abstraction of water from sediment that is retained in a river channel. It is not the removal of sand from a riverbed but rather the removal of water from unconsolidated sediments in the riverbed. UNEP (1998) explains sand-abstraction as the abstraction of water from sand-filled riverbeds during periods in which there is no surface water flow.

The term sand-abstraction is thus easily misconstrued. Documentation by Morton (1958), Van-Der-Watt (1964) and Wipplinger (1958) serves to compound the misnomer by referring to 'sand storage', rather than water storage in sand. The action of the removal of water from saturated river sediment could be explained as the "abstraction of water from sand". Terminology would thus be correct as, "water from sand abstraction". However, although the term sand-abstraction is inaccurate and is in fact erroneous, it is at least in southern Africa, the terminology that is commonly accepted. (Clanahan 1997), Helm (1998), Hussey (1997), Hussey (2000), Hewson (1970), Johnstone (1989), Thomas (1987) and the UNEP (2000) each refer to water abstraction from sand rivers as sand-abstraction. Thus in order to ensure standardisation, this study will adhere to and continue to promote the term sand-abstraction.

Colloquially both commercial and subsistence farmers in Southern Africa also refer to the process of abstracting water from the sediment of riverbeds as 'sand-abstraction'. The term is used irrespective of the manner of abstraction, whether water is abstracted through well-points, caissons or infiltration galleries the system is referred to as 'sandabstraction' and specifically relates to the abstraction of water from alluvium in the river channel. Although the same process and equipment is utilised to abstract water from the alluvium of riverbanks, river flood plains, paleo-river channels and sand or gravelbeds in countries such as Australia and the United States, the abstraction process in those situations are not referred to as sand-abstraction.

In associated and similar technical applications Clark (1988) refers to the use of screens to abstract water from unconsolidated aquifers as, 'water-wells'. Stapleton (1989) refers to narrow-bore wells of 25 to 500 mm diameter as tube-wells, his criteria being wells which are developed by augering, sludging, jetting or percussion and are too small for workers to enter for construction or maintenance. References to similar water abstraction processes from sub-riverbed intakes through Ranney or collector wells are also generally not referred to as sand-abstraction systems. Common terminology for a large diameter well shaft with horizontal galleries drilled beneath a riverbed, is a collector well, (Lovell 2000), (Herbert, Barker et al. 1997), (Davies, Herbert et al. 1995) and (Batchelor, Lovell et al. Undated). Lovell draws several parallels with collector wells and sand-abstraction, stating that sub-river intakes reduce water treatment costs by filtering the induced recharge through the natural filter of the sand, but does not refer to the method of abstraction, as sand-abstraction.

useful supply of water. Such supplies of water are particularly important in regions where other sources are too distant, too costly to develop, or where wells are impractical because of unfavourable geology or excessive drilling costs.

In fast flowing rivers with a steep incline only gravel and cobbles are retained and the depth of sediment does not appreciably accrue, frequently remaining at half a metre or less. In slow moving rivers where the slope of the riverbed has levelled, finer sediment is retained and depending on the conditions and depth of the channel, is likely to be retained to a greater depth, (Owen 2000 (b)). It is not only the incline of the riverbed that determines sediment retention, sediment is also retained in the river channel in depressions and behind rock bars and outcrops, as shown in figure 2.2. According to Nissen-Petersen (2000) sediment is held by underground dykes that prevent the water from progressing downstream. Because water is held in existing natural formations, Nissen-Petersen considers there is a further advantage where people living downstream are not artificially deprived of water.

Figure 2.2: Lateral view of sand river channel showing sediment retention and water levels in relation to the riverbed and sediment surface level.



It is quite apparent, as indicated by (Jacobson, Jacobson et al. 1995) that every river and stream with sediment will at some time and to some degree retain a quantity of water in that sediment. Typically, even small streams which retain water for only a very few weeks in a year may well be utilised for their reserve of water at that time. This has been reported by Witoshynsky (2000) and Wipplinger (1958) and can also frequently be observed in small streams following periods of runoff. The amount of water, which can be retained in a given volume of sediment can be established through calculating the porosity, the ratio of the fraction of pore space or voids to the volume of material of the sediment. The period of water retention within the river channel is dependent on the recharge from rainfall to the river aquifer, the corresponding water-table level and losses from the alluvium. Figure 2.3 indicates the relative position of the groundwater-table in a dryland area to the river aquifer in seasons associated with differing rainfall.

Due to over use of water in a catchment area and because of changing land-use and river management practices, river channel aquifers may be increasingly utilised. In a report on water harvesting systems in Zimbabwe, Mlalazi (1995) states that in certain catchment areas the demand for water has outstripped the total potential water resource of the catchment area. He follows with a statement that many rivers that once flowed throughout the year are now no longer perennial. Cherepansky (1999) refers to the interrelation of surface and groundwater and to the negative effect that over abstraction

of groundwater may have on surface water flow. Andersen (1995) refers to a need to investigate groundwater recharge in response to surface water flow at the subcatchment level and to quantify the sustainable yield of shallow alluvial aquifers which underlie ephemeral rivers in arid and semiarid areas.

Figure 2.3: Unconfined aquifers in wet & dry seasons



Indira (1972) reporting on the situation in Kerala State, India, states that sub-surface water flow may become a major source of water as thick sand beds have materialised in all the river basins. The reason Indira provides for excessive sedimentation of river channels is the construction of numerous dams in major rivers and tributaries that has significantly reduced the surface flow and sediment transport in the rivers. A further contributing factor to this riverbed siltation is reduced residual soil moisture and thus soil stability in the catchment areas that has been caused by extensive deforestation. This, together with reduced river flow has meant that perennial surface flow in many of the major rivers has ceased. According to Jacobson, Jacobson et al., (1995) the Swakopport dam in Namibia has been the cause of excessive environmental deterioration downstream of the dam. He states anecdotal reports refer to falling water-tables, drying springs and dying ana trees.

Hartung and Bruns (1984) has exemplified an advantage of sand-abstraction. During attempts to provide water to a Somali refugee camp he located an alluvial sand bed but found it was highly contaminated by the intrusion of salt water from groundwater. A perennial river was available nearby, but the flow was turbid and tests showed the water to be contaminated with coliforms. The problem was overcome by abstracting water from the sediment in the river channel.

2.2.1. The Abstraction of Water from Sand.

It is a straightforward process to abstract the water that is retained within riverbed alluvium. In fact, in dryland areas a well-point that can be driven, jetted or dug into unconsolidated sediment in a riverbed is not only suitable, but significantly easier to install, than the construction of a well or tube-well on a riverbank. Arid and semiarid areas generally have very little alluvial soil, they are typified by consolidated sandstone or igneous rock which frequently breaks through the land surface. Although these rocks do breakdown to form shallow sandy soils there are often many rock outcrops and many large boulders close to the land surface which prevents the use of well-points. The rivers which cut through igneous soils frequently have a rock base and exposed rock in the channel which continues into the riverbank and precludes the possibility of riverbank abstraction. As it is also not possible to install driven or jetted well-points into consolidated sandstone, sand-abstraction from unconsolidated river sediment does offer a viable water source development alternative.

Larger, surface-dry ephemeral rivers retain significant amounts of water in the river sediment that can be abstracted. In an article, "Refugee water supplies in Somalia concept and development", Thomas (1987) refers to ephemeral rivers as sand rivers and points out that the most obvious source of water in much of semiarid Africa, where basement rocks are exposed and have been eroded into coarse sands and gravel, is found in sand riverbeds. After evaluating the various options for water supply to refugee camps and consideration of catchment, water storage capacity, evaporation and recharge at the various camp sites, he concludes "that a system of development based on the construction of shallow wells and infiltration galleries sited along the sand rivers could supply drinking water to most camps at a rate of five litres per refugee per day during the most critical drought, in years of normal rainfall". Garvey (1985) also refers to the provision of safe drinking water from an infiltration gallery in a 'dry' river to a refugee camp in the Sudan.

2.2.2. Typical Uses of Water from Sand-abstraction

Small-scale, Community Applications

Domestic Consumption - Drinking, Washing, Cooking.

Because of the natural filtration process associated with sand-abstraction, a properly managed system does provide a clean, potable source of water for domestic use. Frequently such supplies are preferred to borehole water supplies which quite often are unpalatable due to tainting with mineral salts, this particularly occurs in arid areas.

The rural business centre of Tsholotsho, in western Zimbabwe draws its water from the sediment of the Gwayi River which flows seasonally 30 kms to the east. Sand-abstraction water provides water for the district hospital, the local Government administration offices, the shops and small businesses of a community of 15,000 people, (Dube 2001). A sand-abstraction system provides water to a similar local government and business centre of some 5,000 people at Kezi in the Matobo District of

south-west Zimbabwe. The author has designed and installed a sand-abstraction water supply for a 50-bed hospital at Tshelanyemba in the Matobo District of Zimbabwe.

Livestock Watering

According to Jennings (1927) sand-abstraction has been a practice in Zimbabwe since the early days of settled farming when it provided an excellent water supply for the beef industry. Even in less than optimum conditions sand-abstraction systems provide a most suitable source of water for livestock. Peters (1996) refers to the advantage of seasonal wells to nomadic groups and their livestock. He states that seasonal wells dictate how long a group stays in one place before moving to new pastures. In this way marginal land is sustained and allowed to regenerate, whereas, where boreholes have been drilled to access deep groundwater, the land has deteriorated through increased livestock numbers and consequent over-grazing and intensive cultivation. Being drawn from a shallow supply, water can be quickly and more easily supplied to animals than from a borehole supply.

Irrigated Gardens

Particularly where gardens can be established on low riverbanks, not too distant from the rivers edge, sand-abstraction systems provide an excellent, low cost option to convey water to nutrition gardens. One small handpump is sufficient to adequately water more than 200 m² of garden – an average size traditional style brushwood fenced garden in Zimbabwe. Windram (1987) who advocates micro-scale irrigation cites the convenience of drawing water from alluvium and states that shallow groundwater can also be used as a domestic water supply. Hazell and Barker (1995) refers to sand alluvium aquifers in the Sahel as a major source of water for irrigation and notes that the recharge is from the seasonal rivers flowing into the district from the wetter south. (UNEP (2000) cites extensive irrigation of wheat, early cotton and sugar cane from sand-abstraction sources in Zimbabwe.

Economic Purposes

Water drawn from sand-abstraction systems frequently supports a variety of smallscale, subsistence level, household and income generating activities. These include building construction, concrete block and burnt-brick making, repairs to the mud plaster floors and walls of traditional households, grass and reed basket making, community beer brewing, water vending and small stock husbandry.

Commercial Applications

Water from sand has contributed to the industrial development of the hinterland of Southern Africa. The railway from Cape Town reached Bulawayo, in present-day Zimbabwe, in 1897. According to Hewson (1970) the lack of permanent water supplies in Botswana posed a considerable problem in the construction of the railway line from Mafikeng to Bulawayo. For most of the route water was transported long distances by rail tanker, except at the Shashi River where copious supplies were found in the river sand and could be drawn by sand-abstraction.

Irrigation Schemes

Irrigation is probably the biggest use of sand-abstraction water. Some of the larger irrigation schemes which draw water from an alluvial source in Zimbabwe have been recorded by Owen, Rydzewski et al. (1989), table 2.1. Many of these, which were first

established in the 1950s, are in remote communal land areas and were intended as community development projects.

Table 2.1:	Irrigation schemes in	Zimbabwe using alluvial	water, (Owen,	Rydzewski et
al. 1989)				

Scheme	Province	River	AlluvialIrrigatedWaterAreaYield(ha)(l/sec)		Comments
Chisumbanje	Manicaland	Save	760	2,400	State farm scheme: Well-point system in the river
Middle Sabi	Manicaland	Save	600	12,000	Commercial scheme 4 boreholes – part supply
Mutema	Manicaland	Tanganda	150?	237	4 boreholes part supply
Gudos Pool	Masvingo	Save	40	?	1 sand-abstraction unit
Malikongo	Masvingo	Mwenezi	35	24	1 sand-abstraction unit
Manjini	Masvingo	Mwenezi	17	35	1 borehole on alluvial plain
Muteyo	Masvingo	Mkwasine	?	15	1 sand-abstraction unit
Fanisoni	Matabeleland North	Shangani	?	11	2 sand-abstraction units and weir
Lukosi	Matabeleland North	Lukosi	15	12	1 sand-abstraction unit Insecure supply
Bili	Matabeleland South	Shashe	17	23	1 sand-abstraction unit
Chikwarakwara	Matabeleland South	Limpopo	90	65	2 sand-abstraction units and 2 boreholes
Jalukanga	Matabeleland South	Shashe	113	121	Sand-abstraction unit
Kwalu	Matabeleland South	Umzingwane	?	120	Sand-abstraction unit
Mambali	Matabeleland South	Shash e	10	28	1 sand-abstraction unit
Rustlers Gorge	Matabeleland South	Shashe	?	70	Sand-abstraction unit
Sabasa	Matabeleland South	Tuli	43	43 60 1 sand-abstr	
Shashi	Matabeleland South	Shashi	200	80	9 sand-abstraction units
Nottingham Estate	Matabeleland South	Limpopo	?	400	Well-point system
Estate River Ranch	Matabeleland South	Umzingwane	?	100?	Well-point system
Grootvlei	Masvingo	Limpopo	360	-	2 test boreholes – no scheme developed

The author was involved in the refurbishment of the scheme at Mambale in 1998 and 1999 when the well-points and manifold and the pump, engine and priming tank were replaced. Chisumbanje, Chikwarakwara, Nottingham Estate, Shashe and Mambale irrigation schemes have also been visited by the author. An account of a visit to these and several other schemes, undertaken with two colleagues, Michelle Clanahan and Stewart Helm in 1999 is presented in appendix 01.

Chisumbanje is reputed to be the world's largest irrigation scheme abstracting water from river sediment, (Broderick 2000), (Dube 1999), (Prince 1983). The original scheme was developed during the 1970's but was enlarged during a severe drought in 1983 in order to irrigate 2,400 hectares of crops for local consumption, (Mpofu 1996). The installation was undertaken by bulldozing away 2.5 metres of surface sediment in the riverbed down to the water-saturated level. This was carried out so that 3.00 metre lengths of screen could be jetted deep into the sediment. The scheme was designed to deliver 1,200 m³ per hour through 24 × 150 mm Johnson screens. Pumping was initially carried out at 1,620 m³ per hour for 1,366 hours in the first dry-season and then at 1,224 m³ with 7.4⁶ m³ pumped in the first 14 months of the scheme. Following the success of this installation further development of the scheme and a further pumping capacity of 43,200 m³ per hour was planned. Estimates of the water storage capacity of the sediment were estimated at 650^6 m³, (Heinze 1989).

During the extreme drought in Zimbabwe of 1991-92 when all main supply dams were dry, Hippo Valley Estates successfully used water from sand-abstraction to irrigate sugar cane, (UNEP 2000). Hippo Valley Estates are also producers of citrus and deciduous fruit, some of which is irrigated from sand-abstraction supplies. UNEP (2000) also state that the parastatal Agricultural and Rural Development Authority (ARDA) of Zimbabwe uses water from sand-abstraction sources for the irrigation of winter wheat and early cotton crops. Nottingham Estate in the Beitbridge District of Zimbabwe draws water from the seasonal Limpopo River primarily for the irrigation of citrus and dates but also grows winter wheat and summer maize crops under irrigation from sand-abstraction, (Matare 1999).

Ranching

At the large-scale commercial level several up-market wildlife and tourist facilities obtain water from sand-abstraction supplies. Cattle and game ranching is also an important commercial activity in areas where the average annual rainfall is between 250 and 650 mm, (Morton 1958). Many of the drier parts of Zimbabwe, Botswana, Namibia and South Africa are within these rainfall limits and many of the rivers are consequently ephemeral and are now sand rivers. Commercial ranchers have used water from sand-abstraction to provide drinking water for their livestock for many years. Several retired pump technicians interviewed by the author, among them (Cooke 1987), (Esterhuizen 1987) and (Schegar 1996) worked for many years in the 1950s to 1970s with commercial pump companies on the installation of sand-abstraction cattle watering schemes. Many of the companies and parastatals involved at that time still undertake commercial installations today. In the early 1960s Schegar developed a portable sand-abstraction pump based on a sand-spear which could be pushed into the river sediment. The sand spear protruded through a steel plate on which was mounted a small diminishing cavity pump, a petrol engine and a priming tank. The unit could be moved from site to site as and where cattle required water.

Small Town Water Supplies

Sand-abstraction systems supply several small towns in southern Africa with domestic water. Swakopmund on the coast of Namibia drew water from a sub-surface dam on the ephemeral Swakop River for many years from the 1920s to the 1960s, (Wipplinger 1958) and (Heyns 1999). However as the river has its headwaters in the dry interior and then traverses one of the world's driest deserts, the Namib, recharge to the river is low and with the continual growth of Swakopmund the sub-surface dam is now unable to provide all the towns' water requirements. Consequently much of the water for the town now has to be provided by desalination. However (Jacobson, Jacobson et al. 1995) states that there are still many small towns in Namibia that rely on sand-abstraction for their water supply.

A similar situation occurred in Botswana where the town of Mahalapye drew much of its water requirements from the alluvium of the Shashe River, (Turk 1979). However as the town developed and required increasing amounts of water, supplies were increasingly met from deep groundwater supplies. Currently a 1.20 metre diameter pipeline is under construction from Gaborone in the south to Francistown more than 500 kms in the north which will pass through Mahalapye. Again Shenkut, Zeleke et al. (1994) reports on the installation of an infiltration gallery in the Baro River, Ethiopia, which he designed to provide water to the town of Gambela to World Health Organisation (WHO) standards.

2.3. Advantages of Sand-abstraction Systems

The system of sand-abstraction is a time-honoured, traditional technology that is completely understood and appropriate to the drawing of water from saturated sand and gravel-beds. It is a basic technology that is very much within the domain of community control and management. In low-level technology schemes, operation and maintenance costs are low, as are in general, installation costs. In the main the water may be considered potable, as the water drawn has undergone a basic filtration process, (Helm 1998).

Low Cost Installations

No drilling, digging or earth-moving is required with small-scale schemes. The chief requirement is labour and the implement, a mere shovel. In this way the dry surface sand can be removed to expose the water-bearing sediment. The most commonly utilised technology is very basic, an installation comprises one or more well-points which are inserted into the river sediment. The well-points keep sand out of the system whilst allowing water in. In a typical low-tech installation well-points are connected by uPVC pipe to a simple handpump on the riverbank and from there the water may be utilised in any manner.

Sustainability

Sand-abstraction is the natural development of a traditional manual system. Most people who live beside sand filled waterways utilise this technology by digging down through the exposed sediment of the river or stream until the water level is reached. Water is collected in scoops and bowls as it seeps through the sediment into the depression. The developed technology of sand-abstraction merely builds on this process by utilising methods of mechanical abstraction rather than a basic hand abstraction method. The technology requires only the minimum of infrastructure, unlike boreholes, dams and piped water schemes. This technology is also suitable in localities where shallow groundwater is held in saturated sand aquifers.

In its simplest form, a pumped sand-abstraction system is also very simple and involves no complex equipment. The essential pump parts used can be plastic mouldings with valves made from vehicle inner tubes that can be easily cut and fitted by the end-users themselves. People with only minimal technical skills are thus able to maintain the entire system. Simple installation and operational training requires only basic technical appreciation and can easily be provided to enable maintenance and servicing of the pumps and well-points.

Filtered Water

In effect the water utilised runs through a huge, slow, natural sand filter and when pumped out is invariably very clean and considerably more fit for drinking than is water collected from open-surface dams or perennial rivers, (Lovell 2000), (Visscher, Paramasivam et al. 1987) and (Helm 1998). Tests have been carried out on water drawn from the sand of several rivers in Zimbabwe and only minimal coliform counts have been found, (Hussey 1998(a)).

Palatable water

Water abstracted from river sediment has not been contaminated by prolonged contact with mineral salts, as is often the case with deep groundwater. A river sediment aquifer typically comprises the upper part of an unconfined, free draining aquifer or is a perched aquifer above the residual groundwater level. Even where there are salt contaminated aquifers near the ground surface, water within the river sediment will form a 'water lens' above the salt water as the uncontaminated water has a specific gravity lower than the salt contaminated water. This constitutes an important advantage of sand-abstraction and in fact may be the salvation of people living in particularly arid areas where salt contaminated groundwater comprises a particular problem, (Jacobson, Jacobson et al. 1995), (Chinemana 1992) and (Mlotshwa 1996). Figure 2.4 shows a sample of sand-abstraction water alongside samples of groundwater containing high levels of coal, sulphur and sodium that were taken by the author from wells and boreholes in the Dongamuzi area, Lupane District, Zimbabwe.

Figure 2.4: Contaminated groundwater samples, (Hussey 1998(c))



Constant Supply and Drought Mitigation

For residents of permanently inhabited areas large sand rivers provide a perennial source of water in seasons of average rainfall. Even in seasons of drought or

inadequate rainfall, precipitation is generally sufficient to cause runoff and drainage to a river system so that the sediment becomes saturated and the river flows. Although in adverse rainfall years flow may be only for a short period, the water source will again be replenished although it is likely that it will be subjected to greater levels of loss and a consequent more rapid deterioration of the water level. Although losses from seepage may increase, water deep in the sediment will not be as prone to the high levels of evaporation usually associated with a drought year. In such circumstances water often drains to a depression in the riverbed from where it may still be abstracted.

Environmentally Friendly

The sand-abstraction method of harvesting water has no detrimental effect on the ecology or the environment. As a part of a high, or perched groundwater-table, the deeper groundwater reserves are not depleted and therefore abstraction causes no adverse effect on vegetation in the area. Water held in the river sediment can be expected to slowly infiltrate the riverbed as part of the recharge of the deeper groundwater-table. Water abstracted from river sediment does little to the detriment of groundwater reserves as much of the water abstracted from the perched aquifer would have been lost either through evaporation or downstream drainage and in arid and semiarid areas, throughout the season, there will be an overall deficit in groundwater levels due to a natural drainage process to lower levels.

To utilise a sand-abstraction system no vegetation need be cut down nor destroyed, the technology merely makes use of water percolating through a natural drainage system. It is however dependent on the heavy sedimentation of rivers but this is, in itself, a natural phenomenon. In a totally natural state, except in a desert environment, most riverbeds would be comprised of open pools of water with trees and lianas, reed beds, sedge and grass throughout. However, in many localities erosion and sedimentation has been occurring over decades if not centuries and thus the ecosystem of wildlife, fauna and flora that a river supports have altered along with the river. Effective conservation measures are imperative and must be undertaken to contain further, excessive erosion of soil in a river catchment area.

2.4. Disadvantages of Sand-abstraction Systems

River-based System

Although water can be abstracted through well-points where groundwater exists in saturated sand or gravelbeds, sand-abstraction systems are essentially river-based. The development of deep groundwater sources however, eases the concentration of settlements along rivers and in surface water source areas by enabling people to settle far from traditional sources of water. A sand-abstraction system generally only provides water in sufficient quantity in the immediate area of collection or storage and necessitates a pipeline or vending system to deliver water to further population centres. People may have to have travel long distances to collect water from a sand-abstraction system, (Hussey 2000).

Bio-fouling

Among several people interviewed by the author, Cooke (1987) and Kempadoo (1994) cite in some sand-abstraction systems, a deterioration in yield due to clogging of pipework or the well-point abstraction zone by silt and fines. In some situations as experienced by Clanahan (1997), conditions become conducive for the growth of iron-

based algae inside well-screens and infiltration galleries to the extent that severe blocking of the abstraction system results in reduced water supply rates. However, indications are that this occurs in riverbed intake systems in perennial rivers, rather than in seasonal river installations. Although Howsam (1990) advocates the use of hydrochloric acid to rehabilitate wells, gravel packs and well screens that have become clogged by bio-fouling, Clanahan reports very little success with acids to clear iron based deposits. Similarly Clanahan (1999) reports that she has achieved little success in removing deposits by back-washing an abstraction system through reverse pumping from a supply tank, but greater success with the use of hydrogen peroxide.

In an attempt to establish the cause and to increase supply rates in an infiltration gallery system designed by Clanahan (1997), Michelle Clanahan conducted a survey of more than 20 sand-abstraction sites in both perennial and ephemeral rivers throughout Southern Africa. Unfortunately the study was not completed as the samples obtained from each site became inextricably mixed at the test laboratory.

Flood Damage

Damage may occur to an installation from a river in spate. Although a well-point placed deep in river sediment may itself not suffer damage, the connecting pipes from the well-point to the pump on the riverbank are vulnerable to breakage or uncoupling if they become exposed during sediment transport. Moyo (1994) reported that it is often difficult to place delivery pipes sufficiently low in unstable, saturated sediment to avoid damage from turbulence of the fluidised sediment during a flood. This situation is particularly acute when installations have been undertaken at a time when water levels precluded the deep installation of pipework or if installations are unsupervised and undertaken by hand. Although the installation is still best effected towards the end of the dry season when the residual water level is at the greatest depth in the sediment and a greater installation depth can be obtained for the delivery pipes.

Where the well-point, tube-well or well reaches the surface of the sediment with no delivery pipe to a riverbank, the well-point itself may be washed away in a flood. Alternatively the tube-well or well may be temporarily rendered useless if filled with sediment. This finding has also been observed by (Nissen-Petersen 2000) and (Jetten 1991).

Little Utilised Supply System

Effective groundwater drilling systems have been developed and a variety of sustainable abstraction systems have been developed to cater for a wide range of situations and conditions. Groundwater drilling has become a virtual standard for the rural water supply industry. Although it is well documented and the abstraction of groundwater through well screens in unconsolidated aquifers is a common practice, the technology of sand-abstraction has remained largely unutilised and undeveloped within the water supply industry, (Hussey 2000).

Many water professionals consider that a standardised system of groundwater abstraction provides the best solution to rural water supplies. Groundwater infrastructure and service and maintenance support systems have thus been developed accordingly. It is now quite possible for one or two women to operate, maintain and repair deep-water handpumps. According to Baumann (2000), with open top cylinders and retractable pump columns it is quite possible for a village caretaker to operate and maintain a handpump system with basic tools, on their own or with minimal unskilled assistance. As a result of the proliferation of boreholes, people automatically relate to groundwater supplies and thus groundwater is often perceived as 'the best', if not the only solution to water supply requirements. Rural communities are often attracted to the technology which requires little input on their behalf and makes water available in a very short time. Drilling technology is also popular because people believe the deeper the borehole, the more reliable will be the water supply. It is generally believed that there will be plenty of water from deep-groundwater drilling, (Hussey 2000).

2.5. Methods of Abstracting Water from Sand

There are several systems of sand-abstraction which have been developed over the years. Each system is dependent on equipment that can be installed into the water-bearing river sediment and at all times remain in free moving water. In a correctly designed system a graded filter zone develops around each well-point or caisson. As water is initially abstracted so fines are drawn with the water from the sediment in the immediate zone of abstraction around the screen of the well-point or caisson. Larger grains of sediment are either unable to pass through the screen apertures or are not transported by the flow of water, smaller grains then wedge against larger grains until the passage of fines is restricted. The flow of water into a well-point is thus improved as the void area in the immediate abstraction zone is enlarged and blockages are minimised. This process has been explained by several writers such as (Johnson 1966) and (Michael and Khepar 1989).

Schemes range in size from small-scale hand operated supplies through to large mechanised, diesel or electric powered irrigation schemes on big rivers.

Abstraction methods generally comprise one of the following:-

Screened Well-point System

In order to draw water that does not contain particles of sediment, most sand-abstraction systems are dependant on screened well-points to separate water from the alluvium. Well-points may also be known as sand-screens, sand-points, sand-spears or drive-points. Slotted screens and synthetic filtering materials which can be used in river sediment or alluvium, are used extensively as tube-well and borehole screens by the water drilling industry, (Driscoll 1986) and (Gibson and Singer 1969).

For abstraction purposes one, or several well-screens are connected directly to a hand or mechanically powered atmospheric pump on the riverbank. Water is drawn through the screen to the point of discharge. A number of fabricated screens in uPVC, steel or stainless steel are commercially available. Installations are best carried out when the river water is at its lowest level, when the well screen can be dug into the sand. Alternatively when the river sand is saturated with water to full depth, well-screens can be pushed, or jetted into the lower levels of sand in an artificial quicksand condition which is caused by a water jet from a motorised centrifugal pump. This system of installation is relatively technically complex and is dependent on materials and equipment often not readily available in disadvantaged areas. It also has the associate problem of not being able to get the draw-off pipe deep enough into the sediment to preclude damage during subsequent river flow.

Infiltration Gallery System

An infiltration gallery induces the same mechanical separation of water from sediment as a well-point. Water enters the gallery from alluvium and is discharged from the gallery by hydraulic head. As there is generally only a small hydraulic head above an infiltration gallery the screen section is of a considerably greater length than a wellpoint screen. Bennett (1970) defines an infiltration gallery as a permeable, horizontal or inclined conduit into which water infiltrates from an overlying or adjacent source. He states that galleries are constructed below the water-table in areas where there is sufficient recharge to offset the pumping rate and where the permeability of the natural soils is sufficient to transmit this quantity of water to the gallery under existing head conditions. By this definition Bennett maintains that rock-lined aqueducts, 'Maui-type' wells and field tile drains are also types of infiltration galleries. According to Stone (1954) North American cities as large as Des Moines, Iowa; New York City, New York and Los Angeles, California; as well as many other smaller cities have exploited infiltration galleries as a means of simple water treatment and supply. Infiltration galleries have been used to great success on several occasions for water supplies at remote locations on the Scottish Isles, (Jones and Singleton Undated)

This type of system is particularly suited to perennial river installations although it is difficult to ensure that any system of infiltration gallery is sufficiently deep in the sediment of seasonal rivers to be maintained in water at all times. Further it necessitates much digging into both the river sediment and the riverbank. However, unless earth-moving equipment is used, it is a relatively inexpensive system and does not require complex equipment or expertise to operate or maintain. A windlass or basic handpump can be utilised to draw water from the false well.

Caisson System

An alternative method of water abstraction from river alluvium is through a caisson buried in saturated sediment. A caisson is typically cylindrical with a base diameter any measurement from 150 to 1,500 mm. The base or sides of the caisson are generally either slotted or drilled to create a screen. Depending on the nature of the screen and the diameter of the caisson, screen entrance velocities are likely to be particularly low, sufficient to maintain laminar flow to the screen. Such a low abstraction velocity makes caissons particularly suitable for use in fine sediments. The caisson is connected by pipes to an atmospheric pump on the riverbank and requires digging into the river sediment as deeply as possible. As the water level drops during the season so it is further lowered to remain in water. The installation is complete once a level has been reached where the caisson remains in water year round, which may not be achieved in the first year of installation.

The system is more awkward with the continual re-digging and lowering of the caisson into sediment but because of the large surface area from which abstraction takes place it may be possible to use where silt tends to accumulate. However, although water can be drawn from very fine sediment, layers of silt are likely to impede the flow of water to the abstraction zone of the caisson and thus abstraction may not ultimately be successful.

Sand Well System

The most basic method of drawing water from a sand river is from an open depression excavated in the river sediment, referred to as a sand-well or scoop-well. The natural upgrade of this traditional form of open well is a protected well. However, a well dug into the river sediment is liable to damage from river flow, either demolished by the flow of water or in-filled by sediment carried in the river flow. The Rural Industries Innovation Centre (RIIC), Kanye Botswana have constructed protected sand wells using concrete rings of 1.25 metre diameter. The rings are installed on the riverbed base and extend to a half metre or so below the sediment surface. The resulting well shaft is covered with a concrete slab. The lower rings are constructed of no-fines concrete to act as a sediment screen. Water is abstracted from the well by a suction pump which is sited in a sump on the riverbank to avoid damage to the installation during the rainy season when the river is flooded, (Rydtun 1992). During the dry season the well may be uncovered to allow direct abstraction of water from the well.

Figure 2.5: Hydrodynamic well-head, (Nissen-Petersen and Lee 1990)



Nissen-Petersen (2000) advocates the construction of sand-wells within river channels. The wells, which he refers to as hydrodynamic are illustrated in figure 2.5 and are designed to allow floodwater to pass over without damage. Nissen-Petersen's well design is constructed from radiused concrete blocks with the lower 8 courses laid without building mortar to allow infiltration into the well. The top of the well protrudes from the surface of the river sediment and is surrounded with rock and rubble overlaid with concrete. This headwork is of a hydrodynamic shape with a cover to exclude river sediment filling the well shaft. The shape of the well head is akin to that of an up-turned boat which allows water to flow around and over the structure and does not collect the debris carried by the river which could build up and lead to its being washed away.

2.6. Historical and Traditional Use

2.6.1. Sources of Water

In harsh environments where there is virtually no surface water and where water is in short supply, people have drawn small quantities of water from the sand since time immemorial. Water has long been abstracted from underlying moist layers of sand in watercourses and pans that act as natural water collection areas. Hodson (1896) states that the San people, the original inhabitants of the dry interior of southern Africa categorised water into five types and refers to an 1856 report of a hunter, Gordon Cummings, who recorded how the San drew water from the sub-surface at what he refers to as 'sip wells'. Van der Post (1958) and Thomas (1959) similarly both record the San people drawing water from underlying saturated sand.

Hodson was intrigued by the effectiveness of a method of abstraction devised by the San which enabled them to draw water from remote parts of the Kalahari Desert where there was no well or river. He recounts that a hole was dug where water was known to exist beneath the surface, a large bunch of grass was placed in the hole and a long hollow reed pushed into this. The tightly packed grass was then covered with sand and the hole filled. Water infiltrated into the grass-filled cavity and by sucking on a reed a woman was able to draw water from the sand. The water was then squirted into ostrich eggs for storage, (Hodson 1896).

This is a traditional method of drawing water from sand in extreme conditions by people whose ancestry reaches back to Palæolithic times and the dawn of humankind. The San, or Bushmen are considered the descendants of Aurignacian man, who was once dispersed widely over Africa and southwest Europe, (Jones 1949). The technique of utilising water held in saturated sand has thus probably been in use for a considerable period of time, probably some 40,000 years. Price (1996) refers to the earliest members of the human race who would be dependent on a spring or river for their water. If during a dry period the river were to dry up he anticipates people digging a hole at a damp point in the riverbed to reach water just below the surface and states that in places like the Sudan, in ephemeral rivers, this system of drawing water is still practiced today.

The occurrence of water in dry riverbeds has been recorded by Stevenson-Hamilton (1929). He states rather poetically, "There are also a multitude of dry watercourses, ranging from the size of considerable rivers to that of small drains, which carry water only during the rainy season, and then, but for a few days after each deluge. In the larger of these, during the remainder of the year, water is found with difficulty in pools – which frequently dry up towards the end of winter – or by digging in the sandy beds. All the rivers run over floors of granite sand, which alternate with natural dams of granite or basalt. The brims are usually margined by dense fringes of tall reeds, while the beds of many of the drier watercourses are choked with masses of handsome dwarf plants".

Rural people living near rivers to this day utilise this method of digging pits in riverbeds to collect clean water for a variety of purposes; domestic, livestock, nutritive and economic. To abstract this water, holes are dug in the sand until the water level is reached. As the water level lowers, so the holes are deepened until they become sand-wells. (Hussey 1998(b)) and (Sutton 1999(a)). Reference is also made by Witoshynsky (2000), (Head 1981) and Ellert (1984) to methods of obtaining clean water from traditional sand water sources and then to methods of keeping the water clean and cool by storage in clay pots. The drawing of water from saturated silt beds is a thus a traditional and a proven technology which has evolved in many arid and semiarid areas.

Historically, limited water requirements were relatively easily met as traditionally use was essentially limited to personal, domestic and household requirements. According to Roark, Yacoob et al. (1989) the basic demand of people is 20 to 40 litres of water per day. The requirement of cattle is also 20 to 40 litres and of sheep and goats 5 to 15 litres per day. Until the advent of irrigation in the 1940s and 50s livestock constituted the largest water requirement. Unlike the Middle East and parts of North Africa, traditionally there was little or no use made of water for irrigation in the Sub-Saharan arid and semiarid areas of the African continent. As exemplified by Grove and Sutton (1989) and Sutton (1989) terracing and diversion runoff farming were restricted to the bush savannah areas of higher rainfall, (600 to 900 mm per annum), rather than in the arid or semiarid areas, (150 to 600 mm per annum), as denoted by (Wood and Ryden 1992).

A further ancient system of obtaining water from colluvial sediment is the ganat. Barrow (1999) refers to ganats which date back some 3,000 years and are a traditional means of exploiting shallow underground aquifers and of capturing runoff from ephemeral or mountain streams. To construct these conduits a 'mother well' is driven down to the groundwater source and a gently sloping tunnel is dug to connect it with a habitable area. Vertical shafts at periodic intervals along the tunnel connect the tunnel with the surface. These shafts were convenient for the construction of the original ganat and today allow access and ventilation for maintenance. Oanats were once used extensively in the present-day Middle East and the Gulf, as far as India and China. Qanats were also constructed in North Africa, where they were known as foggara. The technology has been used in 22 present-day countries including South America and still provides 75 percent of the water requirements of Iran. According to Birks (1984) several million people are still completely dependant on ganats, or as they refer to them, aflaj for both primary and secondary use water. However, they also point out that due to urbanisation and a proliferation of engine-powered pumps, many of the aflaj are deteriorating due to the present trend of little or no maintenance.

2.6.2. Land Use and Water

Typically in Africa, traditional life patterns were based on a system of shifting agriculture, known in Central Africa as *citemene*. To implement citemene, the natural vegetation and bush cover was cleared and burnt to improve the soil for crops. The resultant ash was beneficial over some three years but then soils were generally depleted and a new site was required. The growth of bush and natural grass restored the fertility of the plot and after an average of 21.4 years the land could again be used for cropping, (Allan 1965). Cropping practices within these cultivated plots was also suitable as a symbiotic inter-cropping of cereal, legume and cucurbit crops guaranteed an effective ground cover which minimized soil erosion. Such land management patterns were sustainable and in harmony with nature, they were totally appropriate and a part of the ecology of the region when human and livestock numbers were limited, (Hussey 1987).

With the advance of colonisation at the turn of the 20th century, land was divided and fenced and such systems became impracticable. Because of the new land tenure system, people were frequently settled in areas where water supplies were less available to them, (Ranger 1999). At the same time there was a significant population increase, which resulted in an even greater need for water and more so in the areas of poor water potential where people were forced to settle, (Werbner 1991). In the drier areas the land was best suited to ranching and the settler farmers thus commandeered the better grazing and river frontages. These areas also held the better hydrogeological potential for groundwater development, (Surveyor-General 1984). As a result of this the indigenous people were forced to move away from rivers and to lose their traditional water supplies.

According to Morton (1958) much of the erosion that has occurred in Zimbabwe may be attributed to cattle. He states that cattle have upset the balance of nature that existed before human occupation. Unlike game that forages over a wide area cattle graze and browse over a small area creating narrow tracks as they move. These cattle paths collect water and invariably are the cause of gully erosion. Cattle also graze riverine pasture and much grazing land is subsequently destroyed, resulting in sheet erosion. Morton maintains that the ensuing erosion is largely responsible for the siltation of rivers. As human populations have increased in Africa so to have livestock numbers to the extent that in many areas, particularly the pastoral areas, livestock have outstripped the stocking capacity of the land. Today there is a 'biological' land stocking rate effective in much of Africa. The droughts and low average rainfall seasons, as well as contagious diseases, which are common in the arid and semiarid areas decimate herds of livestock and thus livestock numbers are severely reduced. However with better rainfall seasons and subsequent improved grazing, livestock numbers increase until grazing is again diminished and numbers are reduced in the next drought.

Coupled with poor management of grazing land, frequently there is also poor management of arable lands. With the increase in human population there has been an equal increase in arable land. In order to provide basic staple food requirements subsistence farmers often attempt to crop extensive marginal land. Livestock are turned into these lands to forage the crop residue when harvesting is complete and remain there during the dry-season. Consequently when the rains do come, they fall on dry exposed ground that is easily eroded. Lusigi (1992) refers to the misuse of extensive ecosystems such as the arid savannas which in Africa are changing the Sahel to desert. He states that this widespread impoverishment frequently leads to the destruction of ecosystems and damages the adaptive ecological processes on which survival depends.

Human populations continue to grow in Africa placing further increases on marginal land. In parts of both the Sahel and the Ogaden there are frequent land disputes between the traditional pastoralists and new crop farmers who settle the land. Poor land planning and land utilisation systems and a continuing adherence to inappropriate traditional land use and farming practices based on cultural requirements, create undue pressures on the land and force inhabitants to engage in unsustainable management practices. Unnamed (2000) indicates the need to increase levels of organic matter in order to improve soil fertility and to arrest soil depletion, but also acknowledges the difficulties in achieving this when inappropriate agricultural practices cause soil degradation and high cost limits the transport of organic matter.



Figure 2.6: Mature timber felled for firewood, (Mukwazhi 2002)

Unfortunately the prognosis for the future is not good. With continuing increases in population and poor prospects for industrialisation in Africa, unsustainable pressure can only be expected to increase on the land. The indications are that the economies of southern Africa in particular are becoming increasingly subsistence oriented creating a 'hand to mouth' existence with the threat of increasing pressure on marginal land without the implementation of suitable conservation measures. To worsen the situation wood remains the most common and the most popular method of heating for both

cooking and space heating with generally little regard to sustainable cutting or replanting of timber leading to further environmental deterioration. Mature timber remains especially prized as shown in figure 2.6 with timber cut for firewood from former commercial farmland by resettled small-scale farmers.

2.7. Related Systems and Alternative Sources

2.7.1. Related Systems

Parallels can be drawn between the technology required to abstract water from sand rivers and that of abstracting water from sand and gravelbed aquifers. The materials and equipment which are required to abstract water from river alluvium are very similar to those used to abstract water from sand and gravelbeds. Although the installation technology may differ, a well-point screen is as appropriate in a sand-abstraction application as it is in a tube-well or even a borehole. The criteria for screen technology, the slot aperture, shape and dimension apply equally whether the screen is used in river alluvium or in a sand or gravelbed.

The equipment and methodology required for the productive abstraction of water from sand-abstraction is also utilised in land drainage and the de-watering of construction sites where water is unwanted. The design of materials and equipment primarily manufactured for the continuing drainage of building foundations and basements, bridge pier foundations and applications such as the drainage of unstable motorway cuttings is also relevant to the technology of sand-abstraction.

A whole new concept and technology was required with the need to rapidly absorb the large volumes of storm water that can be expected to fall on car parks with a 100 percent run-off. Storm water has to be able to infiltrate the sub-surface as quickly as possible before the volume of run-off water exceeds the capacity of the drainage system. In some instances to reduce contamination, before the runoff water is allowed to drain into the water-table the oil that has been washed from the car-park surface by the storm water is separated out. The filtering and infiltration process required is relevant in both technology and materials to sand-abstraction technology.

2.7.2. Alternative Sources of Water from Sand

The use of sand-abstraction technology is appropriate wherever alluvium is unconsolidated. Alluvium occurs as a natural formation in present-day river channels, fossil riverbeds and sub-surface sand and gravel beds of paleo river channels. A fact sheet from Queensland, Australia, refers to water drawn from the alluvium of river valleys and states that alluvium is the name given to sediments comprising the flats associated with watercourses, (DNR Water Facts 1997). Beds of alluvium in which water may be stored and subsequently abstracted may also be created artificially as in sand-dams and hafirs.

Sand Dam

In situations where there is a limited accumulation of river sediment, water is only retained for short indeterminate periods during the rains. Although water losses from leaching, drainage and evaporation are reduced in the sediment it is not always possible for water to be retained year round. The construction of a dam may increase the supply of available water but in areas with high rates of environmental degradation there are often high rates of siltation that may render a dam useless in just a few seasons. However where coarse sediment accrues, water is retained in the sand of the dam in the same manner that water is retained in a riverbed. Increasing the depth of the sediment retains more water. A sand dam as shown in figure 2.7 retains the sediment which is carried by the stream or river and the water is retained in the sediment, thus a permanent supply of clean water which will not rapidly evaporate is ensured.

In order to retain coarse sediment a sand dam is constructed in stages to a height generally not exceeding 1.00 metre in the first year and little more than 0.50 metres in each subsequent year. In this manner coarse sand is deposited behind the dam wall and the finer, lighter sand is washed over the wall. Through this construction technique the fine silt which would clog and limit the water storage capacity of the dam is not retained. The coarse material that is deposited will constitute a highly permeable medium with a large water storage potential, (Nilsson 1988) and (Nissen-Petersen 1997).

As a sand dam is constructed above the level of the river sediment, (Gould and Nissen-Petersen 1999), the masonry wall is built in steps to reduce the velocity and height from which the water falls to prevent scour and undercutting and thus the possible collapse of the wall. Water can be drawn below the wall of a sand dam by gravity through a series of slotted pipes in the bottom of the sediment. Vertical pipes can be connected to these to ensure that any silt layers which have formed do not seal the upper saturated layers from the abstraction pipes.

An advantage of a sand dam is that it acts as a large, natural, slow sand filtration system through an aerobic filtration process of sedimentation, straining, adsorption and chemical and bacteriological action. These processes are an effective method of removing impurities such as fine silt, organic matter, bacteria and some mineral salts. In a controlled system where the sand filter is permanently saturated, a biological layer, known as a schmutzdecke, a 'dirt layer', develops and forms an effective barrier against bacteria.



Figure 2.7: Sand dam under construction

Sub-surface Dam.

A sub-surface dam provides an advantage in situations where there is already a significant depth of sediment but where due to excessive downstream drainage water is not retained year round. In areas where rivers have little slope many rivers are now so full that the entire channel is filled with sediment and particularly in flat areas, many rivers have no basin. The construction of a dam or a sand dam is thus not feasible, however the construction of an impermeable barrier within the sediment to raise the

water level, reduces downstream drainage and entraps water which otherwise would have been lost. Figure 2.8 shows a sub-surface dam between a cliff on one side of the river and extensive wind blown dunes on the other. The dam, photographed by the author, is across the Swakop River at Swakopmund, Namibia.

According to Jetten (1991) a common reason for damming a river is to store water below ground level in the reservoir upstream of the dam. A wall which is constructed on solid material in the base of the river and excavated to the same construction criteria as any dam wall will retain water in the sediment of the river channel and the adjoining aquifer thus increasing the volume of stored water. As it is supported by sediment on the downstream side and as there is no vertical drop to absorb, the wall of a sub-surface dam may be less substantial than that of a typical weir. However, as there is movement of the fluidised sediment during river flow, the top of a sub-surface dam wall should only be constructed to some 500 mm below the sediment surface in order to minimise turbulence and thus reduce scour and undercutting. The equipment and installation procedures utilised in sand-abstraction are equally applicable for the abstraction of water from a sub-surface dam.

A simpler version of a sub-surface dam which had been seen in Southern Ethiopia by O'Keeffe (2003) was described to the author. During the dry season, trenches were excavated in the sediment of ephemeral streams and the downstream side of the trench lined with polythene sheet. The trench was then back-filled leaving a vertical, impervious membrane across the river to reduce losses of downstream sub-surface flow. Annual replacement of the membrane was required but as the water was used as a supply for a nearby mission station, this was relatively easily accomplished.

Figure 2.8: Sub-surface dam



Wadi

In arid and desert regions endogenous rivers are known as wadis which may be little more than short, sand-filled ravines. However when there has been precipitation sufficient to induce run-off, water collects in wadis and as the alluvium is unconsolidated, sand-abstraction technology may used to draw water. Al-Sabahi (1997) suggests supplementing the limited water reserve in a single wadi by using galleries or qanats to link one or more further wadis to augment community water supplies in Oman. The FAO Freedom from Hunger Campaign reports that it has supported initiatives to successfully construct sand-wells in wadis in south western Ethiopia, (Bradfield 1992). Mbugua and Nissen-Petersen (1995) refers to check dams which are constructed across wadis and gullies. These structures are small walls that are bonded into the gully base and sides to retain eroded topsoil. Check dams can be constructed of locally available stone, either built with mortar or as a dry-stone wall. These micro-dams retain water in the alluvium of the gully and contribute to the recharge of groundwater. As check dams retain eroded material so they rehabilitate gullies and improve land that has deteriorated through erosion and where they retain sufficient water they may be used as a sand-abstraction water supply.

Sand-filled Water Storage Tanks

Pastoralists south of the Sahara traditionally stored water in a hafir which was an excavated pit in or near a wadi or waterway, (Pacey and Cullis 1986). Gould and Nissen-Petersen (1999) refers to hafirs of 15,000 to 250,000 m³ as common sources of water in central Sudan. These large unlined hafirs are known as 'sump hafirs' where they collect water from wadis, or 'contour hafirs' where they collect from contoured catchment aprons. Hafirs are prone to extensive siltation but when silted are not rendered useless as water may be drawn from the alluvium.

The concept of extending the period of water storage in a hafir by lining the pit with either plastic, uPVC or butyl sheet was developed by Ionides in the 1960's, Ionides (1966) and Gibberd (1968). Cement plastered tanks, known as 'birkads', were constructed in Somalia during the 1940s to collect run-off water, (Abdi 1995) and (Peabody and Yusuf 1999). Subsequently lined hafirs were constructed in Sudan, Somalia, Ethiopia and Kenya, (Wanyonyi 1992) and in Botswana, Zimbabwe and Francophone West Africa, (Pacey and Cullis 1986). Tanks ranged in size from 60 m³ in Botswana and Zimbabwe, (Gibberd 1992) to 200,000 m³ in Sudan, (Pacey and Cullis 1986). Hofkes, Huisman et al. (1981) describes the construction process of a hafir of 10,000 litres volume which is back-filled with sand, the design of the hafir is shown in figure 2.9. To increase the water storage capacity of the hafir, hollow domed structures called 'bee-hives' were constructed within the hafir. Hofkes also states that sand filled tanks have been constructed in Sudan, Botswana, Swaziland, Brazil and Jamaica.

Figure 2.9: Hafir with beehives to increase water storage, (Hofkes, Huisman et al. 1981)



Although the tanks were generally open and mainly used for livestock watering or irrigation, both Ionides and Gibberd experimented with sand filled tanks for domestic water, (Ionides 1966) and (Gibberd 1992). Vernon Gibberd provided household water from roof and yard runoff which was harvested in a sand-filled hafir. The water, which other than its passage through sand, was untreated, was hand-pumped from the hafir to a roof tank and provided water for a family of 5 for 5 years. To increase the water storage capacity of the hafir, porous domes which restrained the sand were constructed

within the filling. The abstraction of water was either through one open dome with a bucket on a rope or by a handpump and well-point in the sand.

Figure 2.10: Venetian cistern, (Hofkes, Huisman et al. 1981)



Sand-filled tanks for initial treatment and water storage such as Venetian cisterns, figure 2.10 and artificial recharge tanks have been referred to by Hofkes, Huisman et al. (1981). Such tanks may be filled from river discharge or from harvested surface runoff water. During a joint programme conducted by the United States and Israel research was carried out in Kenya into the use of sand to clean water before storage. Shallow collection aprons were dug and lined with plastic or butyl sheet which allowed collected water to drain towards an infiltration pipe which discharged into a storage tank, (Muni and Onyulloh 1992).

Gravelbeds, Water Lens

Where water is held in unconsolidated sand and gravelbeds, sand-abstraction installation and pumping techniques may be used to draw water. Where suitable sand beds exist, they may significantly augment urban water supplies. Gordon Maclear has indicated an extensive aquifer on the Cape Flats near Cape Town, South Africa, (Maclear 1995). Maclear (1997) has demonstrated to the author an effective method of jetting and abstracting this water for household use. Appleyard, Davidson et al. (1999) states that one in four households in Perth, Western Australia, draw water for garden watering from an unconfined sandy aquifer.

In a rural application Richard Cansdale of SWS Filtration has effectively jetted wellpoints into gravelbeds in Northern Nigeria, (Gifford and Partners 1986). The jetting of tube-wells has also been successfully carried out in parts of northern Namibia, (McKinnon 2000) and north-west Zimbabwe (Ncube 2001). Jetting of tube-wells is carried out extensively in parts of India and Pakistan, (Repetto 1994). Driven wellpoints are used at suitable locations in the American mid-west, (University of Minnesota 1985), areas of Queensland, Australia, (DNR Water Facts 1997) and parts of rural China, (IDRC 1981). Driven well-points have also been used effectively to abstract fresh water from the water lens perched above a saline water aquifer in Northern Namibia, (Kroll 1994).

Jonathon Naugle (1991) stated to the author that he had experienced considerable success in West Africa with hand augered tube-wells such as those depicted in the cartoon, figure 2.11. A successful tube-well installation programme in gravelbeds was undertaken by an organisation - Peoples Partnership for Development in Maputoland, South Africa, (Deverill, Nash et al. 1999(b)). Sutton and Sutton (1990) refers to a

sand/gravelbed of approximately 100,000 km² in extent and some 100 metres depth in western Zambia. The area is an extensive flood plain of the Zambezi River valley where some 500,000 people are able to access water within 1 to 3 metres of the surface.

Figure 2.11: Tube-well, (Naugle 1991)



Infiltration galleries have been used extensively in sand and gravelbeds in several States of North America; Ohio, Iowa, California, Colorado, Indiana and Virginia as well as in compacted volcanic ash in Honolulu, (Stone 1954). In Mexico, Reyes (2002) reports that towns like Acapulco and Puerto Valharta are dependent on water supplies abstracted from rivers through infiltration galleries. On a greater scale, Stone (1954), Jonge (1994) and Opie (1991) refer to an infiltration gallery scheme which for many years drew water from sand dunes for Amsterdam. A proposal to recharge 36.8 km² (14.2 mile²) of the dunes with 26,500 – 53,000 m³/day (7-14⁶ U.S. gallons per day) for further abstraction with water from the River Rhine is presently under consideration. Halek, Jedlicka et al., (Undated) also reports on plans to recharge fluvial deposits of the Jizera River, Czech Republic. This sand aquifer, which provides water for the city of Prague, has become over-abstracted due to an increase in riverside industries drawing increasing volumes of water from tube-wells.

The abstraction of water from gravelbeds has also been successfully achieved through the lateral infiltration pipes of collector wells. This adaptation of an infiltration gallery system was developed by Leo Ranney in 1933. The system typically comprises a 4.0 metre or so central shaft which is sunk into unconsolidated water-bearing sand or a gravelbed. The well is sealed at the bottom and four or more horizontal, lateral screen pipes are extended for lengths of up to 100 metres, radially from the caisson, (Hardcastle 1986) and (Campbell and Lehr 1973). The author has been shown a Ranney well at Somerville, Keynsham, near Bristol, U.K., which supplied the Cadbury-Fry chocolate factory with clean water for several years. Two lateral galleries extended under the River Avon and a further four into the gravelbed of the river flood plain. The plant was commissioned in 1959 with a design yield of 3,100 m³/day (680,000 gallons per day). The well was initially pumped at 1,200 m³ per day but the yield did not maintain at this rate and had dropped to 720 m³ per day when regular use was discontinued. In the 5 years from 1964 to 1968 a total of 148,855 m³ of water had been abstracted through the system, (Cox 1969).

Two other systems in the south west of England were constructed at Bridport, Dorset and at Dartmouth, Devon. The latter was essentially to abstract water from the River Dart during the summer months when the water level was low. A report of an almost identical design of a collector well system supplying the towns of Banff and Mcduff in Scotland states that wells of a similar design have also been constructed in the U.S.A., Canada, France, Germany, Switzerland, Austria, Italy, Yugoslavia, Spain and unspecified countries in Africa, (McDonald and Partners 1961). According to Lampe and Henson (1998) two North American cities, Lincoln, Nebraska with a population of 180,000 people derives 260,000 m³ of water per day from the alluvium of the Platte River and Kansas City, Kansas draws 105,000 m³ per day from alluvium adjacent to the Missouri River. Denne, Miller et al., (1998), Campbell and Lehr (1973) and Kazmann (1965) refer to the extensive supply and use of water held in glacially deposited sand and gravel deposits in the American Mid West which provide water to cities such as Des Moines, Iowa and Columbus and Canton, Ohio. Many small towns and rural communities in Kansas, Iowa and Ohio draw water from wells in the alluvium, some of which in the Kansas and Missouri river valleys yield up to 1,135 m³/hr, (5,000 U.S. gallons per minute).

British Geological Survey (BGS) has established a number of collector wells under ephemeral sand rivers in Botswana with further applications in unconsolidated aquifers in South Africa and Ethiopia where it is claimed the wells continue to provide water when other wells and boreholes have run dry, (Robbins 1999). Chris Lovell has assisted a number of co-operative gardens in the Zimbabwean lowveld in the south east of the country with collector wells, (Lovell, Murata et al. 1995). Figure 2.12 shows the principle of a typical collector well.



Figure 2.12: Collector well, (Hofkes, Huisman et al. 1981)

Bradfield (1991) describes how 400 mm diameter porous concrete rings were used as false wells in south west Ethiopia where there was sufficient permeable material in the riverbanks. Through excavation the well rings were allowed to sink into the water yielding layer some 2 to 4 metres back from the riverbank. To increase permeability the open excavation around the rings was then back-filled with gravel and stone and the surface sealed with packed clay.

2.8. Geographical Context

Conditions which give rise to the use and further development of sand-abstraction systems occur in ephemeral riverbeds throughout the world in dryland arid and semiarid areas. According to Watson (2001) classification of dryland areas relies on a combination of factors, amongst them the total amount of annual rainfall, the number of

days of rainfall, temperature and humidity. Consequently he states there is no standard description of either arid or semiarid areas. Hancock and Skinner (2000) states that a definition of 'dryland' was devised for UNESCO in 1977 and was based on Thornwaite's index of moisture availability and the ratio of precipitation to potential evapo-transpiration. Watson states that a widely accepted system was developed in 1953 by Peveril Meigs who divided dry regions into three categories according to the amount of precipitation received. A summary of definitions then defines extremely arid land, desert, as an area with a rainfall of less than 100 mm per annum, or at least 12 consecutive months without rainfall. Similarly arid, refers to a region with a mean annual precipitation of less than 250 mm and semiarid to an area with an annual rainfall of between 250 and 500 mm.

In an overview of the physical conditions of Zimbabwe, De-Graaf (1986), refers to a very fragile environment which experiences rapid degradation of the soil with steadily increasing erosion, silting-up of rivers, destruction of ecological balances, disappearance of wild-life and impoverishment of the biological and genetic life in general. He states that the physical environment in many of the communal areas is less and less capable of sustaining the rapidly growing population living there. Such a situation gives rise to conditions whereby sand-abstraction becomes a reality.

2.8.1. Regions and Countries of Use

According to Hancock and Skinner (2000) approximately one third of the world which can be considered 'arid', lies between latitudes 30° north and 30° south of the equator. (Buol, Hole et al., 1973) states that if defined on the basis of climate, the arid regions occupy 36% of the earth's land surface and 35% if defined on the basis of vegetation. Drylands as indicated in figure 2.13 are the desert regions of Kalahari-Namib, Sahara, Somalia-Chalbi, Arabia, Iran, Thar, Turkestan, Takla-Makan, Gobi, Monte-Patagonia, Atacama-Peru, Australia and North America.





Systems of sand-abstraction in a number of variations are known to exist in many arid or semiarid areas of the world. The system is probably most common in southern Africa and is certainly utilised elsewhere in Africa. Water Aid and BGS for instance are working together at a community level water supply and sanitation project in an economically deprived part of Kenya where the Oju traditionally use sand-abstraction for water supplies, (Burn and Davies 1998). As well as southern Africa, west and north Africa, installations have been identified in the south west of the United States, Mexico, north east Brazil, the Middle East and parts of the Indian sub-continent. Possibilities may exist in parts of some countries in Latin America such as Bolivia, Paraguay and Uruguay, (Verweij 2003). Pauline English has under taken several hydrogeological surveys of parts of inland Australia, (English 1998) and (English, Spooner et al. 2001) and in a letter to the author, states that although she is unaware of sand-abstraction being practiced in Australia, the dry rivers generally contain coarse bedload, although only in limited quantities. Nevertheless she is of the opinion that the rivers are no doubt potentially excellent perched aquifers, (English 2003).

The author has traced or has been reliably informed of sand-abstraction opportunities or sand-wells in several countries or global regions. These include the Ogaden; north east Kenya, (Ishmale 2000), southern Sudan, (Oliver 2002) and (Bupta 1999) and Somaliland, (Abdi 1995). Cansdale (2002(b)) has informed the author of traditional sand-abstraction systems and water abstraction from deeper sandbeds in West Africa, Nigeria, Niger and Burkina Faso. In southern Africa, Fisher (1995) and Armstrong (1999), have reported on sand-abstraction systems on the South African Karoo and Clanahan (1999) in KwaZulu/Natal and the Limpopo Province. Other systems brought to the attention of the author are in Barotseland, south west Zambia (Sutton and Sutton 1990), Swaziland, (McBain 1992) and Botswana, (Kgagahilwe 1997).

The author has personally visited sand-abstraction systems at various levels of technology in Zimbabwe, Botswana, Namibia, Swaziland and South Africa. A variety of sand-abstraction systems have been identified in a number of instances in ephemeral rivers or gravelbeds in South Africa by (Clanahan 1997) and in Zimbabwe by, (Hussey 1997), Botswana, (Contact 2001), Namibia by (Wipplinger 1958), in Morocco, (Moore 2000); Sudan, (Helm 1998); and Nigeria, (Cansdale 1983) and (Hazell and Barker 1995). Personal communication has shown that sand-abstraction infrastructure has been developed in countries such as India, (Ramaswamy 1966), the USA, (Dungan 1999) Mexico, (Reyes 2002), Bolivia (Verweij 2003) and Peru (Jeri 2002).

Within Asia, Nagabhushanaiah (1969) states that infiltration galleries have been used in Iraq, Iran and Afghanistan. Evidence of upgraded sand-abstraction systems have been identified in Kerala State, India on the Bharathapuzha River, (Rajagopalan and Prasad 1989). Limited use but a greater potential for sand-abstraction has been reported by Ranganethan (2002) in Ragistan and Orissa States of India. Within these States, which are in the main considered semiarid, water is available from sand beds at depths of about 12,00 metres. Ranganethan however states that within India seasonal rivers generally have only a shallow depth of sediment.

Shallow, unlined seasonal wells are frequently constructed where there is a limited depth of sediment even when such sources of water do not last throughout the dryseason. Temporary wells are also dug into the beds of fast flowing rivers in arid or semiarid mountainous countries such as Nepal and Mongolia, (Muhlenweg 1954). Because of the intense cold in winter in Mongolia all permanent water supplies are from groundwater sources with virtually no use of surface water at all. A potential for direct streambed or riverbank abstraction below frozen layers thus exists, (Godfrey 2002). It is possible that similar possibilities may exist in seasonal riverbeds in former Soviet Republics such as Kazakhstan, Turkmenistan and Uzbekistan, (Lewis 2002) and western China, (Meng 2002). Sand 'spears' are used to abstract water from sand and gravelbeds in parts of both Australia, West Australia and Queensland, (DNR Water Facts 1997) and the United States, Ohio, Iowa, Michigan, Wisconsin, Minnesota, (Fitch 2001), New York State, (Vadala 2002), Georgia and Florida, (Schmied 2002).

Infiltration galleries are used in Algeria, California and Hawaii (Nagabhushanaiah 1969). They are widely in Oceania, particularly Tonga but also in Samoa and Fiji. Within the islands groundwater supplies are shallow and saltwater intrusion is of great concern. Godfrey (2002) has reported schemes of up to 6 lateral infiltration galleries which connect to a central manifold for urban water supplies. Reyes (2002) has informed the author of infiltration gallery schemes for small-scale rural water supplies from seasonal rivers in northern Mexico. In Latin America, Rieder (1999), has reported on a system of run-off water harvesting from seasonal river flow into unlined pits which is used in north east Brazil to recharge riverbank aquifers. Similar systems in sand or gravelbeds or perennial river systems are known to exist in the United States and the United Kingdom, (Robbins and Ball 1984).

2.9. Hydrogeological Context

Arid and semiarid areas are typically comprised of both igneous and sedimentary rock. The igneous rocks are primarily gneiss, granite and basalt and the sedimentary rocks sandstones, quartzite, grits and mudstone. Gneiss and granite are predominantly comprised of quartz and feldspar with some mica. In the generally deeper lying basalt ferro-magnesium minerals take the place of quartz. As sedimentary rocks are in the first place derived from igneous rock they to are frequently comprised of quartz, feldspar and mica, (Fream 1949). Thus the compositions of ephemeral river sediments in areas suitable for sand-abstraction are very largely comprised of quartz, feldspar and mica.

The coarser grains of alluvium are usually inherited from the parent rock. These particles may include relatively hard and unweathered quartz, or partly weathered and weakened material which has derived from feldspars and mica. The clast size of igneous rock is typically larger as the weathering process of igneous rock is not advanced. Hancock and Skinner (2000) states that the constant collision of grains during transport smoothes the sharp edges of the crystals and grains that were released during weathering. Fookes (1997) similarly states that due to the transport and exposure to greater periods of weathering, particles derived from sandstone are smaller than those derived from igneous rock. As the clast diameter of sedimentary rock is smaller than that of igneous rock so the void area of the sediment is similarly smaller and thus the water retention of sediment derived from sedimentary rock is also less than that of igneous rock. The determining factor of sandstone is >25% volume of clasts of sand grade 0.625 - 2.00 mm diameter, (Kearey 1996).

In dry tropical regions organic matter is rapidly degraded and seldom exists below a thin surface layer, (Fookes 1997). The resultant soils are typically coarse sands almost devoid of organic matter with little soil moisture, highly susceptible to erosion and subsequent transport by water runoff. As this material forms the alluvium in riverbeds in areas of igneous rock it is capable of retaining significant quantities of water held in the large void area of the coarse grained sediment.

Further attributes of coarse-grained sediment are lower levels of water loss from sediment with a larger void area than from fine, compacted material. Sediment carried into the river channel is retained behind rock outcrops and in pools and depressions in

the riverbed. In igneous rock areas, the riverbed may be rock which reduces water loss from seepage. Large quantities of silt which might impede the flow of water to an abstraction point are seldom retained in coarse grained sediment. Ephemeral rivers which transect extensive plains, particularly those comprised of igneous rock, are therefore most suitable for sand-abstraction.

Water is only available in the cracks and fractures of igneous rock as it is not itself permeable. As the fissures act as an underground conduit which allows water to drain to lower levels there is effectively no residual water-table and typically very little groundwater available in areas of igneous rock. Depending on the degree of fracture and the subsequent movement and drainage of water within rock, the available water does not always constitute a useable reserve. Apart from sporadic recharge from seasonal storms, in areas where igneous rock is close to the surface, the water-table is under constant discharge with water continuously permeating to lower levels. Abstraction may only take place where a well or borehole draws from a fracture containing water. The availability of water in igneous rock formations in arid and semiarid areas is thus extremely limited.

In sedimentary formations such as areas of extensive alluvium, sandstone, grits and gravel, the sub-surface becomes saturated and creates a residual water-table, (Meinzer 1949). Where a river cuts through sedimentary areas the river aquifer may be a part of the water-table and may, depending on the height at the time, gain or lose water from or to the water-table, (Fream 1949) as shown in figure 2.14. Although the water storage potential of the river aquifer may be limited, it is possible that tube-wells may be developed in close proximity to a river and water may be abstracted from the extended aquifer. Rivers, which transect granite and gneiss before flowing onto aeolian sands or sandstone frequently transport large volumes of coarse material far down the river basin, thus making them more suitable for sand-abstraction. This has been observed by the author in the Shangani and in the Manzamnyama Rivers in Zimbabwe which contain copious quantities of coarse sediment, yet flow predominantly through areas of fine Karoo sandstone and Kalahari sand respectively.



Figure 2.14: River water-table augmentation (Bell 1980)

2.9.1. Properties of Sediment

Water Recharge and Capacity

The water storage capacity of river sediment is affected by the permeability and the porosity of the sediment. These factors in turn affect the amount of water lost through

evaporation from the surface of the sediment and of losses from downstream flow through the sediment. The water storage potential of the sediment is influenced by the void area within sediment which is considerably influenced by the shape, texture and orientation of sediment grains as well as the grading consolidation and packing of the sediment as noted by (Jackson 1970) and (Frye 1974). Variations in sediment patterns induced by natural processes and unnatural compaction due to consolidation by offroad vehicles have been noted by Hamilton (1978), on aeolian and marine sand. During data collection on sediment transport Hamilton recorded changes in the orientation of sediment deposition between flood and ebb tides and the compaction to several centimetres of sediment within vehicle tracks. The cycles of short duration flow and no flow within an ephemeral river, the transport and deposition of sediment, will similarly affect changes of sediment deposit, packing and compaction.

Permeability

The permeability of alluvium is a factor of considerable importance in the effectiveness of sand-abstraction. An aquifer or saturated medium must be capable of yielding water through its interstices. For a sand-abstraction system to be effective it is imperative that a continuing supply of water be available to a well-point through a highly permeable medium. The permeability of a material is a measure of its capacity to transmit water.

Channels and inter-connections between the pore spaces affect the permeability of alluvium. If the channels are tortuous then the permeability is accordingly reduced. Tortuousity is an important factor in permeability as it influences the extent and the rate of free water saturation. Bell (1980) states that tortuosity can be defined as the ratio of the total path covered by a current flowing in the pore channels between two given points, to the straight line distance between the two points. According to Lambe and Whitman (1952) five characteristics influence permeability; particle size, void ratio, composition, fabric and the degree of saturation, but then states that the degree of saturation, composition and fabric have little bearing on the calculation and may be ignored or treated indirectly. Fabric, he says, is particularly difficult to isolate as its characteristics are closely related and depends itself on particle size, void ratio and composition.



Table 2.2: Typical water residence times in inland water bodies, after (Bartram and Ballance 1996)

According to Kazmann (1965) the most productive aquifers are those that consist of clean, coarse gravel, with productivity increasing with the degree of coarseness. Aquifers of uniform coarse grained sand are the next most productive followed by mixtures of sand and gravel. Aquifers comprised of sediments of finer grains such as fine sand and loess are less productive and alluvial deposits containing fractions of silt, clay and rock decay are least productive. Grain size or grade of sediment is however,

not the sole factor in determining the productivity of an aquifer. The volume of the aquifer must also be taken into consideration as a thick deposit of fine sand will often yield more water to a well-point than will a thin layer of coarse gravel. Table 2.2 provides a comparison between the residence time of water within a river channel and water within deep groundwater aquifers.

Quinion and Quinion (1987) states that permeability is the characteristic of a soil or alluvium, which governs the rate of flow through the interconnecting pores. Quinion goes on to say that permeability increases with grain size and that water will pass freely through granular soils, essentially of sand or gravel as indicated in table 2.3. Clays however he states are impermeable, although water may seep slowly through sand or silty inclusions.

Soil Type	Coefficient of Permeability (m/sec)
Gravel	> 10 ⁻¹
Coarse Sand	> 10 ⁻²
Silty Fine Sand	> 10 ⁻⁵
Silt	> 10 ⁻⁶
Clays	< 10 ⁻⁷

Table 2.3: Permeability of soils (Quinion and Quinion 1987)

Table 2.4 shows hydraulic conductivity in relation to the grain size distribution of sand and gravel formations and unconsolidated sediments.

Table 2.4: Permeability in relation to unconsolidated sediments, (Detay 1997)

К (m/s)	101	1	10-1	10-2	10-3	104	10-5	10-6	10-7	10-8	10-9	10-10	10-11
Granulometry	Homogenous		Clean Gravel Cle Sa		ean ind	an Very Fine Sand Silt					Clay			
•	Inequigranular	Coa an Med Gra	arse id ium ivel	Gravel and Sand		Sanc	Sand and Clay – Coarse and Fine Silts							
Degree of Permeability			Very	y High to High			Poor					N	lil	
Type of Formation Permeable				5	Semi-pe	ermeabl	e		Imperi	neable				

Depending on the geology of an area, silted river channels can be expected to have a predominance of coarse material. However clay lenses may form within river alluvium effectively preventing the transmissivity of water from coarse material to a well-point. Within at least anglophone Africa, coarse building sand is referred to as 'river sand' and fine building sand as 'pit sand', primarily determined by grading, (Standards Association of Zimbabwe 1997).

Porosity

Richey (1964) states that porosity gives a measure of the amount of water that an aquifer may hold. Bell (1980) further elaborates that in terms of groundwater supply porosity may be regarded as the pore space from which water can be removed. He also points out that although a permeable formation is porous, a porous formation is not necessarily permeable. The mean values of the effective porosity of the main types of

reservoir formations are shown in table 2.5 and table 2.6., in which Detay (1997) provides a comparison of the porosity of consolidated and unconsolidated materials.

Table 2.5: Mean values of effective porosity in the main types of reservoir formation, (Detay 1997)

Reservoir Type	Effective Porosity %				
Dune Sand	38				
Coarse Gravel	30				
Fine Gravel	20				
Tufa	20				
Coarse Sand	20				
Gravel & Sand	15-25				
Fine Sand	10				
Alluvium	8-10				
Fractured Basalt	8-10				
Coarse Sand & Clay	5				
Clay	3				
Fractured Sandstone	2-15				
Fractured Limestone	2-10				
Fractured Granite	0.1-2				
Shale	0.1-2				

Table 2.6: Porosities for common consolidated and unconsolidated materials, (Driscoll 1986)

Unconsolidated Sediments	η (%)	Consolidated Rocks	η (%)
Clay Silt Sand Gravel Sand & Gravel Mixes Glacial Till	$\begin{array}{r} 45 - 55 \\ 35 - 50 \\ 25 - 40 \\ 25 - 40 \\ 10 - 35 \\ 10 - 35 \end{array}$	Vesicular Basalt Sandstone Limestone/dolomite (original & secondary porosity) Shale Fractured Crystalline Rock	$ \begin{array}{r} 10 - 50 \\ 5 - 30 \\ 1 - 20 \\ 0 - 10 \\ 0 - 10 \end{array} $

Table 2.7: Total surface area of grains in samples composed of uniform spheres, (Driscoll 1986)

Diameter of	Number of	Approximate su	rface area (mm ²)
(mm)	1 mm cube	One particle	All particles
1.0	- 1	3.1	3.1
0.062	4.1×10^{3}	1.2×10^{-2}	49
0.004	1.7×10^{7}	5.0×10^{-5}	850

According to Meinzer (1949) impermeable clay may contain up to 60% more water than sand or gravel, but clay is unable to yield water unless it is subjected to pressure or to drying out as the water is held within the material by surface tension and cannot move freely through the material. Meinzer further states that 1 m³ of water-bearing sand may have interstices with a total wall surface area of several hundred m² (\pm 1,000 m²) and in the case of a silt or clay material with micropores, 1,00 m³ may have interstices with a total surface area of a hectare (10,000 m²) or more. In table 2.7, Driscoll (1986) citing Baver (1956) provides data on the surface area of uniform spheres of different size.

Packing

Porosity is dependent on the arrangement of grains with respect to each other, the spread of grains and the grain size distribution within a material; Detay (1997) states that porosity is strongly influenced by packing.

A detailed analysis of packing in sandstones has been undertaken by Kahn and has also been cited by, Bell (1980), who has defined packing as the mutual spatial relationship among grains. Khan conceptually concluded that packing could be considered to have two basic aspects, aggregate and unit properties. The closeness or spread of grains in the aggregate was termed by Khan to have an aggregate property that is concerned with all the particles in the sample and is an indication of how much space in a given area is occupied by the particles. Khan termed grain-to-grain contact and the shape of the contact area as a unit property.

Variations in packing are controlled by the geological properties of sediment particles and sedimentary processes. Gao and Collins (1996) states that geological properties are, grain shape, grain size distribution and water content and that the deposition rate is the sedimentary process. Gao found that a vertical pressure of around 2,500 kg m⁻² descended the sediment surface by between 0 and 90 mm when conducting experiments over a 6,00 metre length of fine, well sorted saturated sediment of depth 200 to 300 mm which was overlying coarse sand and gravel. He attributes this to different sediment packing patterns.

Figure 2.15: Square & rhombic packing, (Bell 1998)



In experiments with uniform spheres (Bell 1980) found that when packed in a cubic configuration the void area amounted to 47.6% but to only 25.9% when packed in trigonal or rhombohedral formations. In similar experiments Frazer, cited by Detay (1997), also proved that the tightest form of packing was achieved with a rhombohedral formation (25.9%) but the loosest type of packing gave rise to a porosity of 87.5%. Detay claims that within an aquifer a porosity of 15% can be considered as exceptional and states that in practice aquifers generally have porosities of less than 10%. According to Bell, because of the higher ratio of surface area to volume in natural assemblages, as grain size decreases so friction, adhesion and bridging become more important and further reduce the void area of the alluvium.

The arrangement of grains or the type of packing also affects porosity – in square packing the porosity may be as high as 48% whilst in rhombic packing it may be as low

as 26%, which is clearly indicated in figure 2.15. The Standards Association of Zimbabwe (1997) indicates that sand derived from the natural disintegration of rock may have a voids content as high as 48%.

Uniformity

Whether grain size is uniform or non-uniform is of fundamental importance. The highest porosity is commonly attained when all grains are of the same size, grains of a different size lower the porosity of a material. Raghunath (1987) states that a uniformly graded sand has a higher porosity than a mixture of fine and coarse sand simply because the fines occupy the voids within the coarse material. The wider the range in the size of grains the lower the porosity.

Within certain limits, the amount of smaller grains lodging between the larger grains of a material is directly proportional to the reduction of porosity of large grained material. (Bell 1980) states that irregularities in grain shape will result in an increased range of porosity. Theoretically, irregular forms may be packed either more tightly or more loosely than more spherical forms. Angular grains may also cause either an increase or a decrease in porosity but in practice the only angular grains that decrease porosity are those that are mildly and uniformly disc shaped. According to Bell as grain size decreases, so porosity increases. He states that in coarse sands porosity ranges from 39 to 41%, in medium sands from 41 to 48% and in fine sands from 44 to 49%.

As sediments consolidate so there are the further factors of pressure and induration that determine porosity. The determinants are closer spacing of grains, deformation and granulation of grains, re-crystallisation, secondary growth of minerals, cementation and in some situations, solutioning. When present in large amounts in sandstone, chemical cements have a considerable dominant influence on porosity which masks the effect of other factors.

The porosity of a deposit does not necessarily provide an indication of the amount of water that the deposit may yield. The capacity of an aquifer to yield water is of greater importance than its capacity to hold water as far as supply is concerned. Even though an aquifer may be saturated not all the water held can be removed by gravity or by pumping. Fream (1949) states that only gravitational water may be abstracted as a proportion of the total volume of water will remain attached to sediment particles by surface tension or within silt or any organic matter present.

Permeability and porosity are thus not necessarily closely related. Bell again states that although coarser sandstones are more permeable, very fine textured sandstones frequently have a higher porosity than coarser sandstones. From experiments on uniformly sorted sands of known sizes it has been found that permeability varies roughly as the square of the diameter of the grains. When the diameter of the grains is doubled, the throat-plain area between them undergoes a four-fold increase, the rate of flow being dependent on the size of the resultant channel. Any departure from the spherical shape thus affects permeability by varying the size and the shape of the interstices and by causing loser or tighter packing. At equal grain diameters and porosity the coefficient of permeability decreases with increasing uniformity of pore spaces. Hence as the form of the grains departs from that of a true sphere so the permeability increases.

Taylor (1999) recognised three methods of pore space reduction, simple pore filling, solution and redisposition or removal of dissolved material and solid flow of material under pressure. Within an unconsolidated river sediment, simple pore filling can be

assumed to be the influx of smaller grains into the pore space between larger grains. The shape of the grain contacts, concave, convex and sutured contacts are evidence of solution and redisposition of material in sandstone. Taylor concluded that the most important pore reduction process in sandstones was the flow of solid material under pressure.

Storage Capacity

The storage capacity of an hydrological system is the quantity of water contained at a given date or stored over a period of time. It is expressed in terms of volume as m³ or km³, (Detay 1997). While porosity is a measure of the water-bearing capacity of the aquifer, all the water cannot be drained by gravity or by pumping, as a portion of the water is held in the void space by molecular and surface tension forces. In simple terms, the total quantity of water drained after a considerable period of time, divided by the original volume of material is the specific yield. Specific retention is the porosity minus the specific yield, (Kazmann 1965). Or, as explained by Raghunath (1987), the volume of water expressed as a percentage of the total volume of the saturated aquifer that can be drained by gravity, is the specific yield and the volume of water retained by molecular and surface tension forces of gravity is the specific retention.

The resource is the quantity of water that can be extracted from a defined volume over a given period of time. Evaluation of the resource is based on the hydrodynamic and hydro-chemical behaviour of the aquifer. The resource is measured in terms of a mean discharge rate, as m³/sec or km³/yr, (Detay 1997).

	Si	lt	Fine	Sand	Med Sa	lium nd	Coa Sa	nrse nd	Fi Gra	ne ivel	Coa Gra	rse vel
Diameter of Particles	<0 m	0.5 m	0.5- m	-1.0 m	1.0- m	-1.5 m	1.5- m	5.00 m	5.0- m	19.0 m	19.0-7	0 mm
Volume of Sediment	20.	01	20.	01	20.	.0 ℓ	20.	01	20.	01	20.	01
Porosity	1.52 ℓ	38%	1.58 ℓ	40%	1.63 ℓ	41%	1.80 ℓ	45%	1.87 ℓ	47%	2.05 ℓ	51%
Extracted water	0.90 ℓ	5%	3.75 1	19%	5.01	25%	7.01	35%	8.25 1	41%	10.0 l	50%

Table 2.8: Porosity and extractable volume of water, (Nissen-Petersen 2000)

Table 2.9: Representative specific yield ranges for typical aquifer material, (Driscoll 1986)

Sediment	Specific Yield, %
Clay	1 - 10
Sand	10-30
Gravel	15 - 30
Sand & Gravel	15-25
Sandstone	5-15
Shale	0.5 - 5
Limestone	0.5 – 5

Kazmann (1965) states that some water will be obtained when a sample of saturated material is allowed to drain under the action of gravity. The volume of water obtained
depends on the structure of the sample and particularly on the surface area of the rock in contact with water. A surface holds water by capillarity and by molecular attraction. The water held in this way will not drain in response to the force of gravity. Clay with a porosity of 50% yields little if any water to gravitational drainage, but gravel with a porosity of 20% will yield water totalling as much as 18% of its gross volume. One of the earliest experiments to demonstrate the efficacy of slow drainage was performed by King, (Kazmann 1965), who found that the finer the sand, the more water was retained. The finest sand King tested had a porosity of 34% but when completely saturated, yielded only 10% of its total volume in the first 24 hours of drainage. After 10 days of drainage the accumulative yield was approximately 13.5%, a slight increase in yield after several further days of drainage.

Nissen-Petersen provides an indication of the particle size of typical river channel sediments and the associated porosity and extractable volume of water, table 2.8 and table 2.9 provides an indication of the specific yield ranges for typical aquifer materials.

2.10.Technical Context

2.10.1. Traditional Technology

Traditional Open Sand-Well

As the water level drops in the sediment at the onset of the dry-season, so shallow excavations allow people to continue to abstract water. An unlined hole may be dug through dry sediment to the water-bearing layer. However only a shallow depth can be excavated into the saturated sediment before the sides of the excavation collapse. The method requires no financial outlay at all, only a digging tool and the time to excavate the 'well'. In the early stages of the dry-season the exercise may be undertaken almost anywhere within a river channel. At a most basic level of abstraction when water is only just below the surface, indicating just how easy it is to abstract water the author has observed donkeys pawing the sediment with their hooves until they have excavated a depression from which they may drink.

Improved Sand-Well

An improved open sand well has an open ended section of an old drum pushed into the sediment. Sand is removed from inside the drum ring allowing a depth of about 150 mm of water within the drum. As the water level recedes, sediment is removed from within the drum, which is continually pushed deeper. By necessity the sides of the well are also continually enlarged and deepened. The wells are typically fenced with brushwood to prevent destruction of the well sides and fouling of the water by livestock, (Hussey 1997). The open water may be protected with a sheet of metal placed over the drum.

This is a simple and basic technology. A most cost effective and functional well may be constructed by excavating sediment to the water-bearing level, clearing loose sediment from around the drum lining and stabilising steps on the slope of the unstable dry sediment. The limitation is the need for continual deepening and the loss of the well including the drum lining when the river again flows. The brushwood and posts which act as entry barriers to the well constitute considerable environmental degradation both from the initial cutting and from the subsequent clogging of the river when they are washed into the chasm which was the well.

2.10.2. Commercial Technology & Equipment

Well-point Systems

Well-points generally provide an effective method of separating water from alluvium. Larger screened well-points of diameter 100 mm and above, whether fabricated from stainless steel, uPVC or ABS (Acrylate Butadiene Styrene) are general comprised of a series of separated rings. The aperture between the rings is narrower on the outside of the pipe than on the inside. This construction of inwardly widening slots ensures that sediment grains will not become wedged within the slots and thus blockages are minimised. The technique is described and well advertised on the Johnson Screens, (Johnson Screens 2000) and Cook (Soloflo) Screens, (Cook Screens 2000), web site home pages. Such large diameter screens are beyond the requirement of small-scale, hand operated sand-abstraction systems. Although small diameter well-point screens fabricated by SWS Filtration inwardly expand, (SWS Filtration 1997), smaller diameter and field or locally improvised well-points are generally parallel sided, (Soloflo 1997) and (Boode 1994).

The screen is a vital component of the equipment necessary for the abstraction of water from sediment. According to Detay (1997), a screen must fulfil the following functions:

- Ensure a maximum yield of clear, sand free water
- Induce minimal pressure head loss
- Resist corrosion by aggressive water
- Have a long life span

Well-point screens are fabricated with a variety of apertures:

- <u>Round holes</u> Hole diameter is generally dictated by sediment particle size. To avoid particles jamming within the aperture. Detay (1997) suggests that there is a correlation between the diameter of the aperture and the wall thickness of the pipe. Round holes have a low screen open surface area of about 10%
- <u>Oblong apertures</u> usually vertical rectangular slots of a standard length of 30 mm and with a width at least equal to the thickness of the fabrication material, usually uPVC pipe. Open surface area is typically 10 to 20%.
- <u>Continuous spiral</u> horizontal opening which runs the entire length of the screen as a continuous aperture. Slot width varies from 0.50 to 2.00 mm and is typically wider at the interior surface than the exterior. The advantages of such screens are:
 - o The regularity and precision of the opening
 - o Very low risk of clogging
 - o Highest open area coefficient of all screen types
- <u>Bridge slot</u> screens are commonly used as borehole screens in unstable formations. Slots are formed on the upper and lower surfaces of a rectangular protrusion on the surface of a pipe. The ends of the distension remain attached to the pipe whilst a horizontal slot is formed in the top and the bottom surfaces thus forming a 'bridge'. The slots are formed in a flat sheet which is then rolled and welded to form a tubular screen. As no material is removed to form a slot, the screen is mechanically strong. Depending on the dimension of the apertures the open surface area is between 3 and 27%.

• <u>Louvred slot</u> screens are similar in design and construction to bridge slot screens, but have only a single open horizontal slot on the lower edge of a protrusion, in effect forming a louvre or hood. Louvred screens are exceptionally strong with a low open surface area used more commonly as borehole screening than as a well-point screen.

Global companies such as Johnson Screens (2002) produce a wide range of screened pipes suitable for water abstraction from alluvium. Their product range includes vee section stainless steel welded wire screens, woven wire screens, polyethylene and uPVC well screens and includes self-jetting well-points and driven well-points. Other manufactures such as, Moss (2002), Wedge Wire Screens Ltd (2002), Chemdrex Chemicals (2002) and Variperm (2002) also manufacture wedge wire inline screens suitable for sand-abstraction purposes. Big Foot Manufacturing (2002), Boode (1994) and Soloflo (1997) primarily produce uPVC screens which are suitable for use as either well-points or infiltration galleries. Figure 2.16 shows a balancing dam on the White Umfolosi River which has an extensive system of Soloflo screening as an infiltration gallery system.

Figure 2.16: Sand-abstraction scheme for urban water supply



Single Well-point Systems

Small-scale systems typically have a single well-point which is dug, driven, augered or jetted into water-saturated sediment. The well-point is connected directly to a hand piston pump or mechanically powered atmospheric pump on the riverbank. Water is drawn through the screen into a pipe system, to the point of discharge.

A number of commercial companies such as Dean Bennett Supply Co (2002) offer a complete range of small-scale well-points suitable for installation by either driving or jetting. Both well-points and infiltration galleries have also been fabricated by small-scale manufacturing companies in countries such as Australia, South Africa and Zimbabwe, (Esterhuizen 1987) and also by D-I-Y enthusiasts such as (Dungan 1999) and (de-Vries 1999) in the U.S.A.

Multiple Well-point Systems

In small-scale systems where for instance the alluvium is fine and recharge to the wellpoint slow and a slow screen entrance velocity is required, a number of well-points may be connected together. The well-points connected directly to a hand piston pump or mechanically powered atmospheric pump on the riverbank. Water is drawn through the well-points and separate supply pipes to the point of discharge.

As with single well-point systems, screens may be fabricated from borehole screens or from purpose fabricated pipes with several lines of longitudinal or transverse slots or a series of drilled apertures of up to 6,00 mm diameter. In order to minimise displacement or damage to the well-point, installations are best carried out when the river water is at its lowest level, when the delivery pipe to the riverbank can be placed deep in the sediment.

Manifold & Well-point Systems

Many older systems typically utilise well-points with large apertures of 6.0 mm (¼ inch) which do not completely exclude all sediment particles. The separation of water from sediment in a manifold system is partly dependent on a low velocity of water at the point of abstraction and in the passage of water though the system. With a low initial velocity, flow remains laminar, sediment particles remain undisturbed and are not drawn into the well-point. Transfer velocity in the manifold section is further reduced so that any sediment particles that have been drawn in, do not continue into the pump and delivery system. For installations to be fully effective systems are designed with differing velocities in each section of the system.

This system is best installed towards the end of the dry season when the water is at a low level within the sediment. The dry river sediment is removed down to the water-bearing level and the manifold laid on the saturated alluvium. Slotted or drilled well-points are then installed at an angle into the sand by driving or jetting and are joined to the manifold by flexible suction hose. The manifold is also connected to a suction pump on the riverbank. This is probably still the most common system in use in Zimbabwe today, though it is doubtful if abstraction and draw-off velocities in every installation are calculated correctly. In general the materials for such an installation are readily available.

Caissons

Water is abstracted through the slotted basal section of a large, generally 0.5 to 1.5 metre diameter, flat cylindrical or slightly conical caisson. A caisson abstracts water from a considerably larger area than a single well-point and thus has a low abstraction velocity. A caisson of 1.5 metres diameter has a total abstractive surface area of 1.767 m² whilst a single 50 mm diameter well-point, slotted over a 1.00 metre length has a total abstractive surface area of 0.157 m². Water is thus drawn from an appreciably larger area and thus a caisson has the potential to draw water from very fine sediment. However as there is not a free flow of water through silt to the abstraction zone, abstraction rates may not be significantly improved. Because of such a large open internal area, caissons have been known to collapse. In a further possible limitation, due to the larger surface area, caisson are more prone to flood damage, Cooke (1987) advocates securing a railway sleeper or hefty tree branch across the top of the caisson to weigh down and help stabilise the installation.

An alternative caisson method of abstraction shown in figure 2.17 is the use of an openended concrete ring placed in sediment on or near the riverbed. The lower section of the ring may be cast with no-fines concrete making the caisson pervious to water but preventing the entry of sediment into the caisson cavity. In order to reduce flood damage, the structure should not extend to the surface but at an approximate height of 1,00 metre below the sediment surface the caisson should be sealed with a concrete slab and then covered with river material. As the structure is buried and there is free, standing water within the caisson, water can be abstracted from a pump sited on the riverbank. An advantage of the system is that as there is free water within the caisson a simple non-return valve may be fitted to the suction pipe to maintain prime to the pump, whereas a well-point or manifold system requires the inclusion of a sealed tank in the system to hold a supply of water to prime a pump. Jetten (1991) and Kgwarae (Undated) describe three variations of caisson systems utilised by the Rural Industries Innovation Centre in north-east Botswana and Bradfield (1991) a similar system, with the handpump on the riverbank, which he installed with the Freedom from Hunger Campaign in river alluvium in south west Ethiopia.

Figure 2.17: Caisson installation



Infiltration Galleries

Many of the installations which were established many years ago are gravity supply systems and consist of a length of steel pipe projecting from a false well on the riverbank into the river sediment. Typically the main delivery pipe has a number of tee-offs in the sediment which terminate in well-points. The original well-points were generally fabricated from 50 or 63 mm (2 or $2\frac{1}{2}$ inch) steel pipe and were slotted or wire wrapped to exclude sediment. From these well-points water gravitated to a sump or false well sited on the riverbank from where it was pumped out. With the advent of purpose designed infiltration piping, radially slotted pipes and non-rotting synthetic matting which can be used to cover piping with large surface apertures, the system is again viewed as a viable system of abstraction. Such products have significantly reduced fabrication and installation times and generally improve the efficiency and thus the overall potential of the system. Before the introduction of uPVC and synthetics it was difficult to exclude sand from the system when the steel pipe or binding wire began to rust.

Companies such as Soloflo (1997), Boode (1994) and Kaytech (undated) produce infiltration gallery piping and Kaytech also manufactures synthetic material to cover infiltration piping when used in very fine sediment. Christensen (2002) and HDD Well Team (2002) manufacture and install infiltration gallery piping in horizontally drilled collector or Ranney wells. Figure 2.18 shows a large collector well structure beside the Buffels River, KwaZulu-Natal, South Africa, that provides water to the town of Nqutu.

Figure 2.18: Collector well



2.10.3. Associated Abstraction Technology

Driscoll (1986) and Quinion and Quinion (1987) both refer to the use of standard wellpoints to de-water land which would otherwise be too wet for building construction. By the same token, some of the materials and equipment which have been designed and developed for the purpose of land drainage may have an application for the abstraction of useable water. Purpose designed piping and plastic fibre filter medium as shown in figure 2.19, is currently used to rapidly dispose of excessive amounts of run-off water from roadways and car park systems, (Bennett 2000).

Figure 2.19: Piping and synthetic cover used for urban drainage purposes



Trademark materials such as Geotextile, Geofabric and Geopipe which are manufactured by Kaytech are regularly used for drainage in the construction industry. Applications include the drainage of bridge and building foundations, building basements and wet or unstable soil in sports fields and motorway embankments. In some applications the piping may be used without modification as an infiltration gallery and the synthetic textile is a most effective screen for well-points and infiltration galleries in very fine grained alluvium. Slotted, flexible land drainage pipe manufactured by companies such as Wavin (2002) and Preussag (2002) that is designed for installation in continuous lengths to drain moorland has been installed satisfactorily by the author as an infiltration gallery. In a product brochure, Bennett (2000) details a number of ready-made systems such as packaged sand-filter and sewage treatment plants that may have indirect benefits for sand-abstraction.

New concepts and approaches to drainage and filtration have been demonstrated by engineers for the Eden Project in Cornwall, south west England when an infiltration system had to be hurriedly designed. In January 1999 the project faced possible closure when excessive rain fell on the construction site in a disused kaolin quarry. The site was completely flooded when a 1 in 100 year maximum rainfall was exceeded by a factor of 8. Due to the fine kaolin the water did not soak away and some 195,500m³ of water was finally pumped away. Concern with site drainage then led to the construction of what the Project refers to as 'probably' the finest drains in the world. To ensure no further problems with flooding, a 15-metre deep infiltration system of alternating layers of permeable material and granite chips was successfully constructed. The system allows for the initial storage of large quantities of run-off water and then filters this water for secondary use so that storage tanks are not filled with sediment, (Eden Project 2001).

The development and ready availability of drainage units and sewage treatment plant kits may well have benefits for sand-abstraction applications and assist in the further development of suitable equipment or materials for adaptation or direct use. Development of new concepts of drainage and filtration in high profile applications such as the Eden Project raise awareness to the importance of infiltration systems and will subsequently benefit and impact on sand-abstraction initiatives.

2.10.4. Installation and Abstraction

The installation of well-points, infiltration galleries or infiltration wells which are necessary for a sand-abstraction system are easily undertaken within the shallow, perched aquifer that is the alluvium of a riverbed. No complex or expensive equipment is required to undertake an installation.

Well-Points

The installation of well-points into unconsolidated sediment may be accomplished in a variety of ways.

Jetting

A well-point and connecting pipe can be installed deep into river sediment or unconsolidated alluvium by the creation of a fluidised core of material which is then washed away. The effect is created by a jet of water which is released into saturated coarse sediment or fine sediment which has a degree of compaction. The jet of water loosens and dislodges sediment, sand and soil particles and lifts them to the surface with the returning flow of water around the exterior of the pipe. As this quicksand effect is created the jetting pipe or well-point is able to descend into the resulting liquidised cavity provided there is an unimpeded flow of water. The downward jetting process is maintained as long as the flow of water maintains an annular space around the jetting pipe and carries the loosened sediment freely to the surface. If the returning flow of water is interrupted, water pours into the sub-surface, the removal of material ceases and no further lowering of the well-point is possible.

Practitioners often develop individual jetting techniques so that installation is a rapid and continuous process. Basic equipment suitable for jetting may be fabricated from readily available equipment and components as shown in figure 2.20. Self-jetting wellpoints which allow a jet of water from the end of the well-point obviate the need for an adjacent, separate jetting pipe. Soloflo, Johnson Screens and SWS Filtration are among several manufacturers who produce self-jetting screens, these have a ball which acts as a valve in the base that allows a flow of water from the end of the screen, but which closes so that water can only be drawn through the apertures when water is drawn through the screen.

Figure 2.20: Jetting a small-bore sand spear, Capetown, South Africa.



According to both Maclear (1997) and Ncube (2001), jetting to about 6 metres is fairly easily attained with a portable centrifugal pump and hand-held open-pipe equipment. Driscoll (1986) advocates the use of self-jetting well-points that remain in-situ when the required depth is reached. Driscoll states that jetting with a stream of water is not possible to depths below 6 or 7 metres because of fluid loss into the sediment and through slumping of the sediment around the flow pipe when further lengths of pipe are added. Cansdale (2002(b)) has however experimented in Spain with pulleys and a hoist to allow a continuous jetting process that may allow jetting to achieve greater depths. Ambler-Smith (1999) states that he has reached depths of 12 metres by using a venturi to increase the jetting effect and to help maintain the annular space around the jetting pipe. Armstrong (1999) who regularly jets well-points to 7 to 8 metres in unconsolidated sediments is also experimenting with a venturi to increase the velocity of discharge and states that he hopes to reach depths of 30 or more metres with the use of a borehole drilling rig to lowering the jetting equipment in a continuous drop. Driscoll does state that depths greater than 6 metres can be reached with a combination of jetting and driving where a drilling fluid additive is mixed with the jetting water to maintain the sediment in suspension and to stabilise the hole when fluid circulation is interrupted.

Driving

A purpose designed well-point can be driven into sediment with a sledge hammer, (Fitch 2001). Alternatively a beadle, maul or wooden fencing mallet as advocated by Wells (2002) or a fence post driver may be used, (University of Minnesota 1985). An installation in river sediment is easily and satisfactorily accomplished by driving the well-point directly from the surface of the river sediment.

According to de-Vries (1999) screened well-points attached to threaded steel pipe are easily driven to depths of 23 metres (75 feet) in soften ground. Dungan (2001) advocates augering a hole to the water-bearing layer and then driving a well-point whilst de Vries maintains it is sufficient to dig a hole 1.50 to 3.00 metres (5 to 10 feet) deep and saturate the soil for a week before driving the well-point to full depth with hammer blows. The connecting threads of steel well-points require protection during driving either by capping with a screw fitted cover (de-Vries 1999) or with the use of a wood block to prevent steel to steel contact, (Ncube 2001). A uPVC well-point cannot be driven directly into sediment but if fabricated with a steel tip may be driven inside a steel pipe, as shown in figure 2.21, which acts as a sheath bearing directly onto the steel tip. An alternate method is the use of a drive rod located inside the uPVC screen that bears directly onto the steel tip.

Figure 2.21: Installing a driven well-point



Sludging

Sludging, sometimes known as surging, is commonly practiced in areas of unconsolidated alluvium where there is a high water-table. Such conditions particularly prevail in parts of Bangladesh and India. The operation is initiated on a simple platform, often constructed from lengths of bamboo lashed together, (Cairncross and Feacham 1983). A uPVC pipe is driven a short distance into the ground and filled with water. An operator covers the open end of the pipe with their hand to create a seal and when the pipe is raised slightly, saturated sediment is loosened and disturbed. On removal of the hand-formed-seal the pipe sinks into the loosened alluvium. With rapid joggling of the sealed and unsealed pipe the pipe penetrates further into the ground discharging fluidised sediment from the top of the pipe.

When the required depth is reached a well-point is lowered into the surge pipe which is then withdrawn leaving the well-point installed in the sediment. Depths of 6 metres may be obtained in this manner. The limitation to attaining greater depths being the weight of the sediment in the pipe and the effectiveness of the hand-formed seal on the draw pipe.

Installation of well-points by surging is limited to installations in fine river sediment which will maintain some consistency when saturated. Coarse-grained sediments when fluidised have little stability and thus are not drawn but rather flow into the surge pipe. Although the surge pipe can be easily lowered into coarse sediment the surge pipe remains filled with sediment to the water level within the sediment reducing the installation depth of the well-point. Practical evidence of this has been obtained by (Tshabalala 1996) and by (Ncube 2001).

Augering & Bailing

A hand operated tube-well auger, a Vonder Rig, has been used to install slotted geotextile covered uPVC pipes into saturated alluvium in a community based programme in Maputoland, north east, KwaZuluNatal, South Africa, (Deverill and Nash 1999(a)). The operation consisted of filling a 900 mm \times 150 mm diameter bucket auger, raising and removing the bucket, emptying the bucket and removing further cores until the water-table was reached. At this stage a 125 mm uPVC casing pipe with an integral screen was installed into the hole. The hole was then deepened a further 3.50 to 4.00 metres into the water-table by bailing water and sediment from inside the pipe. Deverill notes that bailing had to be accomplished quickly as an uncased hole in unconsolidated sand was vulnerable to collapse, especially after rain.

The author has had similar experiences of unstable holes whilst using a Vonder Rig in unconsolidated fine sand beside a river at Dongamuzi, Lupane District and in coarse sand river sediment at Huwana, Bulilimamangwe District in Zimbabwe. Operators found that stable sided uncased holes could be augered to the water-table. However once the vonder rig bailing attachment was fitted to deepen the hole into the saturated sediment, either the sides of the hole collapsed or fluidised sediment welled up into the casing pipe, precluding installation of a well-point. Efforts were not made to bail from within a screen as recommended by Deverill as the installations were accomplished satisfactorily by jetting.

Deverill notes that bailing is more an art than a science and can only be learned by experience, the intention being to get the slotted casing pipe to sink into the saturated sand of the water-table. The purpose made tube-well screens were fabricated from 6.00 metre stock lengths of 125 mm O.D. uPVC pipe with wall thickness of 4.00 mm (SABS Class 9). 1.00 mm slots were cut over a 3.00 metre length leaving a 0.50 metre sump at the bottom of the pipe. This was necessary to prevent sand, which inevitably entered the pipe from the bottom, blocking a section of the screen before it could be plugged with a gravel pack. As installations were carried out in fine sand which would not have been precluded by a 1.00 mm slot, the slotted pipe was covered with geo-textile with an effective pore size of 250 μ m. Naugle (1991) describes a similar technique for installing well-points in Niger.

Hill (2002) has experienced similar problems with up-flow of fluidised sediment into a bore when drilling through saturated sand heaps which were left after mining tar sands north of Edmonton, Alberta, Canada. Drilling was undertaken with a hollow-stem auger which acted as a temporary casing to prevent collapse of the bore hole during drilling, (U.S. Department of Energy - Office of Environmental Management 2002). To prevent an up-flow of sand and disturbed formation, which would have prevented the installation of a pump column, the casing was stabilised by filling it with water. The pump column was then installed and the casing removed.

Sand-sucker

A novel approach for the installation of well-points into saturated alluvium has been achieved with a sand-sucker. According to de-Vries (1999) this has been used widely in unconsolidated aquifers in the American mid west. The sand-sucker uses the same principle as surging but rather than the use of a hand to effect a seal at the top of the surge pipe, the seal is effected by a steel ball in the base of a tube which fits loosely into a larger, open-ended tube. The pipe with the ball is oscillated up and down drawing fluidised sediment into the interior tube. A full tube is withdrawn from the casing and emptied, 'sand-sucking' then continues until the desired depth is reached.

As with both surging and bailing there are limitations to obtaining sufficient depth in fluidised sediment.

Digging-in

A straightforward method of installing well-points into sediment is a simple digging-in process. Although the system may be tedious and possibly only accomplished over several months or even years of progressive digging, it is nevertheless an effective, low cost option. Installation is achieved by removing dry sediment to the saturated water-bearing level. Depending on the nature of the sediment the usual depth of water in a sand-well is some 100 to 150 mm which cannot be significantly deepened due to slumping of the sides. However by extending the diameter of the open water surface area, a depth of about 300 mm may be obtained. A well-point may then be introduced deeper into the fluidised sediment by forcing in a spade which is twisted and rocked back and forth. Whilst agitating the sediment in this manner the well-point may be pushed deeper behind the spade.

This process may have to be repeated if the installation is undertaken when the water level in the sediment is still relatively high. The system remains effective as long as the well-point remains in water. As the water level drops in the sediment so the well must be re-excavated and deepened to maintain the well-point in water. This will continue until the river floods when the well-point will have been installed at the deepest extent. Depending on the season and the amount of water retained in the sediment in subsequent seasons, the well may or may not require deepening in the following years.

Manifolds and Infiltration Galleries

Although it is not impossible for an extensive manifold well-point system or infiltration gallery to be installed by hand digging, due to slumping of the sides of the trench it is difficult, in fluidised sediment, to reach a depth throughout the length of the trench that will ensure a sufficient hydraulic head over the piping. Where particularly large volumes of sediment have to be removed to the water-bearing layer a dozer or back-hoe is a distinct advantage. However, where a dozer is utilised a particularly rapid wear rate can be anticipated on the tracks from abrasive sand particles, (Mpofu 1996). A dozer was successfully used in what is thought to be the world's largest sand-abstraction installation at Chisumbanje on the Save River, Zimbabwe. Dry sediment was removed to the water-bearing layer and self-jetting Johnson well-screens installed into the saturated sediment, (Prince 2000) and (Mpofu 1996).

Cansdale (2002(a)) has used a backhoe to excavate trenches in beach sand to install infiltration piping for the abstraction of salt water for aquariums and has employed a similar method for fresh water abstraction for a hotel in Jamaica. Where a dozer is used to install an infiltration gallery it is likely that de-watering well-points and pumps would be required in order remove water to sufficiently lower the water level for the installation of the infiltration piping.

Tube-Wells

Recent developments in foundations for bridge piles and building foundations has provided an application for the installation of what is effectively a tube-well in river sediment. Hill (2002) refers to steel casing driven to depths of 12 to 18 metres into sandy alluvium in the Edmonton area of Alberta, Canada. A pile-driver impacts on a core of loose 10,00 mm aggregate in the bottom of the casing, driving down together the core and the casing. The principle is being investigated with the intention of driving by hand, reinforced 140 mm uPVC pipes into river sediment using a loose plug of aggregate in the base.

As the casing is driven to the riverbed, the casing is secure within the sediment. The plug of aggregate in the base acts as a filter pack to allow water to filter into the casing from where it is drawn by a simple valve or bucket type pump. The top of the casing requires sealing to prevent contamination or fouling and to prevent the ingress of sediment during flooding.

2.11. Previous Studies and Reviews

2.11.1. River Morphology

A study of factors leading to the development of a sand river, river morphology, sediment accumulation and erosion in the riverbed has been critical to this study. Ashworth and Ferguson (1986), Yang (1996) and Allan and Frostick (1999) have each provided considerable information on the effect of river flow on the deposition of sediment material and the form of the river channel. Newson (1992), refers to the need to determine the size of grains supplied to the channel as this largely determines the process of transport and sedimentation and particularly refers to the classic work of Hjulstrom on river sediment transport that was undertaken in 1935. Hjulstrom categorised river load into suspended and bedload material where the finer particle size material is transported in suspension and the larger base material by a tractive process of rolling along the riverbed. A process of saltation transports material of an intermediate grain size, where particles bounce along the bed. Using velocity of river flow and sediment particle size Hjulstrom also developed a basic representation of the intervals of erosion, entrainment, transport, and deposition. On the assumption that river flow in an ephemeral river is to a variable depth on each occasion of flow, this concept of transport will alter the layering of the sediment to the depth of flow with each flow of the river.

Extensive research and surveys have been undertaken by the British Geological Survey (BGS) in sand rivers, primarily in Botswana with a view to establishing the potential for sub sand riverbed abstraction. In particular R. Herbert and J. Davies have each contributed a number of reports to a BGS, Hydrogeology Series. Herbert and Pastall (1991), Herbert (1994), Herbert and Adams (1996), Herbert, Barker et al. (1997), Davies, Herbert et al. (1995) and Davies, Herbert et al. (1996) have undertaken significant research into the structure, development and sustainable use of alluvial and unconsolidated sedimentary aquifers. Several of these reports have involved studies and trials undertaken in conjunction with the development of an ODA funded collector well programme. The BGS have in fact undertaken extensive trials of collector wells in both alluvial and crystalline aquifers, (Lovell, Batchelor et al. 1994), (Herbert 1992(b)), (Herbert 1998), (Davies, Rastall et al. 1998) and (Batchelor, Lovell et al. Undated).

BGS has not been alone in undertaking survey work on sand river aquifers in Botswana, Wikner (1980) and Nord (1985) undertook some of the earliest surveys on sand rivers and have provided useful estimates of the expected average yield per kilometre of the major sand rivers based on estimates of the total storage from data on the depth of the alluvium at a number of cross sections of the riverbeds. Sir M. McDonald & Partners (1987) has undertaken an assessment of the water resource of a number of the more prominent sand rivers in eastern Botswana and Wellfield Consulting Services (1998) undertook a detailed survey of the water resource of the Motloutse River. The study was taken to assess the resource of the sand river for the communities along the river as the Department of Lands, Botswana, was under pressure to grant water rights to use the sand river for irrigation purposes.

Andersen, Wheater et al., (Undated) provides a more general assessment of the resource of water in sand rivers in central and north eastern Botswana and states that following the emphasis of rural development projects, abstraction has increased from sand rivers and thus a sustainable guide to abstraction is required together with the identification of alternate resources. Following an assessment of the water resource of sand rivers in Botswana, Herbert (1998) states that a total of over 900 kms of sand rivers in Botswana could supply as much as one third of the country's domestic water needs. Hazell and Barker (1995) who undertook a similar evaluation of alluvial aquifers (fadama in the southern Sahel) provides a case study of three rivers and similarly reports an extensive resource that receives widespread use. Other studies that have been conducted into the morphology and characteristics of sand rivers have been found in working papers such as research and system trial papers produced by commercial companies such as Wellfield Consulting Services and Interconsult, (Mead 1999).

2.11.2. Water abstraction from River Alluvium

Although there are many schemes in existence that draw water from surface dry rivers in several parts of the world there remains surprisingly little documentation available on subjects relating directly to the extractive technology. Two researchers, Hussey (1997) and Helm (1998) refer to a general dearth of available information on sandabstraction technology.

Of practical applications or research that has been recorded, the Rural Industries Innovation Centre (RIIC), Kanye, Botswana, provides a manual (Sand River Abstraction), (Jetten 1991). However, this document appears to have been prepared essentially for the internal use of the RIIC. Kgwarae (Undated), also of the RIIC has supplemented Jetten's manual with a report on the abstraction of water from sand rivers through porous well-rings placed either as an offset-well with an infiltration gallery, or directly into the riverbed. Kgwarae also reports on well-point systems that he has developed satisfactorily. In applications allied to sand-abstraction Kano State Agricultural and Rural Development Authority have produced a basic, stencilled, handbook on wash bore jetting, (Tarcisus 1990). Johnson Filtration Systems Inc. have however produced a technical handbook, Groundwater and Wells, (Driscoll 1986) which provides extensive documentation on aquifers and screen technology. Two other technical working manuals relating to borehole drilling and screen installation procedures have been produced by Ulric P Gibson, (Gibson 1987), (Water Well Manual) and A M Michael and S D Khepar, (Michael and Khepar 1989), have produced another, (Water Well and Pump Engineering). Several commercial companies such as (Moss 2002), (Johnson Screens 2002) and (Soloflo 1997) have web sites with considerable factual and technical detail on their screen products. Of further allied interest, Ismael of Nairobi, Kenya produce manuals on sand dams and subsurface dams and also on the construction of sand-wells, (Nissen-Petersen 2000).

The use of collector wells has been well documented by the ODA/BGS research teams. Herbert and Pastall (1991) reports on two collector wells in Zimbabwe, one in mature alluvium and one in Kalahari sand where the 2 metre diameter shafts were dug using low-cost hand dug well techniques. A 50 mm (2 inch) screen was then jetted laterally 30 metres through a 100 mm (4 inch) temporary casing from the base of the shaft. However Herbert (1992(b)) also reports on problems associated with a collector well shaft in Botswana. As the sand river channel passed through weathered hard rock, the shaft on the riverbank had first to be dug through hard rock and then the collector's adits had to be drilled laterally out through the hard rock using an air hammer before the screening could be installed in the non-cohesive sands of the sediment in the river channel.

These works however, do not adequately review sand-abstraction options and are generally outside the scope of a practical, comprehensive, how-to do-it field survey and installation manual that is considered important by the author. Although significant amounts of literature have been identified in areas that relate directly to sand-abstraction, authoritive works are either complex tomes or brief cyclostyled papers. A clearly defined descriptive handbook of options and alternatives is still very much a requirement.

2.12. The Need for a Study of Sand-abstraction

There is an increasing need for effective and sustainable, low cost water supply systems to which people have easy access. Typical figures are that between a third and a half of all deep groundwater pumps can be found to be inoperative at any one time, (National Coordinating Committee 2000). This situation is unlikely to improve as centralised systems further deteriorate and poorly trained and poorly equipped communities are increasingly expected to manage and maintain their own water supply systems, (Mthuthuki 1996). It is thus imperative to identify systems that are acceptable to end users and which can be operated and maintained as much as possible from within the community. It is important to develop abstraction systems and pumps to which people feel an affinity and over which they are able to exercise control.

- Indications are that sand-abstraction constitutes a relevant and effective water supply technology for resource-poor communities. A study structured to establish the acceptability and sustainability of sand-abstraction will ascertain the potential for reliable community managed water supplies.
- Although considerable information and experience relevant to sand-abstraction does exist within the water supply industry there has been no comprehensive benchmark study to bring together the information available on all direct and indirectly related aspects of suitability, application, technology and products.
- Although the use of upgraded sand-abstraction systems can be traced back some 50 years, the technology has remained firmly in the commercial sector. Recent technological developments have shown the suitability of low-tech sand-abstraction handpump systems, further research and development is required to maximise the potential and to promote the technology. Community based operation and management systems to utilise the technology effectively and to ensure sustainability at the village level are required.
- Sand-abstraction is a little known and under utilised option, even within the water supply profession. There is a need to demonstrate the effectiveness and to use the information acquired to raise awareness of the possibilities of the technology.

Sand-abstraction has been seen to be effective in a wide range of situations in a number of regions and presumed to be possible in other regions and settings. As this thesis hopes to bring a greater awareness of what the author considers an under-utilised potential, a review of the conditions conducive to the development of sand-abstraction was required.

Climatic, Geographical, Geological:

To place the study in context an overview was conducted of the global conditions of climate, geography and geology in which sand-abstraction could be expected to be successful. The process of site identification and selection has been presented as a flow chart, (see 2.1.1, Chapter 8). A review of literature and documentation directly related to sand-abstraction and associated technologies was also undertaken.

Topography:

Sand-abstraction can only occur where quantities of sediment are sufficient to retain water. In situations where there is significant scour in a dryland waterway, sediment is not retained and thus conditions are unsuitable for development as a sand-abstraction site. The possibility of constructing structures to artificially retain transported sediment does however also hold a potential for sand-abstraction utilisation.

River Basins and River Morphology:

Criteria was required for the selection of rivers and conditions suitable for sandabstraction. Of particular importance was assessment of patterns of river flow and velocity of flow and the effect that these have on sediment accretion and on the security of installations.

Erosion and Sedimentation:

The effect that land husbandry and livestock management systems have in arid and semiarid river catchment areas is of significance to conditions where sand-abstraction is likely to be feasible. Consideration of the impact of weathering and rainfall run-off on denuded land and the subsequent transportation of eroded material into river systems was a prime requirement.

Sediment Analysis:

The identification of sediment material and the factors that influence permeability and porosity such as grain size and shape, layering, compaction and orientation were undertaken.

Capacity and Recharge:

The recharge of river basins and the retention and loss of water from sediment through drainage, seepage and evaporation was considered of prime importance to this research programme. A study of technical information and reference material relevant to the water storage capacity and loss from alluvium was conducted. Particular aspects of study were movement, flow, velocity, permeability and transmissivity of water through an unconsolidated aquifer.

Criteria for Abstraction Sites:

Criteria have been developed to assist in the selection of optimum abstraction sites. This will assist in the establishment of secure and workable systems and installations. Factors considered were optimum depths of sediment, sediment particle size and shape and the speed and volatility of river flow. To assist the study practical field research sites were established in four differing river situations to gather data on river basins, the composition and potential water yield of rivers, sub-surface river flow, abstraction and pumping systems.

Sustainability - Medium and Long Term Assessment:

An assessment was made to establish the likely sustainability of equipment and the technical capability of end-users to operate and maintain equipment required for sand-abstraction. A comparative measure was made of community ability to maintain sand-abstraction equipment and existing deep groundwater abstraction equipment for which a community should be trained and equipped. A review of the suitability of equipment utilised as well as the skills, tools and equipment necessary to operate and maintain various systems was also undertaken.

Development of Sites:

In order to extend the use of sand-abstraction systems, methods to develop marginal sites and to increase the capacity of favourable sites were reviewed and trial sites established. Methods considered were sub-surface and sand dams and more innovative solutions such as riverbank water storage and the artificial accumulation of sediment in the vicinity of possible abstraction sites.

Abstraction Methods and Equipment:

As the separation of water from sediment is crucial to the success of a sand-abstraction system a practical study was made of well-points and screens. A review was carried out of the various systems of abstraction, installation techniques and the operation and maintenance requirements of equipment. A series of controlled experiments on pointof-abstraction equipment was considered necessary and was undertaken and basic handpump systems were considered. From this a programme of development for appropriate, low cost well-points and pumping equipment for rural and community use, which took into consideration limitations on tools and skills was undertaken. Technical data related to permeability, velocity of water within a system, abstraction rates and draw-down as related to abstraction and pumping systems was also gathered.

Sociological Aspects:

An assessment was made of community perceptions of both traditional and up-graded sand-abstraction systems. An enquiry into how much control communities felt that they were able to exercise over their water supply systems and how much they felt that they should exercise was also undertaken. As the responsibility for service and maintenance now rests in many industrially developing countries with the end-users, an assessment of community preparedness to contribute financially to the maintenance of equipment was also considered important. Throughout the research and study period community perceptions, particularly around the four research sites was deemed to be a key factor.

2.13. Review of Literature

Information which is directly related to sand-abstraction technology specific to the southern hemisphere is not widely available. However documentation and research material relating in general to the abstraction of water from unconsolidated groundwater aquifers is equally relevant to the abstraction of water from river sediment. The modules and parameters governing permeability and velocity of ground water flow through sub-surface material, gravel packs and borehole screens are also those which

govern the flow of water through the sand, gravel or silt of a riverbed into well-points and infiltration galleries.

Initiatives have been made by a few researchers to document the advantages of using water from sand or gravel-beds and primarily relates to infiltration galleries. WEDC students, Helm (1998), Fewster (1999) and Wear (2002) have produced thesis papers on the subject. Other papers have been found on the subject such as, 'Extracting Clean Water from Streams in SW Ethiopia', (Bradfield 1992), 'Sub-surface Water in Riverbeds as a Source of Rural Water Supply Schemes', (Rajagopalan and Prasad 1989), 'The design and Construction of Infiltration Galleries', (Bennett 1970) and 'Role of Infiltration Galleries in Augmenting Supply to the Pumping Wells in the Deserts. (Nagabhushanaiah 1969). In a proposed project, Chunnett Fourie & Partners (1997) state that a number of areas of South Africa have river waters with high sediment loads and turbidity which causes considerable problems with the abstraction, storage and treatment of water. They maintain that abstraction of water through the natural filtration of river sediment, rather than the direct abstraction of river water, will provide water with low turbidity to water treatment plants and considerably reduce the problems associated with high-sediment load waters. To support this opinion they intend to establish a directory of systems in South Africa that were designed and constructed for the purpose of abstracting surface water from sand beds. Where there are low yields in any of these systems, the study will determine whether there is a correlation between yield and factors such as design, method of construction, geology, surface water quality and total bacteria count. Based on information gathered it is hoped that the study will establish sound guidelines for the design, construction and operation of river sand-bed abstraction systems. Further general documentation by Cansdale (1983) and Driscoll (1986) relates to the abstraction of groundwater from gravelbeds and commercial literature is available on specific subjects such as playing field and building site drainage (Kaytech).

A prime concern has been to develop and fabricate equipment from materials which are locally available. The production of equipment which is not dependent on imported materials, which are expensive and difficult to obtain, has been a core focus of the research programme. In reports such as 'Screen Wells Improve the Yield of Community Water Supplies', (Ramaswamy 1966), research has demonstrated that in many instances the technology is both effective and sustainable.

Suitable, purpose designed products are available in the international market-place for direct use as well-points and others can be converted with very little difficulty into screens, well-points or infiltration galleries. However, there still remains a lack of acceptance or awareness by practitioners, (Helm 1998) which needs to be addressed.

Very few manuals and no installation handbook specific to sand-abstraction has been found and few commercial companies undertake installations, (Clanahan 1997). By developing a more 'hands-on' technology, utilising handpumps, products and materials which are widely available (Promat), the cost of implementing the technology should be significantly reduced and considerably more, safe water sources accessed. The works of Cansdale (1983) and Driscoll (1986) relate to the abstraction of groundwater from gravelbeds and commercial literature is available on specific subjects such as water removal from playing field and building sites (Kaytech undated).

Wipplinger (1958) has provided significant information on the subject and independent workers such as Mutsvangwa (1998) at the National University of Science and Technology, Bulawayo, Zimbabwe and Clanahan (1999) in South Africa have attempted to develop simple, practical methods of assessing the storage potential of river sediment. Although there is little comprehensive data on the abstraction of water from river sediment, there is considerable information available in many standard textbooks and research papers on factors such as soil, erosion, river load and transportation or sedimentation which are pertinent to the technology.

At the outset of the study little information had been found relevant to the establishment of river research sites although some assistance was provided by Gordon (1992), 'Stream Hydrology; an Introduction for Ecologists'. Consequently the research sites were essentially set up by a process of discussion and very largely by trial and error. Technical information was however found on the use and siting of equipment such as piezometer tubes, Karanth (1987), rain gauges Lacey (1934) and manuals such as Department of Meteorology (1982) have provided information on evaporation pans. Information was traced on the Van Der Staay suction auger which was finally, successfully used in the extraction of core samples from sediment surface to the riverbed, (van der Meene, van der Staay et al. 1979) and (Wallinga and van der Staay 1999).

The works of Cansdale (1983) and Driscoll (1986) relate to the abstraction of groundwater from gravelbeds and commercial literature is available on specific subjects such as playing field and building site drainage (Kaytech undated). It is quite apparent that effective well-screens have been developed to prevent the ingress of loose sediment into boreholes by several companies such as Boode (1994), Johnson Screens (2000) and Soloflo (1997). Extensive research on the composition and layering of river sediment has been undertaken by British Geological Survey in conjunction with the development of a collector well programme and the Rural Industries Innovation Centre has undertaken research into the development and siting of false-wells in river sediment, (Jetten 1991). However, there remains little practical, documented research that would assist in the establishment of sand-abstraction installation programmes. Within Southern Africa at least, there are many independent practical exponents of sand-abstraction operating either from, at best inherent knowledge and at worst inadequate knowledge.

Although a number of useful contacts have been established, particularly in Southern Africa and North and South America, so far remarkably little documentation has been sourced which relates directly to riverbed sand-abstraction systems for practical applications in rural, developing world primary user schemes. However from data searches in Zimbabwe, Britain and South Africa, as well as from general reading, there appears to be a generally accepted concept where limited use is made of the technology in gravelbeds or beneath riverbeds. Use has been widespread for both primary, urban water supply schemes and for agricultural land-drainage applications. Personal contacts have proved to be particularly insightful with water engineers such as (Jones 2000) of Mott McDonald most willing to discuss schemes they have been involved with and retired engineers such as Esterhuizen (1987), Cooke (1987) and Schegar (1996) who were actively involved in the design and installation of a variety of sandabstraction schemes, providing a wealth of personal experience.

The causative action of erosion by rain droplets impacting on exposed soil and the subsequent transport of eroded material into river drainage systems is well recorded in many works such as (Bell 1998), (Hudson 1995) and (Pye 1994). Extensive reference to the formation of sediment beds and its further movement through a river is also well attended, (Twenhofel 1932) and other significant information is contained in

documented work on, hydrology, permeability and porosity, (Hallam et al 1967), (Institution of Civil Engineers 1976) and (Tucker 1988). Data on conditions specific to Zimbabwe such as 'The Erosion Surfaces of Zimbabwe', Lister (Undated) has also proved to be of particular assistance.

References have been found relating to infiltration galleries, (Helm 1998) and wellpoint systems, (Driscoll 1986), as well as to allied technologies such as jetted wells, (Maclear 1997), hand augered tube-wells, (Naugle 1991) and (Deverill, Nash et al. 1999(b)) and collector wells, (Lovell, Murata et al. 1995). Contacts have been made with people who utilise systems and materials which have primarily been designed for use in a drainage medium, (Peel 1998), but which can also be used for sand-abstraction, (Kaytech undated). Limited technical and narrative documentation has been found on the application of the system for the removal of pollutants and mineral salts from water supplies through the sands or gravel of riverbeds.

2.14. Summary

Sand-abstraction has been successfully utilised in a wide range of conditions, situations and applications to draw water from saturated alluvium. It is primarily used to abstract water from the deep sediment of seasonal riverbeds but where appropriate the same technology type can be utilised to draw water from riverbanks and gravelbeds of paleochannels. The level of technology required to abstract water from river sediment is at the most basic of levels and provided installations do not exceed 6 metres depth, the same equipment and principles of installation are equally suitable for installation into alluvial aquifers. Information has been found in small parts all over the world; however, of this much has been found to be on related technologies such as jetting or collector wells, rather than the specific process of sand-abstraction. This information is presently being reviewed and correlated so that it may be easily accessed, especially by NGOs and rural communities in the industrially developing countries where it is most appropriate and where it can be most widely used.

As a sand-abstraction water supply is a shallow groundwater source it is not in the main contaminated with deep groundwater salts and has also been filtered in a large 'sandfilter' bed. Generally people with access to water from a sand-abstraction source greatly prefer the 'sweet water' which it yields, to the 'bitter' tasting water which can be associated with deep groundwater supplies. Many people will frequently ignore groundwater supplies in favour of sand-abstraction supplies. Furthermore because water is in effect stored in the sand, supplies can generally be accepted as potable because they are not open surface water which is vulnerable to contamination and pollution. Water drawn from sand-abstraction sources is most suitable for domestic water but also provides water for livestock, food production and income generation.

The drawing of water from river sediment is an acceptable, time-honoured tradition from time immemorial. Pumped systems of abstraction have been available for at least half a century and a variety of technologies have been developed and utilised to abstract water from sand. The opportunity does exist for the development of low-tech abstraction equipment and installation techniques as a basic and acceptable technology. As sand-abstraction does not require complex installation and pumping equipment the technology has in fact considerable potential as a full VLOM system from fabrication and installation to sustainable operation and management.

Apart from the most basic traditional usage, the greatest use of the sand-abstraction technology is presently within the confines of small-scale agro-industrial applications

such as irrigation and commercial agriculture through to small town water supplies. A considerable opportunity exists for the development of sustainable micro level, individual and community abstraction systems to enable a vastly greater number of people to gain access to clean and reliable water supplies which they are able to operate and maintain in a sustainable manner.

It is apparent that there is a great potential for the technology of sand-abstraction both in Zimbabwe and also in other African countries and most probably in parts of Latin America and Asia. The technology is simple, suitable and appropriate. In much of Southern Africa where seasonal rainfall is considerably variable, such an extensive water resource should not be overlooked. The technology requires development and promoting so that more people may benefit from the health advantages of readily available clean water and nutrition in a sustainable, village level technology. It is for this reason that a comprehensive study, research and development programme has been undertaken.

Chapter 3

Research Methodology

3. Research Overview

Rural and small-scale farming communities in dryland areas frequently utilise seasonal water supplies when available. Although impermanent, such supplies help to maximise the use of available water and to reduce the time, distance and fatigue associated with pumping and the collection of water from distant or deep perennial supplies. Scoones and Toulmin (1996) states that it is a common occurrence for the people of dryland areas to dig temporary sand-wells in order to harvest the water retained in the sediment of 'dry' seasonal rivers.

Although sand-abstraction is apparently a widespread and popular water supply option with members of low-income communities, the technology has not received the focus of attention that has been accorded to small-scale, low cost water abstraction systems from groundwater supplies, (Helm 1998). There has been some commercial development of the technology but this has largely been based on the utilisation of equipment principally designed for allied applications such as submersible pumps and well-screens which are primarily used in boreholes.

In the face of a growing global demand for more water for urban use and ever greater volumes of water for irrigation, there is an increasing need to identify and utilise all viable water supply options. As water is drawn from ever larger catchment areas and transported over increasingly greater distances to urban conglomerations it is imperative that marginalised communities in particular are not over-looked. To this end this study has been undertaken in order to review the existing knowledge of seasonal rivers as viable supplies of water. Literature and grey literature reviews and interviews with practitioners and end users have been conducted. Extensive field research work has been undertaken in order to assess the potential and suitability of sand-abstraction water supplies and to develop new and appropriate methodologies and equipment.

It is the contention of the author that many years of opportunity have been lost in the development of small-scale, or low cost, appropriate and sustainable water supply systems. This study and research sets out to demonstrate the sustainability and potential of traditional water supplies and particularly that of sand-abstraction with a view to proving its worth and increasing its application. The study acknowledges the limited and frequently inadequate supplies of water which characteristically beset disadvantaged communities in impoverished areas and considers alternate sources of water which may be developed and improved to enhance viability and sustainability.

A research programme was thus conducted to

- Review the extent of knowledge and use of sand-abstraction systems
- Establish the potential for use, particularly by small-scale users
- Document relevant information
- Develop appropriate equipment
- Establish end-user perception

3.1. Research Outline

The author believes that small scale water supplies that are dependent on a low-level abstraction technology have the potential to make a realistic contribution to improvements in the wellbeing of disadvantaged rural communities. The author further believes that the water retained in the sediment of seasonal rivers constitutes a largely untapped resource and that there is a potential for development which this study and research programme has intended to assess and to develop. This study has gathered practical data on seasonal rivers and the movement of water through river systems in dryland areas which has been used to develop a small-scale sand-abstraction technology, as shown in figure 3.1 which is concomitant with water security, food security and environmental sustainability.

Figure 3.1: Small-scale sand-abstraction technology on the Mtshelele River, Zimbabwe



From an initial observation of an apparent acceptability, low-cost and ease of use of the technology, a study was planned to investigate the potential and sustainability of sand-abstraction.

It was decided to conduct research that would establish:

- What is known of the sand-abstraction technology
- The potential for the utilisation of the technology
- The factors relating to water storage in a seasonal river
- The systems of sand-abstraction in use
- · Which systems of sand-abstraction could be better used
- The possibility of developing alternative abstraction systems
- What design criteria should be applied to installations
- The acceptability of new systems to end users
- What risks, environmental and sociological, are associated with sandabstraction

A comprehensive research approach was undertaken incorporating:

- A review of documentation
- A review of traditional use
- A review of technology development
- A review of development initiatives
- Establishment of field research sites to obtain data from seasonal rivers
- Equipment development
- Community meetings
- A review of the suitability and sustainability of water supplies from seasonal rivers
- A review of associated water storage and abstraction technologies

It is the contention of this study that there is a potential for the use of sand-abstraction in optimum conditions in a sand river. However, the development of less suitable sites may hold an even greater potential for water source development. There are many small rivers and streams throughout arid and semiarid areas where there is considerable water runoff and erosion. Many of these smaller waterways may be considered as sub-optimum sites as they have only limited depths of sediment and thus do not retain water throughout the dry season. By increasing the depth of sediment, which will increase water retention, the possibility may well exist for the development of less than optimum abstraction sites as perennial water supplies.

There is a considerable need for alternative, reliable water abstraction systems which can be sustainably operated and managed by communities utilising their own resources. Research is therefore required into the development of low-cost and lowtech water abstraction solutions which community members are able to install, operate and maintain for themselves.

An increased awareness of the potential of sand-abstraction, coupled with improved site development leads to a need for the development of appropriate abstraction equipment which can be easily fabricated from readily available materials. The final prospect is for an extensive sand-abstraction information dissemination, utilisation and training strategy.

The research and study was essentially carried out to establish the potential for the development of sand-abstraction as a reliable and sustainable community water supply option. From existing systems which abstract water from river sediment it could be seen that sand-abstraction could be utilised in a range of conditions. However, to understand and develop the basic principles, a study of the significant factors related to sand-abstraction was required.

The significant factors for study were considered to be:

Water Storage

It was quite apparent that water was available for abstraction from the river channel of many sand rivers. Research was undertaken to establish the storage potential of the river and how this might be assessed.

Water Loss

Also considered of importance were factors that contributed to a reduction in the quantity of available water. Research was thus undertaken into how abstractable water was lost and how losses could be assessed

Abstractability

Having determined the importance of water storage and water losses it was deemed important to establish how abstractable water could best be drawn from river sediment and what rates of water might be abstractable.

Sustainability

The study set out to establish the sustainability of sand-abstraction systems and to establish to what extent impoverished rural communities might be able to install effective systems and then to keep them operational with effective maintenance systems.

Permanence

Sand-abstraction installations have been seen to be vulnerable to damage during periods of intense river flow. Study was thus required to establish the conditions in which damage might be expected and how equipment should be installed and secured in order to withstand the ravages of flood and time.

Acceptability

The study and development of sand-abstraction might well be considered superfluous if rural communities did not relate to a development of sand-abstraction systems beyond the traditional sand-well. The study thus set out to establish whether or not the communities involved in the research programme appreciated the technical developments.

Installation Criteria

Having established the relevance and importance of factors for study the research was able to focus on the setting of criteria for abstraction sites and consideration of the sustainability and development of sub-optimum sites. Research then progressed to consideration of the methods of abstraction and the development of appropriate equipment. All activities have been related to a community and rural user perspective and the opinions ascertained form a part of the conclusion of the research.

Environmental Considerations

The research was undertaken within a broad over-view of localities and catchment areas where the system of sand-abstraction could be expected to be utilised. It also briefly considered land management issues and general conditions which might give rise to a situation where sand-abstraction becomes possible. Since soil erosion is the main causative factor in the process which engenders conditions appropriate for sandabstraction, aspects of the research have considered the erosion and subsequent sedimentation process.

Significant research and study has been applied to fully appreciate the implication and effect on sand-abstraction of ephemeral river sediment and the subsequent storage, retention and loss of water from this sediment. Analysis has been made of a range of sediment from selected river sites in four differing situations in Southern and Western Zimbabwe. Factors affecting water loss from river alluvium have been considered to be of great importance.

3.2. Research Methodology

The research which was undertaken was largely of a practical nature in order to assist in the identification of appropriate abstraction sites and the improvement and longterm sustainability of both installations and equipment. Particular attention was given to the development of low-cost equipment that can be easily fabricated from readily available material. A range of research activities was thus conducted from a study of river morphology and existing systems to the development and trial of practical abstraction equipment.

After consideration four interrelated methods of research were used to gather information and data.

- Field research sites were established to obtain data on the nature of sand rivers, the characteristics of ephemeral sand rivers pertinent to water storage and abstraction from sediment and criteria for abstraction site installation.
- Controlled experiments were conducted to augment data from field sites. Data was obtained on sediment grading and comparative evaporation tests. Laboratory tests were conducted on sand grain characterisation
- Technology testing was undertaken during the development of abstraction and pumping equipment.
- Four rural communities provided an assessment of the existing technology, critique and feed-back on the development of technology.

From practical field installation experience it was apparent that significantly more knowledge should be gained in order to build up a comprehensive information base for the successful establishment of effective sand-abstraction installations. An extensive understanding of successful practices and those that limited or inhibited successful equipment installation was required. The relationship of the nature and the effect of erosion and sedimentation processes in ephemeral rivers was also considered important. The effect of river flow, both above and through river sediment, water retention and loss, and the water storage capacity of sediment were each deemed crucial factors. Further to this, the criteria for equipment installation and the development of appropriate abstraction methods and equipment were also required.

In order to assist in the establishment of community sustainable water supplies, the focus of research was thus on providing information which would improve the effectiveness, productivity and sustainability of sand-abstraction installations. Study and aspects of the research programme were undertaken in the following topics:

- River Basins and River Morphology
- The Erosion and Sedimentation Process
- Analyses and Storage Capacity of Ephemeral River Sediment
- The Recharge and Water Loss from Ephemeral River Sediment
- Criteria for Abstraction Sites
- The Sustainability of Abstraction Systems
- The Development of Abstraction Sites
- The Development of Methods of Abstraction and Abstraction Equipment
- Involved Community Research and Community Acceptability
- A Dissemination and Training Campaign

Identification of Research Activities

Practical Research Activities

Field Research Sites (Site locations indicated in figure 4.7)

In order to obtain data relevant to conditions which might be suitably exploited for sand-abstraction, field research sites were established in four differing seasonal rivers. Characterisation of the rivers at the sites was undertaken and an assessment made of land use within each catchment area. Research activities were undertaken to augment the limited information available on the nature of sand rivers in flow and their overall suitability for sand-abstraction. Activities were identified which would assist in the development of low-cost, alternate equipment. Data collected related to:

- The water storage capacity of sediment retained in ephemeral rivers
- The depth and rate of water loss from sediment
- Whether there was an attrition or accretion of river sediment
- Methods of water abstraction
- Security and reliability of installations, particularly in times of flood
- Rainfall within the catchment area
- Trials of low-cost equipment developed during the research programme

Off-site Research

Further experiments were selected to provide data on water storage and loss from river sediment and also on the performance of equipment which it was not practical to conduct at the field sites. Experiments which required equipment or conditions which could not be simulated in the field were undertaken within a controlled environment at a central location. Experimentation encompassed

- Grading of core samples taken throughout the full horizon from surface to riverbed at each research site. From this data a grading curve was plotted
- Comparison of water loss from identical tanks, one filled with river sediment and water and one with uncovered, open-surface water
- A demonstration tank containing four well-points abutting an observation window for the observation of water flow patterns and draw-down to the well-point
- Yield tests and performance characteristics of ten differing types of wellpoints. Water was abstracted from a 3.00 metre diameter test tank filled with a random sample of river sediment. Water was drawn through each well-point by a progressive cavity pump at four rates of abstraction

Development of Sub-optimum Sites

Possible ways to develop the potential for water supply from less-than-optimum sites were considered a useful adjunct to the research programme. An investigation was conducted into the possibility of increasing the volume of water which could be made available to well-points. Three possibilities were identified:

- Accretion of sediment. Two systems were considered which would increase the depth and thus the volume of river sediment, which would in turn increase the volume of stored water. A site for a sand dam was surveyed and two stages of construction completed and a 1.7 km section of riverbed surveyed to gauge the potential to construct gabions across the river to retain sediment.
- Sub-surface dams. Two sites were surveyed and work commenced at one site to construct a barrier to reduce down-stream drainage.

• Streambank abstraction. Trials were conducted with well-points which abstracted water from existing sand-beds which had been created as the course of the river inexorably altered. Well-points were either jetted or driven into the alluvium.

Personal Interviews and Documentation Reviews

An extensive review of literature and documentation was required in order to gain a comprehensive understanding of the options and possibilities and existing knowledge that relate to water storage and abstraction from sand. A number of visits to a range of sand-abstraction systems were undertaken and the author has conducted extensive personal interviews with water professionals, commercial farmers, ranchers and subsistence farmers since 1985. Topics selected were:

- The analysis of literature and discourse in order to develop further possible options related to sand-abstraction
- Consideration of the potential for water storage options in sand
- Development and trials of sand filled water harvesting and storage tanks.

Inter-relationship of Research Activities

A characteristic of the study has been the interdependence and linkage of research activities. Each element of research has been a component in a progressive sequence of activities leading to a composite study. Initial observation and appreciation of the traditional technology has lead to a comprehensive survey of potentially suitable rivers and the conditions which have the likelihood for development as reliable abstraction sites. Data collection on water storage and abstraction from sand has been used in the development of appropriate low cost, low technology equipment and will hopefully manifest itself in more widespread use by economically disadvantaged rural people. This process of observation and development has also continued into the improvement of sub-optimum sites for reliable water abstraction.

Commencing with a broad overview and a review of conditions suitable for sandabstraction, surveys have been carried out on river catchment areas. From these wideranging investigations, a more intensive appraisal has been conducted into the nature, use and vegetative cover of the river catchment area which has lead to the observation and study of runoff and erosion and finally progressed to a study of the sedimentation process in a riverbed. Thus background and detail has been established for the development of equipment from the factors affecting water storage capacity, water loss and retention in the sediment and transmissivity to abstraction points.

Data collected has been analysed and developed as an interpretive tool in the identification process of areas and locations suitable for abstraction. Information gathered has ultimately proved relevant to the overall sustainability of installations and abstraction systems. A perspective on the data acquired and on the possible practical use and suitability of design for the equipment which has been developed has been sought from the communities in the vicinity of field research sites. A strong link of needs, one to another, has thus been established between activities.

At the four field research sites the results of three experiments at two sites and four experiments at two other sites have been combined to demonstrate the overall water loss from river sediment and two experiments have been used to demonstrate the characteristics and effect of river flow on an installation. Research activities have been used to complement each other to provide a global picture. Data has been

correlated from a number of experiments to build up an inter-related and combined effect of activities. The interaction of research activities and the use of information gathered in one discipline have been used effectively in conjunction with another to provide an overall perspective and to link viability with sustainability and the environment.

Organisation of Study and Time Frame of Activities

The management of research activities was addressed systematically to ensure a correlated and planned approach to the study which took into account seasonal and environmental conditions and the requirement of data for furtherance of the study. The overall order of activity was a progression from conceptualisation and review to data collection, the development of sub-optimum sites and the development of appropriate equipment. Research commenced with an identification of the factors which were considered essential for effective sand-abstraction and set out to gather data and information which might be necessary to appreciate the value of the technology. Attention was particularly centred on those factors where there was an obvious dearth of knowledge or information.

Initial planning and formation of a broad outline and overview was formulated over several years. As conceptualisation progressed a sequential plan of study was devised which included:

- A review of available sand-abstraction technology
- Characterisation of requirements, river and environmental conditions for effective sand-abstraction
- Establishment of four field research sites for the collection of data on water storage and loss in river sediment and river flow characteristics. Eight local people collected data on a regular basis. A seminar was held annually for the eight assistants to co-ordinate activities and to review their work
- Establishment of a central control site for tests and the development of equipment which could not be conducted in the field
- Development of appropriate low-cost abstraction equipment and the development of sub-optimum sites

The linkage of these activities established a logical sequence of one requirement or undertaking following another in the composition of a comprehensive study. In order to ensure sufficient time for adequate testing and subsequent modification it was important that all practical aspects where possible were commenced early in the research programme.

Review of Technology

From practical involvement, observation of sand-abstraction techniques and technology has been undertaken informally since the mid-nineteen eighties. Importance of this initial assessment phase increased significantly in the early nineteen nineties with the dispiriting realisation that in many situations mechanically complex water supply schemes were neither viable nor sustainable. A technological switch from engines to hand operated water supply systems and the apparent potential and success of small-scale schemes gave rise to the decision to conduct a research programme into the further possibilities and potential of sand-abstraction systems.

A number of visits to a variety of schemes and different technology applications were conducted early in the research to provide background information and to conceptualise and lead into the research programme. This work was largely undertaken between 1998 and 2000 as an introduction to the main research programme. A report of 26 schemes undertaken at that time appears in appendix 01.

River and Site Characterisation

From the outset of the study the importance of understanding the environmental conditions that would likely support sustainable sand-abstraction systems was quite apparent. As there is a link between environmental degradation and sand-abstraction it is important to get a deeper understanding of the ecosystems. River conditions and selected research sites were thus extensively characterised in the early stages of field research site establishment.

Field Research Sites

In order to obtain comprehensive data the need to establish field research sites was identified early in the research process. Equipment which was designed to collect long-term data at the sites was developed and installed within a few months of site identification. Activities that were undertaken just once a year were set up and undertaken at convenient times.

Four field research sites were set up at the outset of the programme in 1998 and contiguous dry season and rainy season activities were carried out into 2003. In consideration of the vagaries of the seasons, from the outset of the research programme, it was envisaged that five years data collection would be required to provide an adequate range of conditions. This assumption was in fact proved to be quite correct as extremes of rainfall and river flow were in fact recorded between 1998 and 2003

During the first year of data collection when the research sites were being set up, the 1998/99 rainy season was a fair, average season. The second rainy season in 1999/2000 however was far from typical. Although the season commenced with 'average' rains, Cyclone Eline poured into Zimbabwe from the Indian Ocean in January 2000 and also drew the Inter-Tropical Convergence Zone (ITCZ), south causing considerably increased rainfall within the country and research areas. Excessive rainfall, in both intensity and duration, resulted in considerably higher groundwater-tables which in turn resulted in far higher levels of water within the river sediment for a much longer period than usual. The 2000/01 season was slightly higher than normal but coupled with the higher than normal levels continuing from the previous season also contributed to an unusually high water level in river sediment for the 2001 dry-season. The 2001/02 season commenced with unusually widespread and continuous rain with the control site receiving an unprecedented 45 continuous days with precipitation. However there was virtually no rainfall following this period, thus it was not until 2002 that a balance of data was obtained with recordings made during a 'drought' year.

Site visits were made to collect data at approximately two month intervals. Occasionally the interval between site visits was altered due to other commitments and occasionally because of the sensitivity of the local political situation. However in the main a complete log of data was regularly collected from each site. Field research workers were paid for the data they had gathered during site visits. When ever possible, check measurements were taken during site visits. Two local people collected data at each site. This was undertaken to establish a support and back-up for research workers and was instigated through their recommendation.

Off-site Research

Initial efforts to obtain complete core sediment samples proved difficult and although some grading of river sediment was undertaken in 1999 at Loughborough, it was not until 2001 that a full range of core sediment samples was graded from all four sites. Well-point observation and yield test tanks were set up in 1999 and 2001 for the testing of well-points which had been designed from the data acquired from the field research sites and sediment grading.

Development of Equipment and Sites

Four well-points which combined efficiency with simplicity were selected from the yield tests for extensive field trials. Basic, easily serviced handpumps were also fabricated and installed on the well-points adjacent to each field research sites for practical testing in the final stages of the research programme.

The development of sub-optimum sites to improve water retention and thus to provide an improved water supply was also undertaken in the latter stages of the programme.

3.2.1. Overview of Field Work

The overriding criterion was to assess the suitability of sand rivers for effective and reliable abstraction of water. To achieve this, a range of conditions was determined which would provide data from a site considered to have a high potential for abstraction through to a site which could be considered to have a limited supply potential. The criteria considered essential for a site with a high potential was determined as a perennial supply of water, ease of abstraction and security of equipment. Conversely, a site was considered to have only a limited potential if yearround water could not be guaranteed, where abstraction was arduous and where the security of the installation could be in doubt. A minimum of four sites was considered necessary to provide data of a reasonable cross sectional representation. In order to assess the suitability of a site in a variety of conditions it was intended that data would be collected over a five-year period.

3.2.2. Selection Criteria

Four sites were selected as it was considered unrealistic to effectively monitor and administer more.

Ideal Research Sites

Prime Storage and Abstraction Site on a Large River

The selection was intended to provide data from an ideal site with copious amounts of water and optimum water storage characteristics for the development of sand-abstraction opportunities.

The ideal data collection point was expected to be sited on a river which was:

- deep and wide in the channel
- part of an extensive catchment area
- continually recharging the research site through ongoing drainage from tributary streams and rivers
- comprise a considerable volume of coarse sand with a large void ratio for optimum storage of water

• to have minimal water losses - a solid, impervious riverbed to minimise water loss by seepage through the riverbed and coarse sediment to minimise losses from evaporation.

Non-prime Site on a Large River

The site was intended to provide data from a large river but with a poor potential for reliable sand-abstraction. A relatively inadequate site was required on a large river with a poor potential where the supply of water was not likely to be secure and where water losses could be expected to be high. A river was required which would provide data on an average site with only a fair potential for sand-abstraction. It was expected that a moderate size river and catchment area with a moderate volume of sediment would be considered acceptable.

Features of the river were intended to be:

- deep and wide in the channel
- solitary, with few tributary rivers
- low recharge characteristics
- sediment with small void area and low water storage potential
- possible high rate of water loss from the sediment

Prime Storage and Abstraction Site on a Small River

The site required was expected to have the potential to be a productive site on a small river. The characteristics looked for were a:

- small river channel
- adequate catchment area
- good recharge
- sediment with good storage characteristics
- reduced water losses through a solid, impervious riverbed to minimise water loss by seepage through the riverbed.

It was assumed that the site would be of relatively low production but within the limitations of the size of the river would have a fair water storage capacity with a good recharge.

Non-Prime Site on a Small River

The intention of this site was to obtain data from a site which was considerably less than optimum. The required site was planned to comprise a:

- small river channel
- limited catchment area
- poor recharge
- poor sediment storage characteristics

An overall poor site was planned as a short, narrow river with a small catchment area and a limited recharge and water storage potential. Ideally the site would have a limited volume of fine sediment over a pervious riverbed.

Selection & Establishment of Sites

Rivers were selected in areas with different geological and topographical conditions. It was also considered necessary to choose rivers of differing size, flow regimes and sediment patterns. Four varied sites were thus selected in southern and western Zimbabwe. Site conditions ranged from a prolific, optimum water supply site, deteriorating to a site with very little water supply potential. To ensure a realistic base-line, each research site was set up at a location which constituted a useable source of water for a community.

A number of sites were considered within the general criteria. The four sites selected were:

- Tshelanyemba. The site met the required criteria of a large river with extensive reserves of water. The mean depth of sediment was not as deep as the ideal site demanded, but this was compensated by the large apparent volume of water available.
- Huwana. This site also met most of the set criteria for a moderate site, a nonprime site on a large river. In years of inadequate rainfall water levels at the site became particularly low. It was anticipated that river sediment would be significantly finer than it actually graded, as, although the river was transecting fine Kalahari sands, the river sediment was found to have been washed down river from the gneissic area in which the river rose.
- Wenlock. The river out-yielded expectations for a prime site on a small river. In the second and third years of data collection the river became virtually a perennial river due to the slow release of water from a well-managed catchment area.
- Dongamuzi. This site met all criteria for a non-prime site on a small river as it proved to be a totally inadequate site. The river had a small catchment area and was itself narrow with fine sediment. The reserve of water was small but was the chief water supply for the surrounding community.

Rivers and Site Locations:

Prime Storage and Abstraction Site on a Large River

Tshelanyemba

Shashane River, Matobo District, Matabeleland South Province, Zimbabwe

Latitude 21° 20 south; Longitude 28°30' east Full co-ordinates 65487404 Zimbabwe 1 to 50,000 Geophysical Map reference: Tshelanyemba 2128A4 Grid references PG 548404

The Shashane River drains due south into the Shashi and then to the Limpopo Rivers which drain east to the Indian Ocean. The headwaters of the river are south east of Marula on the Bulawayo to Plumtree road and the river passes close to and west of Kezi and Maphisa (Antelope Mine). The research site is 20 kms north of the Zimbabwe - Botswana border and 2 kms upstream of Tshelanyemba hospital. The river has an extensive catchment area and is generally slow flowing in its traverse of an extensive gneissic plain well below the watershed, known as the Lowveld. At this point the river is ± 130 metre wide with a depth of sediment ranging between 0,50 m and 3,00 metres. The sediment is clean, coarse gneissic sand and is presumed to retain extensive quantities of water.

Choice of Site.

The river and the research site were chosen as possible examples of ideal conditions for sand-abstraction. As the river drains an extensive gneissic plain it was assumed that there would be fairly optimum conditions for water storage in the river basin. The river was known to have alluvium in its channel reaching back to Antelope dam more than 30 kms upstream. The Shashane River is a major seasonal river draining an extensive basin, there are thus several large rivers to augment river flow and recharge. It was seen to be wide, with a depth of sediment likely to constitute an extensive aquifer. Water retention possibilities were also considered good as the sediment was predominantly clean and coarse grained. Figure 3.2 shows the Shashane River at the point of the field research site which is at the extreme left of the picture.

Figure 3.2: Tshelanyemba field research site



Non-prime Site on a Large River

Huwana

Manzamnyama River, Bulilimamangwe District, Matabeleland South Province, Zimbabwe

Latitude 19° 52' south; Longitude 27°32' east Full co-ordinates 555678034 Zimbabwe 1 to 50,000 Geophysical Map reference: Huwana 1927C4 Grid references NJ 556034

The Manzanyama River (sometimes referred to as the Nata River) is an endogenous river draining eastwards into Botswana where in seasons of good rainfall it contributes to the filling of Lake Ngami. The water in the lake evaporates as there is no outlet, in years of poor rainfall river flow does not reach the lake. The headwaters of the river are 40 kms west of Bulawayo and north east of Figtree. The river is the boundary between Bulilimamangwe (Plumtree) and Tsholotsho Districts and also of Matabeleland South and Matabeleland North Provinces. It is one of only two rivers running west from Zimbabwe into the Kalahari and is a large, slow moving river traversing flat Kalahari sandstone country. Much of its catchment area is on the watershed from where it draws significantly coarser sediment than the land through which it passes. The research site is 75 kms from the Botswana border and 15 kms north of Lady Stanley Clinic. At this point the river varies between 50 and 60 metres wide with a depth of sediment ranging from 2 to 4 metres. Although Huwana is on the edge of the Kalahari Desert which is comprised of fine Aeolian sand the sediment

in the river channel is predominantly clean, coarse gneissic material transported from upstream.

Choice of Site.

The river and the research sites were chosen in order to monitor a river with what were considered to be less than optimum conditions for sand-abstraction. As the river is in predominantly sandstone country it was assumed that there would be significantly greater water loss from seepage than from rivers draining granite and gneiss areas. The surrounding area is particularly flat with no river network, the river thus has no major tributaries to augment river flow and recharge. During times of excessive rainfall water floods extensive areas to a depth of a few centimetres as water drains into pans which have no outlet. Although the research site is located in an area of sandstone the sediment in the river was found to have been transported from its headwaters in an area of granite. Figure 3.3 shows the Manzamnyama River with the field research site which is across the centre left of the picture.

Figure 3.3: Huwana field research site



Prime Storage and Abstraction Site on a Small River

Wenlock

Mtshelele River, Gwanda District, Matabeleland South Province, Zimbabwe

Latitude 20° 45' south; Longitude 28°42' east Full co-ordinates 677677047 Zimbabwe 1 to 50,000 Geophysical Map reference: Mayezane 2028D3 Grid references PH 776047

The Mtshelele River is a tributary of the Toghwana River which is a tributary of the Thuli River. Each drains due south to the Shashi River which joins the Limpopo River, both flow east into the Indian Ocean. The headwater of the Mtshelele is 30 kms south of Bulawayo in the Rhodes Matopos National Park. The research site is 45 kms south of Bulawayo. The river is a small, fast flowing river rising on the national watershed and passing through a batholithic, granite area, above the gneissic, lowveld plain. Much of the catchment area above the research site is in the wellvegetated National Park, consequently water seeps into the waterway for much of the year with the result that the river flows for periods longer than the usual ephemeral river flow. At the research site the river is \pm 30 metres wide with a depth of sediment approximately 3,00 metres right across the river. The sediment is clean, coarse granite and gneissic sand and is seen to remain saturated for much of the year. The Wenlock field research site is shown across the centre of the photograph, figure 3.4.



Figure 3.4: Wenlock field research site

Choice of Site.

The river and the research sites were chosen in order to obtain data from a river likely to provide optimum recharge characteristics. It was considered to be virtually a control site. Due to the dense vegetation in the virgin bush of the National Park and the vleis and swampy areas, runoff water seeps from the catchment area into the river channel for much of the dry-season. As the river drained an area where the underlying granite was close to the surface and is also renown for its massive granite batholiths it was assumed that the riverbed would be substantially rock and therefore would not be subjected to excessive water loss by seepage. The sediment was also seen to be clean and coarse grained and likely to yield significant volumes of water.

Non-Prime Site on a Small River

Dongamuzi

Dongamuzi River, Lupane District, Matabeleland North

Latitude 18° 26' south; Longitude 27°30' east Full co-ordinates 553079624 Zimbabwe 1 to 50,000 Geophysical Map references; Lubimbi 1827A4 & Cewali 1827B3 Grid refs NJ 530624

The Dongamuzi River is a small tributary of the Mzola River which is a tributary of the Shangani River which joins the Gwayi River to flow into the Zambezi River. The Dongamuzi flows south, the Mzola west, the Shangani and Gwayi north and the Zambezi east to the Indian Ocean. The Dongamuzi River and the research site are 50 kms east of the Hwange National Game Park. The river is in fact a small seasonal stream, only some 5 kms long, it has a small catchment area with its headwater just

south of an indigenous forest area. The river has created ox-bow bends as it meanders through flat, Kalahari (Forest) Sandstone over mudrock at \pm 6 metres below the surface, although 150 metres below the research site the stream has cut through to the mudrock and winds back on itself below a 6-8 metre high cliff. The river varies in width from 10 to 15 metres. The sediment is comprised of fine sandstone clasts as the river catchment area is entirely in a flat sandstone area. The field research site on the Dongamuzi River is shown towards the top of the straight section of river in the lower left of the photograph, figure 3.5.

Figure 3.5: Dongamuzi field research site



Choice of Site.

The river and the research site was chosen in order to study a river with considerably less than optimum conditions for sand-abstraction. The Dongamuzi River is small with a very small catchment area in fine sand country, locally known as 'gusu'. The river flow and water storage conditions were thus considered to be very poor. The river is in a fossil dune area where the groundwater typically contains excessive amounts of water contaminated with mineral salts. The river is thus a vital source of water for more people than a relatively small stream should be expected to provide. Water losses were also considered to be higher than normal due to the proximity of the headwaters, the small size and thus limited volume of flow of the river and the presumed losses from the riverbed due to seepage. Information and data on such a less than optimum site were considered to be of benefit to the study

3.3. Research Undertaken

3.3.1. Field Research Sites

As with any source of water that has a potential for development, a site feasibility survey was required for the selection of an optimum sand-abstraction site. A quick but accurate method of site appraisal was thus seen as a useful tool to develop. An indepth survey would then only be required on the more promising sites. Field research sites were set up to provide data which could be used to develop a method of rapid assessment, to corroborate the findings of these initial appraisals and to provide detailed information specific to the water storage capacity of river sediment and water loss during the dry season.
Trials conducted at the four research sites were designed to establish the conditions most conducive for the maximum abstraction of water, the stability of the river sediment during river flow and thus the security of equipment installed for the abstraction of water. The provision of data that could be used to assess the viability of small-scale sand-abstraction systems as a reliable source of water was considered a prerequisite for study.

Water Storage Capacity of Sand Rivers

A critical factor in the feasibility of sand-abstraction is the water storage potential of river sediment. A requirement of the research programme was the development of a system of rapid appraisal that could be used to provide a quick indicator of the potential of a proposed site. Factors which were considered to be of primary importance and which could be quickly utilised were the volume and the grading of river sediment. In order to verify the accuracy of a quick assessment of these immediately observable factors, it was considered necessary to collect data on water storage in sand over a long-term period.

Calculation of Volume of Sediment

An assessment of the volume of sediment in a river channel was used to provide a guide to the quantity of water likely be available. A simple calculation of the depth and width of sediment in the river channel and the approximate length of the sediment bed provided a quick overview of the total volume of sediment liable to saturation following river flow. The depth of sediment was established by probing from the surface to the riverbed and through a matrix of depth probes a profile of the riverbed was established.

Accurate measurements of sediment depth, river channel width and length and slope of sections of sand rivers was undertaken at each of the selected sites.

Storativity of Sediment

The size, shape and compaction of sediment grains critically affects the void area and thus the water storage potential of river sediment. A visual appraisal and rough assessment of riverbed material at a proposed site was undertaken to establish whether it was composed of predominantly fine or coarse-grained sediment.

The American Society for Testing and Materials (1972) states that minimum and maximum dry density testing of sediment is relevant for granular soils and corresponds to the extreme states of loose and dense packing at which sediment grains can be placed. The maximum density represents the densest packing of particles and corresponds to minimum porosity and the minimum density represents the loosest packing and corresponds to maximum porosity. Some testing of density was carried out on sediment in a rudimentary fashion by observing the flow of sediment through a funnel and the formation of the sediment pile that accumulated below. Further simplistic testing was carried out with a 2,000 cm3 graduated glass cylinder and a test for minimum density devised by Kolbuszewski where sediment is loosened within the cylinder and the residual depth then measured, (American Society for Testing and Materials 1972). No data is provided but reference is made to a comparison of sediment density. A sample volume of sediment was compacted by tamping and agitating and the residual depth similarly measured. Consideration was given to the determination of the limiting densities of sediment to British Standard 1377 but was thought to be beyond the requirements of the study.

Core Sampling

Representative core samples were taken throughout the sediment horizon, from the surface to the riverbed. The samples were extracted for analysis and grading in order to establish the range and proportion of sediment grain size, particularly the proportion of fines which would affect the water storage capacity of the sediment. Core samples were taken for sieving in order to assess the relevance of visual grading and to establish a representative grade of river sediment which in turn was used to select the size of the well-point apertures. Figure 3.6 shows the taking of a core sediment sample with a Van der Staay suction coring auger.

Figure 3.6: Extracting a core sample at Wenlock field research site.



Permeability

The permeability of samples of river sediment was determined at each research site to provide data which could be used to accurately assess the water storage potential. Figure 3.7 shows the preparation of a sediment sample for permeability testing at Huwana field research site.

Figure 3.7: Collecting a sample for permeability testing



Local knowledge - Use of perennial sites

The recognition of existing sand-wells within a river provided initial identification of possible sites and augmented the data obtained from the field sites on water storage and abstraction potential. An indication of an area with a worthwhile potential was generally obtained from noting a locality where there was a particular profusion of wells which were in regular use by the community long into the dry-season. The experience and inherent knowledge of the community in the vicinity of each field research site was gathered through discussion and observation and used to evaluate the technical data gathered. Community identification of the most productive water bearing sites was assessed and built on to enhance data on site identification and selection and to improve the overall assessment of the water yielding potential of sand rivers.

Water Loss from Sand Rivers

Recorded Water Levels

Following the saturation of river sediment subsequent to river flow, significant water losses are experienced from the sediment. An essential requirement of this study was to identify and quantify those losses. Data on total water losses from river sediment was recorded by piezometer tubes which were installed at each research site and read weekly. Monitoring of the data collection was carried out by regular site visits and independent readings as well as comparative data collection from equipment based at a non-field control site. Figure 3.8 shows a field worker taking a reading at a piezometer tube with a water level dipper at Huwana field research site.

Preliminary assumptions by the author were that water losses could be ascribed to three factors; evaporation from the surface of the sediment, downstream drainage in the river channel through the sediment and seepage from the sediment through the riverbed into the lower water-table. In order to establish the percentage losses, experiments were undertaken to provide data on the water loss through evaporation with evaporation pans, from drainage with flow measuring equipment and an assessment was made of seepage losses.

Figure 3.8: Piezometer Readings



Evaporation

Indications are that a significant loss of moisture from river sediment can nevertheless be attributed to evaporation although not as considerable as the loss of moisture from open-surface water. The classic work of Wipplinger (1958) 'The Storage of Water in Sand' is essentially devoted to this concept. Wipplinger spent many years in Namibia studying and comparing the water loss from sediment and from open surface water. Owen (2000 (a)) similarly has gained much experience in water loss in arid areas and in discussions with the author has expressed his opinion that water loss from river sediment is primarily due to evaporation. Data was required on evaporation levels in the vicinity of the field research sites to help assess water losses from river sediment. Readings of evaporation from open surface water were taken daily from standard evaporation pans and improvised gauges at two of the sites,

Tshelanyemba and Huwana. Figure 3.9 shows an evaporation pan at a rural home near the Huwana field research site.

Figure 3.9: Evaporation pan - Tshelanyemba



Downstream Drainage

A significant loss of water from sediment was attributed to general drainage from the river basin. The characteristic of ephemeral river flow is a flood peak followed by diminished flow until the river dries up when the riverbed is reached. The principle of sand-abstraction is the utilisation of water which remains in the sediment of the riverbed when above surface river flow ceases. Martin Mansell hypothesizes that the decreasing water level in the sediment can be attributed to a continuing, but diminishing, river flow through the sediment, (Mansell 2002). This premise of water loss due to an on going flow regime through the subsurface was tested at each of the research sites by Mansell and the author, (Mansell and Hussey 2003) following the 2002/2003 rains. The velocity of water through the sediment was used to establish the losses which could be attributed to downstream drainage. Figure 3.10 shows the installation of charge wells and a salt dilution reading being taken at Wenlock field research site.

Figure 3.10: Sub-surface drainage experiments



Seepage

Significant losses were assumed to exist through the riverbed to the underlying groundwater-table. However, although such data was considered to be of prime importance to the study in order to quantify comparative losses from river sediment, the collection of data which would be sufficiently accurate was considered to be beyond the scope and resource of the study.

Aggradation or Degradation of Sediment

Experiments were conducted to establish whether river channels experienced an overall gain or loss in the volume of sediment retained over a number of seasons. The total volume of sediment can be related directly to the quantity of water available for abstraction. Where there is a decrease in the volume of river sediment a corresponding decrease can be expected in the volume of stored water and conversely, where an increase is anticipated in the volume of sediment, a corresponding increase in the volume of stored water is possible. Where sediment depth is continuing to increase, there is a further likelihood of floods from rivers breaching their banks and a risk to the security of equipment where sediment levels are decreasing. In order to establish whether there was an accretion or attrition of sediment, a bench-mark was established on the riverbank and readings taken at the onset of the dry season, after cessation of river flow, to record gain or loss in the level of sediment. Figure 3.11 shows a spot reading height being taken for an annual comparison of sediment level.

Data was also required on sediment movement but due to the unavailability of suitable monitoring equipment this was unfortunately not possible. Note was however taken of experiments conducted in Botswana in rivers with very similar characteristics to those of the research sites. (Davies, Rastall et al. 1998), (Herbert 1998) and (Anderson 1997).

Figure 3.11: Reading sediment levels and bench-mark levels at Huwana field research site



River Flow Characteristics

The security of abstraction equipment within river sediment was considered to be of prime importance. The technology of sand-abstraction could not be considered practicable if abstraction equipment was regularly damaged or washed away. Experiments were thus set up to provide an insight into the movement of river sediment during river flow and an interpretation made of the likelihood of damage to equipment in certain circumstances at differing site locations.

Data was collected on the height of river flow and the maximum height of flow correlated to the maximum depth of water flow within river sediment. Rainfall was further related to river flow although due to lack of extensive data only a bare indication could be made. The study had only the resources to set up a single rain gauge at each field measuring sites, rather than a number of gauges located strategically within the catchment area.

Maximum Height of Flow Meter.

Height of flood at each research site was recorded by purpose made gauges which were designed, fabricated and installed as a part of the study. A chalk-marked gauge was used to record the maximum height of each river flow. Regular readings were taken at each of the four sites throughout four rainy seasons from 1999 to 2003. Figure 3.12 shows the height of flow gauges on the riverbank at Huwana field research site.

Figure 3.12: Height of Flow Meter



Tell-tales

In order to assess the likely stability of installations it was considered necessary to understand the nature of river flow and the relationship of the height of river flood to a corresponding depth and fluidisation of sediment. Tell-tales were used in conjunction with height of flow meters to record the depth to which fluidisation of sediment occurred during river flow. The base level of fluidisation became the effective riverbed for the duration of river flow with anything above this level effectively within the river flow.

Rain Gauges

Rain gauges were installed in the vicinity of each research site and read daily. Although it was precipitation from further up the river catchment which directly affected the flow of water and conditions at the research sites, an idea of the rainfall at each site was seen as an indication of rainfall within the locality.

3.4. Off-site and Laboratory Research

Data critical to water storage within river sediment which could not be obtained from field research sites was obtained from experiments conducted under offsite control conditions.

3.4.1. Off-site Research

A control site with amenities suitable for accurate measurement, monitoring and recording was established in Bulawayo, Zimbabwe. Figure 3.13 shows the rain gauge used for offsite rainfall readings at the Dabane Trust premises.

Figure 3.13: Rain gauge



Sample Sediment Grading

The grading of samples of core sediment was undertaken for general identification of the texture of sediment. Recognition of the percentage grading and a grading curve was used to assist initial assessments in the potential for storativity of sediment and latterly for the selection of the correct size of aperture for well-points.

Core samples were sieved to produce a percentage of grain sizes and a grading curve. A selection of 6 sieves with mesh sizes, 2.00; 1.00; 0.50; 0.25; 0.125 and 0.063 mm

were used to grade the samples on a mechanical shaker shown in figure 3.14 which was suggested by the author and designed and fabricated by Joseph Hussey, (Hussey 1998).

Figure 3.14: Sieve shaker



Evaporation tank

Experiments to provide data on evaporation to augment that obtained from the field research sites were conducted into the potential for loss of water from river sediment. Comparative data was required for evaporation losses from open surface water and from water retained in river sediment to establish the actual reduction in the loss of water to verify the assumed reduction in evaporation from sediment. Figure 3.15 shows the two tanks used for comparative loss to evaporation from a sample of typical river sediment and from open surface water.

Figure 3.15: Evaporation tank



Well-point Test tank

As the study progressed and moved to the practical development of appropriate abstraction equipment further research was required to gather data on the suitability and performance of well-points and handpumps. Performance data on the yield of equipment, which had been designed and developed within the study, was obtained under test control conditions in a purpose designed test tank, figure 3.16, before installation at sites in the vicinity of the field sites. A control test tank also provided a means of visual appraisal of equipment which had undergone practical use, subsequent to its installation at field sites.

Figure 3.16: Well-point test tank



3.4.2. Laboratory Research

Laboratory based research work was undertaken in the Civil Engineering laboratory at Loughborough University on randomly selected sediment grains taken from core samples extracted from the river sediment at field research sites.

Sediment Characterisation

The characterisation and classification of the shape and texture of sediment clasts was undertaken with the aid of a laboratory microscope. An estimation was made of the sphericity of a selection of grains and a smaller number of grains were measured for approximate length, breadth and width. Due to limited sampling this could not in any way be considered definitive, nevertheless an analysis of the shape and size of clasts was undertaken in order to provide an indication of the composition of the sediment. A well graded sample of rounded grains could be expected to provide the greatest void area and the greatest water storage potential whilst a wide range of grain size and shape was considered more likely to provide a compact sediment with a limited void area and limited water storage potential. The American Society for Testing and Materials (1972) refers to a collection of equal spheres which in their extreme states of packing in a two dimensional form can be either densely packed as in figure 3.17a, or loosely packed as indicated in figure 3.17b. ASTM, Philadelphia also states that in the densest packing form, the voids between large particles contain smaller particles and the voids between these contain yet smaller particles. An idealised limit of packing is characterised by the stylised 'Fuller' packing arrangement, figure 3.17c.

Figure 3.17a: Densely packed soil particles. Figure 3.17b: Loosely packed soil particles, (American Society for Testing and Materials 1972).



Figure 3.17c: Idealised 'Fuller' packing, (American Society for Testing and Materials 1972).



3.5. Development of Equipment

3.5.1. Field Research and Off-site Equipment

Much of the recording and sampling equipment utilised at the field research sites was purpose designed by the author and fabricated within the Dabane Trust workshop at Bulawayo, Zimbabwe. The use and refinement of this equipment guaranteed the suitability of purpose and ensured full comprehension of the requirements for data and sample acquisition. Further support for the development of equipment within the research programme was the lack of suitable, readily available equipment and funding constraints for the purchase, freight and importation of more sophisticated commercially available equipment.

Field Research Site Equipment

In-situ Equipment

Following identification of the site a bench-mark was sited above the flood line on the riverbank and concreted in place. Two further pegs were installed in line with the bench-mark and the flow of the river at 3.00 m each side of the bench-mark From

these three locating pegs, measurements were taken to place and monitor the height and position of data collecting equipment across the river. Irrespective of the width of river, four piezometer tubes were installed at equal distances across the river in a straight line at right angles to the locating pegs from which measurements were taken to each tube.

Tell-tales to record the depth to which fluidisation occurred in the river sediment were placed approximately centrally between each of the piezometer tubes. As the expectation was that many of the tell-tales would be washed away with the original placement sites difficult to trace, positions were accurately measured to the locating pegs. Height of flow meters were placed at the edge of the river sediment along the riverbank.

Piezometer Tubes

Piezometer tubes to gauge water levels within the sediment were fabricated from steel tubing. The lower end of the tube was flattened to a chisel point and transverse slots cut alternatively with a hand hacksaw in two rows on the sides of the pipe. The top of each tube was closed with a threaded steel bung to prevent entry of sediment. The required length of each piezometer was established through probing at each proposed point of insertion. Tubes were initially prepared to the probed length but as it proved difficult to accurately determine the depth to which the piezometer tubes could be driven, later installations were made with either 2, 3 or 4 metre tubes. Tubes were driven into the sediment with a 14 pound hammer as shown in figure 3.18.

Figure 3.18: Installing piezometer tube



Initially readings in the first two seasons were taken by measuring the water depth with a dipping rod. The depth of water was recorded and subtracted from the known depth of the piezometer tube. However with the realisation that sediment was slowly filtering into the tubes through the slots and thus affecting the depth of water, the piezometer tubes were removed, cleaned out, repaired, wrapped in geo-textile to prevent further blockages and jetted back into place. Thereafter electronic water dippers were used by the site assistants each week to record water levels in the piezometer tubes.

Height-of-Flow Meters.

In order to record the maximum height of each flood at the research sites, purpose made gauges were designed and installed. Steel tubes were set in concrete at the edge of the river. Holes top and bottom of the tube allow water in and air out. Inside each tube a length of tape measure was attached to a broom handle which was painted with blackboard chalk which was marked with chalk. As the water rose within the tube so the chalk was washed away to record the highest level reached. The first gauge was placed at riverbed level with its top corresponding to the base of a second gauge set further back from the river and if necessary a third gauge was similarly set to the second.

Readings were taken at each of the four sites throughout the 1999/2000 rainy season. However, rain was extensive throughout the area and several gauges were damaged or washed away. Replacements gauges were designed with an angled leading edge to allow debris to be washed over the gauges and to prevent the build up of excessive debris which was the cause of damage.

Tell-tales

Tell-tales were installed at each site to record the greatest depth to which disturbance had occurred in the sediment during a rainy season when the river had flowed. Tell-tales were placed in the dry-season and in order to excavate the site and to locate the remaining tell-tales during the dry season subsequent to river flow, an accurate record was made of the precise point of placement of the tubes. Efforts were made to place markers throughout the depth of river sediment from the riverbed to the surface of the sediment. The assumption was that river flow would wash away the markers to the depth to which fluidisation had occurred in the river sediment during river flow. A correlation could then be made between the highest level of river flow recorded during the rainy season on the height of flow gauges and the depth at which the first tell-tale was found. Figure 3.19 shows a tell-tale chain being cut to length at Tshelanyemba field research site so that the end would be unobtrusively located just below the surface of the sediment.

Figure 3.19: Installing a tell-tale chain



First experiments were with 40 mm diameter sheet metal discs set in a cross formation. These were installed throughout the sediment by jetting or driving a steel pipe to the riverbed. A tell-tale was then dropped into the empty pipe and 300 mm of sand deposited on top. A further tell-tale was added and a further 300 mm of sand. This process continued until the surface of the river sediment was reached and the pipe was withdrawn. An accurate positioning of each vertical line of tell-tales was made from locating pegs on the riverbank. This procedure was abandoned as it was not possible to install markers to the full depth of sediment as saturated sediment flowed into the pipe from the open bottom and precluded any placement lower than the effective water level in the sediment. Accurate placement was also not possible as it proved difficult to keep the tell-tales in place when the steel pipe was removed.

Subsequent experiments were undertaken with short lengths of aluminium tube. A 3.0 metre length of 20 mm I.D. aluminium tube was cut into 150 mm lengths and assembled onto a 19 mm steel rod with a collar at the top. The assembly was then driven to the riverbed and the rod removed leaving a stack of 150 mm tubes throughout the depth of the sediment. It was assumed that it would be a simple task to locate the remaining upper-most tube by excavating the placement site late in the following dry season when the water level had dropped in the sediment. However in spite of accurate recording of the location of the tubes it in fact proved very difficult to locate the remaining tubes in the subsequent dry-seasons and thus this method was also abandoned.

The third and ultimately successful method of collecting data by way of tell-tales was through the use of a length of chain. As chain is an extremely valuable item used on draught animals in the research areas the chain was attached to an anchor so that if the chain was located on the surface it could not be withdrawn from the sediment. Initial installation was by jetting the anchor with a length of 6 mm diameter chain through the river sediment to the riverbed. However as setting up the pump and abstracting sufficient water with which to jet was unnecessarily complex and time consuming, this procedure was simplified by converting the anchor to a driveable point. A 3 metre \times 40 mm steel tube bore on the collar of a steel point to which the chain was attached. The chain passed through the length of the steel tube and so that it could be driven without damage, the chain extended through a slot in the top of the tube. The chain was located by excavation late in the dry-season but efforts were also made early in the dry-season by probing for the chain with a steel rod.

Bench-marks.

Measurements were made each dry-season to establish whether there was an accretion or an attrition of sediment within the river channel. At each site a steel peg of 8 mm \times 500 mm re-bar was concreted into the riverbank as a bench-mark approximately 3.0 m back from the edge of the river. Depending on the width of the river 1 or 2 points were selected within the river channel where it could be seen that there was typically a passage of water when the river was in flow. Measurements to these points were made from the locating pegs and dumpy level readings were made each dry-season from the bench-mark to the selected point for surface level readings.

Rain gauges

An indication of the rainfall within the locality of each research site was gathered from daily readings of rain gauges. A single rain gauge was installed in the yard of homes of each of the research assistants who lived in the immediate vicinity of each research site.

Logistical constraints of travel, time and vulnerability of the equipment precluded a more accurate assessment of the precipitation which fell throughout the total catchment area of the river above each research site. Thus only an indication of rainfall conditions in the immediate area of the research site has been gathered with no assured data of rainfall conditions which would have directly affected the time and intensity of flow of water at each research site from further up the river.

Evaporation Pans

Two research sites were equipped with standard size evaporation pans. Huwana and Tshelanyemba had both conscientious research assistants and an accessible and reliable supply of water to fill the pans. The pans were installed in the yards of the homes of the research workers and water to fill the pans was drawn from the nearest reliable supply. The dire supply of water at Dongamuzi and the distance the research workers lived from an available source of water at Wenlock obviated the installation of pans at these sites.

The pans were fabricated from 0.50 mm galvanised sheet metal, 1.20 metre diameter and 200 mm deep. The pans were securely fenced to prevent the loss of water from livestock drinking and a cover of 19 mm \times 0.80 mm chicken wire netting was placed over the pans to prevent loss of water from birds bathing. This was considered particularly important in localities where open surface water was an absolute rarity and in fact proved to be a problem at Huwana until the cover was raised as on several occasions flocks of birds drank from the pan when it had been refilled. Figure 3.20 shows the evaporation pan prepared for use at Tshelanyemba field research site.

Figure 3.20: Standard evaporation pan



Daily readings of water levels were taken by way of an adapted vernier gauge at each pan as meteorological measuring equipment proved to be too expensive an investment for the research programme. The dial of the gauge was moved through 90° to read correctly when the gauge was mounted vertically on a stand which stood in the water. Readings were taken by setting the depth gauge to lightly touch the meniscus of the water each day and thus reading the drop in the water level. Although meteorological gauges are designed to make contact with the water surface by deforming the meniscus from below, for the purpose of these experiments it was considered to be sufficiently accurate to take readings which made contact with the meniscus from above.

Offsite Equipment

Core Sampling.

Because of the saturation and coarse nature of the sediment it was not possible to use a standard soil auger for sampling. A range of equipment was developed to extract core sediment samples throughout the depth of sediment. Initial efforts were made to fill either 40 mm or 50 mm OD steel furniture tubing. In the first attempt a type of butterfly valve was fitted at the bottom to retain the saturated sample. However, neither this nor 40 or 50 mm open-ended tubes could be filled with a sample of sediment either by driving or by rotating the tubes into the sediment. Once some 1.20 metres of sediment had entered the tube, resistance on the internal walls of the tube proved to be greater than that on the outside and further sediment could not be forced into either of the tubes.

An attempt was then made to obtain a representative core sample by removing a lateral sample by rotating a tube slotted along its length within the horizon of the sediment. A 40 mm tube was opened along one side and driven to the depth of sediment. To prevent the tube filling with sediment as it was driven a uPVC pipe was inserted inside the pipe. The uPVC pipe was raised progressively in stages of 150 mm and the steel tube rotated to extract a sample by scraping. However, as soon as the interior tube was raised the sampling tube was flooded with liquidised sediment to the depth of water in the sediment and although representative samples could be obtained, particularly from the sides of dry sampling holes, the final sample could not be considered sufficiently accurate.

Following these efforts, two trials were made with variations of a Van der Staay suction coring auger. The first attempt was fabricated from a 40 mm I.D. stainless steel tube as a cylinder with two rigid cup seals as a piston. Although these cup seals which fitted a 40 mm ceramic cylinder were an excellent fit, the interior surface of the stainless steel tube was too rough for their use. The cup seals were then changed for rubber 'O' rings fitted over discs of sheet uPVC which were fitted to a length of 10 mm bright steel rod which was suspended from a tripod. Figure 3.21 shows early efforts to extract a core sample of sediment.

Figure 3.21: Experimental core extraction equipment



In an attempt to extract a representative core sample the sediment was saturated to provide some stability. The piston was inserted into the stainless steel tube so that when the tube was placed some 50 mm into the sediment the piston was at the surface of the sediment and attached to the overhead tripod. The piston was then in a static position creating suction above the sediment as the tube was forced into the sediment. It was assumed that this method would provide an even entry of sediment as the cylinder progressed in depth into the sediment. However although composite core samples were obtained these were not always to the full depth of sediment.

Through an internet search personal contact was established with Henk Berendsen of University of Utrecht who provided advice from personal experience, (Berendsen 2001) and recommended two articles which described the construction and operation of the Van der Staay suction-coring auger, (van der Meene, van der Staay et al. 1979) and (Wallinga and Staay 1999). Thus to their design, the final version of the suction coring auger was produced from 40 mm class 10 uPVC pipe. A suction plunger was fabricated from 10 mm bright steel rod with a tee bar handle at the top and 2×40 mm 'O' rings fitted to discs cut from 12 mm uPVC sheet. The coring process was achieved with one person pushing the pipe into the sediment whilst another used short pump action strokes to draw the sediment into the tube. Measurements were taken throughout coring to ensure that the length of core in the tube matched the depth of the pipe in sediment. In this manner a sample of clay from the riverbed was successfully extracted from 3,15 metres.

Permeameter.

A simple permeameter as described in Wipplinger (1958) and used by Clanahan (1999) was adapted as a simplified constant head permeameter to record the permeability of sediment. The method of obtaining permeability readings by timing the passage of a fixed quantity of water which was employed by both Wipplinger and Clanahan was considered significantly less accurate than a classic falling head test, (Elson 1999). Alterations to the permeameter were designed by the author and the fabrication undertaken by an engineering company and informal sector sheet-metal workers in Bulawayo.

The final permeameter comprised a 150 mm deep \times 150 mm diameter sheet metal cylinder open at one end with porous material at the other end held in place with an expanded metal screen fitted between two steel discs around the sheet metal tube. The material was sufficiently porous not to impede the flow of water through sediment within the permeameter. Two \times 6 mm O.D. copper tubes were attached over 4 mm apertures in the side of the permeameter, one placed at 50 mm from the open top and one at 50 mm from the steel discs. 6 mm O.D. polythene tubes were fitted to the copper tubes and attached to a 300 mm ruler to record the variance in readings between water levels in the two tubes. Figure 3.22 shows permeability readings being taken at Tshelanyemba field research site using an on site permeameter.

In order for there to be minimum disturbance to reduce any spreading or consolidation of sediment samples and thus to reduce the risk of distorting data, tests were carried out on site. Sediment at a random site within the river channel was excavated to the water bearing area. The open permeameter without the porous material in place was then pushed to its full depth into the sediment. The permeameter full of sediment was carefully dug from the sediment so that sediment disturbance was at an absolute minimum. Excess sediment above the disc end was carefully and evenly removed and the porous material fitted. The permeameter was then inverted and excess sediment above the open end removed. Plugs from the copper tubes were removed and the polythene tubes fitted. The permeameter was then placed on a stand below a header tank which enabled a constant flow of water to discharge onto the sediment with unrestricted flow through the sediment.

Figure 3.22: Using a permeameter



Further Research Site Test Equipment

Water Dippers

Water dippers to record water levels in the piezometer tubes were made up from basic components and a design taken from the internet, (Hood, Smajstria et al. 1991), figure 3.23. Six dippers were assembled, one for each of the four sites, one for a control site experiment and one as a spare. The spare dipper and spare batteries were carried on each visit to the research sites but the spare was only ever issued on one occasion. A dipper was also used to measure the drop in water levels causing the cone of depression around each of the well-points at each abstraction rate during well-point yield tests.

Figure 3.23: Water dipper



Downstream Drainage

Equipment was designed and fabricated to calculate the velocity of river water flow through the sediment in the river channel and used to establish the likely loss of water at an abstraction point from downstream drainage.

Discussions on the practicalities of designing and fabricating appropriate equipment were conducted with R.J. Elson of WEDC and G.D. Williams of BGS Keyworth, Nottingham, (Elson 1999) and (Williams 2000). Initial plans centred around an idea based on equipment which had been used to monitor radio-activity levels in the soil around early waste disposal sites at Sellafield Nuclear Power Station, (Williams 2000). The intention was to release a 10% salt solution from a homemade injection well or discharge tube into saturated sediment in a river channel and to record the time the solution would take to reach a downstream resistivity recording probe. The strength of the solution at different depths in the sediment was also to be recorded as it reached contacts on the probe.

Stainless steel screws at 200 mm spacing were to act as electrical contacts on a length of 19 mm uPVC rod. An insulated wire was to be attached to each screwhead and then to a multi-connection terminal block. A connection could then be made with a smaller bridging connector block through any adjacent four input wires to a resistivity meter of the type used on geophysical surveys. The assumption was that the resistivity meter would record the salt solution as it reached the probe through an increase in current between the contacts on the uPVC rod. By moving the connection between contacts up and down the rod and noting the strength of reading it would be possible to construct a graph of the velocity of subsurface flow at differing depths. Although the author was keen to test the concept and plans were well advanced for the fabrication of the equipment no one could be found who was prepared to provide or to operate the resistivity equipment and hence the plan was abandoned.

During discussions in 2001 and 2002 with Dr. Martin Mansell of Paisley University, Civil Engineering Dept., an alternative measuring technique was planned utilising a salt solution and hand held resistivity meters and probes. The equipment designed for this comprised an injection well and a slotted, piezometer style tube in which a resistivity meter probe could be freely raised and lowered. The injection well was fabricated of uPVC piping which was fitted with a driveable steel point so that it could be driven to the base of the sediment. The slotted pipe allowed a free entry of water from the surrounding sediment into the tube. After allowing a short period for it to stabilise inside the tube, a conductivity meter reading was made of the water. An approximate 30 gms of sodium chloride was then added to the tube and the solution agitated. Following a further stabilisation period temperature and conductivity readings were taken every minute whilst there was a noticeable deterioration in salt content for 10 to 15 minutes, and then every five minutes for a further 10 to 20 minutes.

Offsite Equipment

Grading Sieves and Sieve Shaker

A selection of 6 sieves with mesh sizes, 2.00; 1.00; 0.50; 0.25; 0.125 and 0.063 mm was used for the grading of sediment samples. A hand operated mechanical shaker was designed by the author and fabricated in the Dabane Trust workshop in Bulawayo. (Hussey 1998). A bicycle pedal and crank directly turned a cam on a shaft to give a

rise and fall of 40 mm and enabled a regular rotation of the stack of sieves to encourage even sieving of samples. However, the original equipment worked on a 1 to 1 ratio with no gearing advantage and hand action slowed to such an extent over a 10 minute period that sieving was no longer effective. The shaker was thus adapted and powered by a 1415 r.p.m. electric motor geared down to give 85 oscillations per minute. Gearing was achieved through a 60 mm pulley and vee belt which drove a 406 mm (16 inch) bicycle rear wheel, an 18 tooth chain sprocket on the wheel drove an 18 tooth sprocket on the cam shaft.

Evaporation Tank

Comparative readings of evaporation from open surface water and water in sediment were undertaken at the control site. Two 1.20 metre diameter brick tanks were constructed 500 mm apart to a height of 1.50 metres and covered with 19 mm chicken wire netting. Tank 1 was constructed to allow a 225 mm depth of open surface water whilst tank 2 was 1.50 metres deep and filled with a typical, random sample of river sediment. Both tanks were filled with water to the same level, tank 2 to the surface of the sediment held in the tank. Measurements of water loss were then made daily with the open surface water topped up as necessary. The water level in tank 1 was made with an adapted vernier gauge to record water loss from the surface and tank 2 was equipped with a piezometer tube and the level of water in the sediment recorded with a dipper.

Well-point Performance Observation Tank

A 1.60×1.75 metre $\times 1.20$ metre deep tank was constructed with a four-pane observation window with heavy-duty 6 mm glass sealed with water resistant silicon sealer. A trial well-point abutted each pane of glass so that in effect an interior crosssectional view could be obtained of each well-point. A seal was effected with silicone sealer between the well-point end and the glass. The tank was filled with a typical random sample of river sediment so that a view could be achieved of the inside of a well-point which was surrounded by sediment. Each well-point was connected to a Rower pump so that water could be drawn through the well-point with the intention of observing the passage of water into the well-point. It was hoped that fine sediment entering the well-point, the development of a sand screen around the well-point and any turbulence of water entering the well-point might be observed.

Well-point Pump Rate Test Tank

Two concrete brick tanks of 3.00 metre I.D. were constructed 1.00 metre apart. Tank 1 had a depth of 1.25 metres and a capacity of 8.80 m³ and tank 2 a depth of 0.90 metre and a capacity of 6.35 m³. A brick and concrete stand joined the two tanks and supported a base for an 1415 r.p.m. 3 phase electric motor which drove a progressive cavity, D4 Mono Pump. The pump was set up with a 5.30 litre ($150 \times 300 \text{ mm}$) priming tank mounted immediately to the inlet flange of the pump.

The priming tank was designed so that it had a greater capacity than the 2.83 litre capacity of the 40 mm ($1\frac{1}{4}$ inch) pump inlet pipe which was connected to the well-point. This inlet pipe extended from the top of the priming tank towards the centre of tank 1 and could be closed with a brass gate valve. A second 40 mm steel pipe which could be similarly closed with a gate valve was also attached to the top of the priming tank and extended to the bottom of tank 2. A 40 mm steel socket and end plug were also fitted to the top of the priming tank. In this way the priming tank could be filled

and, depending on the setting of the gate valves, water drawn into the pump from the priming tank and through either of the inlet tanks into the priming tank to maintain lubrication of the rotor and stator by water at all times.

A steel tee piece was attached to the outlet flange of the pump and 2×40 mm steel pipes leading from this to each of the brick tanks – both pipes could be shut off with gate valves. In this manner water could be drawn from tank 1 and discharged into tank 2, then simply by opening and closing the respective valves the water pumped back from tank 2 into tank 1 for subsequent pump rate tests without shutting off the pump.

Tank 1 contained a typical random sample of river sediment which could be saturated with water. Trial well-points for test pumping could be installed in the sediment in the centre of the tank and connected by flexible hose to the 40 mm steel pipe. 4×40 mm uPVC pipes were inserted in the sediment in a line through the centre of the tank to act as piezometer tubes. Two piezometer tubes were positioned at the edge of the tank and two, 1.00 metre each side of the well-point undergoing test. Combinations of four sizes of pulley provided 4 differing pump abstraction rates, emulating low to high handpump abstraction rates to provide a comparison of the effectiveness of each well-point.

3.6. Review of Literature

Background reading was undertaken to gain an insight into the conditions and processes that are suitable for sand-abstraction and to assess the possibilities for study and data collection that could take place at the field sites. This was undertaken before any establishment, planning or design of equipment had taken place. In this manner consideration was given to the research that might be necessary into the conditions suitable for sand-abstraction, the information that would be required, the collection processes and the design, fabrication and preparation of recording and monitoring equipment. Through a review of literature and a process of planning, further thought was also given to what information or data could be expected to be extrapolated from the data collected.

In the realisation that sand-abstraction is essentially a feature of arid and semiarid areas, an initial review was made of depressed environmental areas. Commencing with a possible strategy for identification of potential areas where sand-abstraction systems might have potential, a review was undertaken of the agro-ecological classification of Zimbabwe which was developed by Vincent and Watson who divided the country into environmental zones referred to as Natural Regions, (Brazier 2001). The classification procedure was completed in 1972 and has subsequently been applied in several other dryland countries. Such an assessment system is still relevant and could be used as a basis for identifying ecological areas where sand-abstraction could have significant potential.

A review of literature that was considered relevant to the environmental factors that relate to sand-abstraction was undertaken. Several researchers such as Dube (2002) refer to the misuse of ecosystems and the need for sustainable watershed management. Lusigi (1992) states that in many arid and semiarid countries there is extensive deterioration in ecosystems through over use due to human intervention, whether this be by domestic animals or game, excessive cultivation of marginal lands or inadequate land husbandry methods. Mead (2000) who has studied river catchment management systems in Botswana also acknowledges the considerable impact of the human influence and siltation processes on the formation of sand rivers and subsequent retention of water in river sediment. Harrison (2001) maintains that considerable damage occurs in river channels through indiscriminate removal of sand and gravel, which he refers to as mining. Butterworth, Reddy et al., (2001) expresses the need to adequately safeguard watersheds if rural water supplies and agricultural production is to be improved.

Continuing the environmental process that leads to sand-abstraction, (Interconsult-A/S 1985) in association with NORAD prepared an extensive survey, termed the 'National Master Plan for Rural Water Supply and Sanitation' for the Government of Zimbabwe. The consultancy was undertaken between 1980 and 1985 and produced considerable documentation. Volume 3.2, 'Soil and Water Conservation' provided much useful information to this study on soil erosion and sediment yield in the arid and semiarid areas of Zimbabwe. Of particular relevance to problem identification, data collection and development of this study were the sections related to siltation surveys, basin surveys, quantity surveys and yield calculation.

The classic work of Wipplinger (1958) 'The Storage of Water in Sand' is essentially devoted to sedimentation of rivers and dams and the potential to turn what could be termed an ecological disaster to good advantage. Wipplinger spent many years in Namibia studying the comparative losses of water from sediment and from open surface water. Owen (2000(a)) similarly has gained much experience in water loss in arid areas and in discussions with the author has expressed his opinion that water loss from river sediment is primarily due to evaporation. Other useful information from Namibia proved to be an article in a NATO Science paper, 'Estimation of Natural Groundwater Recharge', (Crerar, Fry et al. 1988), which reports on the field and laboratory instrumentation prepared for a research project which was designed because of the difficulties of accurately measuring recharge in an ephemeral river channel.

In more extreme situations, but conditions which help to provide an insight into factors that might limit the use of sand-abstraction, Zonn (1986) reports on the compaction of soils and sands in desert and arid areas which inhibit infiltration. He further refers to an elementary pedogenetic process of 'desert crusting' which due to the accumulation of mineral salts can lead to the salinization of groundwater. Further background information on the local situation was obtained from Botha and Goossens (2001) on evaporation, water balance, recharge and storage in the Limpopo basin.

More generalised information was provided by Shentsis, Meirovich et al. (1999) who reports on research undertaken on transmission losses in the Nahil Tsin in the Negev Desert. In his research he subdivided losses into channel moistening which he states subsequently evaporates and deep percolation which recharges groundwater. He concludes that losses due to seepage to groundwater were substantially greater than losses from evaporation but provides no indication of the depth of sediment or the period of retention of water in the sediment of the waterway. Research which had been undertaken by Hughes and Sami (1992) into transmission losses in the Bedford area of Cape Province, South Africa were also reviewed and Malherbe (1962) also provided background information on the loss of water from soils, under-drainage, soil water capacity, pore space and pore volume. A number of papers compiled into a book titled, ' Methods in Stream Ecology' by Hauer and Lamberti (1996) provided much useful information on characterisation of rivers

Useful general background reading in underground water supplies, river engineering, river flow and artificial recharge was obtained from Bell (1980) and Bisson and Montgomery (1996) describes river basins and provided useful information on the classification of stream reach and valley segments as well as the estimation of river

channel size. Gore (1996) provided information on site selection indicating a suitable location to be one which was relatively uniform across its width with no protruding objects to affect the depth or velocity of flow. He also stated that consideration should be given to channel resistance and slope. The relevance of computer software in predicting flood prevention and urban drainage regimes was also considered. Software developed by WinDes includes rainfall generator modelling and flood prevention techniques, (Crawford 2001).

In consideration of the data that would be required during the research, articles and reports in soil physics, soil properties, infiltration, hydraulic conductivity, porosity, permeability, water capacity, river flow and the density and specific gravity of soil were studied. Richard (1984), Selly (2000) and American Society for Testing and Materials (1972) each provided useful reading on these topics. Houghton-Carr (1999) provided useful information on rainfall runoff and Crerar, Fry et al. (1988) on groundwater recharge and infiltration and both Mariño and Luthin (1982) and Croney and Coleman (1961) on infiltration, soil pores and seepage. Topics such as permeability and seepage were covered by Whitlow (1962) and particle size analysis by Smith (1989).

Once an appreciation of the information that was required was established, a documentation search to review possible research site measuring or recording equipment was undertaken before any design or fabrication took place. Although much of the equipment that was eventually installed at the research sites was designed and fabricated within the research programme and later refined by trial and error, research was first carried out on basic strategy and concepts.

Of the practical research site equipment that was required much useful information was gained from 'Stream Hydrology', (Gordon 1992). The final, effective tell-tales design is directly due to Gordon who also provided practical information on sampling and localised factors which may contribute to errors in recording and measurement. Gunston (1998) proved useful with insight and a recommendation to establish regular communication with field researchers and to maintain their good will at all times. He also provided suggestions on management and data collection from evaporation pans, rain gauges and river flow measurement. Hughes and Sami (1992) described hand texturing techniques of soil as well as further information on transmission losses. Linsley, Kohler et al. (1975) describes crest-stage gauges which was of interest when comparing the height-of-flow gauges developed within the research programme.

In a series of articles compiled as 'Erosion and Sediment Yield', Hadley (1984), Elwell (1984), Ward (1984) and Onstad (1984) each provided practical information on predicting and measuring soil erosion. Whilst discussing the erosional behaviour of drainage basins, Walling (1999) provided information on sediment budgets and practical examples of core sampling. Information on sediment transport and the shape and definitions applied to clasts was provided by Pye (1994) and Selly (2000). Of the actual equipment developed Dahm and Valett (1996) provided information on piezometers and Wilson, Fogel et al. (1969) on subsurface river flow in the sediment.

3.7. Summary

Although some survey work had been undertaken on sand rivers, primarily by British Geological Survey in Botswana, it was apparent that little practical data was available on the water storage and water loss characteristics of silted, seasonal rivers in semiarid and arid areas. A need to gather data on river aquifers which are recharged and depleted through natural river flow and water loss was thus perceived and a research programme to establish a log of data and general information on the characteristics of four differing ephemeral rivers was decided on and built up over five years. To ensure the relevance of the data collected, research sites were selected at points where typical sand-abstraction scheme installations might be established.

The research programme set out to collect data that would provide appropriate and relevant information for the development of suitable low-technology abstraction equipment and ultimately to enable the promotion of a simplified sand-abstraction technology. Improved basic awareness and an increase in the knowledge base available with regard to abstractable water supplies from seasonal rivers and their relevance to small-scale sand-abstraction systems was required.

Local field research assistants collected data throughout the year, during both the wet and the dry seasons. An understanding of the research programme was that local communities would be involved from the outset and kept informed of developments. It was also planned that an assessment of developments would be sought from endusers who would test any equipment which had been developed in the process of the study and research.

To this end study and research was undertaken which provided information on the water storativity in the sediment of ephemeral rivers, anticipated volumes of water and the causes of loss of abstractable water from sediment. The information gathered was planned to indicate the likelihood of appropriate and suitable sites with regard to maximum abstractable yield from secure sites where the possibility of damage or loss of equipment was minimal. The intended use of the information gathered was for the ultimate development of suitable low-tech low-cost abstraction equipment.

Research sites were identified and equipment was installed on four differing rivers in southern and western Zimbabwe. As it was considered imperative to collect data from a wide range of conditions, research sites were established to cover a variety of situations. The rivers and sites thus selected varied from a large river with an extensive catchment area where it was assumed that there would be a considerable water resource to a small river system with a restricted catchment and an apparently poor water resource potential. The commonality was that each river selected was in an area where there was appreciable erosion and considerable sediment transport. Each site was established in an area where traditional style sand-abstraction was practised from sand-wells and where differing characteristics and a variety of conditions and sand-abstraction options could be studied.

The development and local fabrication of equipment with which to undertake the research was a significant factor of the programme. Although it was necessary to purchase some equipment, the in-house process of development and refinement of research equipment assisted in the overall appreciation of conditions and helped to demonstrate the local capacity to develop abstraction equipment appropriate for use with sand-abstraction systems.

A purchased soil auger proved to be totally inappropriate for the extraction of core sediment samples whereas the development of local equipment not only assured that composite samples were extracted in the manner and to the depth which was required but, through countering each problem, assisted in a better understanding of the nature of river alluvium and also ensured a significant saving in cost. Through the development of suitable core sampling equipment and repeated efforts to extract composite core sediment samples an appreciation of the fluidised nature of the saturated lower levels of sediment was established. The design and fabricating of core sample sieving equipment ensured a further significant saving in funds which were not readily available to the research programme and also guaranteed access to equipment whenever it was required.

By ensuring local participation in the fabrication and development of research equipment practical abstraction equipment was ultimately developed to which field assistants could relate. As a part of an on-going process of improving and refining equipment, field researchers no longer had any mystique or misconceptions as they had either observed or contributed to the development of equipment which guaranteed its acceptability and ultimately its appropriate use.

Chapter 4

Characterisation Outline

4. Riverbed Analysis and Characterisation

Conditions suitable for sand-abstraction occur primarily in dry, or arid regions throughout the World. These arid zones occur to a varying degree on each continent with the greatest extent in Africa, the smallest in Europe and Antarctica as a totally frozen wasteland. North, Taylor et al., (1999) maintains that about one-third of the Earth's surface is of dryland type and that even though they receive little rain, the surface regions of drylands are dominated by the action of rivers. The Centre for Arid Zone Research, CSIRO (2000) states that typical arid areas are those with inhospitable terrain where the rainfall is too low or unpredictable for sustainable cropping or timber harvesting, noting that such areas are frequently sand plains or stony deserts. A dry region or arid zone is defined by UNESCO as an area where rainfall is generally low and the annual potential evaporation is greater than the mean annual precipitation. Most arid zones experience a completely dry period of at least two to three months. UNESCO refines dry regions into four sub categories, hyper-arid, arid, semiarid and sub-humid, table 4.1. A further characteristic of an arid area is the spatial distribution of rainfall. Often in arid zones the area covered by a storm is small, ranging from just a few square kilometres to 100 to 200 km² and typically only 30 to 60 km² in Africa, (UNESCO 1989), (Graf 1988(a)).

Although an arid zone cannot in itself be defined by soil type, the constituent soils will nevertheless be poorly developed, unstable soils which are prone to erosion. Buol, Hole et al. (1973) and Knuti, Korpi et al. (1972) refer to Aridisols and Entisols as the primary soil groups that occur in regions where the potential evaporation greatly exceeds the precipitation during most of the year and where no water percolates through the soil. The primary residual soils of Africa, including the dryland zones are indicated in figure 4.1. Buol goes on to say that the organic matter content of dry-land surface soil is low and that microbial populations are also usually low, but it is an erroneous concept that all soils in dry regions are sandy, rocky and devoid of vegetation. UNESCO (1989) indicates that trees and shrubs are sparsely distributed in arid zones and the hydrological effects of canopy and litter are negligible which contributes to the formation of a seal on the soil surface due to the impact of rain drops, (Valentin 1981). Infiltration is generally low in arid areas and such a surface seal can further reduce the permeability of large areas and contribute to overland flow and erosion of the soil surface. It is an accumulation of eroded soil surface material in river channels which retains water that may be abstracted.

Table 4.1 Annual Precipitation in dry regions indicating the sub-classification of dry regions and the lower and upper limits of annual precipitation, (UNESCO 1989)

Annual Precipitation (mm) in Dry Regions			
<u>Classification</u>	Lower Limit	Upper Limit	
Hyper-arid	10	75-100	
Arid	40	400-500	
Semiarid	200	800	
Sub-humid	500	1100	

Figure 4.1: Tropical residual soils, (The Quarterly Journal of Engineering Geology 1990).



Figure 4.2: Precipitation minus evaporation in Africa, cm/yr., (Falkenmark 1991)





Figure 4.3: Broad climatic regions of Africa, (Jarrett 1974)

Figure 4.4: Seasonal distribution of rainfall in Africa, (Jarrett 1974)



Figure 4.5: Soil distribution of Africa, many of which are poorly developed or leached, (Collins - Longman 1983).



Figure 4.2 shows in cm/year the annual precipitation minus the evaporation throughout Africa, (Falkenmark 1991). The zone between 0 and 10 mm, where precipitation exceeds evaporation, largely approximates the tropical area 2 of figure 4.3 and the areas of alternating rainy and dry seasons between the areas with no dry season and the areas with little or no rainy season, figure 4.4. These may be considered the areas in Africa most closely suited to water use through sand-abstraction. Jarrett (1974) broadly indicates the climatic regions of Africa. Region 2 is the most suited to sand-abstraction with further possibility in some parts of regions 3, 4 and 5. Figure 4.5 indicates the broad soil areas of Africa, many of which are leached or poorly developed indicating their propensity to erode and thus to contribute to conditions suitable for sand-abstraction development, (Collins - Longman 1983).

Characterisation Outline

4.1. Zimbabwean Context

Within Zimbabwe the arid, semiarid and sub-humid regions have been divided into 5 Natural regions, (Brazier 2001), table 4.2. Sand-abstraction is particularly suited to regions 3, 4 and 5. These natural farming regions figure 4.6, roughly correspond to soil classification, figure 4.7 and rainfall bands, figure 4.8 as well as commercial and communal land classification.

Table 4.2: Natural farming regions of Zimbabwe, after Vincent and Watson 1972, (Brazier 2001)

Natural Farming Regions of Zimbabwe				
Region	Annual Rainfall	Characteristics	Use	
1	Over 1000 mm	High rainfall, comparatively low temperatures, little evaporation, land over 900 m	Intensive livestock, plantations & fruit growing, coffee, tea, nuts, planted forests	
2	750 – 1000 mm	Moderate high summer rainfall, land over 1200 m	Intensive livestock & crop farming	
3	650 – 800 mm	High temperatures, infrequent, heavy rainfall, much lost through evaporation, land 900 – 1200 m	Livestock farming, fodder crops, some cash crops	
4	450 – 650 mm	Frequent droughts even in the wet season (Nov – Mar)	Livestock farming, drought resistant (fodder) crops	
5	Below 450 mm	Low & erratic rainfall, land below 900 m	Livestock ranching	

Figure 4.6: Natural regions of Zimbabwe (Collins - Longman 1983)







Included on figure 4.7 is the location of the four research sites within Zimbabwe

Figure 4.8: Rainfall maps of Zimbabwe, (Collins 1979)







Figure 4.9: River water storage potential in Zimbabwe, (Collins 1979)

Conditions suitable for sand-abstraction occur in river basins in arid zones where there is low rainfall and long dry seasons. Such areas are generally typified by areas of weakly developed soil which are easily eroded from the soil surface and deposited into river channels as siltation. Field research sites, which were chosen in order to observe river conditions and to obtain data on river flow, are all within the arid or semiarid regions of Zimbabwe as indicated on the foregoing maps. Figure 4.9 indicates the water storage potential of the rivers of Zimbabwe.

Table 4.3 indicates rainfall over a 45 period at a site 4 kms from the premises of Dabane Trust, Bulawayo, Zimbabwe where offsite data has been collected. Data has been personally collected by a climatologist Paul Kaufman, (Kaufman 2003).

Table 4.3: 45 year rainfall records, Burnside, Bulawayo, Zimbabwe



Characterisation Outline

4.2. Characterisation, Flow and Storage in Sand

4.2.1. River Basins and River Morphology

The nature of an ephemeral river, particularly the formation and stability of the channel and the form and frequency of discharge are critical factors to consider in establishing the potential for water abstraction, the water storage capacity of a section of river, the identification of possible sites and the security of in-river equipment.

To provide an accurate assessment of a river, Bristow (1996) states that a study should be three-dimensional. It should comprise the planform or physical appearance; the physical characteristics of the channel cross-section, width, depth, length and slope as well as, where possible, the channel pattern or the history of the channel. According to Church (1992), the important factors associated with a river are the:

- Volume of flow and the time distribution of water from upstream
- Volume, timing and character of sediment delivered to the channel
- Geology and riverine landscape
- Local climate, particularly whether or not there is an extended dry season
- Riparian vegetation
- Land use in the basin
- Size of the channel

Flow in rivers in arid and semiarid areas is liable to a wide margin of variance and may range from no flow at all during a year to several weeks of sustained flow. Often ephemeral river flow is for a few hours at a depth of just a few millimetres. Several authors refer to the extremes and unpredictability of seasonal river discharge. In general terms Boering and North (1999), Graf (1988 (a)) and Makaske (1999) each state that the frequency of flow and the subsequent sedimentary processes which occur at times of high discharge are a major influence on the development of dryland fluvial systems. Even within periods of prolonged discharge Beazley (1993) notes that the flow regime is likely to vary considerably. Walker (1992) points out that although rivers in semiarid areas are subject to wide fluctuations in discharge associated with floods and droughts, feeder streams from more humid areas can significantly increase their flow and thus the discharge is likely to be greater than could be sustained by regional rainfall alone.

According to Alexander and Fielding (1999) the discharge in a typical semiarid-land river in Australia stays near peak flow for only a few hours to a few days and then drops rapidly. As an example of flood variability, research undertaken by Fielding and Alexander (1999) shows the discharge of the Burdekin River, a large river in dryland Queensland, fluctuates from 0 to 20 m³ per sec throughout most of a year but may rise rapidly to peak discharges of >20,000 m³ per sec. He indicates that channel-forming discharge is difficult to define but that larger, short duration flow does cause major changes to the channel with events sufficient to cause large-scale change to river channel deposits reoccurring in the Burdekin River at intervals of about 8.5 years.

According to Graf (1988(a)) floods accomplish most of the morphology-changing work in dryland streams, the variance and fluctuation of flow affecting the volume and size of

channels generally remain surprisingly stable with little seasonal alteration in either riverbed levels or bank alignment due mainly to low gradients and the effective soil binding of riverine vegetation. The foregoing opinions are very much the findings of this study as the data to be presented will show.

River Flow and Infiltration into the Alluvium

Precipitation and the subsequent flood events have a significant effect on ephemeral river flow. According to Jacobson, Jacobson et al. (1995) a flood in a perennial river is when it over-tops its banks onto its flood plain, but a flood in an ephemeral river occurs each time the river is in flow. Both Jacobson and Graf (1988(a)) indicate that floods themselves are highly variable, being either flash floods, single peak floods or multiple peak floods.

Flash floods generally increase from zero flow to a peak discharge in a matter of minutes and have a rapidly advancing bore of water which typically carries large amounts of organic debris with a frothy foam created from the turbulence of the flow. Figure 4.10 shows the onset of a flash flood in January 1999 in the Sansukwe River, Bulilimamangwe District, Zimbabwe. Such floods generally last for less than a few hours and are associated with violent thunderstorms in their catchments. Thunderstorm cells are relatively small with diameters of about 8 kilometres, thus flash floods are usually restricted to catchment basins of less that 100 km².

Figure 4.10: Flash flood in the Sansukwe River, Bulilimamangwe District, Zimbabwe.



Single peak floods last significantly longer than flash floods, from several days to several weeks, depending on the rainfall patterns over the catchment. These floods result from broad fronts of precipitation covering thousands of square kilometres. Rainfall over such a large region causes an initial high peak in the river's discharge, which then subsides to a lower stable level of flow for a time, before stopping entirely.

Multiple peak flows result from consecutive rainfalls over many days or in different parts of the catchment. These floods are characterised by steady flow which is interspersed with peaks from different rain events in the catchment. According to Graf (1988(a)) it is the magnitude and frequency of floods, which wreaks the changes on dryland rivers. Significant factors are the annual flood series, the partial duration series and the maximum flood.

The manner and flow of water through the river basin to the river channel is critical as it is at this point that material is entrained. Graf (1988(a)) states that as precipitation reaches the soil surface so it seeps into the sub-surface until it fills the interstices of the soil particles, causing a saturated condition. The amount of water that infiltrates into the soil depends on soil conditions and how the precipitation is dispersed. Bell (1993) refers to infiltration as the balance of the precipitation from immediate runoff and evapotranspiration. When the infiltration capacity is met, water ponds on the surface in small depressions. If water continues to flow into depressions the storage capacity of these natural reservoirs is exceeded and when they overflow, water moves down-slope in the form of run-off which transports loose material to the river channel, (Linsley, Kohler et al. 1975). Graf (1988(a)) encapsulates this by stating that the fluvial processes of dryland rivers are fuelled by the mass and energy of run-off into the channel system.

The infiltration of rainfall is determined by a number of factors. According to Jacobson, Jacobson et al., (1995) when the rate at which water soaks into the soil is slower than the rate at which it falls as rain, pools begin to form on the surface. The rate of infiltration into the surface is slower where vegetation cover is sparse and particularly so where the spaces between soil particles have been compacted by livestock walking over the surface or through clogging by fine silts. In these conditions pooling may occur very quickly with the result that little water will enter the soil, most either flowing away or evaporating from the surface as so often occurs in dryland areas. Jacobson, Jacobson et al., (1995) further state that initial runoff from the land surface of a river catchment enters small channel systems, which guide it downhill, these small channels merge into larger channels and finally into one main channel which drains the catchment.

Huge variances in discharge are possible in dryland rivers, Heritage, Birkhead et al., (1999) for example signifies that in an extreme flood-event, (in the order of 2000 m³/sec), a potential entrainment of 68% of the cohesive bed material may be expected in the channel of the Sabie River, South Africa. On the other hand, a river may have zero flow for an entire season or for several seasons. Further, because of the isolated nature of precipitation in dryland areas and the resultant nature of flow within an ephemeral river system, where there is discharge it may not continue to increase throughout the length of the river system but may actually decrease through the combined effects of evaporation and infiltration into the riverbed. Although ephemeral river channels contain large volumes of alluvial sand and gravel deposits, which fill with water as the flood passes, seepage and evaporation may be so great that in smaller floods the discharge ceases before flow reaches the river's end.

During river flow, water will first infiltrate and then saturate the river sediment. For most of the year the river surface can be expected to be dry, but the water stored beneath the river channel will provide essential water for the communities and farmers along the river. Riparian forests that line the riverbanks into the hinterland, are also supported by this river channel water. Typically, floods passing through ephemeral rivers leave ponds in depressions that have been formed by flood or wind in the river sediment. Such pools may last for several weeks and where fed by groundwater flow may remain throughout the year. This observation is supported by Jacobson, Jacobson et al. (1995).

4.2.2. Characteristics of Ephemeral & Perennial Rivers

According to The United States Hydrological Service, perennial rivers are those that have water in their channels throughout the year, rivers which flow seasonally are intermittent rivers and ephemeral rivers only have water in their channels following heavy rainfall or from melting snow, (United States Geological Service 2003). North, Taylor et al., (1999) describes an ephemeral river as one which flows solely as a direct response to precipitation and which receives insignificant groundwater support. Such flows are generally short-lived and are succeeded by long periods during which the watercourse is dry. Fluvial systems of drylands are as diverse as those of humid regions with braided and meandering reaches common, together with straight and anabranching channels. Perennial rivers in dryland zones are typically vast rivers such as the Zambezi figure 4.11, as they are the result of stabilised flow from extensive areas drained by ephemeral or intermittent feeder rivers.



Figure 4.11: Perennial river, Zambezi River, Victoria Falls, Zimbabwe

Intermittent rivers are not necessarily restricted to dryland areas in arid zones as not all waterways within temperate countries flow perennially. According to Price (1996), during periods of low precipitation streams, or bournes, on chalk land frequently have zero flow. Hauer and Lamberti (1996) affirms that a large amount of runoff may become subterranean flow causing streams to become intermittent where the substrata are porous in both mesic and xeric landscapes.

Generally an ephemeral river is only in flow during parts of a rainy season, Reid, Laronne et al., (1999) reports that two ephemeral gravel-bed streams in the Negev were only hydrologically active for about 2% of time or about 7 days per year. Invariably periods of flow are from just a few hours to no more than a few weeks depending on the nature of rainfall, its magnitude and duration - whether it be short and sharp or continuous and steady. Until such time as the river sediment is saturated, any in-flow into the river channel from the catchment will be sub-surface. Once the river sediment is saturated, whether it be to a depth of a few millimetres or to several metres, the river will flow above the surface and at that time the river flow and the water-table will be as a perennial river, (Gordon 1992).

Characterisation Outline

Typically the channel of an ephemeral river will be filled with sediment which has eroded from the surface of the catchment area. Due to poor soil stability from little soil organic matter, high soil temperatures due to minimal levels of protective groundcover, (Harrison 1987) and livestock over-stocking, erosion is frequently severe in the river basins of ephemeral rivers, (SISP 1999). According to Bell (1998) the processes of weathering, erosion and sedimentation in arid regions are similar to those in humid regions but differ in relative importance, intensity and superficial effects. In arid and semiarid areas weathering is predominantly physical because of the deficiency of moisture and poor vegetation cover. In spite of intermittent flow, streams are important agents of erosion on barren slopes because of the intensity of run-off. The extent to which river courses discharge after rainfall events depends on the magnitude, duration and frequency of the event. According to Graf (1988(a)), dryland regions generally have poor soil development, with poor soil infiltration characteristics and relatively little vegetation, peak discharges for maximum floods are larger for dryland basins than for similar sized humid basins.

The amount of rainfall occurring in arid regions is small and falls irregularly, whereas that of semiarid regions is markedly seasonal. Consequently, runoff events and drainage courses in arid lands do not necessarily activate whole drainage systems and may not be effective for a greater part of the year, however, large volumes of sediment may be transported in exogenous perennial rivers that flow through arid and semiarid zones. Unlike seasonal rivers, sediment within perennial river channels is maintained in a state of perpetual saturation and material entrainment within ephemeral or perennial river systems is subject to similar forces although it can be expected that sediment eroded from a seasonal river within a dryland area will be appreciably larger in grain size than the sediment in a river in a humid area due to a better soil structure in the basin, (Graf 1988(a)). The perennial River Parrett, Somerset U.K., has a gradient in places lower than 1 in 5,000 and transports copious quantities of exceptional fine silt that has in the past been used for brick making, (Williams 1970). Figure 4.12 shows the fine silt deposited by the River Parrett near its tidal mouth at Dunball.

Figure 4.12: Perennial river, River Parrett, Somerset, England


Figure 4.13: Ephemeral river, Manzamnyama River, Matabeleland, Zimbabwe

Ephemeral rivers, as the Manzamnyama, Zimbabwe, figure 4.13, are surface-dry from a period soon after the last significant storm of a rainy season until a period following the onset of the next rains when the sediment in the riverbed becomes saturated. During the extreme drought of 1991 – 1992 in Southern Africa the author noted that the Shashane River in Matabeleland South did not flow from February 1991 until the next significant rain in November 1992. Villagers at Mpande, Beitbridge District, Zimbabwe watched in awe in January 2003 as the dam which had remained dry since its construction in 1999-2000 filled from the flow of an exogenous river, with no visible storm in the area, (Nyoni 2003). In desert conditions Jacobson, Jacobson et al., (1995) observes that it may be many years between river flows. Referring to exogenous rivers, Beazley (1993) contends that peak flows may only respond several months after rain has fallen which by then may be the dry season. In such an instance, river length is a prime factor and although interdependent, rainfall and recharge are thus not necessarily interactive.

An ephemeral river is not necessarily prone to heavy siltation. Where land is well vegetated and an ecological balance has been maintained, minimal levels of siltation are to be anticipated. Areas that are not degraded in Zimbabwe have been observed by the author in some of the National Parks and parts of commercial farming areas. Ephemeral rivers are therefore not necessarily sand rivers where the vegetation is dense in the catchment and where there is consequently little erosion. A further condition for siltation is the slope of the river. According to Owen (2000(b)) a slope of 1:350 is the threshold slope at which sediment is retained in rivers. A riverbed slope steeper than 1:350 will not retain sediment, whereas a slope of 1:500 or less will retain significant amounts of sediment.

Apart from the factors of erosion and slope, there are other issues which may alter the character of sand rivers. Silt, which is transported in floodwater, may be caught in the debris that collects around a lodged tree trunk or around brushwood that protrudes from a dry-season scoop well when the surrounding brushwood fence has been washed into the well during a flood. Over the years more material and silt is collected until vegetation propagates and an island is formed. Larger islands or several islands together restrict the width of the channel and the river is liable to overtop its banks, which may cause

extensive damage along the river, or the river may cut a new channel. The author has witnessed the aftermath of extensive flooding in the Maitengwe region of the Manzamnyama River in February 1987. The river is in the extreme west of Zimbabwe, both homes and crop stores were destroyed leaving the people homeless and destitute for the entire year until the next harvest.

Depending on the nature of the river and the area that it traverses, stream or riverbank erosion is a further factor which may affect an ephemeral river. The Sebungwe River, figure 4.14 in the Siyachilaba area of Binga District in Matabeleland North Province has expanded in width by 17 percent in the four years which the author has been visiting the site. The east side of the river is a stable mudrock bank but the west side comprises unstable fine sand, which is liable to undercutting by the river. Before the elimination of tsetse fly and the subsequent introduction of cattle the western bank was protected by dense clumps of reed beds, as the cattle grazed out all vegetation, so the river ran in spate.

Figure 4.14: Sebungwe riverbank erosion



In certain circumstances an ephemeral river may be prone to scour. The author is aware of a sand-abstraction system installed by a commercial firm at Glass Block 2, on the Mtshabezi River in the Esigodeni District of Zimbabwe. The design criteria ostensibly consisted of the water requirement without an adequate survey of the river catchment and the storage capacity of the riverbed. A motorised-pump system was installed with a large output and, unfortunately, the entire sediment bed was washed away during the next rainy season rendering the scheme useless!

A supply of water within the channel sediment of an ephemeral river cannot be depended upon to the degree of a water supply within a perennial river channel. However such resources are vital and where ephemeral rivers do retain water in their sediment, because of the aquifer and water-table which they create, they invariably support riverine vegetation which may be clearly seen along riverbanks. As well as the reserve of water which is available in the channel of an ephemeral river to communities within the vicinity of the river, vegetation also provides a useful resource often vital for the support of both people and animals in the drier hinterland.

4.2.3. Erosion and Sedimentation

Erosion

Material that is eroded from rock surfaces continues to reduce in dimension until fragments are of a size that may be transported. Steep land surfaces and land devoid of vegetation is particularly vulnerable to processes of erosion through the movement of water. As water flows over a land surface it is liable to remove large volumes of soil particles that are eventually deliver into waterways. If these particles remain within a river channel, a riverbed alluvium is formed that acts as an aquifer.

The Processes of Erosion

Soil erosion is responsible for 40% of land degradation worldwide, (Vaneph and Benites 2001). Jacks and Whyte (1956) maintains that the most actively eroding regions are the semiarid continental grasslands and the tropics, but adds that erosion has only become a serious factor in their existence during the last few decades. For thousands of years these regions had preserved a perfect equilibrium between denudation and soil formation. According to Hagman and Murwira (1996) indigenous soil and water conservation practices which had been systemised by the original inhabitants of dryland areas which maintained this equilibrium, were wiped out by the introduction of the plough in the 1920's. More intensive agricultural systems elicited contempt for traditional knowledge in favour of modern western technology which he maintains was not based on sustainable soil management systems.

Wilson (1990) states that precipitation first wets vegetation and bare soil. When surface cover is completely wet, subsequent rain must either penetrate the surface layers if the surface is permeable, or run off the surface towards a stream channel if the surface is impermeable. The fall of torrential rain on degraded land, whether it be arable or grazing land, is the cause of considerable surface soil erosion, (Sharma and Murthy 1995). According to Savory (1991) the amount of damage is governed by the size and velocity of raindrops. Soil erosion on hillslopes occurs by processes of soil splash from raindrop impacts and sediment entrainment by surface flow, (Nearing, Simanton et al. 1999). According to Knuti, Korpi et al. (1972), water enters the soil through large pores under the influence of gravity. In an ideal soil, water is absorbed as rapidly as the rain falls. However, in areas where the rainfall is intense, the rate of precipitation exceeds the rate of infiltration with a consequent accumulation of water on the soil surface. UNESCO (1991) refers to a number of different types of surface runoff, the primary, 'Hortonian overland flow' (described by Horton in 1933) is generated at a given location by excess rainfall, when rainfall intensity exceeds the infiltration capacity of the soil.

Knuti comments that although sandy soils have large pore spaces between large particles, frequently these are blocked by finer particles so that some sandy soils take in moisture more slowly than might be expected. Hussey and Tator (1950) refers to sandstone spindles which due to cementation are highly resistant to detachment, infiltration and weathering and thus stand proud of the surrounding landscape which has eroded. According to Pettijohn, Potter et al. (1972) compaction and cementation can reduce porosity from 50% or more in certain sands to virtually zero in quartzites and holocrystalline sandstones. Chleq and Dupriez (1988) indicates that soil crusted by

rainfall is virtually impermeable as the surface has become smooth with the smallest gaps between the sand particles clogged with fine material. The consequent surface soil compaction further prevents infiltration and increases runoff. Savory (1991) maintains that his experience, is that of about 355 mm (14 ins) of rainfall, only some 125-150 mm (5-6 ins) actually infiltrates the soil, but that a loosened or roughened soil surface or old, prone plant material will improve on this.

Jackson (Undated) observes that large storms of high intensity create problems associated with surface water and soil erosion as they considerably influence the effect of the rain as it impacts the surface. Tropical storms exhibit greater energy than storms in temperate areas. The heavy impact of raindrops is sufficient to break up soil aggregates allowing the soil to be more easily eroded. The fine particles that are detached from the aggregate remain in suspension in the surface water and block soil pores as the water infiltrates the soil. This process further reduces infiltration and as high intensity storms are more likely to exceed the rate at which water is able to infiltrate the soil, a high proportion of rainfall becomes surface runoff. Runoff tends to be irregular, alternating between flash flooding and zero or low flow during dry periods. A vegetation canopy protects the soil against raindrop impact by minimising these effects and slowing down surface water movement, (Krynine and Judd 1957). However, not only is vegetation cover scant in dry periods and dry areas generally, but rainfall intensities are often particularly high at the start of the rainy season, making the problem even more serious, (Harrison 1987).

Kearn (1970) asserts that as raindrops strike the ground their kinetic energy is expended on the ground which loosens the smaller particles of the surface, in areas of complete plant cover this energy is expended on the foliage of trees and grasses and precipitation reaches the soil as slow drips and trickles which have little energy to loosen the surface. A tabulated indication of the comparative periods of loss of soil from natural land and mismanaged land is provided in table 4.4. In contrast, in areas of inadequate or incomplete plant cover, this kinetic energy is expended on the bare ground. Chleq and Dupriez (1988) points out that in effect this is the difference between the rainfall of humid and arid areas. In humid regions very little surface material is entrained whereas in arid regions the rain on impact immediately starts to pick up a load of clastic material.

Land Use	% Slope	Amount of Soil Removed (mm)	Period of Time (yrs)
Mixed Woodland & Grassland	10	0	-
Woodland	10	10	33,000
Grassland	10	10	4,600
Poor Tillaged Land	10	10	6
Cotton Tillaged Land	10	10	2.5
Bare Ground	10	10	1

Table 4.4: Severity of erosion by land use (adapted from (Booysen and Hofmeyer 1968))

Bell (1998) describes the initial process of runoff as 'micropiracy', where a flooded rill overtops and breaks down a smaller rill. As the rill divides are overtopped, the water

moves to rills at a lower level further eroding the divides. A dendritic drainage system is likely to develop as down slope and cross-grading flows move toward the master rill. Kearn (1970) maintains that the greatest bulk of sediment is transported to the depositional site by running water. The streams and rivers derive most of their load from material carried to them through surface runoff during and immediately following rainfall. Table 4.5 indicates the percentage runoff to be expected in differing river catchments at incremental rates of rainfall and rates of evaporation.

			Runoff as a Percentage of Average Annual Rainfall			
Average Annual Rainfall (mm)	Total Annual Evaporation (mm)	Reliability (Years out of 10)	Shallow Sand or Loam Soils (%)	Sandy Clays (%)	Elastic Clays (%)	
Over 1100	-	8 9	10 to 15 6.5 to 10	10 to 15 6.5 to 10	15 to 20 10 to 13	
901 to 1100	-	8 9	10 to 12.5 6.5 to 8	10 to 15 6.5 to 10	12.5 to 20 8 to 13	
501 to 900	Less than 1300	8 9	7.5 to 10 5 to 6.5	7.5 to 15 5 to 10	7.5 to 15 5 to 10	
	1300 to 1800	8 9	5 to 7.5 3.5 to 5	5 to 12.5 3 to 8	5 to 10 3 to 6.5	
401 to 500	1300 to 1800	89	2.5 to 5 1.5 to 3	5 to 10 3 to 6.5	2.5 to 5 1.5 to 3	
250 to 400	Less than 1800	8	0 to 2.5 0. to 1.5	0 to 5 0 to 3	0 to 2.5 0 to 1.5	
	More than 1800	8 9	0	0 to 2.5 0 to 1.5	0 0	

 Table 4.5: Percentage runoff from river catchments, (Nelson 1985)

Note - Elastic clays when dry develop pronounced surface cracking, which reduces runoff.

Surface runoff of rainfall in arid regions is a major contributor to erosion. A significant proportion of the rainfall runs off downslope as sheet wash and where it is unimpeded by ground litter or plant roots, the runoff velocity and volume are likely to increase and large amounts of relatively coarse material may be carried downslope to gullies or stream channels. The erosive process increases exponentially with increases in the degree of slope and the subsequent increase in the velocity of runoff, table 4.6., Holmes (1969) indicates that during a heavy storm splash erosion may account for the loss of up to 250 tonnes per ha. (100 tons per ac). Wherever there is water movement over the soil surface, material is eroded so that runnels and rills, then gullies and possibly ravines are formed which lead to steams and rivers. According to Chleq and Dupriez (1988) where the angle of a slope increases and the movement of water builds up, so larger soil particles are removed from the surface which eventually leads to the formation of gullies and ravines. As the volume and velocity of the water increases so all material, clay, silt, sand and stone is eroded deepening the gully and causing the sides to collapse. Vaneph and Benites (2001) mentions that injudicious tillage of hillslopes in developing countries can exceed erosion rates of 15 kg/m²/yr (150 tonnes/ha/yr). Whereas, according to Quine, Walling et al., (1999), water erosion rates on tilled terraces on the Loess Plateau China, were less than 1 $kg/m^2/yr$ where slope tangents did not exceed 0.1.

Table 4.6: Exponential effect of slope and velocity on erosion, adapted from (Booysen and Hofmeyer 1968)



In a report on the erosion of topsoil in the Magat catchment in the Philippines, Atkinson (1991) indicates that the relative proportions of sand, silt and clay are 35%, 33% and 32% respectively. Atkinson demonstrates that finer particles erode more easily than coarse material; he provides a sediment size fraction and takes equal proportions of riverbed material at each fraction and then calculates the proportion of eroding material, table 4.7. These in fact decrease as the sediment size fraction increases.

Sediment size fraction (mm)	Proportion in riverbed material	Proportion in eroding material	Ratio	Percentage eroding material
0.06-0.36	0.1	0.29	2.9	67.75
0.36-0.69	0.1	0.07	0.7	16.35
0.69-1.9	0.1	0.052	0.52	12.15
1.9-5.3	0.1	0.008	0.98	1.87
5.3-9.0	0.1	0.003	0.03	0.7
9.0-14	0.1	0.002	0.02	0.47
14-21	0.1	0.001	0.01	0.23
21-30	0.1	0.001	0.01	0.23
30-42	0.1	0.0005	0.005	0.17
42-100	0.1	0.0005	0.005	0.17

Table 4.7: Calculation of delivery ratio from size gradings (Atkinson 1991)

Whiteside (1998) identifies rapidly rising populations in southern Africa and contrasts this with the capacity of the natural environment to provide for expanding populations. He views environmental degradation due to deforestation, rapacious ploughing and livestock overstocking with subsequent soil erosion as a consequence of this increasing pressure. As far back as 1972 Cambitzis, Heath et al., (1972) asserts that whereas the recommended livestock density rate of Matabeleland South, Zimbabwe, could be averaged at 8.1 ha / L.U. (in commercial farming areas), the effective rate was 4.5 ha in communal land farming areas.

Factors contributing to erosion

• Land which is degraded has no vegetation canopy to protect the soil surface from the impact of raindrops and the flow of water over the surface

- Bare, compacted soil restricts infiltration, thus increasing runoff.
- Erosion is typically severe in dryland areas where there is poor soil stability due to little soil organic matter and high soil temperatures due to minimal levels of protective groundcover.

Process of erosion by water:

After Knuti, Korpi et al., (1972) and Hudson (1995).

Detachment: (alternatively referred to as splash erosion).

- The impact of a falling raindrop on the soil surface is sufficiently heavy to create a small crater and to dislodge soil particles and fragments of surface debris.
- Soil particles are detached from the surface when there is a sufficient velocity of water flow. The velocity of water and degree of detachment is controlled by the angle of slope and the volume of flow.

Forms of Erosion:

- Sheet or Inter-Rill; erosion is caused by splash or the impact effect of raindrops which loosen and detach soil surface particles. A thin surface flow occurs with an erosive capacity increased by the turbulence generated from raindrop impact. Much of the loose soil is in fact transported in rills or gullies.
- Rill Erosion; commences with the concentration of water into small rivulets and is caused by the movement of water in small channels across the soil surface. Erosion occurs as the channels cut deeper with the entrainment of soil particles and by the further abrasion of soil particles in transport.
- Gully Erosion; occurs when rills flow together to form larger water channels which cut deep and wide into the soil surface. Gullies tend only to stabilise when the base becomes level with the outlet.
- Bank Erosion; is the cutting of banks by streams and rivers, usually on the outer sides of bends.

Specialised Forms of Erosion:

- Pedestal Erosion occurs where an easily eroded soil is protected from splash erosion by a stone or tree root, isolated 'pedestals' then occur, 'capped' by the resistant material.
- Pinnacle Erosion may occur in highly erodible soils such as gully sides where deep, vertical rills form. These cut back rapidly until they join and leave high isolated pinnacles. Frequently the pinnacles are capped with a more resistant layer of gavel or stones.
- Piping or Tunnel Erosion occurs when surface water infiltrates through the soil surface and moves downward until it comes to a less permeable layer. If there is a pressure gradient water will flow naturally through the porous soil over the less permeable layer. As the fine particles of the porous soil are washed out so channels or 'pipes' are formed underground. As the lateral flow increases the

channels become enlarged often leading to roof collapse whereon the tunnel becomes a gully.

• Mass Movement and Slumping often starts as a result of flood flow in a gully or channel which causes the sides or bank to collapse, but once started continues by slumping alone.

Factors affecting sediment load and discharge: after Blatt, Middleton et al., (1972)

- Relief the degree of slope and difference in elevation between the highest and lowest point of water transfer.
- Climate temperature, rainfall intensity and intermittency and duration of the dry season
- Vegetation the presence or absence of a protective vegetation canopy and mulch.
- Bedrock geology the stability or erodability of weathered material

The causes of erosion and the erosion dynamic are critical factors of land management. Surface erosion is exacerbated in conditions of land degradation which is frequently caused by depleted vegetation, in turn caused by over-stocking of livestock. Degraded land is susceptible to the formation of a compacted surface crust which inhibits the infiltration of precipitation and causes surface runoff which increases erosion. The material eroded from the rock and soil within a catchment area is the source of sediment deposited in dryland river channels and thus land management is crucial to the condition of the river channel.

Sediment Yield

In outlining methods to calculate the volume of water storage which may be lost through sedimentation in open-surface dams, Owen, Rydzewski et al., (1989) says that within Zimbabwe, mean sediment concentration loads from basins with well developed conservation measures and moderate topography may be considered to be 3,000 mg/ ℓ . Basins that are prone to erosion through poor conservation measures and steeper slopes will be 5,000 mg/ ℓ and basins highly susceptible to erosion 10,000 mg/ ℓ . However he also observes that it is necessary to know the density of the deposited sediment which may vary depending on the physical characteristics of the silt. Although density increases with time through consolidation a commonly accepted figure is 1.55 tonnes/m³.

A number of methods of estimating surface soil loss have been developed. Hadley (1984) states that the Universal Soil Loss Equation (USLE) has become the most common technique used, but that several methods have evolved since the 1940's. The USLE was developed in the American Rockies but has been adapted for use in a range of differing situations from rainforest, to tropical soils and dryland crop regions. According to Hadley it is an empirical equation which was developed to predict soil loss from cropland. Calculations are based on indexes of each of the major causal and conditional factors that affect the amount of erosion from a specific site.

Hadley also observes that several limitations of the USLE have been noted and a more qualitative method of estimating sediment yield has been developed by the Pacific Southwest Interagency Committee (PSIAC) for use in the southwestern U.S.A. where the climate is arid to semiarid. The method is based on drainage basin characteristics and

reservoir sedimentation data and is intended for use on drainage basins with areas larger than 25 km² but has been applied, with good results to drainage basins as small as 0.05 km². Elwell (1984) has also reported severe limitations with the USLE model stating that adoption of American factor values has led to considerable inaccuracies in establishing soil losses in Zimbabwe. He asserts that using the USLE, soil loss estimates have varied from low (50%) for bare, fallow soils to high (100%) for cropped plots. Consequently Elwell has developed the Soil Loss Estimator for Southern Africa (SLEMSA).

The SLEMSA, Elwell says, is a mathematical modelling approach drawing on established theory, field based experience, laboratory test data and results from field plot measurements. Elwell rationalises his method by stating that soil erosion is the outcome of a large number of causative factors of varying importance interacting in a complex manner and considers that there is a danger of including a mass of relatively unimportant data, unless assessments are undertaken systematically and logically. The procedure adopted by Elwell has been to divide the soil erosion environment into the physical systems of climate, soil, crop, and topography. He maintains that the overriding factors controlling soil losses within each system are seasonal rainfall energy, the amount of rainfall energy intercepted by the crop, soil erodability, slope length, and slope percent which he says can be utilised as easily measurable and rational control variables.

Soil losses, exacerbated by poor land husbandry methods are of critical proportions within Zimbabwe. Harvey (1999) maintains that since the eradication of tsetse fly and the subsequent introduction of cattle into the catchment area, the Save River valley has reached a state of ecological collapse with the complete destruction of previously perennial river systems. The river catchment, which comprises 11% of Zimbabwe's total, is almost entirely under traditional, Communal Land management where pressure of population and inadequate land management controls have lead to excessive livestock over-stocking and poor tillage practices. These have been the cause of extensive levels of erosion with annual losses of soil and river sand calculated to be many millions of tonnes.

Sedimentation

Supply of sediment to the channel

The supply of sediment to the river channel is dependant on the relief, soils and land use of the catchment area of the river. Agnew and Anderson (1992) remarks that arid areas in general, lack easily transportable fine sediments, although any sediment can be easily eroded due to the virtual absence of natural protection. He adds that the incidence of sedimentation is extremely variable as in most arid areas there is a lack of base flow. This makes the supply of sediment the result of rainfall and runoff which are both unreliable in occurrence and subject to extreme events. According to Hulme (1996) the coefficient of variation of annual runoff varies considerably in Southern Africa, with variations as low as 25% in Central Zambia to as high as 70% in Zimbabwe and isolated extremes of 275% in southwestern South Africa where several season of high rainfall follow long periods of low rainfall.

Muyambo (Undated) provides a rough estimation of the concentration of sediment that is transported in runoff from catchments under differing management practices, table 4.8,

and then suggests a simple equation to calculate the volume of sediment that is likely to be deposited annually in a dam basin:

$$Sed = \frac{In \times Sc \times Te}{m \times den}$$

where

Sed = Mean annual deposit of sediment

In = Mean Annual Inflow, (catchment area of the dam × mean annual runoff) Sc = Sediment concentration (from table 4.8) Te = Trap efficiency m = 1,000,000

den = Density of the deposited sediment, which Muyambo suggests as 1.55 t/m³

As several of the parameters are conjectural the result can only be considered speculative. However, with an assessment of the catchment area the formula is able to provide a useful, quick calculation to indicate the volume of sediment that is likely to annually reach, for instance a sand dam. The extent of the catchment area and the mean annual runoff (MAR) may be determined, the susceptibility of the catchment area may be decided upon and the corresponding value of sediment concentration determined. The trap efficiency, which is a measure of the proportion of the total sediments that enter a dam and are deposited, may be established through consideration of the storage ratio which in turn is established as the mean annual inflow (MAI) divided by the capacity of the dam (m³). According to Muyambo when the storage ratio is 0.1, trap efficiency is 100%. This varies linearly down to 10% when the storage ratio is at zero.

Table 4.8: Sediment concentration from catchment basins with differing management practices, after Muyambo (Undated).

Type of Catchment	Sediment Concentration (mg/l)
Basins with well developed conservation measures and moderate topography	3,000
Basins prone to erosion through poor conservation measures and steeper slopes	5,000
Basins highly susceptible to erosion	10,000

According to Newson (1992), sediment transport at the river basin scale is dependent on the supply of material from source areas, including headwater catchments and the beds and banks of channels. In the river headwater it is the combination of slope and channel which controls the amount and the timing of the sediment removed. As flow from the catchment area progresses from runnels to channels so the volume of entrained sediment is likely to increase. Krynine and Judd (1957) observes that surface runoff transports to streams, soil and rock particles that have been loosened by weathering and erosion and within channels the sediment yield increases through corrasion as, particularly in high velocity stream reaches, the streamload mechanically removes further particles from the channel sides. Hassan and Church (1992) states that the motion of sediment particles through a channel is not continuous but consists of a series of moves followed by periods of non-movement. The entrainment, transport and deposition of sediment are affected by a large number of interrelated variables which can be grouped into three categories flow; material and channel form. According to Hadley (1984) channels of most rivers will scour their beds during periods of high flow and backfill on the flood recession.

The supply of sediment to a river channel due to the nature of the catchment area is considerably variable. The vegetation cover, the slope and the state and condition of the land surface and the material and nature of the headwaters of the channel each contribute to determine the volume and consistency of the sediment. Typically dryland rivers are in an agradational and degradational equilibrium, consequently heavy concentrations of sediment that are transported into a river channel are also transported through the river channel with a resultant sorting of material during river flow.

Flow in the channel

Stelczer (1981) states that the velocity of river discharge is a principal factor governing the movement of sediment through a river channel. Davis and Day (1998) in turn notes that the velocity of the flow within a stream is governed not only by the gradient of fall, but also by the friction of flow caused against the bank and the riverbed. Krynine points out that the longitudinal slope of the river surface and the longitudinal slope of the riverbed may not be the same and that it is in fact the longitudinal slope of the water which controls the discharge, Krynine and Judd (1957)

Chadwick and Morfett (1993) maintains that once sediment is in transport, as two materials, a liquid and a solid are then involved, the discharge is no longer a simple flow of fluid. Graf (1988(a)) makes a point which is most relevant to the security of abstraction equipment. He states that the flow of water over a mobile riverbed entrains sediment so that a water-sediment mixture ensues and consequently displaces itself in the watercourse. Discharge through a channel is itself continually modified by the movement of sediment through erosion, transport and deposition as this in turn alters the elevation, slope and roughness of the channel bed. According to Robinson (1983), although fine material may concentrate near the riverbed, the distribution of fine particles is generally uniform throughout the depth of flow. He also makes the point that the riverbed is composed of particles coarser than those which are moving through a particular reach. Turbulence also affects the topography of the riverbed as, according to Ikeda and Nishimura (1986), the majority of sediment in a sand-silt river is usually transported as suspended load induced by turbulence. Graf also refers to the significance of turbulence, stating that the effect of river flow is more critical to the river channel than the effects of sediment entrainment and thus turbulence plays an essential role in all flows of water-sediment mixtures.

Krynine and Judd (1957) also states that water flow in a river is either laminar or turbulent, but generally turbulent. Referring to a perennial river he observes that tributaries flow from the watershed into the river channel with a certain velocity so that river load is not distributed uniformly across the reach. Irregularity of flow becomes obstructed by mechanical projections which cause turbulence. Yalin (1992) maintains that turbulence is due to a multitude of eddies which he refers to as *fluid volumes of*

various sizes with a sense of rotation. Eddies become superimposed on each other and ultimately on the mean flow, they may vary from micro-turbulent eddies to macro-turbulent eddies which may almost be equal to the flow thickness. Krynine and Judd (1957) indicates that turbulence is accompanied by both horizontal and vertical eddies, which are patches of water with decreased, or no pressure. When sediment particles encounter these spots of calm water they are likely to come to an abrupt halt and are then liable to drop to the riverbed.

Kostaschuk and Villard (1996) suggests that turbulence is evident at the surface as circular patches of up-welling fluid. This he says indicates that turbulence originates behind obstructions, such as rocks, and backward-facing steps such as dunes. Where these are sufficiently large they create slowly rotating vortices that cause larger areas of turbulence as boils or 'kolks'. Ikeda and Nishimura (1985) adds that turbulence further affects the bed profile as flow is not uniform across the river. It is, he says, greater on the outside of bends where it causes scour and pools than on the inside. This is supported by Burge and Smith (1999) who refers to deep scours which occur in unconfined meanders of the Mississippi River.

In its movement through a river basin, at least in its upper reaches, water cascades over rocks and other obvious blockages. The effect of this is a scouring of the sediment around and below the obstruction, (Kay 1998). However in lower, more level and slower sections of a river these obstructions may be submerged in sediment and only apparent when the river is in spate, when standing waves, as indicated in figure 4.15, are created. This turbulence in river flow creates gullying and potholes, (Bell 1993) and a riffle and pool effect is created within the sediment.





Hallam et al., (1967), indicates that in deep water, waves disturb water down to a depth of only approximately half their wave length. However, according to Kay (1998) waves in low velocity perennial rivers and thus also in the shallow floodwaters of ephemeral rivers, depend on gravity for their shape and size and in shallow perennial river water the wave is generally not recognisable and can be several hundred kilometres long. Nevertheless, because of higher peak flows, it is necessary to acknowledge the possible

Chapter 4

effect of waves and turbulence and the detrimental effect they may well have, on the security of an abstraction installation.

River sediment is not in a process of continuous movement but is subjected to a series of stages of partial transport. Wilcock and McArdell (1997) maintains that the rate and size distribution of transported sediment depends not only on the population of grains on the bed surface but also on the population of those grains that can be mobilised by the flow. Only some of the sediment particles in a given size range are mobile at any one time, irrespective of whether the river flow is subject to zero sediment input or experiences a steady state transport of sediment grains entrained from the upstream riverbed. Partial transport of the bed surface continues, particularly with smaller sizes of sediment, even as river flow diminishes and as flow duration increases with decreasing flow magnitude, so conditions of partial transport are common in many rivers and consequently can produce a large proportion of the annual sediment load. In upland areas perennial waterways may well be gravelbed streams or rivers, with a significant proportion of the discharge flowing through the sediment.

Material and material transport

Total river load is comprised of wash load, suspended load and bedload, (Open University 1988). According to Graf (1988(a)) as sediments reach the river channel so fine sediment particles remain suspended in the river flow by water molecules and form the wash load. Particles that come into occasional contact with the bedload and riverbed but generally remain surrounded by water form the suspended load. Emmett (1984) concludes that bedload is that part of the sediment load supported by frequent solid contact with the unmoving bed that in practice is the sediment moving on or near the streambed rather than in the bulk of the flowing water. Chadwick and Morfett (1993) states that large base material is transported by a tractive process of sliding or rolling along the riverbed. Material of an intermediate grain size is transported by a process of saltation and fine particles are retained in suspension within the moving fluid. These differing modes of sediment transport are shown clearly in figure 4.16. Kay (1998) points out that not all particles are in transport at any one time and refers to a 'threshold of movement', when sediment particles that have been stationary, suddenly, rather than gradually begin to move.

Newson (1992), refers to the need to determine the size of grains supplied to the channel as this largely determines the process of transport and sedimentation. He refers to the work of Hjulstrom (1935) in river sediment transport, figure 4.17. Hjulstrom categorised river load into suspended and bedload material and using the velocity of river flow and sediment particle size, developed a basic representation of the intervals of erosion, entrainment, transport, and deposition.



Figure: 4.16: Scheme of the modes of sediment transport, (Graf and Altinaker 1988(b))

Following experimental work on sediment transport in shallow flows, Aziz and Prasad (1985) signifies that it is evident that the bedload is a function of the flow conditions in conjunction with the sediment properties. According to Twenhofel (1932) the shape of the particle influences its transportation. As examples he states that slab shaped particles tend to bounce along the bed surface whereas pebbles are either rolled or rotated by the current. Where a current is too weak to roll large particles they are frequently moved through a process of rotation, as sediment is washed away from beneath the pebbles, so the larger particles fall forward. With further reference to shape Krumbein and Sloss (1963) asserts that the settling velocity is determined by the size, sphericity and density of the particle.

Figure: 4.17: Representation of the intervals of erosion, entrainment, transport, and deposition. Hjulstrom (1935)



Krynine and Judd (1957) observes that coarse sediment particles move obliquely downwards to the riverbed under the combined actions of weight and tractive force. Coarse sediment particles which reach the riverbed are likely to continue intermittent movement from turbulent water flow and saltation. Turbulent flow may cause particles to be pushed in any direction or even to remain static. According to Graf (1988(a)) bedload transport affects larger particles where displacement is intermittent and may occur only briefly.

Wilcock (1998) has divided bed sediment into two distinct populations of sand and gravel and in flow modelling experiments found that critical flow which initiated grain motion, decreased rapidly with increases in the sand content in a transition from a gravelbed to a sand matrix bed. This he felt predicted the movement of excess fine sediment supply and explained the development of the abrupt gravel-sand transition of rivers. Peloutier, Hoey et al., (1999) maintains that sand is often dominant in matrix development in gravel-bed rivers because only the highest flows are able to flush sand particles out of the riverbed. Following further experiments he considered that sediment infiltration decreased with turbulence, particularly in the medium-sand size range.

These processes when they occur during a flood interval in a sand river create a natural sorting and the formation of layers of graded sediment. As flow commences in a seasonal river so the velocity of the water increases creating a greater movement of sediment particles that become transported through the river channel. The surface of the former, dry riverbed is lowered as smaller particles are raised from the surface and are transported in suspension. If the flow continues to increase, so progressively larger particles of material are moved in suspension and in the bedload, increasing the volume of sediment transported and creating a new riverbed with each particular flood event. Variations in velocity and duration of flow produce distinctions in the material of the riverbed with a consequent natural grading process of the river alluvium.

Hofkes, Huisman et al., (1981) provides further evidence of these processes from laboratory experiments and suggests that the exchange of sand between the bedload, the bed-active layer and the sub-surface is distinctly different from that of gravel. He maintains that the presence of significant amounts of sand on the surface of a gravelbed causes changes in hydraulic roughness, bedform regime and ultimately to the watersurface slope. Changes to the bedform will precipitate further sand accumulation, which in turn increases suspended sediment concentrations with the likelihood of an increase in the drop-out of particles from suspension.

Bedform

The effect of continuing soil erosion in the catchment area and the subsequent passage of sediment through the river channel with consequent retention or scouring of sediment has a considerable effect on the bedform of the river. According to Newson (1992) there is an on-going process and continual movement of surface sediment. This inexorable movement of sediment in riffles has been described by Twenhofel (1932) and has been clearly observed by the author in the Sansukwe River, Matobo District, Zimbabwe in March 2000. Following several days of fairly continuous rainfall the river was running gently approximately 250 mm deep, bedform particles could be clearly seen in clear water moving in a tractive process along the low slope of each ripple of approximate

length 175 mm, until they dropped some 25 mm over the leading edge. In this manner ripples in the riverbed were seen to move at approximately 2.00 m per hour.

Simons, Richardson et al. (1972) refers to differing bedforms as the result of different flow regimes; plane bed; ripples; dunes; flat or slightly undulating beds; antidunes; chutes and pools; bars, figure 4.18. Dake (1981), Yalin (1977) and Yang (1996) provide descriptions of riverbed features.

- Plane bed a surface without elevations or depressions larger than the largest grains of bed material.
- Ripples three-dimensional regular wavy features (but irregular in plan) between 100 mm and 300 mm long and up to about 75 mm high. They have a low angle upstream face with a steep downstream face.
- Dunes essentially enlarged ripples with long straight crests. Small ripples may be observed superimposed on dunes. Ripples begin to appear on the surface of the stream and boils, caused by eddies downstream of the dune crests, begin to appear as dunes form. A dune may be from 600 mm to several metres long and from 150 mm to a metre or more high. The profile of the water surface is not in phase with the profile of the dunes beneath.
- Flat or slightly wavy beds occur with increases in stream velocity as dunes are wiped out.
- Anti-dunes which in appearance are reversed dunes, begin to form upstream as flow velocities increase. The water surface shows definite wavy patterns, or standing waves, with the formation of anti-dunes. The wave formation is in phase with the streambed.
- Chutes and Pools consist of large elongated mounds of sediment that occur as large slopes with high sediment concentrations and high velocities of flow.
- Bars occur in alluvial waterways and are large depositional features which generally develop on the convex side of river bends. Bars change both position and form with time and flow conditions, and are related to the tendency of the thread of a current to meander. They have lengths of the same order or greater than the channel width and heights comparable to the mean depth of the generating flow. Bars comprise, point bars, alternate bars, middle bars and tributary bars.

Simons also mentions that although accorded a bedform state, chute and pool conditions rarely occur naturally as the steam power, turbulence and sediment supply required decreases flow velocity so that more stable bedform conditions are imposed.

Yalin (1977) refers to sand waves and the important effect that they have in determining the behaviour of the transporting flow and of the transported granular material. He further maintains that turbulence has a significant effect on bedform, although ripples in fact appear to develop best when conditions are hydraulically smooth. Amsler and Garcia (1997) states that although in general dune wavelengths and amplitudes increase on rising flow regimes and decrease on falling stages, this does not necessarily occur simultaneously at all points on the riverbed. He maintains that local washouts may take place in flat streambeds under the highest streamflows and there may be considerable time lags between stage changes and bedform changes. ten Brinke (1999) reports both the formation and degradation of dunes of up to 2.5 m in the bedform of the River Waal

during stages of falling flow. Although discharge in an ephemeral river is subject to the same forces as those in a perennial river, as the discharge recedes to zero flow and then recedes further into the sediment, so the bedform ultimately stabilises to an eventual level surface. The author has witnessed a standing wave at Tshelanyemba, Matobo District, Zimbabwe with an estimated trough depth of approximately 1.25 m. However when the river receded 5 days later the sediment surface was reduced to shallow level channels, incised no more than 150 mm in the sediment



Figure 4.18: Bedform in an alluvial channel after Simons and Richardson (Undated)

Packman and Bencala (2000) notes that flows in gravel streambeds differ radically from those of sand streambeds. He accords this to the smaller pore spaces of a sandbed, which restricts stream-driven turbulence to a very small layer near the surface of the sandbed. This results in little interaction between stream flow and pore-water flow although a variety of types of bedform may be developed by stream flow in a sandbed. Packman also affirms that bedform-driven processes generally control the exchanges that do occur between the stream flow and the near-surface of a sandbed.

Bedforms are responsible for two distinct exchange processes that, in the terminology of Elliott (1990) in Packman and Bencala (2000), are referred to as 'pumping' and 'turnover'. Pumping is the exchange due to advective pore-water flow and turnover is the exchange resulting from the trapping and subsequent release of pore-water. Pumping exchange occurs because stream flow over bedforms produces a pressure disturbance at the bed surface. Bedforms protrude into the stream flow, resulting in drag due to high pressure at the upstream side of each bedform and low pressure in the re-circulation zone behind each bedform. The periodic high and low pressure regions at the bed's surface produce sub-surface pressure gradients that drive advective pore-water flow into, through, and out of the bed. These advective flow patterns occur in the bed below each bedform producing an overall pumping exchange. Turnover exchange occurs because bed sediment transport causes bedforms to move downstream. As bed sediment is

scoured from the upstream side of a dune, pore-water that was previously trapped in the bedform becomes mixed with stream water. The scoured sediment is then deposited at the downstream face of the bedform in order to maintain the stable bedform shape. In the region of deposition, streamwater becomes trapped in the bedform and the overall trapping and release of water results in a net turnover exchange between the stream and the streambed.

Sorting, Aggradation and Degradation

Asselman (1999) maintains that sedimentation does not increase proportionally with increases in the rate of sediment transport. According to the Open University (1988) it is changes in water-current velocities which are largely responsible for the natural selection, sorting and deposition or degradation of certain grain sizes within a sediment. Fast flowing water in a high energy environment carries all but the coarsest material which is later deposited on the streambed. Figure 4.19 shows layers of sediment, which have been graded during different discharges in the Dongamuzi River, a small river in the Lupane District of Zimbabwe, figure 4.20 shows a uniform, sorted sediment in the large Shashane River, Matobo District, Zimbabwe.

High-energy environments are characterised by coarse grained sediments and low energy environments by fine grained sediment. Sorting, Asselman says, is a measure of the sizefrequency distribution of particles within a sediment. According to Twenhofel (1932) the sorting of sediments by water is a consequence of the way in which they are transported and is also due to the different competencies arising from differing velocities of the discharge. The sorting of particles of greater than colloidal dimensions is due to the specific gravity, size and shape of particles with large and spherical particles with those of high specific gravity coming to rest first. On the assumption that river flow in an ephemeral river will differ in depth depending on the magnitude of the flood on each occasion of discharge, sorting will create a layering of sediment particles from coarse to fine with each flow of the river.

Figure 4.19: Graded sediment, Dongamuzi River, Lupane District, Zimbabwe



Figure 4.20: Uniformly sorted sediment, Shashane River, Matobo District, Zimbabwe



According to Robinson (1983) sediment distribution patterns are usually unstable and changing so that deposition and aggradation takes place over small spaces and times in a flowing stream. Krynine and Judd (1957) contends that deposition of river load takes place in low-velocity reaches or where the velocity of the water-carrying load is checked. According to Owen (2000(b)) where the slope is less than 1 in 350 the velocity of water is not great enough to carry the particles which are then deposited on the riverbed. Owen also indicates that sediment is retained behind natural barriers such as rock outcrops and depressions in the riverbed. Breusers (1991) maintains that general scour occurs because of the increased capacity of a river to carry sediment during flood, though this may not necessarily result in a depletion of sediment within the river channel.

According to the Open University (1988) degradation or aggradation are long-term processes in the evolution of a channel and are encountered when the solid discharge is smaller or larger than the capacity of the transport of sediments. The sediment bed will be eroded or deposited and as a consequence the volume of the channel bed decreases or increases. According to Reid, Laronne et al., (1999) ephemeral streams are several orders of magnitude more efficient at shifting sediment as bedload than equivalent perennial streams, which despite the infrequency and short duration of flood flows, indicate very high yields of bedload-sediment and match the high yield of suspended sediment.

Degradation in stretches of high velocity and aggradation in stretches of low velocity leads to the formation of a uniform longitudinal slope along the whole river. This process leads to gradation of the river where rivers become graded or poised. Where banks cave into the river the river load temporarily increases but material is usually deposited on downstream banks, maintaining the gradation of the river, (Krynine and Judd 1957). Driscoll (1986) refers to Makin (1948) who defines a graded stream as *one in which, over a period of years, slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for transportation of the load supplied from the drainage basin.*

transported sediment and the degree of streambank erosion. He indicates that the deposition or erosion characteristics associated with a discharge are not subject to a regular pattern but rather depends on the sequence of the individual event. According to Hoey and Bluck (1999(a)), sediment grain sizes will remain constant in a particular river reach, despite a considerable movement of mixed size sediment through the reach and bedload material input will usually be significantly finer than existing bed material.

Schumm (1977) suggests that a channel will be maintained in steady-state equilibrium as long as changes in sediment load and sediment size are compensated for by changes in water discharge and river gradient. Taylor (1999) maintains that the Fitzroy River, northwest Australia is in a constant state of adjustment, but the River can be regarded as being in a steady-state equilibrium as the adjustments tend toward an average condition. Many rivers are subject to extensive erosion in their catchment areas and consequently considerable volumes of silt pass through the river channel. Zuemin (1988) estimates that in excess of 495 million tonnes (530 million tons) of suspended silt load passes down the Yangtze River each year. Although the Yangtze River is considered a perennial river, its headwaters are in the dry, arid interior of China. Hyams (1976) maintains that between 65 and 140 million tonnes (70 and 150 million tons) of top soil is carried down the River Nile each year, he then estimates that in the last 7,000 years more than 300 times the total area of the topsoil of Europe has been carried into Egypt.

Tooth (1999) indicates that in spite of the variance and erratic nature of flow-regimes in dryland areas, rivers generally remain surprisingly stable, but he also acknowledges the inaccuracy of any generalisation of dryland fluvial processes. According to Makaske (1999) typical discharge is generally low so that waterways only overbank infrequently and floodplains are only occasionally inundated. He also maintains that many floodplain gradients are low, sometimes as low as 3-4 cm/km., which is the cause of low stream power and consequently creates a lateral stability of the channels. McInally and Nichols (1999) points out that seasonal river channels generally have low width-to-depth ratios in the region of less than 15 to 1, which also creates low stream power. Makaske further indicates that riverbanks are generally stabilised by riparian vegetation or, where there is an absence of prolific vegetation, through cementation of the natural levees. According to McInally and Nichols (1999) ephemeral rivers do not produce laterally amalgamated sand-bodies despite significant deposition of sand and Makaske concludes that where there is channel stability with no rapid or continuous base level rise, the sedimentation rate of semiarid river systems is likely to remain relatively low.

It cannot however be said that all seasonal river channels are stable, Ethridge, Skelly et al. (1999) refers to the Niobrara River, Nebraska which has become elevated above its floodplain due to 43 years of aggradation and Dake (1981) notes that Timbuktu, once on the Niger River, is now some 15 kms distant to due movement in the course of the river. According to Butcher and Thomas (1978) small ephemeral river channels are particularly unstable and vulnerable to alteration due to highly erratic flow and the high levels of grain resistance from the coarse material that they typically transport.

By virtue of unpredictable precipitation in dryland areas, flow within an ephemeral river channel is extremely variable both in volume and in duration. Consequently there is also great variation in the degree of erosion and the subsequent transport of material through the river channel. However, in spite of differing flow conditions, ephemeral river Simons, Richardson et al., (1972) defines equilibrium flow as flow which has established a bed configuration and slope consistent with the fluid flow and bed material characteristics over the entire length of the channel. Lane and Borland (1972) refers to the middle Rio Grande valley, stating that before the commencement of intense agrarian use, the valley had probably reached a sedimentation status approaching equilibrium where the sediment brought in by the river and its tributaries equalled the sediment carried out. However, widespread overgrazing of the watershed increased the sediment load into the valley and increasing use of upstream runoff for irrigation, decreased downstream flow. Consequently in 1953, sediment was accreting in the valley at a rate of 12.5 mm ($\frac{1}{2}$ in) per year and the riverbed at Albuquerque had risen above street level.

4.2.4. Water Balance

The water of a river is in a continual state of transition. United States Geological Service (2003) refers to rivers being influent rivers when they loose water to groundwater and effluent when they receive water from groundwater. There are losses and gains to the outflow from an aquifer so that the inflow does not in fact balance the outflow, (Kay 1998). Blyth and Freitas (1974) indicates that the changes in the elevation of the water-table may be in the order of tens of metres. According to Blyth variations in the water table are due to infiltration and percolation so that when the rate of percolation to the soil exceeds the rate of drainage, voids begin to fill and the level of saturation within the mass rises. Once the rate of percolation becomes less than the rate of drainage, the level of saturation starts to fall until the hydraulic gradient in the mass is no longer sufficient to permit further drainage and the mass is no longer saturated.

Initially rain falls on land in the catchment area of the river where, depending on the vegetation cover and soil surface, it runs off into the waterways which connect to the river, evaporates to the atmosphere or infiltrates into the soil. Within the river it continues to drain downstream, ultimately to the sea and is subject to losses from evaporation and infiltration from the riverbed. However, depending on the season and the extent of precipitation, apart from inflow from streams, there may also be inflow from ground-rock fissures or from the water-table when it is above the level of the riverbed. Fleckenstein, Suzuki et al., (Undated) refers to an hydraulic connection between the river and the groundwater aquifer which means that changes in pressure or stage in one system have a direct effect on the other system with a consequent exchange occurring between the two, figure 4.21. He also asserts that ephemeral rivers often have no inflow from baseflow and sustain flows only during periods of direct runoff from precipitation. Driscoll (1986) signifies that effluent conditions do not occur in ephemeral watercourses.

According to UNESCO (1991) there are further losses that individually are ostensibly negligible in comparison to the main aquifer losses but which require consideration as a part of the global perspective. They state that it is necessary to consider all factors, which influence to any degree, the water which flows in and out of an aquifer, acknowledging that it is difficult to quantify and not at all possible to maintain any degree of accuracy in assessing through-flow and loss. The water balance can be perceived of as an equation which contains all forms of water inputs, water outputs and water storage changes for a given time interval. The water balance equation is referred to by Headworth and Skinner (1986) who lists the equation parameters as effective rainfall, surface inflow, groundwater inflows, surface outflows, groundwater outflows, changes in groundwater storage and changes in soil moisture and follows this up with the studies required to establish each factor. Lerner and Kumar (1991) provides a conceptualised water balance model that indicates the various forms of stream inflow and outflow and indicates how inflow and outflow can be calculated in an unconsolidated aquifer.

Figure 4.21: River channel as a part of the groundwater-table after Hofkes, Huisman et al., (1981)



 $In\bar{f}iltration$ of water into an unconfined aquifer during the wet season



 $\ensuremath{\mathrm{Infiltration}}$ of water into an unconfined aquifer during the dry season

According to Mwaka, O'Connell et al., (1995) most alluvial rivers only partially penetrate underlying aquifers, yet the transfer of water to or from the aquifers may have a significant effect on flow in the rivers. Sorman and Abdulrazzak (1993) contends that groundwater recharge in arid regions is intermittent and usually occurs as a result of flood flow transmission losses from dry wadi channels. He also maintains that due mainly to the diversity of inflow volumes, large variations occur in the scale of channel losses. Factors affecting the magnitude of groundwater recharge in relation to bed transmission losses are the duration of the flood, the soil moisture content and physical soil profile characteristics. Runoff volume and duration are the dominant factors influencing the cumulative infiltrated volume and recharge to shallow water- tables.

According to Simons and Richardson (Undated) alluvial river channels are usually either in a state of inflow or outflow through the bank and the riverbed. When there is outflow, seepage forces act in the direction of gravity, building up bank storage and increasing the stability of the bank and bed material. When inflow occurs, bank storage is effectively reduced and seepage forces act in reverse, which reduces the effective weight and consequently the stability of the bed and bank material.

Allison (1988) notes that as aridity increases, in terms of total recharge to an aquifer, local recharge from surface inflow is likely to become less important than localised recharge, which occurs through the riverbed base. Allemmoz and Olive (1980) in (Allison 1988) state that a neutron moisture meter showed a considerable increase in water content up to 5 metres beneath a wadi bed following a flood event.

According to Alderwish and Dottridge (1995), recharge volumes are strongly influenced by flood duration, but flood discharge and the distribution of flood intensity are of minor importance. He refers to Rushton, (1988) who maintains that wadi recharge is controlled by flow and channel characteristics and by subsurface conditions. Alderwish has carried out modelling to calculate groundwater recharge from surface flows in ephemeral streams in Yemen. He points out that these wadis are normally dry and only experience infrequent floods of very short duration. When runoff does occur, a large proportion of the flow is absorbed into the bed and banks of the wadi, which causes the stream to disappear before reaching its mouth. Alderwish concludes that infiltration of surface flows through the beds of ephemeral wadis is the most important mechanism of groundwater recharge to unconfined aquifers in many arid areas. In further relevance to this study he goes on to say that quantification of recharge is difficult, due to a lack of accurate flow gauging stations and a general lack of data. It is therefore necessary he contends, to develop indirect methods of estimating recharge. Younger (1995) supports this supposition by stating that it is not necessary to effect frequent comparisons of heads in the river and the deep underlying aquifer in order to assess the recharge of aquifers by infiltration from hydraulically disconnected ephemeral rivers and that externally coupled data collection should be viewed as a perfectly satisfactory solution.

Source Water & Inflow

Inflow and Recharge

It has been acknowledged that initial inflow of water to an aquifer is from immediate runoff and that this is likely to be significantly more severe in areas where there is little or no vegetation, as is frequently the case in over-stocked, arid and semiarid pastoral areas. However, even within these areas some water is inevitably retained in localities such as vleis (marshes), scree slopes and the pockets of colluvium and organic matter that collect for example between the granite 'dwalas' of the batholith. From these entrapments, water is released more slowly to the aquifer than from degraded land. Downing (1986) refers to the flow of an aquifer through its natural outlets so that additional water may run into a river channel from fissures and from a groundwater water-table that is higher than the riverbed. This is an unusual phenomenon of arid areas but has for instance occurred in the 1999/2000 rainy season in Southern Africa.

Moyo (1993) is of the opinion that there is little impermeable material between the riverbed and the aquifer so that groundwater recharge consists of directly infiltrating rainwater and seepage from rivers and surface waters which are hydraulically connected

with underlying aquifers. Houston (1988) remarks that groundwater recharge in the Masvingo Province of Zimbabwe amounts to no more than 2-5% of annual rainfall.

Alluvial Aquifers

Driscoll (1986) refers to the gradation of rivers, stating that downcutting chiefly occurs in the headwaters with consequent deposition occurring in the middle and lower reaches. These processes occur simultaneously in various stages of a river with the resultant formation of alluvial aquifers in the depositional stages. Deposited sediments vary considerably in grain size from alluvial fans to floodplains. In high-energy environments, where discharge is high or the gradient steep, river sediment will typically be coarse with a resultant high hydraulic conductivity. As scour also occurs in such an environment coarse sediment accumulates as alluvial fan deposits below high energy reaches, on riverbeds as bedload and at point bars on the inside bends of meandering rivers. The texture and grain size of sediment in these deposits is likely to be mixed as the particles will generally not have been transported far and will have undergone little abrasion before deposition. Deposits in slow moving, low energy sections and recent floodplains will more typically consist of fine-grained silt which will be well rounded and generally well sorted. These deposits generally have a low hydraulic conductivity but also, depending on the average grain size, may vary considerably.

The hydraulic conductivity of an aquifer has particular bearing on its suitability for development as a sand-abstraction water supply. According to Morley-Parker (1913) the passage of water through a layer of sand or fine gravel is the result of capillary flow through the small irregular conduits that are formed by the void spaces in the sediment. In order to successfully develop an alluvial aquifer a relatively unrestricted flow through the aquifer is required. Oakes (1986), in a statement related to horizontal flow through unconsolidated sediment refers to transmissivity as the product of hydraulic conductivity and layer thickness, which he expresses as

 $T = \int Kdz$ where z is the depth and the integral is over the full saturated depth.

Oakes also indicates that storage coefficient is the product of the specific storage and the thickness of the aquifer.

With reference to the flow of water through an aquifer Brassington (1998) points out that the injection of tracers into sediment and their subsequent dispersion may be used to establish the movement of water through the aquifer. In a personal interview, Cooke (1987) stated that he had been able to gauge the velocity of subsurface water flow through the placement of potassium permanganate crystals into river sediment. Unfortunately no documented evidence has been produced to this effect and the author's attempts to replicate this work have proved quite futile. Forster (1999), also in a personal interview stated that he was aware of studies on sub-surface water movement through river sediment involving radioactive isotopes in the Shashi River in Zimbabwe in the 1960's. Price (1996) refers to the use of isotopes to measure the passage of water at distances of over 100 metres when tracers become too dilute.

Storage Capacity of Sediment

There are many popular misconceptions related to the volume and storage capacity of river sediment with little understanding of the recharge or volume of water which might

be available. Local people at Tshelanyemba on the Shashane River in the Matobo District of Matabeleland South, Zimbabwe approached the late Vice President of Zimbabwe, Joshua Nkomo with their concerns over water shortage. Rather than seek assistance to assess the available water in the river his response was to promise to construct a dam across the flood plain of the heavily silted river, (Chronicle Reporter 1999). When an auspicious figure makes such a statement people are liable to underrate the potential of the water supply they have available within the riverbed. Yet, sections of a deeply silted river, which may be several kilometres long, may possibly contain several thousand kilolitres of water.

However, the determination of water yield from sediment is by no means straight forward, nor because of the many variable factors such as, size, sorting, layering, packing, orientation and compaction of particles, likely to be particularly accurate. According to Owen, Rydzewski et al., (1989) many attempts have been made to conduct simple calculations on the hydraulic conductivity of a sediment, simply by determining grain size distribution through sieve analysis and carrying out assessments on the degree of sorting. However he does state that only rough estimates may be made in this way as considerable practical experience is required to assess and interpret the effective grain size, the uniformity coefficient and the shape of the grading curve. Acknowledging the importance of establishing the potential water yield of river sediment Mutsvangwa (1998), has attempted to develop a relationship between hydraulic conductivity and the effective particle size of sieved sediment.

Kazmann (1965) states that the storage coefficient is a macroproperty of an aquifer that cannot be determined in a laboratory. It may be defined as the volume of water that an aquifer releases from or takes into storage, per unit horizontal surface area of the aquifer per unit change in head According to Brassington (1998) the proportion of porosity which is made up of the specific yield is controlled by the grain size in non-indurated materials and as porosity decreases with increasing grain size, specific yield is at a maximum in medium grained sands. He adds that specific retention decreases rapidly with increasing grain size until it remains roughly around 6-8% for coarse sands and larger sized sediment.

In a manual designed to quantitatively estimate groundwater recharge and aquifer storativity, Bredenkamp, Botha et al. (1995) makes a premise that in practical terms, the groundwater that can generally be exploited in an aquifer can be represented by the effective recharge, less abstraction and evapo-transpiration losses. Aquifer storativity is an essential element in a water balance that attempts to relate aquifer water level fluctuations to millimetres of rainfall. This however is difficult to obtain because of interdependence to the responsiveness to the water level of both the recharge and the storativity of the aquifer.

With regard to void area and subsequent storage capacity Allan and Frostick (1999) states that in parts of a sequence, pore space will be completely filled with finer sands and gravels, whereas in other parts the voids will in fact be empty. Brayshaw, Davies et al. (1996) notes that the ultimate effect of grain size and sorting on reservoir porosity and permeability is complex because of the myriad small-scale variations that occur during the depositional stage. The variations are closely linked to the fabric, the detailed packing and the orientation arrangement of grains and makes the relationship of fabric to

porosity and permeability difficult to precisely quantify. Grains in fluvial environments are normal deposited with a tendency to long-axis orientation perpendicular to flow. Grain packing is essentially determined by the interconnectedness and geometry of the pores. Brayshaw also states that packing tightness depends partly on the shape and roundness of grains and the sorting they are subjected to as they are transported and as they locate during post-depositional compaction and partly on the extent of movement and collision between grains as they settle on a bed. Figure 4.22 indicates the effect that the variables of sorting and grain size have on both the permeability and the porosity of an aquifer.

size 100 000 Clean Clean 10.000 1000 Permeability (mD) 100 10 Sortina 1 Very fine Medium Fine Coarse 0.1 0 10 20 30 ۵ñ 50 Porosity (%)

Figure 4.22: Packing graph (Brayshaw, Davies et al. 1996)

The shape and the area of voids vary considerably, which has a significant effect on both the water storage and water retention properties of an aquifer. Otis (1982) observes that the moisture content of soils with similar moisture tension varies with the nature of the pores, with larger pores releasing water more easily than smaller pores that retain water. During drainage the largest pores empty so that in unsaturated soil or sediment water is only held in the finer pores. Scott (1964) is of the opinion that the diameters of the air bubbles that are held in the pores of an incompletely saturated soil are one fifth the size of an average grain and that although grain size varies widely between aquifers and the void area is highly variable, the compressibility of the grains will in fact be the same. According to Smith and Wheatcroft (1993) when fluid pressures decrease within a porous medium, pore space is reduced as the solid matrix is subject to an additional proportion of the overburden.

Bell (1998) maintains that the most important assessment of the water supply potential of an unconfined aquifer is the specific yield, as 'more or less all the water is released from storage by gravity drainage'. Bell, supported by Headworth and Skinner (1986), goes on to cite examples of the specific yield of material likely to form river sediment, ranging from 0.5 - 5% in shale to 15 - 30% in gravel and 25-35% in dune sand. With no source of data provided, Prince (2000) has assumed a probably somewhat arbitrary figure of 50% 'water storage potential' in the sediment of the Save River in south-eastern Zimbabwe. Price (1996) states that calculations of specific yield may be used to establish the volume of water which is theoretically abstractable from an aquifer. The specific yield (Sy), is effectively the ratio of the volume of water that could be released from aquifer material by gravity (Wv), that was initially saturated to the full volume of the material (Vb).

$$Sy = \frac{Wv}{Vb}$$

Oakes (1986) refers to the specific capacity of sediment as, in effect, all the water including the inextricable soil-moisture which is held by particle surface tension as well as the specific yield, the available water of an aquifer. A table, 4.9, also provided by Oakes indicates the specific yield and transmissivity of typical aquifers and figure 4.23, after Mansell (2003) indicates the variation of porosity with the specific yield of clay, sand, silt and gravel.

Aquifer	Specific Yield (%)	Transmissivity (m²/d)	Flow Type
Sand	10-20	50-200	Intergranular
Gravel	15-25	250-2000	Intergranular
Chalk	1-4	20-2000	Fracture or Fissure
Sandstone	5-20	15-1500	Intergranular or Fissure
Limestone	0.5-5	100-4000	Fracture or Fissure

Table 4.9: Specific yield and transmissivity of typical aquifers

Figure 4.23: Variation of porosity and specific yield with grain size, after Mansell (2003).



Water Loss from the Aquifer

There is some disagreement related to the significance of the various factors related to water loss and recharge of sediment. In optimum conditions water will remain in the sediment of ephemeral rivers year round. However, depending on a number of interrelated factors, water levels can be expected to reduce during a dry season and may cumulatively be quite substantial. Factors related to anticipated water losses from an alluvial aquifer are the nature of the physical properties, the depth, extent and storage capacity of the aquifer, the nature and permeability of the boundary surfaces of the aquifer and the bed gradient. Other factors that affect water loss are the volume, duration and frequency of recharge to the aquifer during the previous rainy season. Most notable losses occur from surface evaporation, down-stream drainage and seepage through the riverbed to the underlying groundwater-table. It is most probable that a degree of loss is associated with each factor and that each will vary considerably depending on the nature of the sediment and of the riverbed.

In personal interviews with the author, Prince (1983) has stated that he considers the most significant loss to be from drainage along the riverbed whilst Owen (2000(a)), believes that water loss is primarily due to evaporation. According to Dake (1981) although steeply sloping streams have higher coefficients than gently sloping slow flowing waterways, most of the rivers and streams in dryland areas have runoff coefficients of only about 10% so that most of the annual rainfall is lost through evaporation and transpiration.

Hellwig (1973), in Nilsson (1988) undertook quantitative evaporation tests in the Swakop River, Namibia. His findings revealed that evaporation from the surface of saturated sand was approximately 8% less than from an open water surface. When the water-table was at 0.3 metres below the surface in fine sand the evaporation was reduced to 50% of that of open surface water. When the water-table was at 0.6 metres below the surface in medium sand the evaporation was found to be 90% less than from open surface water. In a classic work 'The Storage of Water in Sand', Wipplinger (1958) cites sand dams as a viable method of minimising the loss of water by evaporation from open surface dams. However, it is interesting to note that in a personal interview with the author, Heyns (1999), now Director of Resource Management, Dept of Water Affairs, Windhoek, Namibia and a former student of Wipplinger, stated, "if the water storage capacity of a sand dam is 30% of the volume and the evaporation loss from an open-surface dam is 70%, what is the difference"?

In further perspectives on water loss, Nissen-Petersen (1997) refers to losses from both downstream drainage and seepage lines along boulders and fractured rock in river-floors. Lacey (1934) suggests that losses are primarily from seepage below the riverbed and Moyo (1993) indicates that, at least in Zimbabwe, there is little impermeable material between the riverbed and the aquifer and thus is of the opinion that there may be considerable seepage. Bradley and Petts (1995) maintains with regard to influent and effluent flows, that as water flows occur in either direction between a river and an aquifer depending upon the relative difference in the hydraulic head and that as flow can quickly reverse from one direction to the other, the permeability and the thickness of riverbed and bank sediments do not therefore appreciably restrict flow. He theorises that the seepage of water may be easily predicted as the water flux is proportional to the gradient between

the river level and the hydraulic head of the aquifer and is mediated by the permeability and the thickness of riverbed and bank sediments.

Harr (1962) divides soils into two basic fractions of sand and clay. He then indicates that in general sands are composed of macroscopic particles that are bulky and rounded or angular in shape and are easily drained. Sands do not swell, possess insignificant capillary potential and exhibit no shrinkage when dry. Thus sands provide an aquifer medium of large voids with a good coefficient of storage which is not conducive to heavy losses of water from evaporation. Clays, are on the other hand composed of microscopic particles of platelike shape, are highly impervious and exhibit considerable swelling when saturated and are thus relatively impervious in comparison to coarse-grained sediments. Harr therefore concludes that clay layers, which generally line the riverbed, effectively form an impervious seal to an alluvial aquifer.

Wipplinger (1958) draws a parallel with an hypothetical alluvial aquifer and the sand reservoir of the Omaruru River at Omaruru, Namibia. He concludes that all the water will eventually drain away during a drought of sufficient duration. Acknowledging downstream drainage, Wipplinger maintains that the retention of water from one flood season to the next is due to the frictional resistance to flow through sand and not to the presence of any positive underground rock barrier extending above the normal rock level.

Interim Summary

The processes of erosion and sedimentation that give rise to river channel alluvium have a great effect on the amount of water that is available and the overall suitability of the sand-abstraction technology.

- •Material eroded from land surface that is transported into waterways as sediment is the cause of alluvium that forms a riverbed aquifer and thus stores water.
- The process of sediment transport through the river channel with the consequent sorting of material, the retention of coarse material and the onward transport of silt and fines influences the storage capacity of the alluvium.
- The water bearing capacity of alluvium is again influenced by the process of deposition and the accretion of sediment affecting the packing and pore space between grains.
- The water available in a river channel aquifer is also influenced by the surrounding water-table. In dryland conditions during the rainy season, where the water-table is high, the river channel aquifer is augmented by the inflow of water from the surrounding land and when the water-table drops in the dry season there is additional loss from the aquifer because of flow from the river aquifer to the water-table.
- The amount of water available within a river is further determined by water loss from the sediment due to evaporation from the surface of the sediment, from downstream drainage through the sediment and losses through the riverbed by seepage as well as water which is abstracted for primary and secondary purposes. Opinion is divided on the degree of loss from each but would appear to be affected by the formation of the sediment. The void area effects both the degree of loss to evaporation and to downstream drainage. The nature of the base of the river channel effects the degree of loss to seepage through the base.

4.2.5. Water Quality

In dryland areas evaporation and evapo-transpiration generally exceeds rainfall for all or most of the year, which over time may cause the aquifer to become a zone of concentration rather than of dissolution of mineral salts. Although the dissolved solids content of rainfall is small, as water is evaporated from the aquifer over perhaps thousands of years, the solids remain in the ground and the salinity of recharge water becomes markedly increased. In addition the dissolved solids content of groundwater will be increased where soluble minerals remain and are not leached from the aquifer and where soluble weathering products are not removed as quickly as they form. Particularly where the water-table is sufficiently close to the surface for groundwater to be lost either by capillary action and direct evaporation or by transpiration there is likely to be a concentration of salts within the soil and subsoil as water is evaporated or transpired and the solutes are left behind, (Price 1996). The limited recharge of aquifers in arid and semiarid regions often means that groundwater has either migrated to the aquifer from outside the area or infiltrated it way back in time. Both situations constitute long residence times of water within the aquifer with the likelihood of incomplete flushing of soluble minerals.

Water within alluvial aquifers is continuously recharged and thus is generally not subject to mineral salt contamination. However Knott (1999) has been instrumental in the construction of an open surface dam on the Umzingwane River, Beitbridge District, Matabeleland South, Zimbabwe as, he maintains that over abstraction of water from the alluvial aquifer of the Limpopo River has lead to an excessive build up of salts within the sediment.

According to Hofkes, Huisman et al., (1981) water quality is basically a determination of the organisms, mineral and organic compounds contained in the water. He contends that basic requirements for domestic water are:

- Freedom from pathogenic organisms
- Low turbidity
- Not saline
- Lack of elements which might cause corrosion, encrustation or staining
- No compounds that might adversely affect human health
- No compounds which cause offensive taste or smell

Hofkes also maintains that groundwater outflows are the usual source of dissolved solids and that surface water is the main cause of turbidity and introduction of pathogenic organisms and organic matter that it collects. However, suspended solids are removed from water which passes slowly through sediment beds whilst organic impurities are degraded through chemical and microbial processes and pathogenic organisms generally die off without a host. Supplies of water which have been abstracted from river sediment may thus generally be considered free from the contamination which is usually associated with both open surface water and deep static or slow-draining groundwater sources. Demonstrating the use of a natural filtration process White, Bradley et al., (1972) reports on open surface dams in Kenya where cattle are restricted to one side of the dam and domestic water is drawn from the other side from seepage holes which have been constructed between 0.6 and 3.0 metres from the edge of the dam to an approximate depth of a metre. Table 4.10 shows comparative data of the mineral salt content of water available for household use in the Dongamuzi area of Lupane District, Zimbabwe. Comparisons are of deep groundwater, shallow, groundwater, open surface dam water and water abstracted from a sand-abstraction system.

According to Visscher, Paramasivam et al., (1987) an alluvial aquifer acts as a large, natural slow sand filtration system. Aerobic filtration processes of sedimentation, straining, adsorption and chemical and bacteriological action, which are the principles of slow sand filtration, are free to take place within the aquifer. These processes are an effective method of removing impurities such as fine silt, organic matter, bacteria and some mineral salts. In a non-mobile sediment body such as a sand dam, where the sand filter is permanently saturated, a biological "schmutzdacke" layer is also able to develop to form an effective barrier against the ingress of bacteria into the system.

Sand dams and sand riverbeds are thus able to yield water that is considerably more potable than open-surface water. The water supplied from alluvial aquifers will in effect be naturally filtered safe water. Since 1990 the author has carried out a number of tests on the quality of water drawn from sandbed water supplies for domestic use.

		D'muzi	Lupane	Madlala	Kwarai	Recom-	Maximum
		borenole	Open well	Open dam	Sandriver	mended	
Conductivity	mS/m	940	1990	100	50	70	300
pН		8.1	7.5	7.6	7.9	6.9	5.5-9.5
Turbidity	NTU	55	2.5	80	2.0	1.0	5.0
Total Hardness	CaCO ₃	370	850	270	130	20-300	650
Calcium	CaCO ₃	100	530	210	120	NS	NS
Magnesium	CaCO ₃	270	320	60	10	100	150
Sodium	Na	910	160	41	20	100	400
Potassium	K	5.8	6.4	1.0	1.5	ŃS	NS
Iron	Fe	0.9	0.3	8.5	0.5	0.1	1.0
Manganese	Mn	0.2	0.01	4.0	0.1	0.05	1.0
Alkalinity	CaCO ₃	500	1000	500	360	NS	NS
Chloride	Cl	58	12	14	2	250	600
Sulphate	SO₄	290	800	4.5	1.7	200	600
Phosphate	Р	<0.01	0.01	<0.01	< 0.01	NS	NS
Ammonia	N	0.5	0.3	< 0.01	< 0.01	6.0	10
Nitrate	N	0.5	0.01	<0.01	<0.01	6.0	10
Fluoride	F	<0.01	0.6	<0.01	< 0.01	1.0	1.5
D'olved Salines		4700	1000	500	250	500	1500

<u>Table 4.10: Mineral salt contamination of available primary water supplies at</u> Dongamuzi Ward, Lupane District, Matabeleland North Province, Zimbabwe

All water samples tested were found to be heavily contaminated with bacteria including faecal types

Source (Hussey 1998(c))

Clark (1988) refers to the quality of water in a source which is open to the atmosphere as being subject to a complex mix of factors:

- The source may be static and thus stale
- Foreign material may enter the water and so foul or pollute the water
- Light may allow organisms to grow, so affecting the organic content of the water and biologically-mediated reactions
- Dissolved gases will exsolve, affecting the pH and the carbonate equilibrium
- Atmospheric oxygen is free to enter the system, affecting the iron equilibrium

Water within an alluvial aquifer is not readily affected by these factors and is therefore not subject to the same limitations, although Clanahan (1997) has reported severe iron bio-fouling of infiltration galleries in KwaZulu-Natal, South Africa. Mikels (1992) reports on extensive testing of water drawn from 9 collector wells in California over 18 month periods of testing with overall results showing no contamination by macroorganisms, giardia or other large diameter pathogens, although small traces of algae were identified in parts of the large diameter well shafts that were on occasion open to sunlight. In a WELL manual Batteson, Davey et al., (1998) indicate that abstraction systems can themselves be sources of pollution. It is thus necessary to protect a source by keeping users, animals and dirty buckets out of the water source and by preventing contaminated water draining back into the source from dirty surrounds. A good design and sound construction of abstraction facilities, backed up with effective community maintenance and operation and adequate hygiene promotion is required to maintain a potable source of water.

4.3. Review of Literature

Concerned with the possible effects of global warming, Hulme (1996) contends that one of the most significant impacts of global climate change is likely to be on the hydrological system and hence on river flow and regional water resources. He considers that this will be particularly true in semi-arid areas such as southern Africa. The droughts and below average rainfall years of the mid 1980's and early 1990's in that region have highlighted the sensitivity of water resources to variability in the climate and particularly to disparities in the rainfall. Consensus at the Johannesburg Earth Summit was that there were considerable threats to global water resources, particularly in Southern Africa and that there was an over riding need for sustainable water use and improvements to environmental management, such as the safeguarding of river catchment systems and improving water management systems, (Hirji, Johnson et al. 2002).

It can be appreciated that river morphology and sedimentation, surface erosion and the subsequent accumulation of sediment within a river channel is a pivotal concern of this study. Amongst much generally related documentation broad comments have been noted from authors such as Younger (1995) who affirms that river-aquifer interactions are at the very core of the hydrological cycle, Walker (1992), who maintains that flow variability is typical in all dryland rivers and affects every feature of the environment; physical, chemical and biological and Ashworth, Best et al., (1999) who states that the aggradation rate is a primary control on the geometry, stacking and heterogeneity of sedimentary deposits. Ashworth has also considered in detail the effect of river flow on sediment material and the subsequent form of the river channel, (Ashworth and Ferguson 1986). Of authors who have provided much material or a useful overview, Hudson (1995) presents a description of surface erosion by rainfall runoff and makes the point that runoff induced erosion is not laminar, as has been understood in the term 'sheet erosion'. The initial stages of erosion are now understood as inter-rill erosion, which incorporates erosion caused by the movement of rain splash increased by the turbulence generated by raindrop impact, and the transport of raindrop-detached soil by initial surface flow. Both Dake (1981) and Hansom (1988) have provided clear descriptions and a wealth of information on waves and saltation and the effect on the riverbed. Hall (1949) has much

useful information on packing and soil moisture and Davison (1938) makes extensive reference to batholiths and the description and classification of rocks.

With regard to a general appreciation of hydrology, runoff and rivers Driscoll (1986) has proved to be most useful. His sections, for instance on guidelines to the function and operation of piezometer tubes, are most adequately described and have assisted the fabrication and installation within the research programme to measure the drop in the water level of river alluvium during dry seasons and the subsequent recharge during the rains. Primlani (1973) also has provided extensive recourse to sedimentation and sediment transport as well as the implications for flow regimes, river channels and reservoirs.

Limitations have also been signified from authors such as Kostaschuk and Villard (1999) who reports that the process of sand suspension in rivers is poorly understood. Researchers such as Stroosnijder (2001) report that data logging of water-generated erosion is receiving increasing attention worldwide. He notes an increasing use of recording equipment for large area flow recording such as rain intensity gauges, discharge meters, turbidity meters, tipping-bucket sediment samplers and water-traps to record suspended sediment. Patry and Marino (1983) refers to an input – output method developed for both urban and rural watershed runoff modelling but notes the limitations. He states that no single model is able to address all types of drainage problems with optimum efficiency as extensive data is necessary for any modelling accuracy and modelling is unable to take into account the cause and effect relationship between a systems input as rainfall and output as runoff.

Although slightly dated and in fact undated (most recent reference 1957), Staples, Vincent et al., (Undated) provides a wealth of information on rainfall within Zimbabwe. He refers to patterns and frequency of precipitation and the diurnal influence on daytime occurrence, as well as providing detailed reference to both temperatures and soils. Staples was also involved with Vincent and Thomas in the early categorisation of Zimbabwe by Natural Regions, from which the five economic farming zones were derived and for which he provides extensive explanation, (Staples, Vincent et al. Undated).

As well as sources of literature, conference proceedings and academic articles, periodicals, brochures, books and journals much useful and interesting information has also been provided through personal interview with individuals who have gained a wealth of experience in the art of sand-abstraction; people such as Richard Cansdale (1992) who has developed a range of very effective well-points as well as developing both the Rower and the Canzee pumps. Noble Moyo, (Moyo 1994), Donald Ncube, (Ncube 2001) and Melusi Mafu, staff members of Dabane Trust who have provided many observations and insights and 'old hands', such as Philip Cooke, (Cooke 1987) and Andrè Esterhuizen, (Esterhuizen 1987) whose experience has been of great insight and benefit to this research programme.

Chapter 5 <u>Research Activities</u>

5. Presentation of Data

5.1. Geology of Research Areas

Zimbabwe is essentially comprised of a craton with a wide range of geological material, (Phaup 1971), (Main 1990). A broad description is provided by Read and Watson (1975) who states that Zimbabwe is comprised of an assemblage of granodioritic rocks, gneiss and migmatites which form domes and broad irregular outcrops (known locally as dwalas), with a supracrustal greenstone assemblage forming narrower tracts of 'schist belts' or gold belts. Igneous and metamorphosed igneous rocks comprise the largest group and account for about 65% of the Zimbabwean craton. The most dominant, forming about 46% of the total area are Precambrian, granite based rocks, mainly comprised of gneiss. These stretch in a broad band from the north east of the country to the south west and into Botswana. Approximately 25% of the land area is of sedimentary or Aeolian origin, predominantly Kalahari Sands of Pleistocene or Tertiary age, with Permo-Triassic Karoo sandstones, (Watson 1962) and (Nyamapfene 1991). These sedimentary formations largely constitute the north and north west of the country, essentially the Zambezi Valley. The two southern field research sites are located in the gneissic region while the two more northerly sites are in the sedimentary area.

Nyamapfene points out that soils in Zimbabwe that are derived from granitic rocks give rise to light to medium textured soils which are characterised by the presence of significant amounts of coarse sand. Granite based soils are relatively rich in sodium feldspars and where they contain clay, may give rise to sodic soils. He further comments that, depending on the quartz component, the sand fraction of soils in Zimbabwe is in approximately equal proportions of fine, medium and large. Under arid conditions soils with these properties are conducive to erosion and large quantities are consequently carried into the river channels.

Extensive geological surveys have been undertaken in Zimbabwe's mineral rich areas, initially by the Geological Survey Office and more recently by prospecting companies. Tshelanyemba is part of the lower Gwanda gold belt and therefore a number of surveys have been undertaken. The Wenlock area, just south of the Matopos has also been surveyed because of its unusual rock formations and geological diversity. There have also been several surveys conducted to the northwest, assessing coal reserves that extend as far as Dongamuzi on the edge of the Lubimbi coalfield. This was surveyed in the 1930s for coal exploitation and again in the 1960's for oil from coal extraction. Whereas Huwana in sedimentary rock on the edge of the Kalahari, has had no extensive surveys and information could only be gathered from general reports. Table 5.1 indicates the main hydrogeological features of the 4 field research sites.

Table 5.1: Hydrogeology of field research sites, adapted from Surveyor General - Zimbabwe (1986)

			·				
River	Type of permeability	Lithology	Groundwater development potential	Average transmitting properties	Av depth of water table (m)	Av specific capacity and yield range (m ³ /d/m)	Av specific capacity and yield range (m ³ /d)
Tshelanyemba Entire river	Secondary	Pre Cambrian older gneiss	Low	Low	>20	2-20	10-50
Huwana Source	Secondary	Pre Cambrian older gneiss	Moderate	Low - Moderate	>30	30-50	50-100
River	Primary	Recent and older alluvial deposits comprising gravel sand and silts	High	Moderate - High	>30	50-5000	100- 5000
Confluence	Primary	Kalahari fine to medium grained Aeolian sand	High	Moderate - High	>80	10-100	100- 1000
Wenlock Source	Secondary	Younger intrusive granites	Low	Low	>20	2-20	10-50
River, Confluence	Secondary	Pre Cambrian older gneiss	Low	Low	>20	2-20	10-50
Dongamuzi Source	Primary	Kalahari fine to medium grained Aeolian sand	High	Moderate - High	>20	10-100	100- 1000
River, Confluence	Mixed	Lower Karoo. Madumabisa mudstone. Mudstone & Siltstone with sandstone intercalations	Low	Low	>20	<1-10	<10-50

Tshelanyemba

The Shashane River drains southwards for 165 kms from the Zambezi-Limpopo watershed to the Shashi River which is the border between Zimbabwe and Botswana. The headwaters are virtually a single river system which rises on the watershed midway between Bulawayo and Plumtree. The field research site is located 100 kms south of the source on an extensive plain of pre-Cambrian gneiss. The entire catchment area of 1,500 km² above the research site is comprised of the same material.

A detailed geological survey was undertaken to identify mineral deposits in the area adjacent to the research site south of Gwanda. The descriptive survey was undertaken by A.E. Phaup between 1930 and 1932 and remains the primary geological survey, (Phaup 1933). Particular reference is made to Sun Yet Sen gold mine which is situated 7 kms due east of the research site in an isolated body of Bulawayo Schists. Other gold mines in the locality at Antelope Mine 32 kms north of Sun Yet Sen and Legion Mine 17 kms south are on similar schist, first named and described by Mennell in 1906, (Stagman, Harrison et al. 1978). The Shashane River on which the field research site is situated flows 4 kms west of Antelope mine and 5 kms west of Legion Mine.

Although the Shashane River basin and the research site are within an immediate gneissic area, Phaup's geological survey report of Sun Yet Sen mine is of significance because of the proximity of the Bulawayan schists which border the catchment area to the east of the river. The report observes that the mine is located on a schist belt which is intensely folded along a north to south axis. The actual reef is a mixture of ironstone, hornblende and magnetite. Black hornblende-schist occurs to the west, towards the research site and within the vicinity of the mine are white quartz veins in pegmatite dykes of younger granite. The hornblende schists and ironstones effectively form troughs flanked by low ridges of actinolite-schist outcrops, which are clearly visible as barren areas of exposed jagged rock.

Huwana

The Manzamnyama (or Nata) River is the largest of the few rivers which drain westwards into the Kalahari depression in Botswana. It is an endogenous river which when there is sufficient inflow drains into the Makgadikgadi Pans where it evaporates. The headwaters are also on the Zambezi-Limpopo watershed divide between Bulawayo and Plumtree on the Botswana border. Here five primary rivers flow north before joining with the Manzamnyama as the only significant river to flow westwards. The total length of the river from its source to the Makgadikgadi is 260 kms with the field research site located 95 kms from the source so that there is a catchment area of 2,300 km² above the research site. Although the research site itself is located in the Karoo sediments which comprise the Kalahari Desert of central Botswana, the headwaters occur within regions of Pre-Cambrian Gneiss. The river then flows through younger granites to fine grained Karoo Forest Sandstone between areas of Upper Karoo Basalt which influences the composition of river sediment at the field site.

The major rivers of southern and western Zimbabwe have been thoroughly prospected for alluvial diamonds, but as there is no apparent mineral wealth to be tapped here, no comprehensive geological report of either the Bulilimamangwe North or Tsholotsho Districts is available. However, in a general report on the geology of Zimbabwe Stagman, Harrison et al., (1978) reports that an area of some 44,000 km² south west of Hwange is covered to a depth of 100 m by unconsolidated Kalahari Sand with Pipe Sandstone beds below, which overlie basalts. The Kalahari Sand is a pink or buff coloured structureless aeolian Sand of well-rounded quartz grains with frosted surfaces and a high proportion of fine dust. The Pipe Sandstone is generally buff or pink in colour and weakly cemented by silica and has sometimes been secondarily cemented into a hard quartzite or silcrete, hard enough for use as railway ballast. In places cementation has occurred with calcite to form calcrete which has been successfully used in the construction of durable, high speed 'dirt' road surfaces. Stagman goes on to say that the Aeolian Sands indicate a long period of aridity over a large part of southern Africa.

Wenlock

The Mtshelele River rises in the Matopos Hills, a spectacular and intriguing granite batholith. The source of the river is some 25 kms south of the Zambezi-Limpopo watershed and 30 kms south of Bulawayo. The river flows due south for 65 kms before joining the Whove River which flows into the Tuli River within 10 kms. The
Tuli flows into the Shashi which joins the Limpopo to flow eastwards to the Indian Ocean. The field site is situated 40 kms from the source, there is a catchment area 320 km² above the site. Much of the first 15 kms of the river is within a narrow valley bordered by massive whaleback outcrops known as 'dwalas'. The entire valley is a virtual vlei which retains water far into the dry season. Although Mtshelele dam is at the mouth of the valley, the vlei and the improved vegetation within the Matopos National Park does help to ensure a more continuous and even flow of water through the Mtshelele River.

A vlei, also referred to as a dambo is defined as a grass covered, generally tree-less valley bottom of hydromorphic soil drained by a poorly defined and sometimes non-existent stream channel, (Wright and Burgess 1992). Lambert (1992) defines dambos as shallow, seasonal water-logged depressions at or near the head of a drainage network. Henson, Kelly et al. (1954) describes 3 vleis in the Mtshabezi valley adjoining the Mtshelele River as marshes comprised of spongy soil as a result of a large amount of organic matter and beds of fine silt with a water depth of 12-25 mm ($\frac{1}{2}$ to 1 inch). According to Henson this water which drains into the vlei from the detritus of the surrounding 'dwalas' seeps slowly from the vlei to continue to recharge drying river channels.



Figure 5.1: Geographical sketch of the Matopos area, Smith and Fripp (1973)

According to Mennell (2003) the Matopos, which was originally surveyed by his father in 1902 and 1904, is an area of porphyritic granite. Mennell's survey asserts that the grey Matopos granite area is surrounded by gneissic granite and greenstone, this is supported by Smith and Fripp (1973) provides a geographical sketch of the Matopos area, figure 5.1 and notes that it is possible to discern in the field a progression from greenstone through banded gneiss to horse tooth granite into Matopos granite. Smith indicates that Matopos granite is marked by clear feldspar with a strong crystallographic orientation. His encompassing statement is that each of the main rock types has a more or less characteristic topographic expression with the rolling hills of the greenstone belt rocks which are well vegetated, contrasting sharply with the low-lying and generally poorly exposed contact facies rocks. He adds that the Matobo Hills are an area of particularly rugged scenery of massive granite with large aplite bodies known as castle kopjes forming tumbled boulder outcrops often with 'balancing rocks' and gneisses and horse-tooth granites forming huge whaleback outcrops.

The Wenlock field research site lies at the upper edge of a gneissic granite plain south of the broken country of the Matobo Hills. The immediate region is described as Pre-Cambrian older Gneiss with an area of younger intrusive granite slightly to the north, (Surveyor General - Zimbabwe 1986).

Dongamuzi

The Dongamuzi River is a small seasonal river in a shallow bed of fine Aeolian Sandstone overlying Mudstone. The overall length of the river is 25 kms from its source to its confluence with the Mzola River. The field research site is 15 kms from the source and the catchment area above this is 58 km². In the vicinity of the field site the surrounding land is remarkably flat so that in several places the river forms oxbow bends. The river rises in a myriad of streams in a radius south of a low watershed. The river and its tributaries flow south until the main river is formed whereupon it becomes a sinuous river until it joins with the Mzola River which drains westward into the Shangani River, this then flows north to join with the Gwayi River leading to the Zambezi draining eastward to the Indian Ocean.

The extreme northerly catchment of the river is in indigenous hardwood forest-land on fine Kalahari sand. As the river continues it moves on to carbonaceous mudstones which overlie Karoo sediments, (Watson 1962). Watson observes that the sediment is predominantly Wankie sandstone, which is fine-grained, white and felspathic, containing coarse, rounded quartzite pebbles and even small boulders at the base of the formation. In the immediate vicinity of the field site the mudstone is beneath 2 to 6 m of fine sand. The silt bed extends for several hectares in places due to erosion of the riverbank and subsequent movement of the river channel. Beside the river channel weathering of the mudstone has occurred to 6 to 8 metres and in places has resulted in unstable soil and pockets of both pedestal and tunnel erosion, figure 5.2.

A significant feature of the area is the high level of mineral salt contamination of groundwater, particularly in the locality to the west of the Dongamuzi River. Where there is no drainage outflow salts are added by water flowing into the area and then concentrated by evaporation, (Cunningham, Hubbard et al., 1992). At Dongamuzi there is no free flow through the mudstone to the Kalahari sediments and hence the accumulation of mineral salts. Tests indicate levels of sodium and sulphur sufficiently high to make the water unusable for irrigation or livestock watering, let alone domestic use, (Hussey 1998(c)).

By virtue of proximity to Kamativi and Gwayi River tin-tantalite mines, the geology of Dongamuzi is included in Southern Rhodesia Geological Survey Bulletin No. 57, undertaken by Watson (1962). Geological surveys have also been undertaken in the locality as Dongamuzi is on the periphery of the Hwange coalfield and the once proposed Lubimbi coalfield. Watson maintains that beds of almost pure sandstone must have been scattered through the original sedimentary succession. These were pelitic sediments which altered to schist, then to gneiss and then to hard, white, recrystallized quartzite. In later times extensive flooding and sedimentation added a considerable thickness of sand with subsidiary muddy bands deposited over the original crystalline rocks. The mudstone is carbonaceous and at one time was surveyed for the possibility of supporting a fuel-oil-from-coal industry. Fossil dunes occur where underlying sandstone has broken through the mudstone and subsequently been eroded to an extensive, level plain. This fossil dune area extends from the proximity of the research site through the Hwange National Game Park and into the Kalahari of Botswana.

Figure 5.2: Pedestal erosion at Dongamuzi field research site

5.2. Climate, Vegetation and Land Use of Research Areas

The climate of the highveld along the central watershed of Zimbabwe is regarded as sub-tropical and the lowveld, the lower lying areas of the Limpopo and Zambezi valleys are considered tropical, (Staples, Vincent et al., Undated). According to Dale (1995), the rainfall of Zimbabwe is highly erratic, he reports that 44 of the seasons between 1900 and 1995 had a greater than 20% variance either above or below the average. Staples makes the point that the reliability of an average monthly rainfall is much lower than that of an average seasonal total as very dry months may occur during an otherwise good season, as well as during poor seasons. He also observes that high intensities of rainfall are common, frequently over 100 mm per hour and that precipitation in an average decad frequently comprises a considerable number of negligible amounts of rainfall balanced by a few large falls. This is particularly evident during the main rainy season in the arid and semiarid south and west.

The 100 year rainfall average for Zimbabwe is shown in Appendix 02: Rainfall Records, as are the 45 year rainfall records recorded by Kaufman (2003) at a site approximately 6 kms from the offsite, control site at the offices of Dabane Trust, Bulawayo. Approximate 20 year records are also shown in Appendix 02, at sites providing data to the Department of Meteorological Services, closest to the four field research sites.

Altitude is the main factor affecting temperature, Staples, Vincent et al., (Undated) states that the decrease in mean annual temperature may be expected to be

approximately 2°C per 350 m (between 3° and 4°F per 1,000 ft) with the hottest part of the country in the north in the Zambezi valley where the mean average temperature is in the vicinity of 27°C ($80^{\circ}F$) with 23°C ($72.5^{\circ}F$) in the south in the Limpopo valley. Comparatively a large part of the country along the watershed has an annual mean below 20°C ($67.5^{\circ}F$). Diurnal variation of temperature is high, especially during the winter months when the skies are clear and long hours of sunshine may be expected during the day with cooling during the night due to radiation. The coldest months are June and July and the hottest October and frost may occur between the end of May and the middle of August.

The upland highveld is characterised by woodland vegetation of several differing types depending on climatic and soil factors. The formation is predominantly of trees with a canopy sufficiently thin to allow the growth of medium or tall perennial grasses in the more favourable rainfall areas and mixed perennial and annual grasses in the lower rainfall areas. Depending on rainfall, tree species are predominantly deciduous and small shrubs and herbs are often mixed with the grass. Woodland gives way to bushland when the effective rainfall becomes too low and sustained high temperatures are experienced. Bushland is characterised by closely spaced shrubs and small trees mixed with a few taller trees and a generally sparse cover of predominantly annual grass. Shrubs are the important feature of the vegetation and can form areas of impenetrable thickets dense enough to exclude even hardy grasses, (Staples, Vincent et al., Undated).

Tshelanyemba

Tshelanyemba is within the Zimbabwean Lowveld at an altitude of approximately 1,250 m. During the summer months maximum temperatures are frequently in excess of 33°C. However in winter the weather is cooler with the possibility of night frosts occurring in the valleys. The area has an average annual rainfall of about 450-475 mm most of which falls between November and March. Phaup (1933) emphasises that the rivers are dry for the greater part of the year and only flow after heavy storms. In general within the Shashane River valley the low and irregular rainfall makes the growing of crops precarious. There is extensive ploughing in the communal lands but these at best are only able to support subsistence farming activities.

In the natural area there is typically dense groundcover. This is now limited to parts of the upper section of the Shashane River where there has been only minimal land degradation and little erosion. The river rises in the Mangwe commercial farming area, an extensive cattle ranching area that has largely been managed within an ecological balance. The livestock carrying capacity of the land is estimated by the Agricultural Advisory Service to be between 7 and 10 ha per livestock unit (LSU), (17-25 acres per LSU), (Staples, Vincent et al., Undated). According to Phaup's 1933 report the greater part of the southern area was covered with bushes and trees which include, mopane, cabbage-wood, marula, syringa, knobby thorn, and African mahogany, it was only in the vleis that open grassland occurred. This situation continues in much of the northern section of the Shashane River today but it is far from the situation in the southern section. In a report to the South Matopos Intensive Conservation Area, a former commercial farming region, Ingram (1960) indicates that the Shashane River Valley may be divided into five vegetation zones. On the watershed in the north the vegetation is predominantly terminalia with hyparrhenia grass. Further down the river basin the veld is predominantly terminalia with eragrostis grass. The middle reaches are comprised of combretum, terminalia and

eragrostis giving way to acacia, combretum and eragrostis grass with colophospermum and eragrostis in the lower, hotter reaches of the river.

The lower reaches of the river are within the Matobo Communal land where the residents do not have title to land. The land here has been overgrazed for half a century and conservation work has not been undertaken for 25 years. Livestock management is 'biological'. Following drought years and years of inadequate rainfall when browse and grazing has deteriorated, livestock succumb and numbers are reduced. Following seasons of better rainfall, livestock numbers naturally increase, (Henson 1992). In recent years cattle numbers have remained depleted through disease and the consequences of the severe drought of 1991-92 when many cattle were wiped out. So many cattle died at that time that natural restocking could not take place in the following years. Unfortunately, to worsen the situation, numbers of the true survivors, donkeys and goats, increased to take the place of cattle. Donkeys and goats are the only domestic ruminants with teeth which enable them to crop grass more closely than other grazing animals. By so doing they can eat even the grass roots, thus reducing vegetation and increasing erosion.

Huwana

Huwana is located on the edge of the Kalahari, which is sometimes referred to as a desert. The topography is remarkably flat with no discernable river valleys. The Manzamnyama river is the only river to flow due west to Botswana although it is joined by smaller rivers flowing in from the south. To the north there are no river systems although there are a few 'fossil' river channels within the Hwange National Game Park. Within the District of Tsholotsho there is no drainage system, precipitation collects in depressions and floods extensive areas to a depth of a few centimetres. Over the years game and livestock have compacted the surface and deepened some of the depressions to form seasonal watering points known as 'pans'.

An eighteen-year average annual rainfall (1980/81-1997/98) recorded at Tsholotsho is 533 mm. The rainy season is generally between November and March following a hot dry period in September and October and a cooler dry season from April to August. The sporadic nature of the rainfall, the high temperatures and high evapotranspiration rates mean that even indigenous staple grain crops have only a limited potential. As rainfall cannot be relied on to provide even a meagre grain crop the residents of the villages which comprise Huwana are very dependent on their livestock. There are extensive grazing lands in the locality and the area is not as densely populated with either people or livestock as many areas. Consequently there is a lower livestock density and with more grassland and less bush the locality is not as degraded or as over-grazed.

The upper reaches of the catchment area of the Manzamnyama River, within the Upper Khami Intensive Conservation Area have been well managed with consequently little environmental degradation. The area is predominantly an Acacia Highveld clay area where little erosion has occurred. The Mananda dam was constructed in this area on the Manzamnyama River in the early 1960's and is remarkably free of silt. Below Mananda dam the river flows through the Samnene Small-Scale Commercial Farming Area, where small-scale farmers have title to their land and where the land is generally better cared for than Communal Area land. Thereafter the river enters the Bulilimamangwe and Tsholotsho Communal Lands which are a predominantly deep Kalahari Sand which support acacias and deciduous softwoods such as Syringa. According to Stagman, Harrison et al., (1978) indigenous hardwood timber forests occur on loose sandy soils, which supports a number of important timber species such as Teak and Mukwa. Stagman also maintains that where the bush has been cleared from the sedimentary soils good crops have been grown for a year or two as the soils have excellent moisture-holding properties and are well drained. However the fertility of the soil drops off rapidly and quickly becomes impoverished causing problems particularly in areas of human resettlement. Erosion is also a serious menace in cleared areas. A survey conducted by Timberlake, Nobanda et al., (1993) indicates varied vegetation with a predominance of combretum species mixed with some terminalia, acacia and mopane. Grasses are mostly annuals such as aristida and eragrostis. In a personal interview, Timberlake (2003) referred to the unusual height of riparian acacia (\pm 36 m) which he attributed to the deep alluvium and retained moisture in the paleo-channel of an earlier, larger river.

Although the Manzamnyama River now contains massive quantities of sediment to a considerable depth, Hodson (1896) records that in a visit to the river in 1887 the river was full and running. He reports that although the river stopped flowing after a few days the pools would retain water until the next heavy rains when the river would naturally flow again.

Wenlock

Wenlock is south of the Rhodes Matopos National Park, which has been a wilderness area since the 1920's. Soil and vegetation within the park and the catchment area of the Mtshelele River are therefore much as they have been over the previous several centuries. McCausland and Timberlake (2000) remarks that the Matobo Hills sit in a belt of deciduous tree savanna with terminalia the most characteristic species. The eco-system is designated a broad-leafed dystrophic (nutrient poor) savanna. However there is a high species number and considerable ecological diversity with more than 200 recorded species of tree and shrub. This diversity does not hold true in the communal land area south of the hills where vegetation is now predominantly combretum shrub with a few mixed hardwoods and areas of stoloniferous couch grass.

From its headwaters the river flows due south to its confluence with the Whove river. The upper reaches are a vlei, some 17 kms in length, which feeds the Mtshelele dam. The Mtshelele Valley itself is a wetland area comprising a dense bed of reeds, rushes and sedges which thrive on the water which seeps into the valley from the rock fissures of the massive whaleback dwalas which flank the length of the valley. Dense thatching grass on the margins of the vlei gives way to thickets of mopane. Due to this wetland area and seepage from the Mtshelele Dam, the Mtshelele River continues to flow long into the dry season. However, below the Mtshelele dam the river enters the Khumalo Communal Area which is densely populated and so over-stocked with livestock that the natural perennial grass during the rains. The area of the field research site is rocky and arid with shallow sandy soil above rock, which although it supports some splendid native hardwood trees, requires a low livestock- stocking rate if grassland is to be protected. As this locality is both undulating and rocky the area is more prone to soil erosion.

As the area is at an altitude of 1,300 to 1,400 metres it is slightly cooler than the other field site areas with an average temperature of 19°C in July rising to 30°C or more in October. In winter cool, windy days can be expected with occasional nights of frost.

The dry winter period gives way to a hot dry period in October and November followed by rainfall from November to March or possibly April. The nineteen-year average annual rainfall at Gwanda is 428 mm (1980/81-1998/99).

In spite of the harshness of the area a considerable number of people reside in the locality and have to wrest a living from the land. The natural resources of the immediate environment are expected to provide all requirements. Shelter is provided from locally available timber for house frames and grass is used for roof thatch. Adobe walls are constructed from clay, anthill and cow dung for homes and grain stores. If earth bricks are used in place of adobe, firewood is required for the firing of a kiln. Firewood is also required for heating for cooking and for warmth in winter. Because of low rainfall and impoverished soils, extensive lands are ploughed for dryland food production. Arable lands are fenced with brushwood and cattle kraals are fenced with close-fitting timber stakes, (Ellert 1984). Livestock graze the crop residues leaving bare arable land exposed to erosion by wind and the first rains. Livestock are also required for drought power, food and financial income. A further use for indigenous timber in this area is for an economic return on carving for the tourist trade in the Matopos.

Figure 5.3: 1:250000 Landsat photograph showing depletion of vegetation, (GAF Image Recording Service 1993). *An arrow indicates the Wenlock site*.



A reduction and loss of species is unfortunately not a recent occurrence, Steedman (1933) reports a proliferation of euphorbia and aloes throughout the Matopos area and a profusion of timber species but adds that many species suitable for construction

timber and fence poles were being felled widely. He further reports that in 1906, Miss Gibbs a botanist recording plant species in the Matopos noted that Pod Mahogany (Afzelia Quanzensis) was widespread but by 1932 Steedman says this species was already rare. Such on-going and increasing demands on each of these natural resources creates an overall drain on the environment which contributes to environmental deterioration through reduced ground cover and increased soil erosion. The degree of land degradation may be clearly seen in the accompanying Landsat photograph of the Wenlock Communal land, bordering the Matopos National Park, figure 5.3. The culmination of such extensive and severe land degradation is increased siltation in stream and river channels.

Dongamuzi

The Dongamuzi River is a small seasonal river considerably silted in its bed with fine Kalahari Sand. The headwaters rise in flat sandveld country where its many branches form a fan of waterways with no discernable channels. The waterways are only recognisable at this point by the reduced vegetation and runnels of sediment. As the river flows south and grows in size, it cuts into the sandveld to the mudrock which it undercuts at its many ox-bow bends. As the channel changes course, so the former channel fills with fine sand sediment in which acacia and perennial grass become established. However whilst the grazing is adequate on the sands and in the pockets of clay it is non-existent on the mudrock which only supports stunted mopane. Away from the river the area is characterised by dark grey to black 'isidaga' soils which are typically developed on exposed mudstone and are mainly mopane woodland. This is supported by Lepper (1992). In a vegetation survey which includes the Dongamuzi River, Timberlake (1988) reports that on the Kalahari sand in the north of the river basin the vegetation is predominantly thickets of combretum with very poor grass growth. Where the river moves on to Karoo mudstone the vegetation becomes colophosperum mopane woodland which is used for firewood and construction. The area again generally has poor grass cover, although the area is heavily grazed.

Due to the expanse of mudrock the area has a very poor groundwater potential and consequently relatively few cattle, thus away from the river the land is reasonably well grassed. The natural vegetation is predominantly open mopane forest, (Watson 1962) with some acacia grassland and bushed grassland, (Gwaai River Stuff 2002). Because of the contamination of groundwater with mineral salts, extensive use is made of traditional open sand-wells within the river channel

In the locality of the field research site mudrock is clearly visible where the river undercuts a 6 to 8 m high cliff. Below the research site the river enters the Kana Block commercial farming area. However in recent years there has been extensive infiltration onto this better grazing land by the local community and more recently villages have been established on the land under the 'fast track' land settlement programme.

The average annual rainfall of the area around Dongamuzi is approximately 620 mm. The average monthly maximum temperatures can be expected to be 24°C in June to 33°C in October. Frost may occur during the months of May to August when ground temperatures may reach -5°C and have been as low as -14°C at nearby Hwange Main Camp, (Gwaai River Stuff 2002). Lepper (1992) states that the rainfall is markedly seasonal with a maximum between November and March ranging from 350-1015 mm. Rainfall usually occurs as heavy showers reaching 75 mm or more per storm, which often causes flooding and surface erosion. He adds that the area experiences semiarid tropical conditions with wet summers and cool, dry winters followed by a hot dry period from September to November. Temperatures are consistently high with an annual mean >24°C and absolute maximum temperatures in September, October and November in excess of 40°C.

The locality differs considerably from the localities of the three other research sites due to better rainfall and a better crop potential. Consequently there is less dependence on livestock, with fewer numbers to contribute to environmental degradation. A significant factor is also that there are virtually no arable lands in the vicinity of the river. Watson (1962) in fact maintains that as recently as 1962 the Shangani and Mzola Rivers into which the Dongamuzi flows, were said to be perennial.

5.3. Criteria for Abstraction Sites

5.3.1. Site selection

Weathered source material that has been eroded, entrained, transported and subsequently deposited in the riverbed of an arid/semiarid area, typically forms a perched aquifer. Where a significant volume of sediment exists within a graded riverbed the aquifer can be expected to yield useable quantities of water. Consideration must therefore be applied and criteria developed for sites suitable for abstraction. Prime requirements for consideration are the volume or the water storage capacity of the aquifer, the permanence of the supply and the permanence or security of abstraction equipment during periods of river discharge.

A suitable abstraction site may be associated with an extensive, stable aquifer with a good storage capacity. Criteria necessary for the selection of an optimum site are:

- Volume an extensive sediment bed. A short, narrow or shallow aquifer will not have the storage capacity of an aquifer of an appreciable length, width and depth. Deep sediment will reduce the likelihood of the aquifer drying out and will reduce the likelihood of damage or loss of equipment during river scour
- Recharge to ensure a permanent or perennial water supply, unless the aquifer is particularly vast, recharge to the aquifer will be required from higher up the catchment area.
- Constituent Material well graded coarse sediment material to ensure
 - High specific yield of the aquifer
 - Good hydraulic conductivity, the presence of fines is likely to reduce transmissivity and may possibly clog equipment
 - o Low rates of evaporation to reduce water losses from the surface
- Low Gradient to ensure reduced water losses through downstream drainage
- Impervious Riverbed to minimise losses from seepage to the water-table

Consideration must also be applied to the security of equipment:

- Gradation, a graded riverbed aquifer that is in equilibrium will ensure a low energy environment with little turbulence and low levels of sediment scour
- River Terrace Profiles, a river flowing through a gorge is likely to have a
 - High energy flow environment with high flood peak levels
 - High static and pump delivery heads

An ideal sand-abstraction site is a former river-pool or the outside of a river bend in deep sediment in a slow moving river, (Hussey 1998(a)). Successful site identification may be ascribed to on-site surveys of the topography of the riverbed and identification of the deepest points of the river, stages of the river channel with deep sediment and sediment filled depressions. In any successful installation it is imperative to install the well-point, infiltration gallery or caisson where there is sufficient depth and volume of sediment to maintain a year-round water supply.

There is a need to establish the likely permanence of water within the river channel aquifer. Methods through which this may be achieved:

- 1. Local knowledge of the area. Local people will generally be able to provide an accurate, if only preliminary assessment of the sustainability and water supply potential of a prospective site
- 2. An appraisal of a possible site may be gathered through the inspection of any existing sand-wells or scoop-wells which have been excavated in the river sediment towards the end of a dry-season in the proposed site locality. If there are useable quantities of water, sand-wells will generally be in use, if the water level has dropped, the wells will only be dry, sand filled depressions.
- 3. An indication of water supply potential may be obtained by observation of riverine vegetation, which will generally be large and possibly verdant where there is a plentiful water supply.
- 4. Probing the sediment depth with a rod or sand spear. This is a quick and relatively easy method of gauging whether or not water is present below the surface simply by noting the depth of sediment and whether or not there is moisture on the probe on removal from the sediment. By observing particles adhering to a probe it is also possible to get an indication of the proximity of fine and coarse sediment layers. However, there is little evidence of the depth or quantity of water available.
- 5. Installing a piezometer tube. A gauge of the depth of water can be recorded through a piezometer tube through the depth of sediment.
- 6. Identification by dowsing may have potential although its relevance is suspect. Although it may be possible to identify a source of water, it is unlikely that reliable data can be regularly obtained on depth to and depth of the aquifer.
- 7. Electromagnetic Resistivity. Geophysical techniques are used to establish both the water-table and the riverbed. However, in a personal interview with the author, Mead (1999) reported adversely on a geophysical assessment he had made to quantify available water in the Motloutse River, Botswana in 1998. An electro-magnetic survey of the river had been undertaken to establish the depth and profile of the riverbed. This had however, only worked to a limited degree, as although the boundaries of different materials had been highlighted, it had not always been possible to identify actual material and whether it was the riverbed base or a gravel layer caused by bedload sorting. Efforts to confirm the identification of materials by augering to the river basement, had not proved possible due to the collapse of the saturated sediment. Augering had also been undertaken with the intention of assessing particle size for hydraulic conductivity and specific yield of the sediment. Computer modelling, based on profiles to assess water availability under different rainfall and abstraction regimes was also undertaken.

Further consideration may be applied to factors such as riverbed topography and rock outcrops, which will affect the retention and consistency of sediment. The likely

success or failure of a sand-abstraction system may in part be determined by the depth of sediment and the extent and the proximity of fine or coarse sediment to a wellpoint system. These factors affect the recharge and thus the drawdown at the wellpoint. This is borne out by Michael and Khepar (1989) who cites a variety of components which generally affect groundwater recharge.

5.4. Field and Off-Site Research

5.4.1. Field Research Undertaken

Four field research centres were established to obtain data on factors of river discharge which might affect the potential to develop and abstract water from streambed aquifers. Sites were set up in southern and western Zimbabwe during the 1998 dry season and were fully functional before the onset of the 1998/99 rainy season. Data collection continued until the cessation of the 2002/03 rainy season and the onset of the 2003 dry season. Local research assistants collected data daily from rain gauges and evaporation pans which were set up within the proximity of their homes. Data on water loss was gathered weekly from piezometers at the field sites with other data such as rainfall, crest level and sediment attrition and degradation collected as necessary following river discharge. Further measurements that were required annually were taken each dry season. Accuracy of data collection improved with each season as equipment flaws were corrected and as the overall competence of the field research workers improved.

Data collection consisted of:

- 1. Rainfall at each centre
- 2. Evaporation at Huwana and Tshelanyemba sites. Inadequate access to a regular supply of water to top up evaporation pans precluded their use at the Dongamuzi and Wenlock centres.
- 3. Total water loss from riverbed sediment obtained from readings of water levels in piezometer tubes installed across the river at each research site
- 4. Peak flood flow readings taken from crest-level gauges at each field site
- 5. Depth of flow (i.e. the greatest depth to which flow occurred below the surface level of the dry season riverbed, in effect the riverbed or deepest bedload surface during the greatest river discharge) recorded at each site in each season.
- 6. Benchmarks (to establish whether the river channel was experiencing aggradation or degradation levels) taken each dry season between a benchmark on the riverbank and spot sites within the channel.
- 7. Speed of flow (attempts to establish the speed of river flow) made during two seasons at Dongamuzi.

Data was also collected from:

- 1. Core samples that were obtained throughout the sediment horizon at each site. Depending on the width of the river between 2 and 4 samples were obtained at each site. Samples were classified and graded and a grading curve produced. Note was taken of particle texture and shape and dimensions were taken of a representative sample of particles under a microscope
- 2. Permeability saturated sediment samples were obtained and to minimise disturbance of the samples, permeability tests were conducted on the bank side

- 3. Subsurface flow velocity experiments were conducted to establish the flow of water through the channel sediment as water levels dropped within the sediment.
- 4. Characterisation of each site was undertaken to establish the:
 - a. Gradient of the riverbed
 - b. Riverbed profile
 - c. Vegetation
- 5. Assessments were made of the nature of each river over significant lengths above each field site and a general record also made of land use above each site

Data obtained from the study has been correlated with the rainfall at each research site. This has helped to provide a check on the accuracy of data collected and to provide an indication of river flow and aquifer recharge and discharge in relation to the precipitation, flood intensity and duration and length of dry season. As precipitation data has only been collected from one rain gauge, placed within the vicinity of each research site, the data obtained is only indicative of the rainfall within the catchment area. However, that limitation of accuracy accepted, the data gathered is nevertheless considered sufficiently indicative of events.

- Dongamuzi field site the catchment above the research site is 58 km². Precipitation data gathered from within the relatively small catchment area can be considered to be appreciably more relevant than that from a larger catchment. However, accuracy of the data has been reduced, as the rain gauge was sited 8 kms from the research site for security reasons.
- Huwana field site catchment above the site is 2,300 km². It is accepted that the accuracy of precipitation data from one site at the base-line of such a large catchment area is severely limited.
- Tshelanyemba field site catchment above the site is 1,500 km². Although not as extensive a catchment as Huwana, it does extend some 100 kms above the research site and thus also the accuracy of precipitation data is limited.
- Wenlock field site catchment above the site is 320 km². Although not a particularly large catchment area, the slow release of runoff into the river from the water retentive environment of the Rhodes Matopos National Park rather than the rapid commencement and cessation of discharge from typically degraded dryland areas also implies only indicative status.

5.4.2. Off-Site Research Undertaken

A control research centre was set up in Bulawayo, Zimbabwe, for comparative purposes and for detailed analysis of samples collected at field research sites. Data collection and research comprised:

- Rainfall data collection
- Comparative evaporation
- Grading analysis of core sediment samples

Further analysis of sediment was undertaken in the Civil Engineering Laboratory, Loughborough University.

- Sediment clast identification
 - o Geological material
 - Shape and texture
- Particle dimensions

5.5. Data Presentation

The selection of a suitable site is imperative for the establishment of a viable and permanent sand-abstraction scheme. Criteria are a worthwhile supply of water and the possibility of minimal damage to equipment when the river is in spate. Installations are best undertaken where there is a sufficient volume and depth of coarse-grained sediment to ensure a perennial supply of water in a low energy environment to minimise the possible damage or loss of abstraction equipment. Trials have thus been undertaken in order to provide a simple and relatively accurate assessment of depth, grading and stability of sediment bodies which can be conducted on-site.

5.5.1. Field Derived Data

Field research sites were staffed by local community representatives in order to attempt to quantify, or at least qualify an assessment of conditions and the general viability of sand-abstraction in differing situations within southern and western Zimbabwe. Areas selected were those where extensive use is traditionally made of sand-abstraction for household and subsistence farming purposes.

Research assistants in the main part conducted their work reliably and responsibly and continued to take readings during the political upheavals in Zimbabwe during late 2001 and early 2002. Initially a person with basic literacy and numeracy skills was asked to assist by recording readings. However several of the assistants considered that this was too onerous and time-consuming for one person and thus two people assumed duties at each site. At two sites instances of jealousy or friction occurred between either the field assistants or another member of the community which led to a further early change of assistants. However of 8 field assistants, 6 undertook readings throughout the duration of the trials.

In an attempt to minimise any confusion, assistants were shown how to take readings to the nearest whole number mm or cm, which could be read on a gauge or tape measure. On each occasion that a field visit was carried out, more proficient research staff checked readings and the latest records which had been taken by the field assistants. Field assistants undertook their duties within the restrictions of their daily routines so whilst requests were made for, for example, weekly measurements to be taken at seven-day intervals at the same time of the day, discrepancies did occur. A particular shortcoming was experienced with evaporation data. Pans were only set up at two sites, Huwana and Tshelanyemba as the pan could only be set up at some distance from a reliable source of water at Wenlock and the supply of water was considered far too precarious at Dongamuzi for any reliable readings to be made. A further complication with evaporation occurred during periods of rain with the field assistants only attending to the pan after a downpour and then attempting to recalibrate readings or adjust pan levels during the day. Variations in the manner of record keeping which came to the attention of staff were of an old lady who assumed a role in the research programme. She regularly sent her granddaughter to the river to

take piezometer readings, however the girl was a GCE 'O' level scholar who on these occasions recorded the depth of water in mm's rather than cm's.

Less satisfactory was a situation at Tshelanyemba where a particularly spiteful woman who was considered to be a witch, tried on several occasions to demoralise the women undertaking the research so that she might carry out the work in their place. Her vindictiveness came to a head when the field assistants were offered a place on the light aircraft hired to take aerial photographs of each field site with the 'witch' becoming particularly vengeful by threatening to call up spirits when she could not have a seat on the plane.

Inaccuracies in reading and data collection did occur but strangely readings across the river, between the piezometers were more marked than differences, or possible anomalies between the weekly readings, which may have been due to inaccuracies in a correlation of levels between the tops of each of the piezometer tubes and the surrounding dry sediment levels. Occasionally it was apparent that the figures recorded had been inverted and these were corrected. Further anomalies may have been caused in the adjustment of readings to the nearest centimetre and when new tape measures with a differing display of figures were issued, at least in the early stages of data collection. Readings taken during 1999, the first year of data collection, should be particularly viewed with some suspicion and some compensation in the adjustment or removal of apparent inconsistent high and low readings was made. With the foregoing restrictions of limited control over both the readings and the field workers, readings may only be considered indicative. However through continual appraisal and checking and correlation with experience and relevant available data it is considered that the data does provide a general overall representation of the conditions at each research site.

Water loss from the sediment

Complete data tables for the 5 years of research conducted at each site are included in Appendix 03. Figure 5.4a and 5.4b show the water recharge from river flow and total loss from the sediment beds recorded from piezometer readings at Huwana field research site in two years, 2000 and 2002. Also indicated are the maximum height of the river flood and the greatest depth of the streambed below the dry season level, during flow in the channel. A correlation between the depth of water retained in the river alluvium and the rainfall at the same site in consecutive seasons may be seen in Figure 5.4c and 5.4d.

Fair rainfall during November 1999 and the unusually high rainfall from Cyclone Eline in January 2000, the latter indicated in figure 5.4a, ensured a high water-table in a balance with the river aquifer which ensured a slow and regular depletion of the water level in the river channel sediment. Conversely, a poor 2001/2002 rainy season as shown in the 2002 rainfall bar graph, figure 5.4b shows a markedly faster depletion of water during the early stages of water loss, probably due to effluent flow from the river channel. Although the scale of this rapid, initial loss reduced as the dry season progressed, water loss did continue to a greater depth in the river sediment as shown in a comparison of figure 5.4b with figure 5.4a.





Depth of residual water within the sediment

Records show that the level of water retained in the sediment drops rapidly on cessation of river flow and then decreases more gradually, reducing as the depth and volume of water in the sediment decreases. The even reduction in loss was not reported at all sites in each dry season as two sites exhibited a mid season levelling off in the rate of loss, before resuming a more typical even reduction. The rate of loss was significantly linked to the rainfall and river flow in the previous season or seasons and the level of the groundwater-table in relation to the water level in the river aquifer. It was apparent that in a low rainfall or drought year, the water level dropped quickly but that in a year of adequate or good rainfall, water loss from drainage from the sediment was considerably reduced. For instance, at the Wenlock site, the river flowed for most of the year in 2001 and the sediment was saturated for the entire year, whereas at Huwana where there was a markedly reduced effect of the cyclone and where there was less recharge to groundwater, the sediment remained saturated until the third week of April and then reduced more rapidly, appendix 03





Typically, in the early stages of a rainy season during the first surface river flow, it was found that the sediment did not become fully saturated and within a few days the water level in the sediment had already dropped significantly, figure 5.4b, whereas sediment which had become fully saturated as figure 5.4a drained more slowly. At the end of a dry season the groundwater table can be expected to be considerably lower than the water level within a river aquifer causing influent flow to the groundwater water-table from the river channel. In the same manner, unusually intense heavy winter storms that cause flow within the channel cause the water level within the sediment to rise significantly, but not to become fully saturated, figure 5.4d and appendix 03, Dongamuzi site. In lighter dry season storms where there is no surface runoff, precipitation causes the dry river sediment to become damp, but has no effect on the water level within the river alluvium as the water is held by surface tension around sediment particles without draining to the saturated water level, appendix 03, Huwana and Tshelanyemba sites, April 2002.

Insufficient data was gathered to indicate the nature of sub-surface flow throughout an entire season. However the overall rate of loss indicates that there is a recession in the rate of flow as the depth of water reduces in the alluvium. A significant proportion of the initial rapid loss of water from sediment saturated to full depth can also be attributed to evaporation. Data recorded at two field sites indicates the annual water loss from open surface water to be in excess of 2.5 m. Following periods of prolonged flow as shown in figure 5.4c, when the sediment remains saturated to surface level, water loss to evaporation can be expected to be as high as from open surface water. However, as the water level drops within the sediment the rate of loss to evaporation reduces. Controlled, off-site experiments, appendix 03, (off-site research), recorded a water loss from saturated sediment of 378 mm compared with a loss of 2,241 mm from an adjoining open water surface tank. Figure 5.5 indicates the daily loss to evaporation together with compensatory recharge from rainfall and subsequent evaporation from the replenished level within the sediment.

Figure 5.4c: Deterioration in sediment water level following two consecutive seasons of adequate rainfall



Figure 5.4d: Deterioration in sediment water level following a season of less than adequate rainfall



Figure 5.5: Comparison of water loss from open surface water and from sediment



Depth of river flow above the surface

Little data was found and very little opinion has been expressed on the reduction of the dry level sediment surface that occurs as sediment is transported through the channel during periods of river flow. Figures that were provided to the author anticipated a drop of the surface level of an approximate one third to one half the depth of water above the dry sediment level. Data gather at the four sites from tell-tale markers placed in the sediment indicated that the depth varied with the intensity of the flow. Flood water within in the river channel at a depth of a few centimetres appeared to depress the dry sediment level by approximately 25% but river flow at a depth significantly greater indicated a lowering of the bed level by some 50% of the depth of flow.

Following particularly high levels of river flow during Cyclone Eline, efforts to recover the tell-tale markers failed in spite of excavations to the full depth of dry sediment available in the subsequent dry season. This led to the introduction of a tell-tale chain in subsequent seasons which it was considered would be more easily located than the sections of aluminium tube which had been in earlier use.

Recharge from rainfall

Figure 5.6a and 5.6b shows the rainfall precipitated during 2000 and the rainfall and evaporation at the same site in 2002. Data gathered as shown in appendix 03 from both the Huwana and Tshelanyemba sites demonstrates a considerably greater total level of evaporation than precipitation.



Figure 5.6a: Rainfall at Huwana field site 2000

Figure 5.6b: Rainfall and evaporation at Huwana field site 2002



Downstream drainage

With further regard to water loss from the sediment beds, figure 5.7a and 5.7b and 5.8a and 5.8b provide an indication of the velocity of downstream drainage. Figure 5.7a shows the calculation of velocity through the sediment using the Darcy formula. Data obtained appears consistent with observations and knowledge of the slope, permeability and sediment grading analysis of each site. Salt dilution tests however conducted three times in eight weeks, at approximately one month intervals at Dongamuzi, four times in eight weeks at Huwana, four times over a period of 11 weeks at Tshelanyemba and five times in 12 weeks at Wenlock, whilst generally consistent, provided appreciably lower rates of velocity. Figure 5.7b shows subsurface velocity rates calculated from salt dilution rates, consistent with velocities calculated from the water surface gradient at Dongamuzi and Wenlock, but inconsistent at Huwana and Tshelanyemba. The variance in the rate of in velocity has been identified as an inconsistency between the water surface slope measured with a dumpy level and the water surface slope established from the dilution readings. In spite of the apparent large discrepancy the difference can be ascribed to irregularities in flow through the alluvium. Water gradient readings were obtained over 100 m at Dongamuzi and Wenlock in sections of the riverbed where there was uninterrupted flow and over 200 m at Huwana and Tshelanyemba. At Huwana the water level was known to be low, with the remaining water largely contained in depressions in the riverbed, thus the water surface slope between two or three depressions over a distance of 200 m would be expected to be greater than the velocity of water across a single depression. The prevailing situation at Tshelanyemba is known to be similar, with a number of rock bars and protruding rocks causing an irregular bedrock surface, contributing to local variations in the water surface slope. A detailed system of probing to a grid formation would be required to verify this assumption.

Disparity may also be attributed in part to localised variations in the porosity and permeability of the sand. Permeability was measured in a vertical direction from a vertically cut core, any horizontal bedding could result in a difference between the vertical and the horizontal permeability.



Figure 5.7a: Graph of sub-surface water flow calculated from water surface gradient at four field research sites 2003

Other possible causes of inconsistency of readings may be due to insufficient time between background readings, the introduction of salt concentrate into the piezometer tubes and the commencement of dilution readings. Some anomalies occurred in the readings, which may be attributed to an insufficient delay before obtaining readings and consequently some difficulty occurred in interpreting some of the data with resultant inaccuries to the linear plot that is required. Complete readings obtained from the four field research sites from which subsurface velocity calculations were made are shown in appendix 06.

Figure 5.7b: Graph of sub-surface water flow calculated from salt dilution tests at four field research sites 2003



Figures 5.8a and 5.8b show the rate of salt dilution against time from which the velocity of subsurface water flow may be calculated, after Davies, Herbert et al. (1995) and Mansell and Hussey (2003).

Figure 5.8a: Log graph of downstream sub-surface water flow at Tshelanyemba field site 2003



Unfortunately no calculation of the probable water loss due to seepage through the riverbed was possible primarily due to extensive variation of rock, shale and clay material affecting the permeability of the riverbed. Accuracy in an assessment of the losses was considered to be beyond the scope of this research programme.

Figure 5.8b: Log graph of downstream sub-surface water flow at Wenlock field site 2003



Losses to evaporation are known to be substantially lower from river sediment than from open surface water. Wipplinger (1958) conducted experiments to determine the rate of water loss from sediment of the Bulskop sand dam, table 5.2. Dry sediment was placed in a cylinder of diameter 152×203 mm high (6 × 8 inch) and moderately compacted. The sample was saturated and the cylinder placed in the sun, by weighing the cylinder and subtracting the known dry weight the amount of water loss was determined. Results indicated an initial loss rate of approximately 2.4 m (8 ft) reducing to almost zero after 40 days.

Table 5.2: Rate of evaporation of water from a sediment sample from a sand dam, after Wipplinger (1958)

Time	Average water content (% of volume)	Rate of evaporation (mm per month)	
Initial condition	40	671	
After 0.5 days	36	519	
After 1.5 days	28	366	
After 2.5 days	22	335	
After 3.5 days	17	305	
After 4.5 days	12	274	
After 5.5 days	9	91	
After 9.5 days	7	30	
After 27.5 days	4	15	

Further information gathered from the field makes it apparent that each riverbed is in equilibrium as table 5.3 shows neither appreciable aggradation nor degradation. Figures 5.9 a,b,c and d provide an indication of the depth from river sediment surface

to river channel base and the river channel width, which when calculated with the length of the sediment bed may be used for rough calculations of the volume of river sediment. Table 5.4 indicates the approximate permeability and the porosity of the sediment beds which allows for an interpretation of the water storage capacity of the calculated volume of sediment.

4 year Variance in Sediment Surface Readings (m)						
		1999-2000	2000-2001	2001-2002	2002-2003	4 year Total
Dongamuzi	1	-0.12	- 0.06	0.19	- 0.11	- 0.10
Huwana	1	0.06	0.08	- 0.02	- 0.14	- 0.02
	2	0.03	0.09	- 0.09	- 0.20	- 0.17
	3	0.10	0.01	- 0.01	- 0.13	- 0.03
	4	0.00	0.05	- 0.02	- 0.11	- 0.08
Tshelanyemba	1	- 0.08	0.06	0.01	0.01	0.00
	2	0.06	- 0.08	0.04	- 0.05	0.07
	3	- 0.01	0.15	- 0.05	- 0.17	- 0.08
Wenlock	1	0.02	0.06	- 0.12	0.03	- 0.01
1	2	0.04	0.03	- 0.09	0.02	0.00

Table 5.3: Sediment surface equilibrium at field research sites

Table 5.4: Permeability and porosity of sediment at research sites

Site	Reading	Permeability (m/hr)	Porosity (%)
Dongamuzi	1	0.55	28.8
	2	0.65	
Huwana	1	7.27	27.5
	2	7.80	
	3	7.59	
Tshelanyemba	1	4.01	32.4
	2	4.13	
Wenlock	1	5.72	30.7
	2	5.55	
	3	6.05	
	4	5.69	

Figure 5.9a: Profile of riverbed at Dongamuzi field research site





Figure 5.9b: Profile of riverbed at Huwana field research site

Figure 5.9c: Profile of riverbed at Tshelanyemba field research site



Figure 5.9d: Profile of riverbed at Wenlock field research site



Data derived from the research provides an insight into the:

- viability of sand-abstraction the source of water and the likely volumes of water stored.
- duration of supplies the significant losses, how long they might last and how quickly they might be depleted by natural means
- ease of abstraction sediment grading curves and the permeability of the sediment
- likely security of equipment installed within river sediment the position of the streambed during river flow

5.6. Assessment of Data

5.6.1. Description and Classification of Sediment

Classification of sediment samples taken from each of the field research sites was undertaken in accordance with the general descriptions of the British Soil Classification System (BSCS); BS 5930, (British Soil Classification System 1981), used by the British Geological Society (BGS). Description and terminology relates to the constituent material, size, shape and texture of sediment grains. Samples taken from each field site have undergone sieve analysis to indicate the suitability of each grade as a medium for sand-abstraction. Sediment sieve analysis and grading curves are shown in Appendix 04. The appendix also includes a visual assessment and a description of a selection of sediment grains taken from these samples. Terms used are those generally applied by BGS and as such provide an indication of the packing of grains and thus an indication of the suitability of a sediment for yielding water. British Soil Classification System (1981) states that visual examination and description are a most important aspect of investigation. BSCS also states that it is useful to supplement any laboratory test with field testing which in many cases will provide more realistic results because of reduced problems with sample disturbance. Figure 5.10a and 5.10b shows the grading curves of two samples of river sediment, 5.10a shows a sample of sediment taken from the east side of the Shashane River, Matobo District, Zimbabwe. Water is easily drawn from this sediment through a well-point and shows a gradation of sediment that will have an adequate specific yield and thus a high potentially for a useable source of water. As a comparison 5.10b shows a sample of sediment from the Kana River, Lupane District, Zimbabwe which indicates a significantly finer grade of sediment with an appreciably smaller water storage potential. Abstraction from this sediment would best be accomplished through an infiltration gallery and false-well.



Figure 5.10a: Grading curve of river sediment sample of high water storage potential

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Figure 5.10b: Grading curve of river sediment sample of poor water storage potential

Core sediment samples have been extracted from each research site in order to analyse the consistency of sediment and to obtain a grading curve. Grading has been undertaken on samples of fine sediment in situations where recharge to a well-point has been seen to be slow. Samples have been drawn from the surface, centre and base of the sediment. The results have been used to determine the possibility of grading a filter pack from the available sediment or whether there would be a need to import a suitable grade of pack to the site, (Appendix 04).

There is no one definitive description of the shape of sediment particles. Graham (1988(b)) however goes so far as to say that shape comprises the form, roundness and surface texture of clasts. Similarly there is no standard description for the texture of sediment clasts. Pettijohn, Potter et al., (1972) points out that the shape and roundness of particles reveals the modification of angular grains by abrasion, solution and current sorting. Bond (1954) maintains that a very long period of transport may be required to change the shape of a sand-size particle, whereas only a comparatively short journey may alter the texture of the particle. He refers to rounded aeolian quartz grains from Kalahari sands that have frosted surfaces, but after travelling only a few miles in the Zambezi River above Victoria Falls, the surface texture has been altered to a glassy polish. According to Trewin (1988) crucial environmental interpretations can be made on the basis of characteristic surface texture; he provides 30 surface texture characteristics for quartz grains of various sedimentary environments. Where appropriate particle shape may be described by reference to the general form of the particles, their angularity which indicates the degree of rounding at edges and corners and their surface characteristics, (British Soil Classification System 1981). Terms recommended by BSCS and used by this study follow, table 5.5 and table 5.6

The American Geological Institute has developed a visual comparison chart to estimate the roundness and sphericity of sediment particles, Graham (1988(a)), after Powers (1982), Figure 5.11. Sediment samples from the four research sites have been assessed

by these indicators, the results appear in Appendix 05. Graham also provides a description of the four principle classes of form that may be ascribed to the overall shape of particles, after Zingg (1935). The parameters used include the sphericity of particles in relation to the proportions between the shortest, intermediate and longest diameters of grains, figure 5.12. Graham notes that comparisons made to standard images allows for considerable variation by operators. A Geological Society Engineering Group Working Party (1995) also utilise a chart to indicate the basic, primary shapes of boulder, cobble and gravel size particles. According to Tucker (1982) roundness is more significant than sphericity as a descriptive parameter and provides a chart, table 5.6, similar to that of the American Geological Institute which he states is generally quite sufficient for assessment. He also makes formulae available for the calculation of sphericity and Gordon (1992), as well as providing descriptions of shape also has made software available to calculate the sphericity of particles which was used in this study, Appendix 05. The degree of sorting within a sediment body is also usually made through visual comparisons with standard images.

Table 5.5: Descriptions of particle shape and composition, (British Soil Classification System 1981)

Angularity	angular subangular subrounded rounded
Form	equidimensional flat elongated flat & elongated irregular
Surface texture	rough smooth

Figure 5.11: The American Geological Institute visual comparison chart for estimating roundness and sphericity, after Powers (1982), (Graham 1988(a))



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Figure 5.12: Pictorial indication of the sphericity of sediment particles, (Graham 1988(a))



The selection of particles for sphericity determination within this study was made by a visual appraisal of clasts of a typical appearance, which were taken from an initial random selection of sediment grains that were obtained by placing a 25 mm length of adhesive office tape onto the surface of a small random portion of a core sediment sample. Several researchers including Gordon have recommended this procedure.

Grading curves of the core sediment samples extracted at each site from the surface to the base of the sediment body are shown in appendix 04. Categorisation and analysis of grain particle shape, size and texture are available in appendix 05. An assessment of further factors that govern water storage in a sediment body, such as the consolidation, orientation and packing of sediment particles is beyond the scope of this research programme and has not been possible. A checklist, Table 5.7, has been developed to assist, quick in-field assessments of possible sand-abstraction development sites.

Table 5.6: Description of Crystalline Rocks, after (Tucker 1982).

Informal terms for describing crystalline rocks				
2 mm				
	very coarse crystalline			
1 mm				
	coarsely crystalline			
0.5 mm				
	medium crystalline			
0.25 mm				
	finely crystalline			
0.125 mm				
	very finely crystalline			
0.063 mm				
	microcrystalline			
0.004 mm				
	cryptocrystalline			

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Table 5.7: Checklist for quick, in-field assessment of river channel sediment

- 1. Water resource:
- Volume of Sediment bed Width×length×breadth, measure sediment bed width and length by pacing or tape measure, assess depth by probing and measuring. Accuracy will be increased with the number of probe depths made within the aquifer
- Vegetation Prolific and/or massive vegetation indicates a large perennial supply of water
- 2. Specific Yield:
- Coarseness of sediment Run a sample of sediment through fingers, assess texture between
 palms of the hand (see table 5.11 Field Estimation of Plasticity)
- Grain Size, Shape & Sorting of Constituent Grains Observe the general size of particles, Check the uniformity of size and roundness or elongation of grains
- Void space Check for fines & cementation
- · Void space Check for compaction, look for any orientation of clasts
- Fluidisation of sediment Examine matrix-grain relationships, saturated sediment indicates matrix-supported and very permeable, an unsaturated sediment indicates a grain supported sediment and less permeability
- · Permeability A thorough assessment would require an in-field permeability test

3. Losses:

- Coarseness of Sediment A fine sediment indicates greater losses through increased capillarity and subsequent evaporation
- River gradient A steep gradient indicates a greater propensity to drain than a more level bed
- Riverbed Base An unconsolidated bed provides a susceptibility to seepage to the underlying water-table

4. Security of Installation:

- High or Low Energy flows Observe the riverbed gradient, occurrence of cobbles, depth of river bank sides
- Flotsam Observe height to which debris is evident above the riverbed.

Mechanical sieving is required for a reliable assessment of the suitability of an alluvium for water storage and well-point sand-abstraction. However, as the focus of this study is primarily to develop technology and systems that are suitable for use at a rural community, subsistence farming level, simplified alternatives must also be considered. Thus a system is required to categorise sediment and to determine a classification, or point at which it can be expected that a reduction in the storage potential of sediment will occur, sufficient to reduce the specific yield or to impede the transmissivity of water to a stage where a potential scheme is rendered impracticable. A kitchen sieve used to sieve cooking ingredients enables such a rough on-site assessment. A typical hand-held sieve as shown in figure 5.13 has an aperture of ± 1.25 mm, a comparison of the sediment that passes through, to that retained in the sieve, provides a rough and ready assessment, or division of the grade of sediment. From a range of grading tests undertaken at successful abstraction sites it can be seen that the better sites are those where 50% of sediment or less passes through a 1.00 mm sieve. Thus the volume of sediment that passes through a 1.25 mm aperture hand held sieve should be approximately equal to the volume retained in the sieve. However an approximate 60% passing will still be acceptable, or to continue this crude assessment an approximate ²/₃ passing to ¹/₃ retention has been found

to be suitable. Table 5.8 shows the results of \pm 1,000 grams of sediment that was sieved in the field at each of the four research sites. At site 1 (Dongamuzi), 98% of the sample passed through a 1.25 mm hand-held sieve, indicating the unsuitability of this site for water abstraction through a well-point. This assessment is confirmed from grading of core samples, (Appendix 04) and practical experience. Indications at sites 2, 3 and 4 however indicate that the use of a well-point is suitable, which is also borne out through practical experience and the sediment grading contained in appendix 04.

Figure 5.13: Makeshift trials to determine suitability of river alluvium for water storage and well-point sand-abstraction



Table 5.8: Field sieving samples for a quick indication of sediment suitability for sandabstraction

	Site	Time (secs)	Particles >1.25 mm (gms)	Percentage of total retained (%)	Particles <1.25 mm (gms)	Percentage of total passing (%)
1	Dongamuzi	8	0.4	0.5	999.6	99.5
2	Huwana	49	202.4	20.2	798.5	79.8
3	Tshelanyemba	31	345.6	34.5	654.9	66.5
4	Wenlock	48	400.4	40.0	600.5	60.0

Grading

According to McManus (1988) the size and texture of component particles is a fundamental characteristic of fragmentary deposits, with coarse, medium or fine grain the descriptive terms in use from the early days of lithology. le Roux (1999) observes that sieve analysis determines grain size by the shape of the particles but that size is in fact elusive, as it can be expressed as volume, weight, surface or cross-sectional area, intercepts through particles or as a settling velocity. According to Pettijohn, Potter et al.,

(1972) size commonly depends on the method of measurement but discrepancy between measurements becomes progressively greater as particles become less equant.

The Geological Society Engineering Group Working Party has categorised sediment particles by size, from very coarse to very fine and has applied the following description; cobbles/boulders, gravel, sand, silt, clay, table 5.9.

Class	Size Limits (mm)	Term
1	>60	Very coarse grained (cobble/boulder)
2	60 - 2.0	Coarse grained (gravel)
3	2.0-0.06	Medium grained (sand)
4	0.06 - 0.006	Fine grained (silt)
5	<0.006	Very fined grained (fine silt/clay)

Table 5.9: Particle size classification

(Geological Society Engineering Group Working Party 1990)

Tucker (1982) provides terms for grain size classes developed by J. A. Udden and C. K. Wentworth which he states is a widely used scale, table 5.10.

Table 5.10: Terms for classes of grain size, after (Tucker 1982)

	boulders	conglomerates
256 mm	2.000.000	(rounded clasts)
	cobbles	(/
64 mm		and
	pebbles	
4 mm		breccias
	granules	(angular clasts)
2 mm		
	very coarse	
1 mm		
	coarse	
0.5 mm	SAND	6
	medium	
0.25 mm	SAND	STONE
	fine	
0.125 mm		
	very fine	
63 microns		******
	very coarse	
32 microns	MUD	ROCKS
	coarse	Other types
16 microns	SILT	SILTSTONE
	medium	mudstone
8 microns	1	shale
1.14	fine	marl
4 microns		slate
	CLAY	CLAYSTONE

Sieving of sediment samples from the vicinity of the well-points of ten successful smallscale sand-abstraction sites has indicated that medium grained material - sand, comprises the material of the most suitable size. Limited possibilities for abstraction exist with material of a particle size in the upper range of the fine-grained material and also with coarse and very coarse material. However, material in the range of coarse, are generally associated with a high-energy flow environments and thus consideration of equipment security must be raised.

A field guide provided by The Geological Society Engineering Group Working Party, for the estimation of soil plasticity is most relevant to the selection of sediment suitable for abstraction purposes. Observation and sieve analysis has shown that only river sediment of a non-plastic nature, as categorised in Table 5.11, may be considered useable for sandabstraction. The proportion of fines sufficient to provide stability to a 40 mm roll of sediment has been shown to also be sufficient to restrict the transmissivity of the sediment to levels unrealisable for the utilisation of sand-abstraction.

Table 5.11: Field estimation of plasticity

Class	Term	Definition
1	Non-plastic	A roll 40 mm long and 6 mm thick cannot be formed
2	Slightly plastic	A roll 40 mm long and 6 mm thick can be formed and will support its own weight, but one 4 mm thick will not support its own weight
3	Moderately plastic	A roll 40 mm long and 4 mm thick can be formed and will support its own weight, but one 2 mm thick will not support its own weight
4	Very plastic	A roll 40 mm long and 2 mm thick can be formed and will support its own weight

(Geological Society Engineering Group Working Party 1990)

The distinctions which the British Soil Classification System, BS 5930 have adapted from *Unified Soil Classification for field use on suitable tropical soil materials* also provide a useful guide to the selection of sediment material, table 5.12. By observing the divisions achieved through sieving, it is possible to select suitable sediment bodies. Sediments which contain high proportions of fines may be considered as unsuitable whereas clean gravels and sands may be broadly considered suitable.

Quick practical tests such as the plasticity test, table 5.11 above are most useful in the field. Even the rubbing of sediment between the palms of one's hand or between fingers will provide a 'feel' and a rudimentary assessment of the coarseness and proportion of fines within a sample of river alluvium. An assessment of the grading of excessive fines within alluvium or the constituent of a silt lens can be indicated by nibbling a small piece between the teeth. A gritty, abrasive feel will indicate a presence of silt grade quartz whereas a lack of abrasion and a generally greasy or soapy feel will suggest a dominance of clay, (Graham 1988(b)).

In pursuit of a simple method of field grading Graham suggests a practical gauge, figure 5.14, for on-site use that he refers to as a simple grain size comparator, after Blatt, (1982). Blatt suggests that particles of sediment that have been retained on standard 1.00, 0.50, 0.25, 0.125, and 0.063 mm sieves can be used to make comparisons with small

samples of river sediment. Sediment particles from five grade bands, 1.00 to 2.00, 0.50 to 1.00, 0.25 to 0.50, 0.125 to 0.25 and 0.063 to 0.125 mm are adhered to the base of a shallow depression made in a card or plastic ruler. Samples are placed in similar depressions alongside the graded material. A quick indication of the coarseness of sediment particles may then be drawn between the graded sample and the field samples. Figure 5.15 shows a gauge fashioned in such a manner from compact discs, with graded sediment glued into the indents.

Major Divisions	Typical Names	Description		
Gravels: more than 50% coarse fraction retained on	Clean gravels	Well graded gravels/gravel-sand mixtures. Little or no fines.		
2 mm sieve		Poorly graded gravels/gravel-sand mixtures. Little or no fines		
	Gravels with fines	Silty gravels, gravel-sand-silt mixtures		
		Clayey gravels, gravel-sand-clay mixtures		
Sands: more than 50% coarse fraction smaller than 2 mm sieve	Clean sands	Well graded sands, gravely sands. Little or no fines		
	Sands with fines	Poorly graded sands, gravely sands. Little or no fines.		
		Silty sands, sand-silt mixtures		
		Clayey sands, sand-clay mixtures		

Table 5.12: Grading description for coarse grained soils for use with field sieves

(Geological Society Engineering Group Working Party 1990)

Figure 5.14: Simple grain size comparator, after Blatt, (1982)



Figure 5.15: Use of compact discs to form a sediment comparator.



Representative samples of sediment were extracted from each field research site. Depending on the width of the river samples ranged in number from 2 to 4 and were extracted from the full depth of the unconsolidated sediment. Each sample was graded through standard sieves and was considered sufficient to provide an indication of the sediment typically transported through the river stage although it is noted that researchers such as Milan and Large (1999), consider 5 core samples with a total weight of between 20 and 25 kg will not provide sufficient accuracy.

Porosity and Permeability

According to Pettijohn, Potter et al., (1972) porosity and permeability are central to the analysis of flow in pore systems. Harwood (1988) states that the effective porosity of a sediment is dependent on the degree of interconnection of the pore spaces which are utilised during fluid migration through the sediment. Pettijohn, Potter et al., (1972) indicates that it is the pore system of a sediment that permits it to store and transmit fluid but that the size, shape and pattern of a pore system is difficult to specify. The chief obstacles to accurate determination of pore space are the small size and the lack of any geometric regularity. According to Pettijohn, size analysis studies are frequently undertaken in an effort to relate physical properties such as permeability and transmissivity to size distribution. However, he adds that care is required as aggregate physical properties are a complex function of grain size, shape, fabric and composition and thus to achieve accuracy may have to be determined by way of regression analysis. By applying a stepwise regression procedure, the introduction of independent variables may be used to test the effect of adding successive variables.

In general terms, it can be assumed that sediment within an ephemeral river channel will have a high porosity due to continual sorting and transport of fines through successive river stages. Geological Society Engineering Group Working Party (1990) states that the permeability of residual soils may be measured in the laboratory or in the field but to determine results that are fully representative, measurements in the field will be required. An indication of the permeability of the river sediment has been undertaken at each field research site, table 5.4 and Appendix 06

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5.6.2. Specific Capacity and Specific Yield

The Institution of Civil Engineers (1976) state that the porosity of an aquifer provides no indication of the amount of water that can be obtained, thus the capacity of a material to yield water is of greater importance than its capacity to hold water. Although water may completely fill the inter-connected voids of a deposit, not all of it can be removed by drainage or pumping as some water will be held against gravity by molecular attraction. The total water content, or the specific capacity of an aquifer and the ratio of the volume of the water that cannot be withdrawn to the specific capacity is the specific retention and the specific yield is the ratio of drained water to the total water content.

Tucker (1982) maintains that the amount of fine grained matrix and matrix grain relationships affect the packing and fabric of a sediment and are important in interpretations of depositional mechanism and environment. Where grains in a sediment are in contact, the sediment is grain supported. Matrix can occur between the grains as can cement. Where grains are not in contact the sediment is matrix supported.

Much depends on the nature and packing of sediment and in the manner in which it was originally deposited and subsequently disturbed or compacted. Theoretically it can be appreciated that sediment could become uniformly aligned and compacted through the agitation and sorting of particles by the turbulence of water. If this occurred in sediment with an even horizon of particles an almost solid mass of sediment would virtually ensue. In this instance the resultant void area would only be a minimal percentage of the whole. Conversely, if well-graded sediment remained loose and randomly orientated a considerable void area could be expected, perhaps to 50% as indicated by Prince (1983) and Gibberd (1968).

In certain circumstances it has been found that silt bands may infiltrate, accrete and also disperse in river sediment. Whilst certainly not true of all rivers, the observation has been borne out by Cooke (1987) and has at times been recorded both in slow moving and in wild, turbulent rivers. Whilst this has not been of any particular significance within the study in that no installations have been affected and only 2 of some almost 100 installations undertaken by Dabane Trust have become silted, probing conducted over 4 years has revealed the elimination of the silt bed in a high energy environment and an extension of the silt bed in the low energy environment. In the regime of high energy flow it is assumed that silt is retained in a natural 'stilling pond' in years of low or moderate flow but that this is flushed out during years of high discharge. In the low energy flow regime it is assumed that the velocity of flow is low enough for heavier particles of the suspended load to be deposited.

Silt may be introduced into sediment as river flow floods traditional sand-wells which fill with fines in transport. A record of the number of brushwood fenced sand-wells in the vicinity of each research site was made by each research assistant. Table 5.13 provides an indication of distance between the wells, the total excavated volume of the wells liable to fill with silt and debris and the volume of brushwood available to fill the wells. It is not possible to know when a river may flood, consequently brushwood and silt is swept into open wells. Exposed lengths of brushwood invariably hold more brushwood which in turn gathers an accumulation of silt until a veritable mound is formed which may throttle river flow. Brushwood in the sediment impedes both the digging of traditional

wells and the jetting of well-points in future years, whilst silt and fine sediment reduces the efficiency of an abstraction system.

	Site	No. of sand wells	Approx. total distance (m)	Approx. distance between (m)	Approx. Volume of excavation (m ³)	Approx. Volume of brushwood (m ³)
1	Dongamuzi	10	1,500	10 - 400	43	200
2	Huwana	6	1,100	50 - 500	50	150
3	Tshelanyemba	6	800	±200	21	113
4	Wenlock	6	650	50 - 100	12	94

Table 5.13: Average annual number of brushwood-fenced sand-wells in the vicinity of each research sites, 1999 - 2003

Considerable variation in the texture of river sediment has been noted during the rains. Following river flow at the commencement of a season which was comprised of short, sharp flash floods that have quickly drained away, gravel and coarse sand has been most apparent on the surface. Towards the end of the rains, however, when flows are often more sustained and river sediment is saturated so that flows do not drain as quickly, fine sediment and silt forms a layer on the surface. As the surface sediment dries out, this silt layer is broken up by the passage of livestock and people and a mixed layer of sediment then constitutes the surface. At the end of each rainy season visual assessments have been made of the ingress of material from fine silt to large gravel and quantities of debris from small plants to entire trees mixed into the sediment.

5.6.3. Water Loss from the Aquifer

Evaporation

Further to the field site evaporation pan readings, two tanks were constructed for a comparative evaporation trial to compare total moisture loss from open-surface water and from water retained in typical river sediment. The trial consists of two water tanks, both 1,20 metres in diameter. One tank was 2,00 metres deep, filled with sediment and water and the second, an adjoining tank, 250 mm deep. The surface of both tanks was at the same level. Water loss from the open surface water was measured with an evaporation pan gauge and the water loss in the saturated sediment tank through dipper readings in a piezometer tube. Table 5.14 shows the comparative loss of water from an open-surface tank and from a tank of saturated sediment, both open to natural recharge from rainfall. Recordings commenced during the rains when the sediment was saturated and were then continued for a complete year.

2002	Rainfall (mm)	Open surface losses (mm)	Losses from sediment (mm)
January	27.8	229.3	62
February	0.9	224.3	18
March	8.1	213.4	5
April	123.1	148.1	25
May	0	139.5	30
June	1.4	106.8	10
July	33.0	131.3	6
August	0	167.7	1
September	10.1	210.4	2
October	38.2	238.2	1
November	35.4	224.4	27
December	84.3	207.7	66
Total	332.6	2,241.1	253

Table 5.14: Comparative water losses from open-surface water and water within sediment

Drainage

The loss of water by down-stream drainage through an alluvial aquifer was determined to be a significant factor of water loss. The velocity of subsurface water through the sediment has been established in experiments conducted by Martin Mansell and the author, (Mansell and Hussey 2003). The rate of lateral drainage along the river course at each field research site is shown in table 5.15a and table 5.15b. Two methods were determined to establish the velocity of flow within the sediment. The first method was an estimation from the gradient of the water surface (i) and the permeability (k) of the sediment using the Darcy relationship.

v = k i

Table 5.15a:	Water surface slop	es and velocit	y of flow, ((Mansell and Husse	y 2003)
	1				

	Field Sites				
	Dongamuzi	Huwana	Tshelanyemba	Wenlock	
Average Slope of Water Surface (%)	0.53	0.12	0.31	0.21	
Sub-surface flow Darcy Velocity (m/hr)	0.32	0.89	1.26	1.18	

The results show the greater velocity of flow through the sediment at the Wenlock site, which is the channel with the greatest incline, closest site to the central watershed.
The velocity was also estimated using a salt dilution method proposed by Herbert, Barker et al., (1997) in which a salt solution is poured into a piezometer tube installed in saturated river sediment and the dilution of the concentrate recorded at regular intervals. If no flow is experienced through the piezometer there will be almost no decrease in salt concentration, but where there is flow, the salt concentration will decay exponentially and can be estimated from

$$v = -\frac{\pi D L_{SAT}}{4nL_{SCR}\alpha t} \ln \left(\frac{C - C_B}{C_I - C_B}\right)$$

where

D is the piezometer diameter

 L_{SAT} is the depth of the bottom of the piezometer below the water surface L_{SCR} is the slotted length of the piezometer

n is the porosity of the aquifer

α is the ratio of the width of the alluvium that is contributing flow to the piezometer, to the diameter of the piezometer tube

 C_B is the background salt concentration

 C_I is the initial salt concentration in the piezometer

C is the salt concentration in the piezometer after time t.

Table 5.15b: Subsurface velocity of flow from dilution tests, (m/hr)

Site	Position	Date	Velocity (m/hr)
Dongamuzi	South	19/05/2003	0.32
		22/05/2003	0.42
		25/06/2003	0.25
	North	19/05/2003	0.32
		22/05/2003	0.47
		25/06/2003	0.27
Huwana	South	12/06/2003	0.24
		01/07/2003	0.14
		15/07/2003	0.11
	North	12/06/2003	0.19
		01/07/2003	0.15
		15/07/2003	0.10
Tshelanyemba	West	20/05/2003	0.57
		30/06/2003	0.51
		07/08/2003	0.43
	Centre	20/05/2003	0.56
		30/06/2003	0.49
		07/08/2003	0.41
	East	20/05/2003	0.54
		30/06/2003	0.47
		07/08/2003	0.39
Wenlock	West	18/05/2003	1.63
		11/06/2003	1.54
		25/06/2003	1.15
	East	18/05/2003	1.56
		11/06/2003	1.41
		25/06/2003	1.11

The value of α depends on the zone of influence of the piezometer as the free area within the pipe attracts flow from a width greater than the diameter of the pipe. The velocity ν can be estimated from the slope of the graph of $ln\{(C-C_B)/(C_I-C_B)\}$ against t. The results of dilution tests carried out at each of field research sites are shown in table 5.15b.

Decreases in velocity correspond to the deepening of the water level within the sediment and indicates the small reserves of water at the Dongamuzi and Huwana sites. Tshelanyemba sited on a river with a well supplied channel and a moderately steep gradient to the riverbed maintains a more even velocity of flow. The marked drop in velocity at the Wenlock site is the result of the greater proportional loss of water from a river channel closer to the watershed with a steeper gradient than the other sites.

Seepage:

It is anticipated that there will be significant losses from the riverbed through seepage, particularly in sandstone areas. Rana and alia (1999) reports on ground geo-physics tests in conjunction with production well installation and test pumping to identify fresh water aquifers in Maun, Botswana. Salts contaminated water was identified at varying levels in semi-confined aquifers from which it was concluded that the downward leakage of infiltrated surface water was the dominant recharge mechanism. Further tests revealed that the predominant recharge source to the groundwater systems along the river valleys and flood plains was river water.

Unfortunately any quantitative data on possible seepage losses from a riverbed was considered beyond the scope of this research programme. Losses from seepage were considered too variable and problematic with many unknown factors such as the rock formation, degree of broken rock, faults or fissures and the depth and grade of clay that formed the base of the river channel. Dependant on the form and material of the riverbed, water losses to seepage may range from considerable to virtually nil. Figure 5.16 indicates theoretical nature of flow as seepage from a river channel. From such a, model calculations may be made to estimate seepage where the nature of the channel bed and basin is known.

Figure 5.16: Theoretical seepage flow net from a river channel, used to calculate water loss, after (Harr 1962).



Water loss from the aquifers at four sites

Data collected at each research site has been used to assess the water loss from each river channel. An indication of daily water loss from a notational section of riverbed as perceived by Mansell and Hussey (2003) is shown in figure. 5.17. Evaporation figures have been drawn from the surface area of a notational section of riverbed and from data obtained in a control, evaporation from sediment trial, that was undertaken at the Dabane Trust yard, 2002, appendix 03. Losses due to downstream drainage have been calculated from the channel cross-section at each research site, (appendix 03, characterisation) and from velocity tests undertaken by the author, appendix 06. As stated no test to establish losses due to seepage have been conducted in the riverbeds, however, for comparative purposes, from indications of the riverbed that were recorded during probe work of the river bed, a seepage rate of 10% of the drainage rate was deduced. The volume of water abstracted from the notational river channel has been calculated from a field survey undertaken at each site by Magumise (2003). Considerable variation has been recorded in readings during the data collection period, both between each year and during each year. Data tabled below provides a global perspective of comparative water loss accumulated from readings, observation and empirical assessment.

		Empirical '	Water Loss	From Riv	er Alluvium	1		
Site	Av Daily Surface Evaporation		Av Daily Downstream Drainage		Av Daily Bed Seepage (10% of drainage)		Av Daily Abstraction	
	m ³	%	m ³	%	m ³	%	m³	%
Dongamuzi	13.9	22.9	5.3	59.6	0.5	2.3	3.6	15.3
Huwana	229.5	26.9	89.6	68.9	9.0	2.7	5.1	1.5
Tshelanyemba	257.8	18.9	1,074.7	78.7	25.3	1.9	8.1	0.6
Wenlock	49.9	49.0	46.0	45.1	5.0	4.9	0.9	0.9

Figure 5.17: \	Water	loss fi	rom riv	ver all	luvium
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5.6.4. Water Quality

Experience has indicated that water abstracted from typical sand-abstraction systems is of an acceptable quality for both domestic and small-scale agricultural purposes. Table 5.16 provides an analysis of water samples abstracted from the 4 field research sites at Dongamuzi, Huwana, Tshelanyemba and Wenlock, undertaken at the City Council, Criterion Laboratory, Bulawayo, Zimbabwe, 13th to 17th May 2002, (Ncube 2002). The report makes a comparison of the water samples with limits recommended by the South African Bureau of Standards. Unfortunately due to a present lack of test material or defunct or outdated equipment at the laboratory not all results were conducted.

		Maximum Recommended Limit (mg/l)	Maximum Allowable Limit (mg/l)	Measured levels Dongamuzi (mg/l)	Measured levels Huwana (mg/l)	Measured levels Tshelanyemba (mg/l)	Measured levels Wenlock (mg/l)
Conductivity	(mS/m)	70	300	49	10	20	10
рН		6-9	5.5-9.5	7.1	7.7	8.0	6.4
Turbidity	(NTU)	1	5	0.2	6	0.3	3.5
Hardness	as CaCO ₃	20-300	· 650	1.24	NR	120	NR
Calcium	as CaCO ₃	150	200	64	NR	80	NR
Magnesium	as CaCO3	70	100	60	NR	40	NR
Sodium	Na	100	400	NR	NR	NR	NR
Potassium	K	200	400	NR	NR	NR	NR
Iron	Fe	0.1	1	NR	NR	NR	NR
Manganese	Mn	0.05	1	NR	NR	NR	NR
Aluminium	Al	0.15	0.5	NR	NR	NR	NR
Alkalinity	as CaCO3	NS	NS	264	64	112	32
Chloride	<u>C1</u>	250	600	8	8	14	8
Sulphate	SO4	200	650	NR	NR	NR	40
Phosphate	PO ₄	NS	NS	0.2	0.2	0.04	0.06
Ammonia	<u>N</u>	1	2	NR	<u>NR</u>	NR	NR
Nitrate	<u>N</u>	6	10	0.06	0.9	NR	0.8
Fluoride	F	1	1.5	0.6	0.6	NR	0.2
TDS		NS	NS	245	50	100	<u>50</u> ·
PV	O ₂	NS	NS	1.2	0.4	0.3	0.8
Coliforms			100	Positive	Positive	Positive	Positive
Faecal Coliforms per 100 ml			100	Positive	Negative	Negative	Negative
48 hr plate count			100	132	127	108	92

Table 5.16: Analysis of water abstracted from four field research sites

5.7. Site Analysis

The selection of a suitable site for abstraction is of prime importance. The site should ideally have sufficient capacity or recharge to yield water throughout the dry-season, should not be vulnerable to damage or loss and should be acceptable to the end-users. An unsuitable or inadequate site will not provide the required security, neither of water supply nor of installation, and consequently will not be utilised or maintained by the users.

The importance of user involvement cannot be over-emphasised. Unlike deep groundwater supplies, the use of state-of the-art survey and ground analysis equipment cannot be relied upon in the identification of an optimum site within such a transient water source. Visual assessment and experience together with physical probing will provide a useful impression or overview of a potential site, but a community statement on whether or not the sediment retains water perennially is of far greater assistance.

Water Storage Capacity

A guaranteed water supply throughout the year is of course the ideal, whether this be by way of a sufficiently large alluvial aquifer approximating a confined aquifer or an aquifer subject to sufficient inflow. As stated above, the more significant appraisal is best made by members of the community who, in dire circumstances may by necessity be required to ration or allocate supplies. During 2001 the Dabane Trust installed an infiltration gallery and false-well in the Dongamuzi River, Lupane District Zimbabwe. For many years the community had been successfully managing abstraction from this river thorough traditional open sand-wells. However with the installation of the well, significantly more water was made available. Members of adjoining communities came with drums and donkey carts so frequently that the site was over-abstracted and dried up. Subsequently the 'home' community rationed the abstraction of water.

If no community assessment of the water storage capacity is possible assessments of the volume of sediment and the permeability will be required. These should be tempered if possible with observations of water retention during a dry season.

Optimum sites

Well-points, through which abstraction occurs, are placed within the river sediment at times when the river is dry and there is no transport of sediment. During river flow sediment is transported through the river channel to a depth dependent on the energy of the discharge. Transport may occur to a depth of a few millimetres or to several metres below the dry-season sediment surface level. A well-point is thus vulnerable in fast flowing, high energy flow regimes. Optimum sites require either security of abstraction equipment and connecting pipes, or satisfactory securing of equipment to the riverbed.

Where possible an optimum site would have a low pump suction lift and delivery head to minimise the energy requirement of pumping.

Community Assessment

To be successful, it is imperative that site selection, abstraction and pump technology satisfy any community criteria that may be associated with existing practices or concepts related to the proposed technology. This may effectively be achieved by involving the community in initial discussion and appraisal undertaken at the outset of any intervention.

5.8. Storage Development of Sites

5.8.1. Potential for Increasing Water Storage

Ideal sites will provide sufficient water for worthwhile abstraction, however it is possible to improve the retention capacity of less than optimum sites. A number of initiatives have been considered which might improve water storage potential.

In less than optimum sites where the reserve of water is not vast, the installation of infiltration galleries and false-wells, figure 5.18, jetted tube-wells figure 5.19 and large surface area caissons has been undertaken.

Figure 5.18: Installation of infiltration gallery and false-well alongside Dongamuzi River, Lupane District, Zimbabwe



Figure 5.19 Jetted tube-well and Canseze handpump, Dongamuzi, Zimbabwe



5.8.2. Sediment Accumulation

Sand-abstraction is the removal of water retained in alluvial sediment. By increasing the volume of sediment an increased amount of water is available for abstraction from the extra void area available.

Chapter 5

Sand Dams

Wipplinger (1958) categorically states that in rivers where there is an excessive amount of siltation it makes practical sense to utilise sand dams or sub-surface dams for water storage. Water from such constructed sources may be abstracted through the use of either gravity flow or pump technology sand-abstraction equipment and are thus a simple and effective development of the sand-abstraction technology and a solution towards an improvement in the increase of available water.

A sand dam is a free-standing structure designed to retain coarse sediment rather than open-surface water. The increased depth of coarse-grained sediment will in turn retain more water. The barrier is effectively a masonry weir designed with a slope or steps on the down-stream side to reduce the velocity of discharge to allow water to pass over without undercutting or damaging the structure. The wall is raised incrementally to increase the depth of sediment in the basin over a period of time, depending on river flow and sediment load this is usually just some 0.3 to 0.5 metres per year and certainly no more than 1.0 metre, (Rosenfels 2000). In this manner the structure impounds only the coarse sediment carried in the bedload of the river, whilst allowing the fine sediment, which is carried in the suspended load to be washed over the top of the structure, (Bell 1998). It is imperative not to retain fine sediment as layers of silt effectively seal the sediment and prevent the infiltration of river water through the sediment and also the abstraction of water from deeper levels, (Tshabalala 1996).

Sand dams have been extensively referenced in various literatures such as Water Aid (2003), Baurne (1984), Cherry (1985), Fewster (1999) and Mombeshora (2003). Useful descriptions and data relating to sand dams and subsurface dams is available on the web site of Water Aid (2003) and a practical manual on the construction of sand dams has been developed by Nissen-Petersen and Lee (1990). Designs of a sand dam constructed by the Dabane Trust at Mkaya Wokhoza, Matshetshe in the Gwanda District, of Zimbabwe is shown in appendix 07.

Salient points of a survey conducted for the Mkaya Wokhoza sand dam

A dam basin and catchment area survey of Tinago stream above Mkaya Wokhozi sand dam was instigated by the author and undertaken by Mukata (2001) during September 2001 as a project assignment for students of the National University of Science and Technology, Bulawayo, Zimbabwe. Five students camped for three days in the locality to undertake a topographical survey and assessment of land use and vegetation cover within the catchment area. Unfortunately no documentation of the survey became available before Mukata resigned his post. However, Ekron Nyoni, (Nyoni 2000), of the Dabane Trust who accompanied the survey team recorded the following significant facts from notes, observation and interviews he made at that time.

General observations of the north – south 3.5 km^2 catchment indicated the presence of six substantial gullies that had been caused by soil erosion. Two gullies occurred to the east of the stream amid rock outcrops and four to the west, principally on relatively flat land on a low ridge between the Tinago stream and the larger Zaba stream. This land had not fully recovered from a time when it had been ploughed and cropped. One kilometre above the basin of the sand dam, some fifteen years previously a 0.75 m high trap dam

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had been constructed immediately above a borehole in order to impound water that might infiltrate to the aquifer to increase the level of water available to the borehole. The trap dam was now completely silted. Some 150 m below and 250 m above this trap dam two smaller streams branched to the east, both were less than 500 m long and rose in low dry, clayey depressions that local people stated had once been waterlogged vleis with tall grass and reeds until the 1950s when they began drying out. By the 1970s the vleis were completely dry.

Above these tributaries the land steepened and the stream narrowed and deepened to $\pm 1.00 \text{ m}$ by 1.00 to 1.50 m deep. The head of the stream was ploughed arable land that provided the material for much of the load when the stream flowed. The catchment area was assessed as approximately 50% arable land, 40% grazing and 10% rock and degenerated land. The latter had been left to regenerate but an excessive number of livestock had prevented a complete regeneration of perennial grass cover. Until Independence in the 1980s the area had been essentially scattered settlements with indiscriminate allocation of arable and grazing land. Subsequent to Independence, in a bid for improved services, people had moved their homes into village lines and cleared and ploughed new land for collective arable fields. Little regeneration of vegetation had occurred on the former arable lands and thus there was a continuing and appreciable level of annual erosion.

Significant tree species found on the grazing land were acacia, such as Acacia karoo and Colophospermum mopane with several species of wild figs, such as Ficus capensis, amongst the rocks. An assessment of vegetation cover on the grazing land was conducted in five randomly selected $1.00 \text{ m} \times 1.00 \text{ m}$ squares with counts that showed an average of 18 plants, ranging from 15 - 23 plants per m². Significant grass species were couch, Cynodon dactylon and a short 'thatching' grass, Aristida congesta. Under good growing conditions the latter is a vigorous tufting grass but due to over grazing all specimens were severely stunted. The crown of many of the aristida were above the general level of the soil and exhibited some 50 mm of exposed root and an approximate 150 mm radius of bare soil around each plant. Bare soil was essentially loose and unstable due to the over grazing and breaking of the dry soil surface by small cloven hoof animals such as goats. Insufficient soil moisture was present for any compaction to occur in the coarse grain soil, which was then vulnerable to erosion. Numerous livestock tracks from kraals to water points and grazing areas created further water runnels that would subsequently yield further surface material to the stream.

Although no sediment trap yield trials were conducted in the catchment of the dam, the generally steep land of the grazing area amongst rocks and the large proportion of arable land which is regularly ploughed, together with the foregoing assessment led the study team to assess the catchment as a "basin highly susceptible to erosion", according to ranking devised by a team representing The Zimbabwe Institution of Engineers and The Construction Industry Federation of Zimbabwe as shown in table 5.17, (Muyambo Undated). According to Muyambo sediment yield from land categorised as such is assessed at 10 kg per m³ of runoff. An assessment of annual sediment delivery to the dam is indicated in appendix 07.

Table 5.17: Dam basin classification and mean sediment yield, after (Muyambo Undated)

	Basin description	Mean sediment concentration
1	Basins with well developed conservation measures and moderate topography	. 3,000 mg/l
2	Basins prone to erosion through poor conservation measures and steeper slopes	5,000 mg/l
3	Basins highly susceptible to erosion	10,000 mg/ <i>l</i>

The grading data of sediment likely to reach the basin of Mkaya Wokhoza sand dam is shown in Appendix 07 with the grading curve shown in figure 5.20.



Figure 5.20: Grading curve of sediment upstream of Mkaya Wokhoza sand dam

Sub-surface Dams

Where there is no natural dam basin and where there is already a significant depth of sediment a sub-surface dam constitutes a structure designed to prevent the loss to down-stream drainage of water from saturated river sediment. A sub-surface dam is constructed as a barrier within the river sediment that impounds water within the channel. This causes increased seepage into the sides and base and thus an increase in the storativity of the channel basin.

There are several approaches to the design of sub-surface dams; on the one hand, solid permanent barriers and on the other impermanent membranes with a third school adopting a mid-line approach by advocating a thin permanent barrier, which is supported on each side by sediment, (Smith 1990). As an alternative to solid structures, in an interview, O'Keeffe (2003) reported to the author the use of plastic sheet dug into the sediment of a wadi in southern Sudan. He maintained the practice was employed over several seasons, with a new membrane installed each year which substantially improved the supply of water to a mission station.

As with an open surface dam constructed above ground level, it is necessary that the foundation of the barrier be constructed on an impermeable base to prevent losses due to downstream drainage. It is also advisable to leave some 0.5 metres of sediment above the crest of the barrier to prevent turbulence over the barrier which would scour sediment on the lower side of the barrier, (Heyns 1999). The author has witnessed inter-locking beach piling used to retain water in sediment in the Swartkop River, Swartkopmund, Namibia. However, although the piling had been installed with the tops below the sediment surface as advocated by Heyns (1999), sediment had subsequently been eroded in the main stream of river flow to a depth of 2,40 metres on the down-stream side. In support of substantial barriers Mukata (2001) maintained that in his experience a barrier which did not have an adequate foundation would be rolled over or swept away during periods of high energy discharge. Appendix 07 shows the design of barriers utilised at Hingwe in the Bulilimamangwe District and at Dongamuzi in the Lupane Districts of Zimbabwe.

Gabions

Richard Owens in a personal communication has suggested a further possibility, that of creating an increase in the depth of sediment by placing a series of gabions on the surface of the sediment across a river. Owens theory is based on the premise that there will be an accretion of sediment behind each gabion and that with an increased depth of sediment there will be an increase in available water. He has a further supposition that water loss is primarily from evaporation, rather than from drainage or seepage into the sides and bed of the river and flow out of the river basin, thus he maintains that water loss will stabilise at a depth below where there will be no further evaporation, (Owen 2000(b)). Although they have not advocated the use of gabions within a river channel, OXFAM has amassed considerable success and experience in the application of gabions in its development and charity work. Cherry (1985) reports that many communities have been assisted to construct rock barriers which contain topsoil and sediment that would otherwise have been transported out of the local environment.

The author, (appendix 08), undertook a survey of a river channel which was considered suitable for this development. However after reviewing the data it was decided better use could be made of a site, which, in the course of the survey, had been identified as a possible site for a sand dam.

In a recent development, Gould (2001) reports on the use of synthetic material 'geotubes' as a convenient and inexpensive in-situ method of retaining sediment that is likely to be eroded from a site, such as a beach. A similar method of sediment retention could well be used to increase the volume of sediment in a river channel. Gould reports that empty geotubes are easily transported to a site and can then be filled with available material to construct a barrier that appears to be at least 1.00 metre high. According to Gould emergency or even permanent groynes may be constructed through a series of lines of geotubes to secure areas that are vulnerable to erosion or flood as the geotubes, geobags or sandbags can be formed relatively quickly and easily by filling with the sediment available. An extension of this technology, the artificial retention of readily available sediment to retain further volumes of sediment, may have an application to build up sediment levels in a river channel in the same manner as a sand dam, sub-surface dam or gabion system.

5.9. Unconsolidated Aquifers

Successful application of the sand-abstraction technology is based on a reliable supply of water retained in alluvial sediment. However, considerable potential may still lie in the possible development of apparently inappropriate sites, where the sediment is too fine for reliable abstraction. Infiltration galleries as visited by the author in Southern Africa and as described by Helm (1998), may be used in the horizontal horizon and borehole development technology, such as gravel packing around well-points, used in the vertical horizon.

According to Mharapara (1994) there are some 200 million ha of wetlands in sub-Saharan Africa with some 3 million ha under cropping. These lands are known as dambos in east and central Africa, vleis in southern Africa and fadamas in West Africa, with localised names such as mapani in Zimbabwe, mbuga in Tanzania and inland valleys in Sierra Leone. Mharapara states that dambos are areas subject to seasonal excessive wetness. Subsequent to an extensive joint study and survey by the Universities of Zimbabwe and Southampton, Owen, Rydzewski et al., (1989) states that dambos constitute a water source for domestic and livestock use, cultivation of cereals and root crops in the wet season and cultivation of vegetables in the dry season. Andreini, Steenhuis et al., (1994) is of the opinion that such sources of water have tremendous potential for low-cost irrigation as most plants are able to draw water from the unusually high water-tables. However there is a further potential for irrigation that may be developed through the use of screened well-points. Mkwanda (1994) and McFarlane (1994) however both point out the extensive degradation of wetlands in Zimbabwe and the need for sustainable management. In a study of dambo configuration McFarlane states that there is a continuing extensive reduction of dambo area resulting from watertable lowering with a consequent insetting of dambos into the terrain and a thinning of the weathered profile below them.

Tube-wells

Tube-wells, augered or jetted into saturated sand or gravelbeds may provide a useful alternative to well-points in river channel sediment. Extensive use is made of this technology in North America, (de-Vries 1999), Australia and South Africa, (Maclear 1997) with considerable application of surging tube-wells in Bangladesh, (Ahmad 1979). Where sediment beds are relatively shallow, tube-wells with well-points have been augered to a depth of 20 metres in saturated sub-surface gravelbeds in Maputoland, South Africa.

Sand-abstraction technology has also been used successful in alluvial sandstone areas where the tube-well can be offset from the river and the well-point installed to a depth greater than would be possible in the riverbed. Such installations have been undertaken by the Dabane Trust who have jetted 6 tube-wells at Dongamuzi, Lupane District, Matabeleland North, Zimbabwe, mid 2000.

5.10.Summary

A review of the effect of erratic precipitation in dryland areas has been conducted and research has been carried out to determine the nature of dryland river aquifers and the

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water resource that may be utilised as well as the losses which may be anticipated. The catchment areas of dryland rivers are generally subject to considerable losses of surface material through erosion due to precipitation runoff. The duration and intensity of precipitation and the resulting accumulation and subsequent movement of water impact significantly on the flow of water in an ephemeral river channel. Dryland river flows are highly variable, the result of flash floods, single peak or multiple peak floods. Land-use surveys have been undertaken in the catchment areas of 4 rivers in Zimbabwe which have helped to establish the extent of bare, over-stocked grazing areas and fallow arable land that have no erosion control measures in place.

As the movement of water commences in a river basin and discharge increases, the erosive strength of the water also increases as it flows from one level to another. The effect of this is a scouring of the sediment around and below obstructions causing undermining and the onset of transport. In lower, more level and slower sections of a river, obstructions may be submerged in the sediment and create turbulence in the flow as they emerge in the riverbed as it lowers during periods when the river is in spate. Turbulence in turn can be the cause of further erosion and abrasion and is also likely to have a considerable and detrimental effect on an installation.

Eroded material is carried into waterways where it is deposited until a stage of equilibrium is reached when further sediment is transported through the channel. The volume of sediment and the concentration and calibre of the sediment moving down a river channel has considerable bearing on the nature of the channel. Predominantly finegrained sediment delivered to the channel is largely carried in suspension and during floods may be deposited on the channel sides or in excessively high discharges on flood plains where these exist. In this manner relatively high, cohesive banks are formed with a relatively narrow, single thread channel that is likely to meander. Coarse sediment is transported nearer the riverbed with successions of flow continually sorting the river alluvium and importing new material into the river channel. The channel is then more likely to undergo continual change but to consist of deep, well-graded sediment in equilibrium. As sediment is deposited it is likely to be deposited in bars, which fill the channel and may deflect the river in an expansive and uneven pattern. According to the supply of sediment such channels may meander irregularly, wander or become braided. These channels are characteristically wide and shallow with non-cohesive lower banks formed in the coarse material. Consequently riverbanks are more prone to undercutting with further erosion and channel realignment. Most of the sediment deposited in active gravel-bed rivers is recycled from previous deposits rather than from material supplied from outside the alluvial channel.

The division between fine and coarse sediment depends in some measure on the energy of the stream but can be roughly placed between 0.3-1.0 mm, the medium to coarse sand range. Grading has shown that sediment from rivers in Zimbabwe that are suitable for sand-abstraction is predominantly within this parameter.

A prime consideration of the research programme has been to improve the permanence of installations and to develop equipment and systems which may be securely placed within the sediment of dryland rivers, even when the sediment into which the equipment has been installed is in the process of transport. Research has been undertaken in order to establish the depths at which there is a likelihood of damage to installations. It was

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considered important to correlate the riverbed depth during flow; the level at which saltation occurred, to the depth of water flowing above the previously dry sediment surface. Whilst a well-point that has been jetted or dug into the riverbed remains undisturbed where damage does occur often it is the connecting pipe which becomes disconnected or broken and exposed.

Studies have been made of the incline and course of selected rivers. Assessments have been made of deposits in slow moving rivers over wide plains through to those of fast moving rivers in gorges off the watershed. Long, straight, fast flowing sections were seen to have little sediment whereas long slow sections contained deep sediment, often retaining significant supplies of water. Wide meandering rivers were seen to have deep sediment on the outside of bends due to increased gouging of the riverbed and were thus thought suitable as abstraction sites, but were also seen to be vulnerable to damage during high energy flows.

A research programme has been conducted to assess the suitability of abstraction sites. Probing has been undertaken to establish the depth of sediment and field visits undertaken to sections of rivers to assess the potential of possible sites. Core samples of sediment have been taken and inspection pits have been dug at each of four sites in differing rivers to study the layering of deposits. The material and data obtained was classified and samples from several layers within sediment bodies have been graded. Benchmarks were set at 4 field research sites and spot heights of river sediment taken over 5 years. Data gained has indicated that the sediment bodies in each river are in a state of equilibrium. A guide has been developed to assist in the selection of possible abstraction sites (Chapter 8).

Research was also undertaken to establish the losses likely to occur in river alluvium aquifers. Data over some 5 years was obtained on water levels in the river sediment throughout both the rainy and dry seasons. Estimates of losses were prepared from open surface evaporation and from likely down-stream flow in the sub-surface. Estimates of losses due to streambed seepage were not possible to assess.

The research conducted into the levels of water which are retained in river alluvium and the losses to which the aquifer is subjected indicates that sediment-filled, dryland rivers may constitute a viable source of groundwater. However it must be acknowledged that as with any aquifer, the supply of water during a dry season is greatly dependent on the recharge and inflow that occurred during the previous rainy seasons. Overall, research and practical application have shown that useable quantities of water are retained in ephemeral rivers.

Chapter 6

Technical Research

6. Technical Perspective

It is a contention of this study that sand-abstraction is a technology that is both valued and utilised by members of rural communities. A review of existing abstraction technology has been conducted ranging from an evaluation of traditional open sandwells that are easily contaminated to closed, mechanised systems that are capable of abstracting potable water direct from river sediment. A variety of differing systems is considered and an assessment made of systems suitable for sustainable small-scale community use. The review also considers the increment or development of sand aquifers that are not optimal as well as the equipment or methods that may be used to abstract water from such sites.

The review outlines the existing technology, states the limitations and shows how the research assisted in the design and development of new and appropriate equipment. It then considers the possible development and application of sand-abstraction equipment to a scale wider than its present use but one where it can still be utilised and supported at a rural community level. Substantial consideration is given to the design, development and testing of equipment with a view to its being manufactured by local artisans, and certainly installed, used and maintained by rural communities. A presentation is made of data relating to the design and testing of improved and alternative equipment.

6.1. Abstraction Technology

Sand-Wells

A relatively simple strategy to obtain water from river sediment is the construction of an open well. Such wells are unprotected, unlined and generally impermanent, as they last no longer than the immediate dry season in which they are constructed. This type of well is variously referred to as a shallow sand-well or by Sutton as a scoop well, (Sutton 1999(a)). As access to the water is gained by entry to the well rather than by drawing water to the surface, the unlined wells may also be considered as 'ceane' wells. However this term is generally applied to much larger wells, as those typically constructed in the Sahel.

As the water level reduces within river sediment so the removal of the dry surface sediment is necessitated in order to reach water. A simple cone shaped excavation 750 mm deep in sediment will provide an open-surface water diameter of 500 mm and only requires the removal of 1 m³ of sediment. However as can be seen in table 6.1, appreciably more sediment must be removed as the water level reduces, particularly if a working area of 500 mm is to be provide around the open water to prevent sand slippage from the sides into the well.

Depth (m)	Surface diameter (m)	Base diameter (m)	Volume (m ³)
0.75	2.00	0.50	1.00
1.00	3.50	1.50	5.20
2.00	5.50	1.50	21.30
3.00	7.50	1.50	55.00

Table 6.1: Volume of sediment to be removed in the construction of a scoop well of frustrum shape

Figure 6.1: Typical well in a sand river – Huwana, Matabeleland South, Zimbabwe.



Figure 6.1 shows a typical sand-well. In order to safeguard the well from livestock, large volumes of fence material are required to prevent livestock from trampling the unstable sides of the well and from filling it with sediment. To construct a 2.00 metre deep well more than 20m³ of sediment is removed which is deposited in a ridge around the well, the crest of this ridge has a circumference of some 26.00 metres and a 3.00 metre deep well a 35.00 metre circumference. Figure 6.2 indicates the large amounts of brushwood that are required to encircle such a well with a fence, as well as several stout poles to act as a removable entrance barrier. Both the brushwood and timber are invariably felled in the locality, only to be washed into the river sediment and lost when the river first flows in spate. Thus to replace the wells, similar work is required each year with a similar depletion of material from the environment.

In order to maintain a useable depth of water within the well, an open-ended cylinder such as a section of a 20-litre drum is dug into the base of the well. Such impermanent lining, often utilising a section of discarded drum, successfully prevents slumping of the well sides below the water level. However this well protection is also lost when the river flows and many rural families do not find it easy to acquire such lining. Within these sand-wells, even with a section of lining, it is not possible to maintain a water depth of more than 75 mm due to the ingress of sediment from either surface erosion, slumping of the sides or an up-welling of water which carries sediment into the lining from the saturated sediment beneath. Depending on conditions of the well and the organisation of the drawers, abstraction from open sand-wells is only minimal with typical yields in the range of 250 to 500 litres of water per hour.

Figure 6.2: Use of excessive brushwood for fencing sand-well



Well-points

Efforts to abstract water from river sediment by mechanical means were initially made in Zimbabwe in the 1920's. Efforts continued through to the 1950's when substantial use was made of the system for the provision of water for communally grazed livestock in the small-scale farming sector of the day. However these schemes received little maintenance and fell into disuse during an ensuing war of liberation in Zimbabwe in the 1970's and 80's. Subsequently there was no extensive use made of sand-abstraction and schemes became limited to specialised, purpose designed schemes that were virtually limited in use to problem groundwater areas.

The basis of early schemes was a supply of water, gravity fed to a point from where it could be mechanically pumped. Typically this comprised of a number of 50 mm (2 inch) steel well-points installed vertically in the sediment and joined in an offset grid system to a 50 mm (2 inch) steel water pipe. The steel pipe passed through the river sediment far enough downstream to create an hydraulic head which would siphon water into a pump house on the riverbank. The pipeline was connected directly to a positive displacement pump, to pump water to the surface or into a delivery line. Inlet pipelines were often equipped with non-return valves both at the well-point and at the pump to help maintain a prime. Delivery pipelines ranged from just a few metres to sometimes several thousand metres in length. These early systems were known to be quite effective but sediment fines, exacerbated by oxides of iron from the steel pipe, invariably clogged the non-return valves and the relatively narrow bore of the pipeline. Rust caused fines to bind and created further problems by causing the enlargement of the apertures in the steel well-points. Steel wire which was sometimes wound around the outside of a well-point to create a sieve effect was also liable to be either clogged or broken down by rust.

By the 1970's and 80's typical mechanical abstraction systems still used steel wellpoints but these were connected with lengths of flexible irrigation pump suction hose to sections of large bore (\pm 150 mm) steel manifolds which were installed transversely in the riverbed. This system reduced the blockages caused by fines. The manifolds were connected to a sealed tank that extended below the manifold level and into which the inlet pipe of an atmospheric pump was installed. If the tank was too deep for the effective use of an atmospheric pump, a standard borehole pump was installed with the pump head on the surface and the pump cylinder in the sub-surface tank. As water was pumped from the sealed tank, provided the well-points remained in water, further water was drawn into the tank even when the manifold was above water level. When pumping ceased, the tank required replenishing with water to ensure sufficient prime for the next pumping period. Typically, replenishment was achieved by opening valves to allow water to drain from the delivery line, by-passing the pump back to the tank. The design of a typical well-point and sealed sub-surface tank system as recommended by the Ministry of Water Development, Zimbabwe, Workshop Foreman (1987) is shown in figure 6.3.

Figure 6.3: Typical well-point and sealed sub-surface tank system, (Workshop Foreman 1987)



From the 1980's well-points have been commercially available in Zimbabwe and more use has been made of high quality stainless steel screens and well-points sheathed with synthetic material. Pumps too have improved with more use made of progressive cavity and centrifugal pumps. Present well-point systems are often of a design that connects to manifolds and in turn to vacuum tanks that are placed above the level of pump inlets. Vacuum tanks of a capacity larger than the manifold and inlet pipe ensure a ready prime to the pump, sufficient to draw water through the system. As with the sub-surface system, this system also requires a pump by-pass to maintain the prime between pump sessions.

Variations or modifications of some of the foregoing systems are also presently in use. Some engineers maintain that vacuum tanks are unnecessary and are content simply to use a non-return valve at the top of each well-point to maintain the prime of a pump system. The advent of the compact submersible borehole pump unit has enabled a pump to be installed into a sealed borehole casing or a vertical section of manifold with sealed connections to the well-points. The basic system remains the same and must be fully sealed and primed in order to draw from a lower level. Figure 6.4 shows the design of a screened submersible pump unit capable of drawing water from a sand river.



Figure 6.4: Screened submersible pump unit suitable for use in sand rivers

In spite of the overall success of large-scale commercial systems, there has been comparatively little development of systems suitable for small-scale sand-abstraction. The single well-point system, also known as a sand-spear, remains virtually alone as a system suitable for small-scale mechanised abstraction. Sand-spears are typically narrow bore (25 mm) perforated pipes, which are jetted or driven into saturated alluvium or sediment. Low output self-priming, electric centrifugal pumps connected directly to sand-spears have been used for domestic and garden water supplies in Cape Town, South Africa by Maclear (1997) and in Wisconsin, USA by de-Vries (1999). A commercial self-jetting well-point that when in place can be direct coupled to a mechanical suction pump is shown in figure 6.5. In a further development Motorcare.com (2001) advertises a sand-spear that can be temporarily augured or 'screwed' into a water-table of fresh-water to a depth of a few feet. Motorcare states that in coastal areas a temporary water supply is available for showers and washing down salt-encrusted vehicles.

A single sand-spear system for the direct mechanical abstraction of water from river sediment was designed in the 1960's by Engineer Schegar, (Schegar 1996). The system comprised a single well-point mounted below a 500 mm diameter \times 6.00 mm (¹/₄ inch) steel plate. Fitted above the plate was a small stationary engine with a veebelt drive to a progressive cavity, Mono pump. The pump was connected to an outlet in the bottom of a priming tank and the sand-spear to the top of the tank. The unit was forced into the river sediment until the steel plate was on the surface of the sediment and the sand-spear in saturated sediment. The motorised unit was then able to draw water from the sediment through the priming tank and deliver water a short distance to the riverbank. As the unit was not a permanent fixture, it could be moved to other sites on the river and removed from the river when there was a likelihood of flood.

Figure 6.5: Self-jetting well-point, (Driscoll 1986)



One of a very few small-scale well-point options available to rural communities has been developed by Richard Cansdale of SWS Filtration, (Cansdale 1992). Cansdale's system comprises a single, composite well-point which can be connected to a Rower type handpump on the riverbank. Other than a foot valve in the base of the Rower pump there are no in-line valves. With careful priming of the pump, water may be drawn through the pipe work to discharge from the open end of the Rower pump.

Infiltration Galleries

Infiltration gallery schemes hold considerable potential for the abstraction of large quantities of water from sand rivers. Clanahan (1995) reports on a 150 mm \times 1,288 m slotted pipe gallery system she designed for installation in a balancing weir on the White Umfolozi River. The scheme was designed to provide 1,127 m³/hr by gravity discharge to a pumping station for the town of Ulundi, the royal town and capital of KwaZulu, South Africa. Unfortunately however there have been severe limitations to the output of the scheme due to problems primarily associated with bio-fouling.

Particularly where the depth of sediment is limited, but where there is a sufficient recharge of water, the point of separation of water from sediment may be through infiltration galleries rather than well-points. Infiltration galleries allow water to be abstracted from a smaller vertical depth but a larger horizontal area of sediment than a well-point system. Water seeps into an infiltration gallery due to an hydraulic head. Once in the gallery, water is able to flow laterally due to a gradient and hydraulic head to a collection or false well from where it may be pumped to the surface. To assist in the most advantageous placement of galleries within a waterway, Hunt (1983) proposes a mathematical solution for calculating the difference in seepage flow rates into collection galleries that are placed either parallel or orthogonal to the aquifer boundaries. The aquifer geometry and boundary calculations involve the gallery length, boundary spacing and the distance between the gallery and the recharge boundary.

The collector well and proprietary Ranney well systems, when constructed in the vicinity of a river channel, are variations of an infiltration gallery system as the lateral

abstraction pipes are usually drilled or jacked into the alluvium beneath the riverbed as described by (Herbert, Barker et al. 1997). The description of the installation of a collector well near Cape Town, South Africa by Engelbrecht and Rosewarne (1999) provides a useful insight into the technical requirements. Apparently a number of conventional groundwater abstraction methods were considered prior to installation, with the final decision in favour of a collector well in a riverbed. The installation comprised five individual concrete caissons installed 80 metres apart along the riverbank to a depth of 8.0 metres. Fifty metres of 150 mm slotted screen were installed at a depth of 5.50 m across the riverbed from each caisson. Pre-dewatering was undertaken for three days before the installation of each caisson. Between 40 and 50 well-points were used to de-water an area of approximately 1,000 m². An excavator with a 2.5 m³ bucket then had 3 hours to excavate a caisson and gallery trench before the site became flooded. Gravel packing was added to each gallery trench before back-filling. The design was for any three wells to be used at any one time with a combined delivery of 7.2 m³/hr.

A slightly different approach is reported by Drake (1981) who used a backhoe to dig a trench in clay, four metres deep and a one third distance across a valley. He does not state the length of this trench nor how close it was dug to the river channel, only that a 250 mm perforated pipe was placed in the bottom and covered with 600 mm of coarse gravel and a further 1.6 metres of clean sand, then backfilled with the original excavated material. The infiltration gallery discharged to a well shaft with a sub-surface pump to provide water to a household. Drake experimented with two similar installations at other excavated sites where he maintains the water quickly became crystal clear. Excavations were fully supported by a back fill of sand which he says prevented silt sized particles from being transported with the water and when compacted, formed a firm seal which in effect became a large graded filter through which only groundwater and dissolved solids were free to migrate.

6.1.1. Technology Shortfall Affecting Installation and Use

Rural communities make widespread use of the water which is available in the sediment of sand rivers. Typically water is abstracted from the sediment at an open scoop well. This is a simple, low-cost and effective method but with inherent limitations:

- The wells are not perennial
- A significant amount of maintenance is required to ensure that the wells do not become clogged and regular deepening is required to maintain a useable level of water
- Considerable amounts of brushwood and stout poles are felled annually to constructed fences and entry barriers to prevent livestock entering the wells
- The river channel becomes clogged with the brushwood which is swept into the wells and that in turn collects silt
- Only limited volumes of water may be drawn from scoop wells.

A range of suitable materials and purpose-designed equipment is available for improving the efficiency and increasing the output of water from sand-abstraction. Well screens suitable for use as infiltration galleries and self-jetting well-points are available on the market. However equipment such as a self-jetting well-point, is either complex in itself, or requires sophisticated installation equipment and procedures. Sand-abstraction is a resource widely available to disadvantaged communities but lacks a basic, effective technology to enable people to easily draw water and to maintain sustainable operation, maintenance and control systems.

When compared with the on-going technical and material improvements which have been made to handpumps, low cost drilling techniques and equipment, there has been very little development of equipment which is suitable for low cost or hand operated sand-abstraction systems. The equipment that has been developed, is generally complex and sophisticated, more suited to large-scale development schemes. Consequently there is little that is available to enable rural communities to develop their own sustainable, community based water supply systems. Unlike other sectors of the water supply industry little attention has been provided, either in the development of small-scale hand operation well-point abstraction systems, or in the development of installation systems which might be used by disadvantaged rural communities in the industrially developing world. In spite of 'Water Decades' and international targets intended to provide "water for all" by dates within the next decade, there remains only a very few options between traditional sand-abstraction and large-scale commercial systems.

6.2. Development of the Technology

Lined Sand-Wells

Permanent lining provides a straightforward and immediate option to upgrade and improve the efficiency and effectiveness of a river sand-well. Pre-cast well-rings normally used in well construction may be utilised to provide a suitable form of lining within river alluvium placed on the bed of a river channel. To ensure a stable structure that will not be overturned during river flood, a secure and level foundation is required which may not be easily found within a river channel. A solid foundation is also required to prevent the entry of fluidised sediment into the base of the well. A porous first ring lining is necessary to allow water into the well. In its simplest form, water abstraction from the well can be with a rope and bucket, however it is also possible to install a pump, such as a submersible, within the well to pump water to the riverbank.

Apart from the need for stability of the well lining, it is imperative that the top of the well be sealed satisfactorily to prevent infill of sediment during river flow. Several reports exist of raging rivers ripping the tops from river intakes. Although apparently adequately designed, Glover (1997) reported to the author that a sandabstraction/river-water intake scheme he had designed for use on the Mona River. Zululand, South Africa, was badly damaged in river floods five years after installation. Jetten (1991) also reports on damage to sand-well covers in rivers in north eastern Botswana that resulted in the shafts filling with sand and fine sediment. A limitation with well shafts which extend through the river sediment, is the surface area of the well-rings that extend into the channel during river flow. The structure is more secure where no access is required to the well for abstraction. Where mechanical pumps may be installed in the bottom of a sand-well shaft, the well lining need not extend to the surface of the river sediment and thus will not collect mounds of debris that increase the vulnerability of the well to damage by the flow. An alternative well-ring structure has a well-head designed to allow a relatively unimpeded flow of water over and around it, which minimises the exposed surface area available.

Infiltration Galleries and False Wells

The position of an abstraction well in firm material on a riverbank rather than within the river channel significantly improves the security of an installation. However a method of transferring water from the storage medium to the well is then required. False wells dug into the riverbank, charged with water from infiltration galleries are one of a very few sand-abstraction options which could be successfully constructed by a community without appreciable outside assistance. Trenches and excavations for infiltration galleries and false wells are a realistic community initiative where wells may be equipped with standard handpumps to draw water and thus are a realisable community option.

There are however severe limitations in the construction of false well and infiltration gallery systems by a community as it is imperative that a gallery be installed within a saturated medium. Experience has shown that due to the instability of fluidised sediment it is not possible to install a gallery to a depth greater than 150 to 200 mm without the use of shuttering and a high output de-watering pump, neither of which are readily available to rural communities. With no surety of gaining sufficient depth to ensure that the gallery remains within saturated river sediment, the reliability of a community infiltration installation cannot be assured.

Suitable materials are however readily available for the construction of infiltration galleries. Purpose designed piping in a variety of diameters and wall thickness and a range of slot lengths and widths can be used as a suitable screen in medium to coarse sediment when matched to sediment grain size. An envelope of porous, synthetic fabric fitted around piping with large apertures is equally suitable to prevent the ingress of fine sediment into a system. There is however nothing readily available for the effective installation of lengths of piping in a horizontal plane deep within saturated sediment. To overcome this and in an effort to keep construction basic, Peterson, Aljibury et al., (1974) suggests that rather than an infiltration gallery, a sand filled trench of about 1.0 metre width be used to convey water to the base of an offset well.

Well-points

The difficulties likely to be experienced with the installation of well-points, also constitutes a limitation on most communities ability to undertake an installation of much of the equipment which is commercially available. Although some driven well-points are obtainable, many of the commonly available well-points have been designed for installation by jetting, thus installation remains an intractable problem for rural communities. On particularly large schemes, bulldozers have been used to clear dry surface sediment in order to reach sediment in which jetting may be undertaken, (Mpofu 1996).

A selection of well-points is available on the market with a choice of design, construction material and size. Screening used in the design of several well-points has been designed primarily as borehole casing, or for de-watering purposes. Installation of these well-points is generally accomplished by jetting with several designs incorporating a self-jetting mechanism. A self-jetting well-point connected to a centrifugal pump ejects a concentrated stream of water from the end of the wellpoint, sufficient to loosen sediment in front of it as it is pushed into the sediment. This jet of water creates an ever deepening, fluidised cavity in front of the well-point. As the flow of water continues, a back-wash is created up the outside of the well-point carrying the loosened sediment to the surface.

Hofkes, Huisman et al., (1981) advocates jetting which he maintains makes for a faster installation than a driven well and requires no mechanical force. Consequently, lighter plastic may be used instead of steel in the construction of the well-point. However, he concedes that jetting may only be carried out in unconsolidated formations such as sandy aquifers as clay and hardpan often offers too much resistance to the jet stream of water.

Stapleton (1983) is of the opinion that well-point screens may be made locally from a range, or combinations of several materials. He states that steel, plain galvanised or stainless; brass, plastic, wood, bamboo, burnt clay or coir may all be used in the construction of well-screens. He also points out however that well-screens should be made of materials which are compatible with the chemical and bacteriological characteristics of the available groundwater. Stapleton further contends that whilst commercially available well-screens may be preferable by outlasting and outyielding locally available alternatives, often their lack of availability or the time required for delivery will outweigh the advantages they have over alternatives locally available. This is particularly so at isolated wells and those expected to only supply small quantities of water.

The U.S. Agency for International Development (1982) provides information on different methods of installing tube-wells. Driven well-points are said to be the simplest to construct. Their example is to fit a threaded drive cap to the top of the well-point pipe and to strike it repeatedly with a sledgehammer or drive pipe which fits over the pipe. However, the experience of the author is that irrespective of protective measures, considerable damage is likely to occur to any thread fitment, sufficient to prevent a further connection to the pipe. An alternative is to use a driving bar that fits inside the well pipe, to strike the well-point tip or to impact on a removable end cap fitted within the well-point.

Development of Suitable Technology

Both well-point and infiltration gallery systems constitute proven methods of abstraction and both hold considerable potential for the abstraction of water from river sediment. However, although there are successful examples of small-scale alternate sand-abstraction systems there still remains an absence of appropriate equipment suitable for widespread, small-scale community use. In order to develop the water supply potential of dryland, sand rivers and to make more water available from sand river aquifers, a suitable installation and abstraction technology is still required.

Appropriate equipment is required to meet the needs of arid-area communities. It is vital that equipment and a technology level be developed to a standard at which rural communities can relate and at which they are able to set up effective operation and support systems. It is further necessary that all operation and maintenance systems can be effected with minimal skills and equipment and that they are appropriate to the water source.

6.2.1. Achievements in Small-scale Technology

Several Non Government Organisations in Southern Africa have developed sandabstraction systems or similar type initiatives that they use to provide water to families or communities.

Well-point & Infiltration Gallery Systems

The Dabane Trust operating in western and southern Zimbabwe has assisted more than 50 rural community groups with more than 100 simple well-point abstraction systems. The crux of the system is a single well-point jetted to the base of the river sediment. The well-point is connected with an alkathene pipe to a Rower type pump on the riverbank. Water is discharged into a sub-surface sump from where, if the riverbanks are low, it is drawn by a second Rower pump to a garden or livestock water tank. If the water in the sump has to be raised more than a few metres, use is made of a simple piston force pump. Using Rower pump components, the pump has been designed, developed and fabricated by Dabane Trust staff and is referred to by them, as a Joma pump.

Although the pump system is unsophisticated, well-point installations are carried out with a jetting pump, which elevates the installation beyond a community capability. However instances are known, where a well-point which has become high and dry, has been reinstalled by a group who have simply dug into the sediment until the wellpoint can be placed back into saturated sediment. This system of installation by excavation has also been used by Dabane Trust to install infiltration galleries into riverbeds where the saturated river sediment is too shallow to install well-points. The infiltration galleries discharge water into false wells on the riverbank from where water may be drawn by either the Rower or Joma pump.

The handpump system used by the Dabane Trust is of simple design and construction enabling a satisfactory degree of village level operation and maintenance, (VLOM). To ensure sustainability the Trust invests considerable time in the technical training of group members as well as in the social development of the group before commencing any installation. Figure 6.6 shows a diagrammatic representation of a Dabane Trust sand-abstraction system.



Figure 6.6: Representation of a simple well-point sand-abstraction system

Lined Sand River Wells

The Rural Industries Innovation Centre (RIIC) at Kanye, Botswana has developed a system of inter-locking well-rings which have been installed in riverbeds in north eastern Botswana. Each ring is 450 mm high with a wall thickness of 40 mm and an I.D. of 900 mm, figure 6.7. Re-bar built into the rings extends vertically some 400 mm above the top of each ring and locates in tubes built into the ring fitted above. Following identification of a suitable rock base on the riverbed, installation into the sediment is by extracting sand from inside and under the bottom edge of the first ring,

so that it sinks into the sediment. The first ring is made with no-fines concrete and thus is porous. As the ring sinks into the sediment so second and third rings are fitted until the first ring sits in water on the rock base. Efforts are made to secure the well-rings to the rock but this has to be either carried out under water or, if conditions are dry, in the knowledge that the water supply is unlikely to be perennial. Due to the depth of saturated sediment, wells often do not extend to the full depth of sediment but are only constructed deep enough to install a screened submersible pump which is either mains or solar electricity powered.

The RIIC system does provide for a good inflow of water into what amounts to a 900 mm diameter caisson but due to installation difficulties is seldom installed in deep water and thus can run dry. Instances are also known of the well linings collapsing during river floods and of well caps coming loose so that the wells fill with sediment.

Figure 6.7: Concrete lining for sand-wells

DHV Consulting Engineers (1978) provide a detailed description of a shallow well programme involving the installation of well-rings in river alluvium in the Shinyanga Region of Tanzania. Well-ring diameters of either 1.45 or 1.20 metres were used with 0.40 metre diameters used at greater depths. DHV refers to a number of problems that they encountered, but not to any difficulty with well covers. Where sediment was more than 3.00 metres deep, problems were experienced with fluidised sediment welling up in the lining during digging-in. Apparently quicksand conditions could occur very quickly within the lower well-rings as they were lowered into the river sediment. Advice given is not to expect to dig into river sediment to a depth greater than 3.00 metres. DHV recommends that the digging of the well and concomitant lowering of the well-rings should be undertaken as a continuous process to prevent lodging of the lining. If installation is held up, sediment will settle around the wellrings binding the upper rings in place so that when digging continues only the lower, cutting well-ring will continue to drop. The alternative recommendation is that wellrings should be linked to each other so that they are lowered together as a single unit. Mann (1992) has prepared a detailed manual on the construction of wells using cutting-edged well-rings. The paper includes mortar mixtures and designs for the well-ring forms and handling equipment.

Hydraulic-head Sand-Wells

The Regional Land Management Unit, (RELMA/Sida), Nairobi, as explained by Nissen-Petersen (2000), have produced a design for a well which is suitable for use in a sand river. The large diameter shaft has a head that allows flood water to pass over the well without damage. The head is constructed at sediment surface level and approximates an up-turned boat with the 'bow' shape facing up-stream. The intention is that water and debris that might damage the structure will have no surface on which to catch and thus will by-pass the well shaft.

The well shaft is constructed from an initial ring which is cast in an excavation in the river sand with a bevelled leading edge. This lining sinks into the sediment under its own weight as sand is removed from within and under the ring. The well shaft is constructed from pre-cast radiused concrete blocks, which are fitted onto reinforcing rods on the initial ring. The first eight courses are laid without mortar to allow entry of water to the shaft. Water is abstracted by handpump or rope and bucket through a cover over the well shaft in the 'stern' end of the boat shape. Figure 6.8 shows the design of a hydrodynamic well-head and figure 6.9 the design of a sinking well-shaft.



Figure 6.8: Design of a hydrodynamic well-head, (Nissen-Petersen 2000)





Tube-Wells

Although not a sand-abstraction technology per se, the development of tube-wells, and by extension a tube-well installation programme, has much of relevance to the development of successful initiatives in sand-abstraction technology. Slotted screen tube-wells are used extensively in parts of Bangladesh, Pakistan and India to a depth of approximately 6.0 metres. Van Herwijnen, van Steenbergen et al., (2002) confirms that low cost, hand-drilled shallow tube-wells for irrigation have become very popular in many parts of the world. Traditional hand sludge techniques are particularly successful in areas with sandy or loamy substrata, such as large parts of the Indian Terai. Installation of the tube wells from the surface into the water-table is frequently undertaken by surging, a simple technique very much in the domain of local people. Tube-well augurs, such as those produced by Nordmeyer (Undated) and V&W Engineering, (Morgan 1990(a)) also provide communities with an installation option where they are able to exercise significant control. Successful tube-well auguring programmes have been recorded by Paul Deverill, (Deverill, Nash et al.,1999(b)) in Maputaland, South Africa and by Jonathon Naugle, (Naugle 1991) in Niger.

The Mvula Trust in South Africa has developed a community supported tube-well installation programme using a simple tripod-mounted hand-operated drilling rig known as a 'Vonder Rig'. The drilling procedure is slow but is a very basic technology which engenders a high degree of community involvement and control. A complete account of the auguring procedure is described by Morgan (1990(a)). The Mvula programme supported three teams each of 4 or 5 people to bore to water at depths of up to 20 metres. Each tube-well successfully provided water for up to 25 families. Figure 6.10 shows a group of rural women using a Vonder Rig to auger bores to install tube-wells in riverbank alluvium at Dongamuzi, Matabeleland North, Zimbabwe.

Figure 6.10: Vonder Rig operated by a community group



Since 1988 the Lutheran World Federation has supported a programme of tube-well auguring in Niger. Naugle (1991) describes the construction of 180 mm diameter hand operated soil augers and drive shafts that can be used to auger to depths of 14.00 metres, including 4.00 metres into the water-table. A variety of augers enables drilling in clay soil conditions through to sandy soils. The resultant bores allow the installation of 160 mm uPVC casing into which smaller diameter slotted uPVC pipes can be fitted. Naugle states that it is most important to tightly fit a 100% synthetic polyester filter cloth over the slotted pipe to prevent the entry of fine sand into the well. Once the uPVC casing is installed to full depth, 4 to 6 metres into the water-table, it is necessary to plug the bottom of the well with gravel to prevent fine sand filling up the well. Water has been abstracted from these tube-wells by hand drawn bailers at up to 1,350 ℓ /hr, shadufs at 3,600 ℓ /hr, rope and washer pumps at 3 to 6,000 ℓ /hr and treadle pumps at 5 to 7,000 ℓ /hr.

6.2.2. Limitations to Use of the Technology

In areas of poor water supply sand-abstraction has a particular relevance, however these areas are subject to a supply vulnerability that may be exacerbated by improvement or more widespread use of the technology. Communities in water deficit areas have learnt to manage their water resource wisely, due in part to the sheer difficulty of abstracting limited amounts of water over a long period. The introduction of less tedious and apparently more plentiful supplies which are easily pumped may quickly lead to over-abstraction and a breakdown of the delicate balance of supply and demand, leading to the drying up of a supply.

The introduction of a gallery, false well and handpump system is known to have caused considerable inconvenience and difficulty for a community at Dongamuzi, Lupane District, Zimbabwe. Groundwater in the area was so highly contaminated with mineral salts that the water was completely unpalatable for both humans and livestock. In the dry season water was drawn from a thin water lens on impermeable sediment below the river alluvium. People queued for long periods and consequently were only able to abstract limited amounts of water. Following the installation of an infiltration gallery, water flowed copiously and people came from near and far to use the 'sweet' water. Donkey carts appeared with small bowsers and took away large volumes of water so frequently that the flow in the stream dried up – but there was no other source available and people then had to dig wells in the silt of a dry dam basin to obtain a daily dribble of muddy water.

Although both Mansell, (Mansell and Hussey 2003) and Magumise (2003) indicate that abstraction may generally be considered the smallest cause of water loss from sediment a large number of abstraction systems may well reduce the amount of available down-stream water. High expectations and increased use generally accompany any 'improved' water supply, thus when a supply does dry up through whatever cause, considerable hardship may be caused to rural communities who may have few other resources.

6.3. Development of Abstraction Systems at Less than Optimum Sites

The technology of sand-abstraction is essentially related to the withdrawal of water from saturated river sediment. However, the same methods of abstraction may be applied to the drawing of water from saturated alluvial aquifers of a non-prime nature where there are difficult geological conditions or minimal reserves of water. Such conditions may exist in gravelbeds, paleo-channels, fossil rivers, vleis and alluvial riverbanks. Cansdale (1983) records that many of the rivers in northern Nigeria have deep beds of coarse sand, which extend for considerable distances from the main river channel and retain water throughout the dry season.

In a large scheme planned to store water in sand, Water Online (1999) reported an intended discharge of 51,000m³/hr (225,000 U.S. galls/min) over four months from the Colorado River onto the desert floor east of Palm Springs, California. The plan was to pump water into a dry lakebed from where it would seep into the underlying sand and then permeate to the east where pumps would be located to retrieve the water when required. The intention was to store up to 111,000 ha m (900,000 ac ft) of water in the sand. Significantly smaller run-off water catchment and storage schemes,

both artificial and natural, also hold considerable potential for water storage and abstraction. Bigeastern (1998) explains how wetlands are often misunderstood, but are a critical part of the functioning of a sand-country ecosystem and are likely to store considerable volumes of water due to their permeability. Kanyanda (2001) is of the opinion that more water could be abstracted for use from vleis, or dambos, and wetlands within Zimbabwe.

In order to work effectively within less than optimum conditions for abstraction, modifications have been made to standard sand-abstraction equipment to make it more effective. In order to preclude the ingress of ultra fine sediment through a screen for instance, synthetic textile has been used to cover well-points and infiltration galleries.

- Tube-wells have been installed by Ncube (2001) in fine Kalahari sand in the alluvial sediment deposited during river channel realignment and also in paleo-river channels. To prevent the entry of fine aeolian sand into the handpump cylinders, the screens that were installed on the pump inlets were wrapped in geotextile.
- Deverill and Nash (1999(a)) reports on a procedure adopted to augur tube wells into sub-surface collapsing sand beds in north eastern South Africa. The screens were wrapped in geotextile to prevent clogging of the tube well.
- Tube-wells with small-bore slotted screens (slot width 0.30 mm) are a further option and have been successfully installed by jetting. Maclear (1997) has described jetting such screens into the fine sands of the Cape Flats, Cape Town, South Africa
- Driven sand-spears have been used to abstract water from gravelbeds at depths in excess of 6 metres (20 feet). Both de Vries (1999) and Dungan (2001) describe their experience of driving well-points by hand through clay layers to underlying gravelbeds.

Other sub-optimum sites are river channels where there is a shallow depth of sediment, but nevertheless contain useable quantities of water due to adequate recharge. These conditions which preclude the use of vertically placed well-points may be developed through the use of horizontal infiltration galleries. Watt and Wood (1977) is of the opinion that tunnels or adits which are dug or driven laterally from the base of well, even if only half a metre long will considerably improve the yield of a well. Watt also suggests that perforated galvanised steel pipe may thrust horizontally through the sides of a well with the use of car jacks, a strategy which he considers is both simpler and less costly than driven adits. Similarly in thin aquifers, caissons or large diameter lined wells may be appropriate as the larger diameter from which water may be abstracted enables a reduction in the height of the caisson or porous well shaft.

6.4. Development of Water Abstraction Equipment

Improved abstraction systems for sand-abstraction schemes have been designed and implemented but have primarily been one off schemes for specific needs for individual ranches, farms, mines or hotels, generally in remote areas. The sandabstraction systems that have been developed have been for cattle water supplies and irrigation schemes of 10 to 20 hectares or more. There has been virtually no attention given to the development of basic small-scale hand operated community schemes in industrially developing nations. The lack of suitable equipment has necessitated the development of appropriate, low cost well-points and pumping equipment which would be suitable for rural, community use in conditions where tools and skills are limited and at a premium. This in turn has required study into the operation and maintenance of equipment.

Much of the early development work that has been under-taken was provided by personnel of para-statal organisations and commercial firms within Zimbabwe in the 1950's and 1960's. However, much of the information on these installations and the resultant abstraction technology that was gathered was undocumented and has subsequently been lost when the designers left the industry. Systems have been described to the author by Cooke (1987), Esterhuizen (1987) and Schegar (1996), but the practical experience gained by these artisans was not passed on and not fully recorded. It has now largely been lost to posterity. This study and research has been undertaken in part to not only document and correlate the information that is presently available, but also to regain some of the information that has been lost.

Driscoll (1986) however has provided much background information in his reference book, Groundwater and Wells and much data that is required for the design of sandabstraction systems. Much of Driscoll's data includes information on screening and suitable velocities for abstraction systems. Wipplinger (1958) also has provided much practical data on abstraction and the storage of water in sand.

Because of a general lack of design guidelines and standards, many of the schemes that are installed today are under-designed and as a result frequently draw greater volumes of sediment through the system than is practicable. Under-designed systems are either starved of water or draw more fines into the system, which in time clogs up and blocks the entire system. Inadequately designed systems have certainly been seen to fail to abstract water satisfactorily. In a personal interview Germann (1991) stated that on more than one occasion volunteer water engineers who had been lured by the apparent volumes of water in river sediment had tried without success to satisfactorily draw water with low-volume pumps. A sound design, with a correct screen aperture size and entrance velocity that will prevent the entry of sediment into an abstraction system, together with the correct velocity of water through the pipe system is thus imperative. Kempadoo (1994) has described to the author a sand-abstraction system installed at Mzimuni, Gwanda District, Zimbabwe, where a progressive cavity pump of output 5 m³ per hour was connected to a single 50 mm steel well-point with a design yield of 1 m³. The result was that within six months the entire inlet pipe and vacuum tank before the pump had become blocked with sediment to the detriment and failure of the pump. Following several repairs and the replacement of several pump rotors and stators, the under design of the scheme was brought to the attention of maintenance engineers.

The effect of inadequately designed or poorly fitted equipment is made clear by Shekwolo (1999) who states that a systematic deterioration of well performance occurred in the Bida Basin of Central Nigeria due to the installation of screens with an incorrect slot size. Apparently clogging of well-points by fines occurred to such a degree that the average yield of the basin was reduced by between 25 and 30% over a period of two years due to inappropriate methods of abstraction leading to a decline in abstraction from the aquifer. Shekwolo states that encrustation of iron and manganese hydroxide deposits caused further clogging of the well-points and is of the opinion that well-points of a more suitable and appropriate design such as multiple slot sizes or double-rap netted screens would have avoided any deterioration of the system.

Well-screens

Most abstraction systems are dependent on screening to prevent the ingress of sediment into pipes and pumps. Following the deterioration of water output from systems where an on-the-spot well-point has been hastily manufactured from steel, flexible polythene or rigid uPVC it is apparent that practical research into slot design; shape, formation, length, width and percentage cover is critical. Correct slot or aperture shape and size is crucial to the effectiveness of a well-point to ensure the successful separation of water from sediment. A suitable size of entry aperture is also necessary for the development of an adequate 'gravel' pack around a well-point. The importance and benefit of a naturally developed grading pack around a well-screen is critical and has been well documented in Driscoll (1986) and in several drilling manuals such as Dando Drilling International (2000). Johnson (1966) has recorded an improvement of nine times on the original yield after most of the smaller particles had passed through a well screen.

The importance of a suitable velocity of water through a well-point system is also critical to ensure that any sediment which may have entered the system, from one cause or another, does not proceed to the detriment of the system. The optimum velocity of abstracted water through systems of differing capacity and output should be determined. Cooke (1987) has suggested velocities in various sections of a system which may well act as a starting point in establishing optimum design. He opts for an abstraction point velocity of 0.077 to 0.107 m/sec, (0.25 to 0.35 ft/sec) and a velocity of 0.61 to 0.91 m/sec, (2 to 3 ft/sec) through the well-point, which he refers to as a stilling tube. He finally indicates a delivery velocity of 1.22 to 1.52 m/sec, (4 to 5 ft/sec).

As outlined in earlier sections of this thesis, a number of purpose-designed wellpoints are commercially available. Although there is a wide range available, many are high volume self-jetting screens which are considerably over designed for smallscale schemes and require complex equipment and copious volumes of water for installation. Jackman (1997) of Soloflo, Con-slot (Undated), Boode (1995), Paparelli (2000) and Johnson Screens (2002) each provide details of a considerable range of products designed for water-wells. Between them, these manufactures produce wellscreens which range from diameters of 16 mm $(\frac{5}{8}$ in) to 1.220 metre. Figure 6.11 shows a 3.00 metre × 150 mm Johnson self-jetting well-point of the type installed in the Save River to supply water to the 2,500 ha Chisumbanje irrigation scheme in the Zimbabwean Low-veld. Boode (1994) also provides a brochure with details of infiltration galleries, de-watering systems, gravel packs and commercially available well screens and casing which are suitable for use in gallery and well-point abstraction systems. The technology of both screening and synthetic filter materials in the water-well and borehole drilling industry is widely used as evidenced by the wide range of advertisements in comprehensive water manuals such as 'Developing World Water', (Pickford Undated). Further useful reference material is provided by Gibson and Singer (1969) who presents a most detailed explanation of the fabrication and installation of well-points.

There are however exceptions to these high volume, high performance well-points. Richard Cansdale of SWS Filtration has developed both a uPVC self-jetting wellpoint and a very effective composite well-point for small-scale schemes. The selfjetting screen is fabricated from Boode slotted uPVC pipe and the composite screen from a series of open centre discs. Each disc tapers, narrowing from the outside edge to the interior edge. Eighty discs are assembled over four spokes similar to those used on cycle wheels to form the screen. The discs do not come into complete contact with each other, thus as they are stacked on the spokes a 1.50 mm slot is formed between each disc on the outside and 2.00 mm on the inside of the screen. Figure 6.12 shows the components and assembly of an SWS Filtration well-point.

Figure 6.11: Johnson self-jetting well-point



Boode (1994) also produce a range of smaller, low volume screens. An innovation for use in fine sediments is the application of a bonded or so-called ceramic cover, which can be applied to any of their slotted pipes. A slotted pipe is covered with a 12 mm layer of graded sand held in place with an emulsion. The emulsion envelopes the sand particles and forms a bond between them but does not infill the particles nor seal the surface, thus water is free to permeate the voids between the particles. The cover in effect becomes an integral, finely graded pack that can be used in conditions of fine sediment. This process is typically used on short lengths of narrow bore pipe to form well-points which can be linked together for the de-watering of extensive areas. Figure 6.13 shows an 850 mm long \times 65 mm O.D. ceramic well-point cover over a 41 mm O.D. uPVC pipe.

Figure 6.12: SWS Filtration well-point



Figure 6.13: Boode ceramic well-point for multiple or single application small-scale use.



With further information on well-points which may be used in small-scale, one off applications, Gollnhuber (1995), representing WESA, a South African Company and part of the Preussag group of companies provides information on a "Stahl-Rammfilter" (SBF) drive pipe which he says may be used for de-watering and to draw water from sand rivers. Gollnhuber also provides a useful sketch for the fabrication of a small bore 32 mm (11/4 inch) self-jetting steel well-point. Industrial Merchants (Undated), another South African company, provides data on a range of slotted uPVC well-screens and casing in either plain or ribbed piping. This company also produces 'ceramic' gravel pack screens of graded quartz bonded around slotted screens of diameters from 35 to 400 mm. Other products are double walled screens, combination jetting/driven well-points and driven well-points for de-watering. Surescreen Manufacturing (Undated) advertise that they produce slotted uPVC, steeland-brass and stainless steel sand-spears which can be installed by jetting, driving, auguring or bailing into sandy water-bearing formations such as dry riverbeds or coastal dunes. Johnson Division (Undated) also advertise small bore, 32 and 50 mm (1¼ and 2 inch), stainless steel driven and jetted well-points in a variety of slot and mesh sizes.

Shield and Montbron (1998) advocates uPVC borehole casing and screening which he says is lightweight but tough, non-toxic and corrosion free with smooth surfaces that do not encourage encrustation. Boode (1999) states further advantages for uPVC with a wide range of pipe diameters that may be slotted ranging from 25 to 630 mm and a wide range of slot sizes available, from 0.3 mm; 0.5 mm; 0.75 mm; 1.0 mm; 1.5 mm; 2.0 mm through to 3.0 mm.

Of non-commercially available screening, a simple method of fabricating a water inlet strainer is described in a US AID brochure, Water for the World, (U.S. Agency for International Development 1982). Although the construction of the screen has been described for use as a stream water intake, the brochure outlines the pipe work, drilling and screening which could equally be used as a sand-abstraction well-point. A completely alternative method of using bamboo in the construction of well-points is described by I T Publications (1991) with two methods of fabrication cited. One method creates a length of bamboo pipe by removing the internal blocks caused by the nodes. Slots up to 100 mm in length are then cut longitudinally around the circumference of the bamboo with a circular saw. A second construction system comprises strips of bamboo 25 mm wide and 10 mm thick. Lengths up to 5.00 m long are fixed to 100 mm diameter rings to form a tube, which is then tightly wound with a single layer of coarse coir string. Although not stated it is to be assumed that installation would be undertaken by surging.

Further information is provided on well-points which Stapleton (1989) says may be made locally. Stapleton refers to bamboo and coir covered well-points and provides basic information on driven well-points such as perforated steel piping which is wrapped in turn with perforated brass sheet that is soldered to the steel pipe. He also refers to a "common type of well-point screen" that comprises a length of trapezoidal section wire wrapped continuously around a frame to leave a slotted open area through which water may pass. Michael and Khepar (1989) also makes reference to a range of locally made well-points or well-screens in steel, brass and uPVC with some designs incorporating materials such as wire, rope, bamboo or coir. Michael also advocates the use of pre-pack filters to improve screen efficiency.

In a somewhat simplified account, U.S. Agency for International Development (1982) maintains that screens may be produced from any metal, plastic or clay tile casing merely by forming holes or slots in the material. However they do state that there is a disadvantage with such screens when compared with commercial screens as the size of slots cannot be made small enough to screen out fine sand and the lower percentage of open-surface area will restrict the entry of water.

Although in certain situations infiltration galleries may be preferable, the author is of the opinion that the simplest and most effective method of abstracting water from saturated sediment is through the use of a well-point. Although a range of well-points is commercially available, many of these have been designed for large-scale schemes and have the associated limitations of over-design, complexity and expense. Further, although it is possible to construct well-points from naturally available materials such as bamboo, these would appear to be more suitable for installation in stable tube-well conditions, installed by surging, rather than in the turbulent conditions of an ephemeral river channel. In river channel conditions sediment is occasionally in a state of flux and sediment has been seen to damage or clog abstraction equipment that is not robust or adequately designed or installed. Options to overcome many of these shortcomings have been considered and a decision made to design and fabricate a range of well-points for small-scale use by disadvantaged communities.

Installation Methods

Sound but simple installation methods are as critical to the success of small-scale sand-abstraction systems as the actual abstraction screens. Typically well screens are installed by jetting as purpose designed self-jetting well-points. Alternatively wellpoints may be installed through the creation of a jetted bore into which a well-point can be inserted or by attaching a well-point to the side of an open jetting tube. To be effective, jetting from the surface is best carried out in at least moist sediment, either when the sediment is still wet before the onset of the dry season or in wetted sediment. When an installation cannot be undertaken into wet or moist sediment, dry material may be removed down to a level where jetting may be carried out. This may be accomplished by excavating by hand, or in particularly large schemes by dozers. However even this method has its limitations as wear is excessively high on the tracks of tracklaying equipment in loose, coarse sand.

Alternatives to installation by jetting are digging-in, however with severe limitations to deep digging in aqueous sand is not at all easy to initially install a well-point to a sufficient depth, unless the installation is carried out within a few days of the sediment becoming saturated throughout the river channel. Even then, the water level in the river sediment may drop below the well-point in subsequent, drier years. Successive re-digging-in of the well-point is generally required until a satisfactory depth is reached.

The driving of purpose designed well-points generally overcomes the foregoing limitations. Well-points may easily be driven to 4 or 5 metres which is usually the maximum depth of accumulated river sediment. Dungan (2001) maintains that he is able to drive well-points to depths of 20 m (67 feet) using an ordinary fourteen pound steel sledge-hammer. Detail is given by both Stapleton (1983) and Visscher, Paramasivam et al., (1987) on effective methods of driving well-points with percussion weights impacting onto drive caps on the top of well-point connection pipes. Alternatively he suggests driving weights which impact onto sealing rings at the top of well-point connection pipes, as well as driving bars used inside well-points to bear onto the leading point of the well-point.

The differing methods of jetting, driving, auguring or digging well-points into position are each most disruptive of the natural sediment formation. However there appears to be no discernable effect on the ultimate development of the natural gravel pack with any installation method in the abstraction zone of a well-point. Decisions on installation procedures ultimately proved critical as they limit both the design and the materials that might be utilised for the development of abstraction equipment.

6.5. Research Undertaken

6.5.1. Criteria and Selection of Equipment Design

Preliminary research and planning was undertaken over several years to the possible design, fabrication and installation of well-points. The following criteria was accepted as crucial to successful design:

- The use of any alternate design or materials should not impair the efficiency or effectiveness of equipment
- Construction materials should be those which ideally are available in industrially developing countries
- Materials for construction should be durable
- Fabrication should not be complex nor dependent on the use of complicated tools or intermediary equipment
- Installation procedures should be straightforward and easily achievable
- Material strength should not be compromised
- Physical design should ensure:
 - Lateral and axial flow characteristics low enough to minimise particle inflow and transport through pipework
 - Overall screen length short enough to ensure that the screen is not rendered inoperative as water levels diminish and drawdown increases

The correct identification of suitable fabrication materials was thus critical as selection impacted significantly on each of the design criteria. The ideal well-point was intended to be constructed, assembled and installed without the need of specialist components or tools and without any infringement of the performance of equipment. Note was taken of general comments such as those from Stapleton (1983) who points out that well-points should be able to withstand the stresses of installation and the hydrostatic pressures at the abstraction point and also to have as many perforations as possible to maximise water flow. Decisions on installation procedures however proved critical as they limited the design and materials that might be utilised for the development of abstraction equipment.

From prior experience and from a study of available well-points and screens, seven differing concepts of sediment/water separation were conceived. Efforts were then made to develop effective systems of fabrication, installation and delivery for the proposed draw-off systems:

- Open aperture well-point
- Open slotted well-point
- No-fines concrete clad perforated pipe
- Open aperture caisson
- Open-ended caisson
- Shielded gavel pack around perforated pipe
- Large pipe perforations restricted with synthetic material

Material Selection

Moffat (1980) is of the opinion that the selection of the correct and appropriate well screen is important in any context, but especially so in a developing country where equipment and personnel may not be available to correct any future failure or fault. Moffat states that an appropriate screen should:

- Have a life expectancy similar to that of the rest of the well installation
- Be constructed from material which should not be corroded by the groundwater and if encrustation is expected the screen material should be unaffected by the chemical or method used to remove the encrustation
- Be of material that is workable, easily slotted and locally available.
- Be of a weight and construction such that it can be transported easily and safely by whatever means are readily available
- Not deteriorate in storage under hot and/or humid conditions
- Not be sufficiently expensive to restrict the number of installations

Moffat goes on to say that some factor should be included for the social and psychological benefits obtained from a regular and constant source of water and considers that if screen problems such as blockages or collapse occur frequently the users will lose confidence in the scheme and revert to their former, perhaps polluted sources. He concludes that cheap first cost and low life materials may thus not be the most satisfactory selection.

Initial research work, to enable ease of installation, design and fabrication of draw-off systems, was undertaken on steel pipes as they were relatively easily worked and were of a strong and rigid material that could be easily driven into saturated sediment. However the initial expense of steel pipe together with the expense of equipment required to work in steel and subsequent poor performance precluded the eventual acceptance of steel for well-point manufacture.
uPVC was selected as a primary material suitable for most of the proposed wellpoints. A sales brochure produced by Promat (Undated) states that uPVC is durable, malleable when heated, easily worked, relatively cheap and generally widely available in industrially developing countries. However, it lacks tensile strength and is liable to shatter on impact. As one design criteria was easy installation, sacrificial steel points were designed to allow the uPVC well-points to be driven by impact into sediment. The drilled or slotted uPVC piping which formed the well-point screen was riveted to a tapered steel drive point. The upper edge of the tapered point engaged with a length of steel drive-pipe of the same cross-sectional dimension, allowing the uPVC wellpoint pipe to fit inside. Sufficient impact on the steel pipe enabled well-points to be driven to the full depth of river sediment. As depths in excess of 3.00 metres could be easily reached, initial driving was required from a step-ladder or some form of scaffolding. The driving tube was sufficiently loose around the well-point pipe to allow it to be raised by hand from the sediment after driving and to leave the wellpoint in position within the sediment.

Hazelton (2000) is of the opinion that flexible high-density polyethylene (HDPE) is a more suitable material for pump columns than rigid uPVC pipe. He states that it is more versatile than uPVC, due to its characteristics of flexibility and an ability to stretch without breakage and is likely to be more durable and less prone to fracture. However as the product is not available in Zimbabwe and is unlikely to be widely available in industrially developing countries it was not considered for development and test purposes.

Cement and stone were other materials considered suitable for use in the construction of abstraction equipment. The use of these materials for screening effectively produced a caisson that was not suitable for installation by driving. By virtue of larger dimensions and bulk, each caisson required installation by digging-in.

Other materials were considered but not actually utilised. Although commonly used in de-watering and drainage applications and occasionally used within the research programme to make a comparative check with other materials, little attention was given to the long-term use of synthetic fibres. This was primarily due to difficulty of regular supply and of cost. However a review was undertaken of products such as high quality industrial filtration bags as used in the waste industry and produced by many companies, such as Technical Fabrics, (Tunstall 2002) and Ocmis (UK) Ltd. Study showed that extensive use is made of synthetic textile for drainage, particularly in the building and waste industry. James (1999) for instance reports on the use of Kaytech U24 geotextile designed to draw some 300 l of water through a 4.5 m deep by 600 m long drain from agricultural land above a hazardous waste containment site near Johannesburg, South Africa. The geotextile was placed as a curtain throughout the depth of the trench to prevent the movement of water onto the site. Kaytech (Undated) provides an extensive range of synthetic textile, mesh and piping. Both Raymond, Bathurst et al., (1996) and Koerner, Koerner et al. (1996) detail installation procedures and report on the satisfactory use of geotextiles in highway drainage applications and erosion control measures.

Whilst apparently satisfactory in performance in correctly designed infiltration schemes, it was not immediately evident that geotextile would necessarily be suitable as a well-point screen under pump conditions. Some scepticism was identified in the assessment of the hydraulic performance of synthetic materials, which was said to be not easily ascertained. Dierickx (1996) for instance, points out that a straightforward measure of the hydraulic gradient across the textile is insufficient to assess the passage of particles and the risk of blockage and clogging within the textile. He states that in order to fully appraise synthetic textiles a comparison must be made of the evolution of the hydraulic gradient in the soil and the hydraulic gradient across the textile. Dierickx concludes that although permeameter tests have been designed to evaluate geotextiles, they require careful preparation and accurate execution and may be unduly influenced by soil types and soil conditions. Lafleur, Assi et al., (1996) however does provide some data on pump tests that he has conducted on non-woven, needle-punched geotextiles which he maintains adequately prevented piping into the into the sub-base. His results disclose that the geotextiles were sensitive to a filtration opening size of O_{95} and that particles entrapped in the sheets of textile contributed to a 12 to 17% increase in their mass per unit area. Morris, Talbot et al., (1991) report on pilot tests using corrugated uPVC pipe wrapped in woven nylon or plastic fabric to draw water from slow sand-filter systems. He expresses concern that there would be limitations to such a method of drainage as he considers that pipes wrapped in synthetic fabric would require installation at closer centres than piping that was covered with a graded gravel pack.

Recent developments in filtration technology such as the sintered porous plastic tubing manufactured by Porvair (2001) were considered worthy of investigation as a possible integral component due to the flexibility of the product. However, although probably most suitable, their high quality forced them to be excluded due to high cost. Useful information on pipes and fittings was also found in brochures such as that available from Pipeline Center (2001) and Shipham, (Addis 1996). The use of tubing and fitting components in uPVC, ABS, rubber and stainless steel as used in the dairy industry were also investigated through sales brochures such as that of Dairy Cel (1999). A review was also made of data relating to micro-sand and industrial sandfilters such as those reported on by Minting (2001) and produced by Screen Systems Ltd., (Greenall 2000) and the Organo Corp (Undated).

Material Suitability for Localised Well-point Fabrication								
Material	Local Manufacture Suitability	Durability	Ease of Installation	Likelihood of Availability	Effectiveness	Cost		
Plain/Galvanised Steel	VVV	111	<i><i>√<i>√√√√</i></i></i>	1111	11	11		
Stainless Steel	✓	~ ~~~~	44	1	1111	1		
uPVC	11111	<i>√<i>√√√√</i></i>	11	111	1111	VVV		
ABS	11111	<i>√<i>√√√</i></i>	111	~	4444	✓		
Plastic Mat'ls	11111	\ \ \ \	111	<i>√√√√√</i>	1111	\ \ \ \		
Synthetic Textile	~	V V V	11	~	1111	11		
Natural/organic Mat'ls	VVV	~	~~	~~	11	<i>√√√√√</i>		
No-fines Cement	<i>√<i>√√√</i></i>	\$\$\$\$	111	1111	111	<i>√√√√√</i>		
High-tech Mat'ls	✓	<i>√<i>√√√√</i></i>	11	¥.,	1111	✓		

Table 6.2: Suitability of materials for localised well-point fabrication

Table 6.2 indicates ranking of the suitability of materials that might be used by rural artisans in the fabrication of well-points, that are likely to be available in Zimbabwe and other Third World Nations. A single tick indicates lowest ranking with five ticks

the greatest suitability in each category. Scoring has been based on the results of surveys and interviews. A survey was conducted by telephone on the availability and cost of materials stocked by five pump and hardware supply companies in Bulawayo, Zimbabwe. Ranking of the likely durability of materials is based on some 30 years experience of the author and that of the manufacture and install team of the Dabane Trust. The Dabane Trust team which has experimented with a number of materials in sand-abstraction systems from 1990 to date also provided an assessment of the suitability of materials for manufacture, ease of installation and effectiveness.

Effective Criteria and Efficiency

The efficiency of a well-point may be gauged by its capacity to effectively separate water from sediment. Randall (Undated) maintains that the success of a well cannot be measured simply by the production of water but should be by:

- Efficiency of operation
- Production to a pre-determined yield
- Provision of a reliable, clean, long term source of sand free water
- Suitability of design to minimise installation and completion costs

Randall goes on to say that screen design is critical to the efficiency of a water-well and that the application of improved technology may both improve efficiency and reduce costs. He further states that well efficiency can be more important than pump efficiency in the reduction of water production costs and maintains that many wells have efficiencies as low as 30%, but had they been better designed would be operating at efficiencies of 80% or better. Randall, as well as Con-slot (Undated), conclude that well screening should be adequately designed to:

- Support the water-bearing formation
- Permit an unobstructed entry of water
- Allow development of the formation to improve water yield

To enable this, well screening should have the largest possible open-surface area consistent with strength requirements and slot openings should be arranged so that water may directly enter the screen from the void areas of the alluvium. Randall points out that where a screen has a limited open-surface area of say, 3 to 5%, 95 to 97% of the screen is blank pipe, which is not available for the abstraction of water. Table 6.3 indicates as a percentage the internal open area of typical uPVC pipes available in Southern Africa

Con-slot (Undated) also makes the point of the effect on screens that might be caused by changes in environmental conditions. Changes they say may occur in water temperature and possibly in the analysis of water with long operation times. Material stress, which could be induced during installation, during the development of the alluvium around the screen, or through the cleaning of the screen, may subsequently cause alteration to the shape or material of a screen.

A suitable abstraction velocity is imperative to avoid undue turbulence or disturbance of sediment which might be liable to cause an increase in the movement of fines and result in the clogging of small or narrow apertures. Shekwolo (1999) has indicated the need for adequately designed well-points maintaining that a suitable well-point slot or aperture entrance velocity is of a critical importance for satisfactory water/sediment separation. According to research undertaken by Kovacs and Ujfaludi (1983) suffosion of fine-grained matrix present in the voids of coarse sediment occurs increasingly with a progression of flow velocity.

Percentage Area of Openings for uPVC Well Screens									
Standard design to DIN 4925									
	Typical No.	No. of	Total slot	Slot dimensions ($b \times l$) (mm)					
		uPVC	rows of	length on	0.5×20	0.75×20	1.0×20	2.0×20	
Nominal	Nominal		pipe	internal	Open	Free Area as % (Mean Value)			
Size ins	Size mm	<u> </u>	circum.	cheum	%	%	%	%	
1.5	38	37	3	85	6	8.5	9.5	12	
2	51	50	3	108	6	8.5	9.5	12	
3	76	75	3	168	6	8.5	9.5	12	
4	102	110	5	216	6	8.5	9.5	12	
5	127	125	5	240	5.5	7.5	8.5	11	
6	152	140	5	285	5.5	7.5	8.5	11	
8	203	200	6	390	-	7.5	8.5	11	
10	254	250	6	450	-	7	8	10	
12	305	300	8	530	-	7	8	10	
14	356	350	8	640	-	-	8	10	
16	406	400	8	720	-	-	8	10	
			Slot P	5.5	5.5	9.5	9.5		

 Table 6.3: Calculated Percentage Area of Slot Openings for uPVC Pipes with Smooth

 Surfaces, after (Con-slot Undated)

The importance of laminar flow as shown in figures 6.14a and 6.14b, to screen apertures is stressed by both Con-slot (Undated) and Paul (1990) as this reduces turbulent flow with a consequent reduction in corrosion of the screen.

Figure 6.14a: Free, laminar flow to a newly installed screen. Figure 6.14b: Restricted, non-laminar flow through sediment pores partially blocked with bacterial precipitation, after Paul (1990)



A WEDC paper on design procedure and the development of natural pack in pumped boreholes provides useful data on the design and application of screening that is also appropriate to the design of a well-point, (WEDC 1997). The student handout states that in order to minimise the movement of fines, the diameter and length of a screen must be large enough to provide sufficient open area so that the entry velocity of the water is less than 30 - 60 mm per second. A screen slot size should be selected to allow between 40 and 70% of aquifer material to pass through, 50% being the generally accepted standard. However, a higher percentage passing may be accepted when there is a high proportion of gravel in the alluvium. With reference to slot blockage, the WEDC paper states that a system should be designed to allow for a

blockage of up to 60% of the open screen area, thus the remaining 40% of the open area should be sufficient to maintain the inlet velocity low enough not to transport fines. Con-slot (Undated) states that the intersection between 40% retained grain size and the sieve curve normally determines the slot size.

Oaks and Bishay (Undated) is of the opinion that in general terms soil particles are moved at velocities above 0.35 m/s. Table 6.4 indicates the velocity of water at which it is to be expected that sediment grains of a given size will be lifted from the surface.

Table 6.4: Velocities of water that will cause grains of a given sediment to rise, after Driscoll (1986), from W.S. Tyler Co.

Velocity of Water, (m/sec)	Diameter of Grain, (mm)
0 to 0.03	Up to 0.25
0.04 to 0.07	0.25 to 0.50
0.08 to 0.10	0.50 to 1.00
0.11 to 0.17	1.00 to 2.00
0.18 to 0.80	2.00 to 4.00

The U.S. Dept. of the Interior - Bureau of Reclamation (1981) provides a figure of 0.0305 m/sec (0.1 ft/sec) maintaining the important factor is the percentage of the saturated thickness of the aquifer which is open to the well. The Department considers a generally accepted principle of well design to be based on a screen with an average entrance velocity of 30 mm per second (0.1 feet per sec) or less, based on the percentage of open area of the screen and the desired yield. The rationale of this is that flow at such a low velocity is entirely laminar and thus turbulence is not likely to contribute to any loss of well efficiency. They go on to say that the concept of an average entrance velocity may well be misleading due to the likelihood of considerable variation of velocity over the length of a screen where in an ideal aquifer the entrance velocity in the upper 10% of a well screen may be possibly 70 times faster than in the lower 10%. Depending on slot size and shape and sediment grain size and graduation as much as 78% of the open area may be lost, although 50% is considered a more practical estimate. Beyond an open-surface area of about 60%, practically no increase in efficiency is obtained. For practical purposes, a percentage of open slot area of about 15% is acceptable. The slot coverage of a well screen is also critical as abstraction through close spaced apertures is more efficient than through more widely spaced apertures. An increase in the acceleration of stream flow through a greater convergence of flow lines through the alluvium is created and consequently there is a greater loss of head to wide spaced apertures than to more closely spaced apertures as is demonstrated in figure 6.15. A large open-surface area is particularly necessary in the design of a well-point to ensure a short length of screen which will reduce the possibility of apertures becoming open to unsaturated sediment and a consequent loss of pump prime as the water levels in the river alluvium decrease.

Parallel-sided slots such as those made with saws or banks of fine cutting discs appear to be the least efficient type of orifice and in addition are more prone to clogging by sediment grains. Although screens that are wound with a wire of a round cross section may create very narrow apertures, and uPVC pipe may be slotted with ultrafine cutting discs, the small cross-section of the slots results in high friction losses and tends to promote encrustation. Slot sizes of 0.5 mm (0.02 ins) and less should be restricted to small, low capacity wells.

Figure 6.15: Distribution of flow to well screens after (U.S. Dept. of the Interior -Bureau of Reclamation 1981).



Tapered wedge wire screens minimise clogging as sediment particles that enter the slot apertures are then free to pass through the slot without the possibility of jamming. The parallel surfaces of slotted screens however provide a greater likelihood of trapping particles that enter the apertures. Randall (Undated) indicates that parallel slot screens are liable to become permanently clogged which greatly reduces the effective open area and in extreme cases when completely blocked have been known to collapse.

Industrial Merchants (Undated) state that well-points and infiltration galleries using piping with slots arranged transversely to the pipe axis provides for better flow characteristics than piping with longitudinally placed slots. This company also maintains that piping with transverse designed slots is mechanically superior to resist lateral pressures than is piping with longitudinal slots. Several researchers such as Singh and Shakya (1998) have developed mathematical equations that might be used to calculate the flow of water through a slot, (Singh: q2 = Ks[(hs - hw)/d]!/n), however, in this instance Singh concludes that the results showed a failure to accurately demonstrate the orifice flow.

In a most useful handbook of 'Basic Instructions for Dam Construction', to ensure satisfactory flow within a screen Louwrens (1976) states that the total open area of the screen apertures should be not less than twice the cross sectional area of the pipe. As uPVC pipes are manufactured to a standard O.D., the I.D varies with the wall thickness, or each class of pipe of a given size. However, from a simple calculation of pipe I.D and slot size, the requisite or minimum number of slots may be determined.

Piché (1998) reports on the advantages of high performance, high quality specification screens with slot sizes of 0.15 mm that have been used successfully in aquifers of fine sands of aeolian origin. In spite of such small slot dimensions, the

screens had maintained high levels of open area. According to Con-slot (Undated), continuous V-slotted screens have by far the best hydraulic characteristics of all screens on the market. The high permeability of such screens allows for laminar flow conditions which keeps the entrance losses, corrosion and abrasion to a minimum.

6.5.2. Equipment Designed and Developed

Design characteristics to ensure an abstraction velocity of 0.0305 m/sec and prevention of the passage of 50% of sediment particles from the alluvium in which a screen has been installed have been accepted as a basic requirement. In typical river sediment, to achieve this a slot width or aperture diameter of a mere 1.00 mm is required. Although SWS Filtration has achieved this with its own innovative idea, this is a most exacting standard for a locally fabricated well-point. Maintaining a clean internal surface to prevent the entrapment of fines further compounds the difficulty of satisfactorily constructing such a narrow orifice. Thus a balance of the foregoing criteria has to be reached. The application of narrow apertures for instance, effectively creates relatively long lengths of screening which are more suited to use as an infiltration gallery, than for the shorter requirements of a well-point.

In the course of time, the ideas initially conceived required adjustment. With the suggestion that a screen may be developed successfully with 78% of sediment grains able to pass through the screen a decision was taken to construct well-points with larger apertures. The assumption was that in due course a naturally graded pack would be formed around large apertures and would ease the difficulty of the construction of so many small or narrow apertures. It was accepted that this would allow a greater percentage of fine sediment to pass through the well-point screen in the immediate period following installation but it was assumed that this would stabilise. Screens were initially drilled to 3.00 mm and performed satisfactorily during controlled pump yield tests. However following initial field testing, later screens had to be drilled to 2.5 mm and 2.00 mm as it was found that small volumes of sediment were continuously drawn through the 3.00 mm apertures sufficient to block the pipe. Through the use of a spreadsheet, calculations were easily made to adjust the intervals between the apertures and to alter the length of the screen in order to construct a well-point of a suitable length and diameter which would operate at an abstraction rate close to the optimum 0.03 metres per second.

Well-points & Screens

Several principles of screening and methods of installation were considered for localised fabrication of possible abstraction equipment. From an analysis of the foregoing criteria, 10 well-screens, well-points or caissons, were developed to fabrication and initial trial stage. Of these, four were rejected with six ultimately subjected to pump testing, leading to field testing.

Primary considerations for manufacture:

- Material selection availability, suitability and workability; considerations, the availability of welding equipment and skill of welders
- Overall design influence on fabrication, installation and efficiency
 - Shape and size of apertures ease of forming each orifice and the expected efficiency of the well-point or caisson to act as a screen; considerations, the availability of drilling equipment and skill of operators

- Dimensions of abstraction points without compromising expense, driven well-points were required to be of a diameter that could be easily driven to 3.00 metres or more and comprise a short screen length to ensure continued abstraction if and when water levels become low within riverbed alluvium
- Open surface area not low enough to throttle typical handpumps nor high enough to compromise the strength of the well-point or caisson.
- Durability, maintainability and likely sustainability
 - Equipment should not rot, decay nor corrode excessively
 - Ideally equipment should be able to be withdrawn from sediment if necessary for servicing
 - Equipment should not clog, but maintain the design open surface area

Proposed designs and overview of criteria to meet requirements

- 1. Driven uPVC well-point with round apertures and steel point
 - Ease of fabrication uPVC and steel are materials easily worked
 - Relatively cheap to fabricate uPVC is both cheap and readily available
 - Ease of installation the principle of driving a point is simple and ensures installation to a suitable depth
 - Apparent success on initial trial
 - Accepted for further testing
- 2. Driven uPVC well-point with slot apertures and steel point
 - Ease of fabrication uPVC and steel with slots easily formed
 - Relatively cheap to fabricate uPVC and steel
 - Ease of installation driven point
 - Accepted for further testing
- 3. No-fines concrete screen caisson
 - Very easy to fabricate requires only uPVC piping, a mould, building cement and aggregate
 - Cheap to fabricate
 - Ease of installation by simply burying the well-point however this is best achieved late in a dry season when the water level is low in the sediment
 Accepted for further testing
- 4. Plastic basin caisson
 - Very easy to fabricate requires only the fitting together of 2 plastic basins with limited pipe fittings
 - Cheap to fabricate
 - Ease of installation late in the season when water is low in the sediment and the caisson can simply be buried
 - Accepted for further testing
- 5. uPVC pipe caisson with round apertures
 - Easy to fabricate comprised only of uPVC and assembly with solvent cement
 - Cheap to fabricate
 - Ease of installation late in the season when water is low in sediment and the caisson can simply be buried
 - Accepted for further testing

- 6. Driven steel well-point with round apertures
 - Ease of fabrication only basic welding skills are required, although the drilling of a large number of holes in steel may create problems
 - Expensive material for fabrication
 - Ease of installation driven point
 - o Accepted for further testing
- 7. Open ended uPVC pipe caisson
 - Very easy to fabricate requiring only uPVC and solvent cement
 - Cheap to fabricate
 - Ease of installation late in the season when water is low in sediment and can simply be buried
 - Failed to work on initial test as the caisson became fully clogged with sediment
 - o Rejected
- 8. Driven steel well-point with synthetic material pack
 - Relatively complex fabrication significant amount of preparation of steel work
 - Expensive material for fabrication
 - Ease of installation driven point
 - Failed to work on initial trial as the synthetic material did not act as filter but created a seal in the draw-off pipe
 - o Rejected
- 9. Driven steel slotted well-point
 - Ease of fabrication only basic welding skills and slots easily formed
 - Expensive material for fabrication
 - Ease of installation driven point
 - Earlier trials indicated problems of clogging in the parallel-sided slots • Rejected
- 10. Sheathed steel well-point with integral gravel pack
 - Relatively complex fabrication significant amount of preparation of steel work
 - Expensive material for fabrication
 - Ease of installation driven point
 - Dimensions suitable for abstraction made the well-point a disproportionate size pipe dimension to size ratios proved unsuitable
 - Rejected

Driven uPVC well-point with round apertures and steel point

A spreadsheet, appendix 09, was produced to assist with the design of this type of well-point. From data entered, a range of core uPVC piping and aperture sizes may be calculated. A suitable correlation can be made of pipe bore, aperture size and velocity of water flow through the proposed well-point. Appendix 09 shows the spreadsheet with the calculations that have been generated for the production of the well-point, which after a series of tests, was deemed most suitable for general use. A target of a water abstraction velocity of 0.076 m/sec (0.25 ft/sec) was initially selected from data recommended to the author by (Cooke 1987), a former branch manager of Mono Pumps, Bulawayo, Zimbabwe. The original source of this data is unknown but

Cooke has had considerable practical experience installing well-points. Although a rate of 0.0305 m/sec is more usually applied to screens, WEDC (1997) and Driscoll (1986), it was felt that this generally related to borehole casing or infiltration galleries where it could be more easily achieved with screen diameters of \pm 150 mm and lengths in excess of 3.00 metres. Practical experience had indicated that the higher rate of velocity is acceptable for use with well-points. Well-point apertures were related to the sediment grading curve of the four research sites which were taken as a fairly representative cross-section of possible sand-abstraction sites. A 75% passing was thought to be acceptable.

The eventual design of the well-point comprised a variation of pipe diameters and aperture sizes dependent on the sediment grade and form of screening. Although aperture size had to be reduced and although a considerable number of apertures were required, it proved possible to fabricate screens with a calculated optimum velocity of 0.0305 m/sec, albeit with an impractical but assumed even lateral and axial velocity. Adjustment to increase or decrease screen length was also possible to formulate a screen of near optimum characteristics.

The design that met several criteria was based on a 50.00 mm O.D. uPVC pipe which was able to fit comfortably into a nominal 61.00 mm O.D steel driving tube of a nominal 52.00 mm I.D. Steel drive points were fabricated from 250 mm sections of 32.00 mm (1¼ in) water pipe, which could be easily joined by riveting to the 50.00 mm uPVC piping, selected for the well-points. This pipe was formed into a point with a taper length of 120 mm, a 50.00 mm (2 in) pipe was fitted above the taper as a collar on which the drive tube could impact. Short, stub wings which formed a part of the point were fitted to hold the well-point in place in the sediment. The wings primarily overcame the initial resistance met when withdrawing the drive tube after each installation, due to compaction of some sediment between the well-point and the drive tube. Figure 6.16 shows a round aperture driven well-point which was designed during the research programme.

Figure 6.16: Round aperture driven well-point



Driven uPVC well-point with slot apertures and steel point

Well-points with oblong slots, rather than round apertures, were constructed in a similar manner to the round aperture well-points described above. Figure 6.17a shows a slotted aperture driven well-point which was designed within the research programme. Sections of the same 50.00 mm class 10 (2.75 mm wall thickness) uPVC pipes were fitted to a driven steel point of the same design. A dovetail saw was chosen in favour of a hacksaw blade to cut slots of 1.25 mm width as there was less wander of the saw blade and thus a more even kerf was produced. A spreadsheet was also used to calculate the slot length and frequency for a desired velocity. Satisfactory slots were not easily produced although the choice of a dovetail saw, as well as producing a more even slot, did produce a less ragged slot. Nevertheless on completion, many of the slots still had fragments of uPVC attached to the inside radius of the slots. These fragments of pipe frequently prevented the free entry of sediment fines and thus caused the slots to clog.

A further complication of the slotted well-point occurred during field trials. Although initially successful when tested under controlled conditions, they were later largely abandoned after poor experience during field test installations. Although the slots cut into the pipe were offset from each other across the pipe, the pipe frequently broke at the level of the first few slots during installation due to the vibration caused by the impact of the heavy driving blows, as shown in figure 6.17b.

Figure 6.17a: Slotted aperture driven well-point. Figure 6.17b: Broken well-point



No-fines concrete screen caisson

A well-point encased in no-fines concrete was produced in an attempt to develop a method of abstraction which would be effective in a variety of conditions without recourse to calculation and which could be manufactured in a more rough and ready manner than the aperture well-points. In spite of the likelihood of extremely variable performance with such a haphazard construction, the idea was considered worthy of a trial. Expected limitations to performance were associated with the lack of uniformity during casting. An acceptable casting might perform well and another not at all, due either to insufficient conduits or excessively wide conduits.

A 50 mm uPVC pipe was drilled with 20×8 mm diameter apertures over a length of some 250 mm. This perforated pipe was fitted loosely through a hole in a standard 15 litre plastic bucket so that the perforations were entirely within the bucket. The pipe within the bucket had two pieces of 4.00 mm galvanised wire inserted into it to hold the concrete frustrum in place and the end of the pipe was sealed. The bucket was filled with no fines concrete with 12 mm graded chippings to cover the perforated pipe. The bucket mould was easily removed from the well-point when the concrete was set and could be re-used. Later versions of the well-point were constructed in lengths of 140 mm O.D. class 6 pipe. This made for a less bulky well-point, but with a smaller surface area and reduced material to act as a screen. As the sides of the uPVC pipe were not tapering this required the mould to be cut from the well-point. Figure 6.18 shows the structure of no-fines concrete screens.

Figure 6.18: Two forms of no-fines concrete screens.



Plastic basin caisson

Caissons were experimented with in an attempt to design equipment which could be used to improve the abstraction of water from fine or compacted sediment. Two round plastic basins were used as a cheap and readily available source of material. The two basins were wired together at the lip to form a caisson – or small tank. The lower surface was perforated to allow entry of water and the upper fitted with a flange for fitment to an abstraction pipe. Prior to design it was assumed that a large surface area for abstraction combined with a low velocity through the basin would assist in the abstraction of water in difficult sediment conditions. However the surface area for abstraction area that could be achieved on a 50 mm pipe, which was not compensated for in the lower velocity of water through the caisson. The advantage of the caisson was then reduced to simply being more suitable in shallow sediment. A further complication arose when the upper basin collapsed under atmospheric pressure during tank testing. Figure 6.19 shows the collapsed caisson after its first pump yield test.

Figure 6.19: Collapsed caisson



uPVC caisson

Efforts were made to develop caissons that would be effective through a low abstraction velocity. However these were not at all successful and were disbanded. The caisson was fabricated from a 330 mm length of 140 mm O.D., class 6, uPVC pipe. The velocity of water at the abstraction point was calculated to be sufficiently low to preclude the drawing of sediment grains of over a 2,00 mm diameter into the system, (Hussey and Hussey 1999), (Appendix 10). The top of the caisson was reduced down to a 50 mm O.D. uPVC pipe for fitment to abstraction piping. The caisson was fitted to a Rower pump and installed vertically against the viewing glass of an observation test tank. A 40 mm wide section along the length of the caisson was removed with the intention of observing turbulence and any movement of sediment within the caisson. Unfortunately and rather unexpectedly, presumably due to the percentage of sediment particles which were <2.00 mm, the caisson immediately filled with a core of sediment with three strokes of the Rower pump.

Although this effectively curtailed any further development of this principle, one caisson of this design which had been intended for testing was closed with a uPVC plate at the open end and drilled in the same manner as the well-points on the lower outer surface of the pipe. The intended caisson then effectively became a functioning low velocity well-point which required installation by digging-in rather than driving as shown in figure 6.20.

Figure 6.20: uPVC Caisson



Steel well-point

A steel well-point of a type typically used on sand-abstraction systems in Zimbabwe from the 1940's through to the 1980's, was manufactured and tested for comparative purposes. The 750 mm long well-point as shown in figure 6.21 was fabricated from 65 mm ($2\frac{1}{2}$ in) galvanised steel water pipe with 6 mm apertures over a length of 200 mm. Four sections tapering over 250 mm from one quarter of the circumference to a point on the pipe were removed and the remaining 'prongs' drawn down to a point which could be welded together. The top of the well-point was reduced down to the test abstraction pipe diameter.

Figure 6.21: Steel well-point



Other Attempts to Develop Well-points

An initial attempt was made to design equipment that could be used in a variety of situations with little or no calculation or assessment of conditions. In particular, two systems were designed and tested in fine sediment conditions. Development was undertaken to some degree on four systems which were later discarded as being inadequate or inappropriate.

Well-point with synthetic material pack

A 50 mm steel pipe with 6.00 mm apertures was loosely packed to above aperture level with bunched-up polypropylene strands. A steel pin across the inside of the pipe prevented the polypropylene from being drawn in the pipework. The concept was that water would be drawn through the system whilst the fine sediment particles would be retained by the wad of polypropylene strands. However, under test no water could be drawn through the system as the polypropylene compacted to the extent that it formed an impervious plug.

Subsequent test were successful with synthetic geo-textile inside the well-point. However, although the geo-textile did not block the pipe, the system was disbanded due to the high cost and general unavailability of geo-textile at the rural third world level.

Well-point with an integral gravel pack

A 50 mm steel pipe was used as a sheath around a 32 mm steel pipe with 4.00 mm apertures and the cavity between filled with graded 6.00 mm gravel. Water entered the well-point at the top of the sheath and was drawn down through the gravel pack between the two pipes. The concept was that natural grading of the fine sediment would occur in the gavel pack which extended 1.00 m above the apertures. However test conditions showed that the entry orifice was so restricted that water was not drawn through the system. Although a replacement model was fabricated with a 75.00 mm outer sheath the cost of this size steel pipe and the difficulty of driving such a large bore pipe deep into fine sediment totally precluded its further use. The system of using a separate pipe to drive this well-point into the sediment did however give rise to the design of smaller diameter uPVC well-points with sacrificial steel points which could be driven into sediment. Further limitations were the resultant height of the inlet above the base of the well-point and consequently above the riverbed which created a reserve of water which could not be abstracted and the limited vertical distance through which water was abstracted also created a high velocity at the point of abstraction.

Open-ended Caisson

Efforts to draw water from sediment by simply utilising a low velocity at the point of separation were also tried, but were not successful. The concept was based on a realisation that quite frequently, well-points which had become filled with sediment appeared to continue to operate satisfactorily. Attempts to abstract water through large diameter caissons that create only a low entry velocity were further encouraged by equipment which hobbyists use to clean fish tanks. A simple device for removing algae and fish excrement from the sand at the bottom of hobby fish tanks works on the principle of low velocity. The gadget comprises a narrow bore tube used to siphon water from the tank with an appreciably larger bore plastic entry tube, (cross sectional area 25 times larger than the smaller bore siphon tube). Although the device is placed within the base sand layer no sand is raised from the surface due to the low velocity of water within the entry tube before it passes into the narrow bore discharge tube. Figure 6.22 shows the device used to flush extraneous material from the base sand layer of a small fish tank without the removal of the sand.

Figure 6.22: Drawing water through sand, by applying a principle of low velocity abstraction.



In an effort to utilise this principle as a well-point system a spreadsheet was designed by Hussey and Hussey (1999), to calculate the possible diameter of a caisson from available sediment particle size and estimated velocity. This principle was based on Driscoll (1986) who refers to a chart 'Velocities of Water that will Cause Sand to Rise', which he attributes to the W.S.Tyler Company. This chart indicates the velocity of water required to raise a grain of a specified diameter. The developed spreadsheet (Appendix 10) was used to determine the diameter of sediment grains likely to be raised at a given velocity in a caisson of a predetermined diameter. Inputs for the calculation were the rate of abstraction (m3/hr) and a pre-determined well-point diameter. Either however when the principle was employed, sediment was drawn into the caisson, or if open-ended, the caisson was drawn into the sediment. Either way, sediment quickly permeated an abstraction system and hence further development was abandoned. Table 6.5 indicates a typical calculation used in the design of a caisson which was intended to draw water from river sediment through a suitably low velocity. As calculations were related to a single action piston pump drawing water on the outward stroke only, the velocity was determined at a yield of 2.50 m3/hr and not at 1.25 m³/hr which is often accorded to handpumps. The author is of the opinion that the concept may yet be applied successfully, provided flow to the caisson remains laminar. The theory is supported in textbooks such as those of Douglas, Gasiorek et al., (1995) and Duncan (1987) which relate to the basic principles of specific density and fluid mechanics involving flow around an object.

Table 6.5: Determination of sediment particle size to be raised at the given pump yield and caisson diameter, (Hussey and Hussey 1999).

Determination of size of particle raised at a given pump yield				
Pump Yield	1.25 m³/hr			
I. D of Caisson	133 mm			
Velocity of water through the caisson	0.6944 <i>U</i> /sec			
Size of particle which can be raised	<= 1.00 mm			

Appendix 10 provides a detailed analysis of the theory and analysis used to determine the size of sediment particles likely to be raised at a given yield in the given diameter of a caisson.

Steel slotted well-point

A well-point of inadequate design is typically fabricated from 40 mm $(1\frac{1}{2} \text{ in})$ or 50 mm (2 in) galvanised steel pipe. Slots are cut over a length of about 400 mm with a hand hacksaw, giving a slot width of approximately 1.3 mm, depending on the condition and use of the blade. However, practical use has long shown that this type of well-point is under designed and the slots are liable to rust with the result that they become impacted and clogged with sediment. Consequently a decision was made not to conduct tests using a slotted steel pipe as a well-point. Figure 6.23 shows a typical homemade 40 mm (1¹/₂ in) steel well-point with slots clogged with fine sediment embedded with rust.

Figure 6.23: Steel well-point with impacted slots



Pump Equipment

The situation with appropriate pumps for small-scale sand-abstraction systems does not appear as dire as that for suitable well-points. Many rural gardeners in Zimbabwe have stated their preference for a Rower pump which has been shown to be a most appropriate handpump. It is also known that a diaphragm pump, the 'Bumi pump' which is manufactured in Zimbabwe, has been used on single well-point installations. Owen, Rydzewski et al., (1989) has recorded use of the widely known Treadle pump to draw water from vleis, in situations not dissimilar to sand-abstraction. There are also known instances of a hand operated piston pump, known locally as gaMinagaWena, (to me, to you) drawing water in similar situations, possibly through wellpoints.

However, there are also many instances of attempts at small-scale sand-abstraction schemes that are now redundant because of faulty or inoperative pumps which the users have been unable to repair. A typical small-scale scheme once used to water livestock comprised a locally made Bumi Pump and a single well-point. However this pump has a high output rate and thus requires a lot of hard work to operate. Whilst the pump is very simple in design, it also has a large rubber diaphragm that is both difficult and expensive to replace and is liable to perish in the hot dry conditions of southern and western Zimbabwe. Difficulties have also been experienced with the valves and the general complexity and difficulty of manufacturing a treadle pump. Further limitations have been found with the abysmal standard of manufacture of a locally, Bulawayo made piston pump. Such shortcomings have encouraged the staff of Dabane Trust to develop a handpump considered appropriate for small-scale sandabstraction systems.

Handpump design was based on the basic principles of the Rower pump which seemed particularly appropriate. A handpump was thus developed using uPVC piping and standard, off-the-shelf ABS pipe fittings. Pistons and valve seats were constructed from either 12 mm uPVC sheet or 12 mm discs made from off-cuts of Zimbabwean teak hardwood. These blocks were drilled to allow the passage of water and had a rubber disc cut from a car inner tube fixed to the top to act as a valve. This arrangement was fitted to a length of 1.20 metre re-bar to act as a piston body and shaft. A second value of similar construction was located at the top of the well-point column and inside an ABS fitting to which the pump could be screwed. The pump thus had two values which were easily made from hardwood timber scraps and scrap inner tubes and could be easily accessed. No tools were required to access either value or to repair them.

Figure 6.24 shows the basic piston pump which was designed primarily to draw water for domestic and livestock use. Well-points were driven into the sediment with the column cut at sediment level and equipped with a fitting housing the valve. The handpump described above could be attached to this fitting to draw water to the surface. When not in use the pump can be simply unscrewed and the valve covered with a protective cap.

Figure 6.24: Simple bucket pump



The design of these pumps is extremely basic, only delivering water to the sediment surface or with an extension to the riverbank, in neither situation is the pump able to deliver water to a head above the pump cylinder. A pump capable of delivering water to a \pm 6 metre head was thus designed and developed. This single-acting piston type pump which became known as a Joma pump, figure 6.25, was designed to use a Rower pump piston and two Rower pump valve bodies although non-return valve bodies were used on occasion. The pipework and cylinder is fabricated from 63 mm uPVC piping and painted to avoid deterioration in the sunlight. The assembled piping and valves are held in an angle iron frame incorporating a handle on a pivot to which the piston rod is attached.

Figure 6.25: Low-cost, low-tech piston pump suitable for sand-abstraction use (Joma Pump).



In an attempt to pump larger volumes of irrigation water, efforts were made to develop a donkey powered pump, appendix 11 and as shown in figure 6.26. The concept for this pump, said to have been made by the Lutheran World Federation, was first seen by the author on a smallholder farm near Zvishavane, Midlands Province, Zimbabwe. In his book, Water Pumping Devices, Fraenkel (1997) ascribes the design of the pump to the New Alchemy Institute, which unfortunately now no longer appears to exist. The pump is a virtual diaphragm pump based on a light truck size tyre, $(205/215 \times 14/15 \text{ or } 7,50 \times 16)$. Steel plates cover the open centre of each side of the tyre and are sealed to the beads to provide an airtight cavity. An inlet and an outlet valve are fitted to the back plate with the opposite plate free to move in and out, creating suction and exhaust strokes. The back plate is fixed to a rigid upright and the moving plate to a crank by a pitman which causes the plate to move back and forth. The crank is rotated by a boom which is pulled around in a circle by a circulating donkey at each end. Although the pump worked, output was sporadic, reducing after each prime due to incomplete sealing of the valves which only opened and closed every 15 seconds. Improved spring loaded valves have been designed by Hussey (2001(b)) and have been fabricated, but are yet to be effective as they still require bedding-in. Plans are also in-hand to replace the spring-loaded valves with valves which are positively opened and closed. However, this will considerably complicate

the overall simplicity of the original design with a complex linkage mechanism, which it can be assumed would require regular adjustment. Earlier modifications were made to the pump pitman which initially moved in a fairly circular motion so that the tyre cavity was distorted to the side and thus did not compress evenly during pumping. This was rectified by coupling a scotch yoke to the crank and passing the pitman through a teak block to prevent any lateral movement.



Figure 6.26: Trial donkey powered diaphragm pump

6.5.3. Testing of Equipment

A total of ten well-points were pump tested, of these four were commercially available and six were designed and fabricated within the research programme.

- 1. Driven uPVC well-point with round apertures
- 2. Driven uPVC well-point with slot apertures
- 3. Steel well-point
- 4. No-fines concrete screen
- 5. uPVC caisson
- 6. Plastic basin caisson
- 7. SWS well-point
- 8. SWS self-jetting well-point
- 9. Section of Boode slotted screen
- 10. Ceramic Boode well-point

programme designed programme designed programme designed programme designed programme designed commercially available commercially available commercially available

Three categories or principles of design were selected for well screening:

- · Well-points with apertured screens
- Well-points with a bonded exterior screen
- Caissons

In the testing of the abstraction equipment, three measures of measurement were decided upon which would establish a broad based assessment:

- Practical yield test
- Calculation of velocity
- Assessment of aperture size

These were considered to be of significant indication and easily measurable.

Barker and Herbert (1989), who has carried out extensive tests on well screens states that a comparison of well screens cannot be reduced to a simple issue of hydraulic efficiency. He maintains that if no other parameters are involved, there will be insufficient data available to accurately assess screen performance. In his assessments, he submits screens to pump tests involving axial and lateral flow induced by two separate pump systems through the screens. Barker calculates friction factors from the data gathered and as a further measurement parameter calculates a momentum factor, this he uses together with the friction factor to evaluate the screens.

From his trials, Barker contends that all the momentum possessed by water is lost as it enters the apertures of a screen and that some momentum is lost due to turbulence as water rises up the screen. He further maintains that the friction factor calculated on the diameter of a screen, which would cause the momentum factor to be at unity, would reduce the characterising parameters to just the friction factor and the effective radius, which he contends would not be sufficiently accurate. Barker also states that the calculated momentum factor is quite likely to be at unity, but is often significantly larger than unity making it unwise to over-interpret the results in terms of the physical processes involved.

A more practical approach to screen testing was adopted within this research programme. A range of criteria considered optimum for small-scale use was determined (table 6.6) and a comparison made between these standards and the test results of the screens. Screens were tested to establish the yield and flow rate and consideration was given to a suitable aperture size in relation to the likely sediment particle size and a tolerable ingress of fine sediment through a proposed system. An optimum percentage aperture cover and a suitable screen length together with appropriate overall dimensions was a further consideration involving the calculation of the screen aperture size for various grades of sediment.

The criteria set were considered to be optimal and in some instances one countermanded another. No one screen could be selected as being better than another, but rather the criteria were set as a measure, with the most suitable screen being a balance of the criteria for a given set of conditions.

Yield test

Within the limitations of hydraulic heads, many handpumps have a yield of about 1.00 m³/hr. Taylor and Mudege (1996) reports that a 'standard technology' Zimbabwean Bush pump has a yield of 1.20 m³/hr. These approximations were considered suitable for a typical, desired output of a well-point. Screens were tested at five outputs from approximately 1.00 m³/hr to four or five times that amount.

A simple comparison was made of each well-point at 5 identical pump speeds. There was however no control over the grade of material in the proximity of each well-point which might affect flow to the well-point. After testing a well-point, material was thrown out of the tank, the well-point removed, a new well-point installed and the material thrown back. No test was made to determine any reduction in pump efficiency during the tests. No compensation was made for any wear which might have occurred to the pump rotor or stator through passage of abrasive sediment during testing.

Velocity Test

For test purposes, an optimum flow rate, both through the apertures of the screen and through the cross-sectional area of the screen was set at 0.0305 m/sec. A calculation was made of the velocity of water through the main stem of each well-point. The calculated velocity provided an indication of flow characteristics through the screen and the size of sediment particles likely to be drawn through the system. Where possible the open-surface area of the screen was calculated. Indications are that laminar flow, or flow with minimal turbulence is achievable in well-points with an open-surface area of around 60%.

Velocity was calculated through a mathematical formula that assumes that the volume per second may be calculated as length per second multiplied by the cross sectional area.

$$vel = \frac{vol}{\pi r^2}$$

The formula does not take into account the effect of any friction losses the pipe may exhibit on flow. Although friction losses might be significant, particularly with a number of small screen apertures, as inflow through a vertical screen is not uniform, friction losses were considered to difficult to accurately calculate. The difficulty of obtaining a uniform flow to a screen, with compensatory mathematical formulae is fully discussed by Barker and Herbert (1989) who states that the axial flow rate in a well ranges from zero at the bottom of the screen to that of the pump discharge rate at the top of the screen. To determine a range of tests Barker arbitrarily accepted a maximum lateral slot inflow velocity of 0.122 m/sec, being four times the commonly recommended maximum of 0.0305 m/sec (0.1 ft/sec).

Aperture Size

Screen apertures should allow for the development of a natural screen within the sediment surrounding the well-point within a 30 minute pumping period. As this was not possible to determine within the limitations of the research programme an alternative measure was sought and determined as a somewhat arbitrary figure of less than 200 grams of sediment retrieved from within the well-point on completion of each of the five yield tests irrespective of the length of time pumping had occurred.

Where possible the fines which remained inside each well-point after the five pump tests were collected, weight and graded. The volume of sediment which had entered the screen provided an indication of the limitation of the effectiveness of the screen.

Screen Length

A nominal length of \pm 400 mm was considered a suitable length of screen. Such a design length was thought to be achievable and at the same time provide for satisfactory rates of abstraction as water levels diminished during a dry-season

Ease of Fabrication

Whilst a prime criterion was effective abstraction, a further consideration was the ease with which a well-point could be fabricated. From initial designs and early tests, it was indicated that small apertures were required to form an effective well-point screen in 50 mm uPVC pipe. Designs using 2.00 mm apertures produced acceptable rates of flow but required more than 2,900 apertures over a length of 630 mm, a degree of precision which was considered unlikely for the average local artisan to meet. By increasing aperture size to 2.50 mm, the number of apertures was reduced to just less than 1,800 and the screen length to 470 mm which was considered more acceptable.

Ease of Installation

A relatively easy, yet simple and effective method of well-point installation was considered a prime design requirement. Installation by driving by impact was thought be most suitable and thus a well-point of a suitable O.D. was required for this to be accomplished. However a small O.D. correspondingly required a small I.D which in turn increased internal flow rates.

Drawdown

Although not considered a prerequisite to establish the efficiency of a well-point, a nominal attempt was made to establish the drawdown around each well-point during pumping. Piezometer tubes were installed at 1.50 and 0.50 m each side of the well-point. However it proved difficult to maintain any accuracy in the placement of the tube closest to the well-point during the change over of well-points, through either movement of the piezometer or of well-point itself. Although space was a limitation, a third piezometer mid-way between the two piezometers would have provided a more accurate impression of the cone of depression.

Frictional Loss and Momentum Loss.

Coefficients of friction are readily calculated from adjustable scales or from published or online tables such as those of the Depco Pump Company (2003). However, coefficients vary considerably with the pipe or screen I.D., and as reported by Barker and Herbert (1989), cannot be considered relevant where only nominal bore is provided. Although friction coefficients might be considered pertinent in the narrow bore screens developed within the research programme, no consideration was given to their inclusion due the very short lengths of screen used.

Following a series of screen performance tests, Barker and Herbert (1989) suggests that the momentum which water possesses is lost as it enters the slots of a screen and as it rises up the inside of the screen, probably due to turbulence. Although Barker uses a momentum factor in his calculations of screen efficiency, he states that it is actually a dimensionless parameter introduced to indicate the extent to which momentum is conserved.

Control site testing

Two, round, 3.00 metre diameter brick tanks were constructed 1.00 metre apart for pump testing well-points. The first tank, 1.20 metres deep, contained river alluvium from a typical sand river, the second tank, 1.00 metre deep, was an open tank to hold water drawn from the first. A progressive cavity pump was installed between the two tanks with pipework that allowed the pump to draw from one and discharge to the other with a reverse flow achieved simply by adjusting on/off valves. Well-points for test were installed in the centre of the sediment-filled tank and connected through a swimming pool filter hose to a priming tank directly above the pump. Four piezometer tubes were installed to measure draw-down, one at each side of the wellpoint at 1.00 metre centres and a further tube in line with these, positioned at the edge of the tank. A depth view gauge was fitted to the outside of the sand-filled tank.

An electrically driven pump was used to provide a regular and continuous rate of abstraction. Four pulley sizes were used to vary the rate of flow through the well-

points by changing either the driving or driven pulleys. Pumping was undertaken at five rates of abstraction at yields at which the well-points could be expected to perform satisfactorily. Yields ranged from approximately that equal to a handpump supply through to approximately three or four times that of a handpump supply. In hydraulic tests undertaken by Hydraulics Research Ltd, Barker and Herbert (1989) subjected screens to rates of axial and lateral flow, which would cover the range of conditions likely to be encountered in the field, and particularly indicate the need to include rates at which poorly designed wells might be subjected. It is noted that Barker also subjected each screen to 50 rates of pumping, however, for the purpose of practical trials preparatory to field trials, this was considered unnecessary.

Comparative yield and draw down at a given pump rpm was recorded for ten different well-points. On removal of each well-point, once pumping was completed, the fines remaining in the well-point were collected and graded by sieving. Unfortunately initial attempts to collect all the fines that passed through the system were not successful and efforts to achieve this were not vigorously pursued due to the difficulty of providing a standard grade sediment in the vicinity of the well-point undergoing testing. From the pump/well-point yield, a calculation was made of the velocity of water though the pipework of the well-point. This data was compared with recommended levels provided by commercial screen manufacturers and was used to help determine the most suitable screen for installation at a given site. Velocity data will also be useful as design criteria for the possible development of equipment in the future.

A further well-point observation tank was also constructed with four differing wellpoints visible through a viewing window. Trial well-points with open ends abutted the glass to observe disturbance within the sediment immediately around the wellpoint screen during pumping. It was intended to observe the entry of sediment into the trial screens and the initial fines removal and subsequent grading effect which occurs during the development of a natural sediment screen around each well-point. Abstraction through each screen is effected by a direct-coupled piston action Rower pump which emulates on-site conditions. To date screen tests in this tank have not been satisfactorily completed.

Field site testing

Well-points which performed satisfactorily, simply by providing useful quantities of water during pump yield tests, were installed in field site conditions for further testing with handpumps. The intention was to set up a maximum of five pumps at roughly 500 metre intervals each side of each field research site where generally sand-wells had already been excavated for livestock watering purposes. However as testing was now in the hands of the local communities the trial well-points were actually installed at points identified by the communities with no assessment other than probing the riverbed to establish the deepest point. It was considered that this manner of test site selection most closely matched reality and would provide the most useful data on well-point performance.

6.6. Presentation of Data

Trials were undertaken to establish the effectiveness of well-points against predetermined criteria. Ten of the more promising well-points and caissons which largely conformed to the criteria in table 6.6 were selected for performance testing. The criteria to which well-points were expected to conform were developed from broadly acceptable standards. A yield of 1.00 m³/hr equates to a typical groundwater handpump and a flow of 0.03 m/sec is an accepted screen standard. Other criteria were accepted on the basis of ease of fabrication or installation and suitability for sustainable operation. Programme designed well-points were compared to similar, commercially available well-points or sections of well-screen which were made up as well-points. A complete record of well-point and caisson performance is included in appendix 11.

Requirement	Accepted Criteria
Suitable yield for handpump use	1.00 m ³ /hr
Recommended rates of flow	Flow of 0.0305 m/sec through the screen
Minimal ingress of fines to the screen	<200 gms collected from the well-point after 30 mins of pumping.
Short screen length for use in narrow aquifers	<400 mm in length
Suitable for easy installation	O.D. <=50 mm to fit within a nominal bore 50 mm (2 inch) steel drive pipe
Suitable for easy fabrication	<500 apertures

Table 6.6:	Well-point assessment	criteria
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Notes:

Recommended rate of flow: Although an overall general flow of 0.0305 m/sec was determined, it was appreciated that axial flow would vary considerably over the length of the screen

Ingress of sediment fines: A natural sediment screen should be developed within 30 minutes of continual pumping

6.6.1. Research Designed Abstraction Equipment

Well-points and Screens

Driven uPVC well-point with round apertures

The driven well-point (1, Table 6.8) proved to be suitable in a variety of situations. Through the use of a spreadsheet, (appendix 09), a 50 mm diameter × 385 mm long screen was designed with an aperture size of 3.00 mm diameter. This provided an aperture velocity of 0.035 m/sec which met the criteria of velocity and dimensions. However the total number of apertures was found to be 1,288 which was considered to be too many and 395.5 gms of sediment were retrieved from inside the screen which was also considered excessive. To compound this problem when the initial screen was tested under field conditions the pump drew water but only with an excessive amount of sediment. When the well-point was retrieved it was found to be completely full of sediment. A second well-point of the same materials but with 2.50 mm apertures was thus fabricated and operated satisfactorily in the field. This well screen had a velocity of 0.0302 m/sec and a length of 475 mm. It was considered that this screen allowed for a number of design options within the set parameters.

Driven uPVC well-point with slot apertures

A hand slotted well-point fabricated from PVC pipe (2, Table 6.8) with the same dimensions as well-point (1) performed surprisingly well in spite of an open-surface of only 3.5% and a correspondingly high entrance velocity of 0.156 m/sec. The screen length factor was quite satisfactory and, with a total of only 76 slots to be cut,

fabrication, aided by a jig was certainly most straightforward. A considerable drawback however occurred during field trial installations when four of five well-points severed between the lowest slots during installation. Class 10 uPVC pipe with a 2.75 mm wall thickness was used for the well-point and a 20 mm pitch between slots was included in the design to allow for sufficient material to retain strength. Slots were also offset from each other on opposite sides of the pipe.

Steel well-point

A driven steel well-point as used typically in Zimbabwe was fabricated and tested (3, table 6.8). The spreadsheet design of a typical point did not compute well. The flow rate velocity was considered too high and following actual testing, due to the large aperture size, almost a kilogram of sediment was recovered from the well-point. The well-point diameter was also considered too great for easy installation and steel a difficult material with which to work.

No-fines concrete screen

In an endeavour to make a simple screen that would not require a degree of calculation an attempt was made to form a screen with no-fines concrete (4, table 6.8). As no control can be exercised over the formation of the pack and as a consequence the conduits within it, it is a somewhat haphazard design with no two screens having the same characteristics. When tested, the screen performed satisfactorily for both yield and rate of flow, however it was not possible to accurately review the quantity of sediment retained within the screen. Although fabrication can be considered to be easily achieved, installation, by virtue of the bulk of concrete which requires digging-in, is not easily achieved.

Caissons

uPVC caisson

Tests were undertaken on a caisson which required installation by digging-in rather than driving (5, Table 6.8). The advantage of a larger diameter screen was immediately apparent with the calculated screen length of >200 mm. The spreadsheet, (Appendix 09), enabled designs with a useful variety of aperture size, flow rates and screen lengths. The screen selected for testing with 5.00 mm apertures, performed satisfactorily with only some 210 gms of sediment retained within the caisson due to the very low flow rate of 0.020 m/sec through the body of the caisson. The initial plan to use 140 mm O.D. uPVC pipe as a well-point, called for an openended caisson. However, as previously reported, this concept failed to materialise. Thus, in order to test a larger bore abstraction point, the planned open-ended caisson was converted to a screen caisson.

Plastic basin caisson

In a further attempt to both utilise relatively cheap and available equipment and to assess the potential of a caisson, an abstraction point was fabricated from two plastic basins (6, Table 6.8). Flow characteristics proved to be suitable with an abstraction velocity of 0.0304 m/sec and remarkable low velocity of only 0.0041 m/sec through the caisson. This ensured a quantity of only 177 gms of fines retrieved from within the caisson. Although easily fabricated with few apertures to form, installation is not easily achieved as a wide basin of some 350 mm diameter has to be installed below saturated sediment level.

Variations of performance

An overview of the performance of locally made equipment considered suitable for abstraction purposes is shown in table 6.7. The table demonstrates the effect that pump yield and the size and number of apertures of well-point or caissons exhibits, on the velocity of water through the screen; sufficient in fact to cause the equipment to operate within or beyond acceptable design criteria.

Table 6.7: Optimum well-point performance data and the effect of yield and aperture size on the performance of locally made abstraction equipment

	Yield (m³/hr)	Aperture size (mm)	Diameter (mm)	Screen length (mm)	Axial flow into screen (m/sec)	Lateral flow within screen (m/sec)	Comments
Optimum	1.00	1.5-2.0	50	400	0.03	0.03	
Pump test: Driven well- point (No.1)	1.23	3.00	50	382	0.102	0.220	Excessive ingress of fines to screen. Flow rates too high
Pump test: Driven well- point (No.1)	0.85	3.00	50	382	0.070	0.152	Tested well screen under field conditions. Excessive ingress of fines to screen. Flow rates too high
Field test: Driven well- point (No.1)	0.85	2.50	50	383	0.32	0.152	Meets criteria. Limitation – 7,500 apertures to be accurately formed
Caisson (No.5)	1	2.50	140	483	0.031	0.020	Meets criteria due to increased cross- sectional area of screen – thereby making installation more difficult

6.6.2. Commercially Available Abstraction Equipment

Reference has already been made to the extensive range of commercially available well screening. Commercial screening with some possibility for small-scale sand-abstraction installations were tested along with screens developed during the research programme.

SWS Filtration, assembled disc type well-point.

A purpose designed, small-scale, low capacity screen which comprises a series of inward sloping discs fitted over 4 bicycle type spokes (7, table 6.8). Each disc is 2.00 mm thick with a 61.50 mm O.D. Four small bosses around the aperture for each spoke, ensure a single, even and continuous 1.50 mm slot around the well-point. When assembled eighty discs make an effective screen of 280 mm with a large open-surface area of 75%

SWS Filtration uPVC continuous slot well-point.

Purpose designed well-point with a continuous 1.00 mm spiral slot extending 345 mm on a 75 mm O.D class 10 (4 mm) uPVC pipe (8, Table 6.8). The screen has parallel sided slots with an aperture width of 1.00 mm and a material thickness of 4.00 mm between the slots. Internal, lateral PVC securing rods maintain the rigidity of the screen. The screen was reduced in length to fit the test tank and to comply more closely with similar well-points under test. The screen which was tested was reduced to a 69-turn spiral, 345 mm in length had a 25% open-surface area.

Boode slotted uPVC pipe.

A well-point was formed from a 330 mm length of 75 mm class 10 (4 mm) uPVC slotted Boode pipe (9, Table 6.8). The screen comprised 5 bands of 28 longitudinal slots which were each 1.00 mm wide and 52.50 mm in length, distance between the slots was 7.40 mm achieving an open-surface area of 9.4%. The well-point was made by reducing one end to a standard fitting used throughout the test and closing the other end.

Boode ceramic well-point

A 42 mm \times 850 mm uPVC pipe with a 12.50 mm porous, bonded, graded sand cover (10, Table 6.8). The internal pipe is slotted with characteristics, but not dimensions similar to the Boode slotted pipe above.

Well-point Type	Test No.	Open- surface Area (%)	Nominal Bore (mm)	Screen length (mm)	Yield (m³/hr)	Velocity of Flow at Yield given (m/sec)	Weight of Fines Remaining in Well-point after 5 Pump Tests (gms)
uPVC 3.00 mm round aperture	1	5.6	44.5	380	1.23	0.220	395.3
uPVC 1.30 mm slot aperture	2	3.5	44.5	425	t.27	0.227	?
Steel 6.00 mm round aperture	3	10.0	68.2	200	1.26	0.096	913.0
No-fines Concrete Caisson	4	-	44.5	220	1.33	0.237	-
uPVC 140 mm Caisson	5	5.1	133	150	0.74	0.015	209.1
Plastic Basin Caisson	6	3.8	330	lateral	1.22	0.004	177.2
SWS 1.50 mm slot Modular	7	75	50	285	0.94	0.133	310.2
SWS 1.00 mm Spiral Slot	8	25	70	345	1.26	0.094	129.1
Boode PVC 1.00 mm Straight Slot	9	9.4	69	330	1.12	0.083	63.3
Boode Ceramic	10	•	32	850	1.31	0.452	

Table 6.8: Comparative efficiency of similar well-points tested

No single abstraction appliance can be said to be more effective or *better* than another. Table 6.8 provides data gathered from the tests conducted on a range of well-points, which were developed in conjunction with the spreadsheet (Appendix 09) used to design suitable well-points for a variety of given conditions.

6.6.3. Research Designed Handpumps

Ease of installation and ease of abstraction through the use of simple technology and basic handpumps are considered important aspects in the development and promotion of successful and sustainable water abstraction systems from river sediment. A policy, considered paramount to the development of suitable handpumps and well-points, has been one of *making it work and keeping it working*. Pumps which are suitable for use

in conjunction with locally made well-points, that are simple to fabricate and easy to operate and maintain, are as vital to the success of a small-scale sand-abstraction system as the actual well screens. A study has been undertaken on the suitability of a number of pumps, both mechanical and hand operated. Progressive cavity pumps, such as those manufactured by Mono Pumps/Dresser and Orbit Pumps Ltd., are probably the most common pumps used on mechanised sand-abstraction schemes, although more recently, increasing use has been made of submersible pumps.

As a source of information on handpump mechanisms and diagrammatic representation, a reprinted 1907 edition of 'Pumps and Hydraulic Rams', Hasluck (1907) proved to be invaluable. Efforts were made to make an extremely simple handpump to be used in conjunction with the fabricated well-points. The intention was to use readily available materials such as uPVC piping together with virtually waste materials, such as old inner tubes, for the piston and valves. Designs were made of both piston suction pumps and single-acting lift pumps, simplified versions were fabricated and trials were conducted. Other useful designs provided by Hasluck (1907) include plunger pumps and a variety of wooden bodied pumps, some of which have also been seen by the author at Bliss Hill, Ironbridge Museum. Darrow and Saxenian (1986) also provides information on wooden pumps and simple valves. He also gives an outline to such pumps as the Chinese chain and washer pump cum rope and washer pump as well as pumps such as the Shinyanga Lift Pump and the Salawe Pump which are made from 50 mm (2 inch) galvanised steel pipe with regular off-theshelf pipe fittings. Darrow maintains that the Salawe Pump is limited in use as he considers that it has been over simplified. The Shinyanga however has been used extensively in Tanzania from designs available free from the World Council of Churches, Geneva, Switzerland.

Piston Suction Pump

The pump that was designed, fabricated and used primarily within the research programme was a simple suction pump as described by Hasluck (1907). This pump comprises a single flap valve in the base of the pump cylinder with a further flap valve fitted above the piston body. The piston body has apertures through which water may pass on the down stroke, but which are sealed by the valve on the up stoke, thus raising the water within the cylinder to a point of discharge. Both the valve body and the piston body were fabricated from locally available hardwoods that were drilled with 5×5.00 mm holes for the passage of water. A seal was effected between the piston body and the cylinder walls with two discs of inner tube sandwiched between three wooden discs.

A satisfactory performance was achieved during static testing, but as yet no long-term assessment has been made of field performance. Early indications are that the hard wood is liable to crack due to continual wetting and drying out. Quite severe wear has been noticed on the sides of the piston body due the excessive quantities of abrasive sediment drawn through the pumps in the early stages of field trials as fines were evacuated. Hopefully wear will be reduced with the installation of well-points with smaller apertures.

Single Acting Lift Pump

It was hoped that by using the simple principle of a single-acting lift pump which does not require a relatively complex piston body, basic materials and components could be utilised. In its most basic form, the manufactured components comprise only an inlet valve, an outlet valve and a solid piston. To fabricate this pump a composite pump rod and handle was fabricated into a 'T' shape from a length of ordinary 6.00 mm rebar, with no welding or joining. The rod was simply folded back on itself in a continuous length with a wad at the lower end to form a piston. Initially attempts were made to form the piston from layers of narrow strips of inner tube, known commonly throughout southern Africa as 'eregeni'. Many people exhibit considerable skill with this material, which is used very widely in any application that requires binding, as in the sealing or securing of articles. However, the atmospheric pressure exerted on the plunger during pumping was sufficient to cause the strips to pull off the handle. Later attempts were made with discs cut from cross-ply tyres, but difficulty was experienced with satisfactory attachment of these. Flat India-rubber valves were used with the valve body made from hardwood blocks and the valve flap from circles of car inner tube.

This pump was tested to a height of 6.00 m from a surface water level to the centre of the pump piston. The pump is shown in figure 6.27 while the output of the pump is shown in table 6.9.

	Time (secs)	Yield (m ³ /hr)	Strokes per min
Test 1	88.80	0.88	50
Test 2	94.03	0.77	46
Test 3	96.17	0.75	45
Test 4	88.54	0.81	48

Table 6.9: Yield of a simple piston handpump at 6m

Figure 6.27: Testing a simple piston pump at 6 metres



6.6.4. Abstraction Equipment for Less Than Optimum Sites

Well-points are best suited to conditions where river alluvium is deep and the sediment saturated throughout most of the horizon and consequently likely to

maintain a depth of water over the screen section. In less than optimum conditions, where either the river sediment or saturated horizon is not deep, a horizontal infiltration gallery may be more suited to supply water to an offset-well through the hydraulic head in the sediment. During the research programme infiltration galleries were installed at two river sites, one where there was a limited depth of river sediment, but a good reserve of water and one where there was a good depth of sediment but a limited depth of water. Three further infiltration galleries were installed, one within a sand dam, one at a sub-surface dam and one within a dry dam basin.

Flow rates or other substantive data is unfortunately not available from any gallery installation. This lack of data is due either to sociological difficulties; pump limitations or the difficulty of obtaining in-flow readings below the water surface. Out-flow readings will be easily obtained at Mkhaya Wokhoza sand dam, however construction is not yet sufficiently complete. Herbert (1993) and MacDonald (1992) both make reference to the hydraulic superiority and positive benefits of infiltration galleries but also lament the difficulties of obtaining substantive data to support such claims.

Infiltration Galleries

Slotted Casing, Geopipe and Geofabric,

Sixty-six metres of 110 mm, class 16 slotted uPVC piping was installed in a herringbone pattern in the basin of Mkhaya Wokhoza sand dam during the construction of the masonry wall. The gallery was constructed from piping with parallel surfaced slots arranged transversely in five rows along the length of 3.00 metre sections of pipe. Each length of screen has a total of 27,500 slots each measuring 0.50 mm × 38.50 mm, placed at 5.00 mm centres to give an open-surface area of 5%. The pipe system was dug into the existing riverbed sediment during early stages of construction of the sand dam. Ten lengths of the same slotted pipe were fitted vertically into the horizontal gallery to facilitate seepage through any impermeable layers which might form within the basin. The pipes will be closed on top and will be below sediment surface level on completion of the dam. Discharge of water will be effected from the gallery system through pipes in the dam wall to a secure site on the stream bank below the dam. This type of abstraction system is used extensively in slow-sand filter plants. (OXFAM U.K. Undated), for instance outlines the layout and provides specifications for a herringbone gallery system and gravity discharge using uPVC drainage piping.

Water from the Hingwe sub-surface dam (figure 6.28), Bulilimamangwe District, Zimbabwe, is to be drawn from the base of the dam wall through 110 mm geopipe to an offset-well. This pipe is designed as a drainage pipe and is intended to be installed with a wrapping of synthetic geotextile. Apertures in the pipe are approximately 5.00×3.00 mm in an even formation around two-thirds of the circumference of the pipe, opensurface area is approximately 20%. In this installation the piping will be inserted into a shelf at the base of the weir wall and back-filled with graded 6,00 mm granite chips to ensure a restricted entry of fines.

In a third initiative, an offset-well was dug at Silonkwe, Matobo District, Zimbabwe to draw water from shallow sediment over rock, in the riverbed of the Semukwe River. Two laterals extend diagonally 20 metres into the river and discharge into a single false well. The abstraction system comprises 110 mm geopipe, as described above, which was wrapped with grade U34 geotextile. Discharge to the well from the river occurred

through the hydraulic head, water was then pumped by handpump to a garden tank 5.85 metres above the water level in the well. Water was sufficient to crop a 0.75 ha vegetable garden year round.

Figure 6.28: Design of Hingwe sub-surface dam



Moorland, flexible drainage pipe.

To assess the suitability of materials for possible infiltration gallery use, a roll of flexible plastic pipe of the type used in the drainage of moorland was imported to Zimbabwe from the United Kingdom. It was thought that long lengths of this piping might be more easily installed in flooded trenches than short 6.00 m lengths of rigid uPVC pipe that required joining. As the pipe is designed and primarily used in the drainage of water from clay, it was assumed there would be no loss in abstraction efficiency. According to Peel (1998), a drainage contractor operating on the Somerset moors and levels, this piping is typically installed at about 10.00 m intervals at a depth of ± 1.00 m. Peel uses a trenching machine that is set to follow a laser beam to install the piping at a even slope of between 1 in 100 and 1 in 200. To increase the area of infiltration around the pipe the installation rig also back-fills the trench with clinker. According to Peel in this way there is sufficient drainage to effectively lower the watertable in clay land over a distance of some five metres.

The piping used in the experimental infiltration gallery was 70.00 mm I.D., with 7 rows of 6,00 mm \times 1.50 mm slots placed transversely along the length of the top and sides of the pipe at 22.00 \times 38.00 mm centres, providing an effective open-surface area of only 1.3%. However, due to the 23 metre length of the gallery in a low volume situation, the low open-surface area was considered suitable. The piping was used in conjunction with two offset-wells. Figure 6.29 shows the excavation for the false well and the trench for the infiltration gallery across the riverbed at Dongamuzi. The shorter length gallery of 23 metres was used in a riverbed of fine, compacted sediment and was wrapped in geotextile. Although the use of synthetic textile was effective, costs for the gallery system were considerably escalated. The second, longer length of 55 metres was installed in an excavation in the basin of a shallow dam during construction. The trench was back-filled and covered with a 6.00 mm graded granite gravel pack.

No substantive data was obtained from either installation, due in part to the precarious water situation in the localities where they were installed. The river abstraction was so successful that people came from far and wide to draw water with the result that there was an over-abstraction of water and an unfortunate drying out of the river sediment.

Figure 6.29: Construction of Dongamuzi infiltration gallery and offset-well, Matabeleland North, Zimbabwe.



6.7. Review of Literature

Scoop wells, which by virtue of their nature include traditional sand-abstraction wells, are an accepted and sustainable, low cost technology (Sutton 1999(a)) and (Nissen-Petersen 1997). Jacobson, Jacobson et al., (1995) also refer to the extensive use made of water supplies in ostensibly dry rivers in their book Ephemeral Rivers and their Catchment, Sustaining People and Development in Western Namibia. The low-technology development of such sources of water as advocated by the author are merely an extension of this proven and accepted technology. Hazelton (2000) makes useful comparisons between Village Level Operation and Maintenance (VLOM) pumps and non-VLOM pumps and also between the different concepts of VLOM pump. Hazelton is of the opinion that because of the improved reliability of modern handpumps, the limiting factors to consistent pump operation have been reduced to management and spare part supply.

A number and variety of reports cite the advantages of sand dams, sub-surface dams and 'trap-dams' for the 'artificial subsurface storage or water'. Baurne (1984) provides information on the siting and construction of what he calls, 'trap dams', for the artificial subsurface storage of water and maintains that sediment filled dams could provide cost effective solutions to increase the availability of clean drinking water in arid and semi-arid regions of the world. Smet and Visscher (1989(a)) also extols the usefulness of below ground level storage and provides diagrams of sand and subsurface dams. Diagrammatic representation of dam construction is provided by Smith (1990) on 'groundwater dams' and Davis and Lambert (1995) who also lists the advantages of 'sand-storage dams'. A general description and comprehensive construction criteria for dam construction is provided by Nelson (1985). Barrow (1987) gives details on the construction of 'percolation dams' and describes the construction of sand-filled 'check-dams', suggesting that the incremental layers of the dam wall should be rock filled gabions which would retain coarse sediment, whilst allowing fine sediment to pass through the gabion. This permeable barrier should then be either sealed or replaced with masonry work and capped with another gabion.

Significant interest is shown in trap dams to store water and/or sediment that will hold water for later abstraction, Shama (2001) refers to 170^6 ha m of rainwater that is estimated to fall on India in 100 hours of rainfall, indicating the need to store even an additional fraction of this. Other information on sub-surface and sand dams is available on the Internet at sites such as UNEP (2000). The Internet also proved to be a source of information with regard to the design and function of gabions at websites such as UNEP (1998). Amongst several sites devoted to gabion construction and use, sites such as Bogart (2000), Maccaferri (2000) and Lane Enterprises (2000) provided information on the successful application of gabions in streambank protection and erosion control, their potential to retain river sediment was made very clear.

The US AID sponsored range of leaflets, 'Water for the World' proved to be a very useful source of basic information relating to well-points and screens and methods of installation, (U.S. Agency for International Development 1982). A further wealth of information has been provided on the design, siting and construction of sub-surface and sand dams by (Nissen-Petersen and Lee 1990).

Considerable research and expense has been committed to collector well technology which was initially developed to improve the yield of dug wells in hard rock aquifers. MacDonald (1992) provides comprehensive solutions to improving the yield of hand dug wells by either installing screening vertically through the base or horizontally outwards from the base. Herbert, Ball et al., (1988) states that collector wells out yield ordinary hand dug wells by about three times and that sustained yields have been maintained throughout the dry season with safe yields calculated in the range of 1.4 *l*/sec during an assumed 3-6 month dry season. Several reports provide information on the background and concept of the British Geological Survey work and of tests conducted in Botswana, Zimbabwe and Sri Lanka, Davies, Herbert et al., (1994) and Herbert, Barker et al., (1992(a)) and also in Fiji, Davies and Herbert (1994). Later trials were undertaken to abstract water from sand rivers through the use of offset wells and infiltration pipes that were jacked-in beneath riverbeds. Initial trials were conducted in Lincolnshire, U.K. and were followed by further trails, primarily in Botswana.

In further reports Herbert (1990) refers to collector well trials which he says were conducted in alluvial aquifers with a relatively high transmissivity, such as wadi beds and riverside silty-sandy plains. He states that a new drilling technique had to be developed to cope with the collapsing material of such aquifers. According to Morris, Talbot et al., (1991) a system of moling was developed using a thrust-boring mole of the type used in the construction industry to install sub-surface service mains without excavation. Small diameter adits were developed to minimise construction and installation costs, but as small bore adits could be expected to run full in very transmissive aquifers, Herbert points out that a sufficient number of adits is required for optimum flow to the well.

The system is said to have been developed with the aim of utilising groundwater resources which are present in thin shallow uncemented sandy aquifers where exploitation by borehole or shaft-only dug-wells would be expected to be marginal due to small available draw-downs and moderate to low permeabilities. Laterals have been installed from the base of a collector well shaft to lengths over 20 m with jacking forces of less than 7 tonnes. Installation comprises the horizontal jacking-in of a temporary steel casing containing a mesh wrapped plastic screen. The casing is then retracted whilst the screen is under a small positive hydraulic head to avoid sand-locking and ingress of any formation into the lateral and main shaft. Screening of 28 mm I.D. has been used and rapid auto-development of the formation around the radials has provided the wells with yields of 1.5 *U*/sec/radial from a head of just 98 mm in fine running sands. Lovell, Batchelor et al. (1994) provides details on the construction and costs of a collector well within a low yielding water lens and maintains that radial drilling increased the safe water yield from 0.4 *U*/sec to 0.78 *U*/sec.

With further reference to screening, Bakiewicz, Milne et al. (1985) refers to noncommercial attempts in the 1960's to construct well screening for use in the alluvial complex of the Indus River system. Screens were apparently made with saw cut slots in black steel piping, which were then installed with 'pea' grade gravel-packs. However Bakiewicz reports that many of the wells suffered from 'sand pumping' and a consequent rapid deterioration of specific capacity which was attributed to corrosion of the well screen and associated encrustation of the screen slots. He maintains however, that modifications to the screen design resulted in an almost immediate solution, at least to the problem in the short-term. Bakiewicz speculates that the deterioration which occurred in the long-term well performance was due to chemical mechanisms affecting the alluvium/filter gravel interface.

In work related to recharge and water loss from river sediment, Senarath (1988) has undertaken work to estimate recharge to an aquifer on the basis of water balance. Data required are the daily precipitation and the potential evapo-transpiration, water balance can then be verified as a comparison of estimated stream flow with measured stream flow.

6.8. Summary

Sand-abstraction is a water abstraction technology which is readily available to disadvantaged people for the drawing of water from saturated river sediment. It is a very simple, yet effective method which is fully sustainable through intuition and innovation at the family and community level of industrially developing nations. Although pump technology has been developed, sand-abstraction has very largely remained in the arena of large-scale, high technology installations and development.

Considerable use is made of screening in boreholes in unconsolidated aquifers and much use is made of a variety of screening ranging from commercial through to innovative solutions using locally available materials in low-cost tube-wells. Screening is also used extensively in the construction of infiltration galleries and in collector well adits. However, although a wide range of well screens is available, including small-bore well-points for multiple use, little use has been made of the technology for the development of small-scale abstraction schemes in semi-arid and arid regions within under-developed areas.

Through this research programme initiatives have been made to develop small-scale, low-level technology well-points and handpumps which might be suitable for community use. A design study, reviewing materials, construction, installation, operation and maintenance methods together with the effectiveness of differing apertures of screening has been undertaken to assess suitability for well-point fabrication. A variety of well-points has been assembled and pump trials have been conducted on a range of well-points which have been fabricated or are available commercially.

In-field pump tests are presently in hand at the community, local user level as a final assessment for suitability. Early indications are that the well-points and pumps are effective and have been well received, particularly amongst communities who experience severe limitations to a reliable water supply. Long term monitoring of pump manufacture, together with the installation, operation and maintenance procedures of the introduced pump and abstraction technology will continue. An easily operated and potentially sustainable technological is a significant factor towards ensuring an effective water abstraction system, but there are also non-technical issues that are relevant and must be addressed to ensure a permanent development.
Chapter 7

Use and Sustainability

7. Community Acceptance

Africa is unfortunately strewn with failed development projects and failed water delivery systems. Decisions to implement many of the early water supply solutions were often made by a centralised authority far removed from the recipient communities and did not take into account local requirements and capabilities. In spite of this detachment from society, such systems were in the main effective, as long as the full process of site selection, installation, maintenance and repair was also effected by a centralised, well-equipped and trained team of technicians. However, once the responsibility for both funding and effecting maintenance and repair was passed to the communities, many systems fell into neglect and decline and ultimately became abandoned. Weinrich (1971) cites an instance of a chief in the Bulilimamangwe District of Zimbabwe who, without consulting his headmen, approached the authorities of the day with a request to have three boreholes drilled in his area. Although the District Administrator agreed, the boreholes were never a success as the headmen were unable to convince the communities to take responsibility for the pumps.

The prospect of accepting responsible for their own water supply is daunting for most communities. Many find it difficult to switch from an effective, centralised, ostensibly free, repair/maintenance service that was undertaken on their behalf, to one for which they must take financial responsibility. Although a system of devolvement to community structures was undertaken, it was largely ineffective. At a primary level, pump committees were set up with responsibility for the daily management of a pump and at a secondary level pump minders were made responsible for pump service, repair and maintenance. However, in many countries this was hurriedly implemented and the pump minders were poorly equipped in both training, and tools and equipment.

Consequently the devolvement to communities of localised water supply operation and management systems has been virtually stillborn. During a survey undertaken by the author for Plan Afric, (Gunby, Hussey et al.1998), Moses Mthuthuki the Matabeleland South, (Zimbabwe) Provincial Water Engineer stated that almost all pump minders within the province had insufficient tools and training. To compound this, as well as a number of expensive heavy-duty tools, the Zimbabwean Bush Pump, the pump most commonly used, requires specialist lifting equipment forcing most pump minders to share equipment. Thus in order to effect repairs to a pump, a pump minder has first to locate the equipment required and then to organise transport from that point to the borehole requiring repair. Having effected this the pump minder then has to persuade a number of people to assist him to lift and repair the equipment. In such circumstances it is not uncommon for a high degree of improvisation, which coupled with limited training, often results in heavy 50 mm (2 inch) steel pump columns being dropped down a borehole, with further dire consequences. To further undermine a localised pump service and maintenance system there is a general reluctance amongst community members to make a regular stipend to a pump minder for maintenance work. According to Dube, Ntini et al. (2001) most people are quite prepared to contribute to pump repairs, but not to pump maintenance. However in a survey she conducted to assess peoples' perception of responsibility and ownership of water supplies, Ntini and Dube (2001) found that many interviewees were dissatisfied with the repair service which was available to them, because a lack of availability of spares often precluded an effective repair.

It is imperative that communities be fully involved and encouraged to accept full responsibility for their water supply systems. Community leaders should be required to initially identify community water supply needs and then, once these are known, the communities should be challenged by an implementing authority or organisation, on their ideas and capability of sustaining the supply. The involvement of ultimate recipients in any technical development is thus considered to be of paramount importance. With this in mind it was considered most appropriate to establish and maintain a substantive connection between communities and the research programme.

The need for a community linked, integrated research and development programme came about through on-going requests from communities for assistance with sustainable water supply systems. Many of these communities were already making extensive use of sand-abstraction systems and showed that they were only too aware of the limitations of traditional systems; the impermanence of sand-wells, the desecration of trees and brushwood in the environment of river sand-wells and the difficulty of drawing sufficient water from the shallow depth of open water in a sandwell. People then demonstrated a wish to be involved in the development of up-graded abstraction systems that might lead to improvements in the security of an abstraction system, reduce environmental destruction and which would hopefully provide more water.

The research programme was conceptualised as communities continued to make approaches to Dabane Trust, a Non Government Organisation in Zimbabwe with which the author is involved, to assist with the implementation of small-scale irrigated projects and the establishment of livestock watering schemes. The systems used by the Dabane Trust were considered effective by the communities and were seen to be largely sustainable at a community level, but nevertheless remained dependent on a large degree of input from outside the community. The systems utilised, were comprised of well-points installed within the river alluvium, connected to a pump on the riverbank. Representation was made to four communities where Dabane Trust was known and was engaged in community development work. It was suggested, that a joint programme be initiated to develop effective, simplified systems of abstracting water from river sediment.

Commencing from a perception of the traditional use rural communities make of sand-abstraction systems, it seemed likely that involvement of present-day rural community structures would ensure the acceptance and sustainability of any improved systems. End user involvement in the design and development of equipment was considered imperative to ensure a thorough understanding of the principles and mechanics of abstraction equipment that would in turn ensure the success of the development initiative. Involvement of community members throughout the research and development programme ensured the participation of rural artisans, using their

skills and perceptions, allied with local tools and make-shift materials and equipment. This concept was thought to improve the chance of the absolute sustainability of both the institution and the infrastructure. Further, involvement of the community throughout the development period was seen to improve overall community acceptance and responsibility and to ensure the popular participation of competent, responsible people with sufficient knowledge and training who could be charged with the responsibility for any new system that would ensure the continued function, management and maintenance of the system.

7.1. Community Based Research

A number of meetings were held with representatives from the four communities in the Matabeleland Provinces of Zimbabwe where the field research sites were established. Thus a number of meetings were held at Wenlock on the Mtshelele River, at Huwana on the Manzamnyama River, with others at Tshelanyemba on the Shashane River and at Dongamuzi on the Dongamuzi River. In order not to inadvertently raise expectations of an immediate end to the restricted use of water within their communities, discourse was conducted in an exploratory manner with just a few people and was restricted to the possibility of establishing practical research sites in differing conditions. These meetings culminated in agreement to arrange further meetings to which the entire community was invited. At these further meetings people were introduced to the idea of setting up research sites and identifying research assistants to both collect data and provide feedback and monitoring on the development of practical systems which might assist in the abstraction of water from sand.

The first meetings were organised in order to request information from people and to discuss the proposed methods and intentions of the research into sand-abstraction systems. Such meetings were therefore not directly connected to the supply of water to the community. Judged by the number of people and important local leaders who were prepared to attend these meetings it was apparent that water was of great concern to each of the interviewed communities. Only at Wenlock where the water level is seldom more than a metre deep in the riverbed and where a supply of water can be guaranteed, were there only a few participants. Involvement was slightly better at Tshelanyemba where water can also be guaranteed year round, but many people became involved at Huwana where water is certainly temporal and where livestock are a vital component of food security and income generation activities. At Dongamuzi, where water available for abstraction could be measured in millilitres and is liable to run out at any time, the largest number of people attended.

Community meetings were facilitated by Mr. Douglas Nleya of the Dabane Trust and were conducted in the vernacular language, isiNdebele. At various times he received support from Mandlankosi Tshabalala, Florence Ndlovu, Duduzile Dube, Donald Ncube, Melusi Mafu and Peace Ncube. The author also participated in the meetings and made a record of the proceedings but was certainly grateful for the assistance of Nleya who clarified many points of interest.

At each meeting participants were most helpful, both with the input of their traditional and community knowledge and in their acceptance of the establishment of field research sites within their communities. Once communities fully understood the intention of the research work they were quite prepared to safeguard site equipment. Many people showed a keen interest and provided considerable encouragement to the research work and proposed development of sand-abstraction systems. Each community identified people whom they felt would be suitable assistants to collect data and to monitor the research sites. Two people were selected at each of the four sites, six women and two men. At Wenlock the meeting appreciated the need for a local person to monitor the site and recommended the secretary of the garden group, Mrs Sithembile Sibanda with MaSisiba as an assistant. At Huwana, a young lady, Letshane Nkomo, who had lost both her parents and had had to leave secondary school in order to take on the responsibility for her brothers and sisters, was selected to monitor the research site. She was assisted by Mrs. Ncube. At Tshelanyemba another small-scale sand-abstraction system user and member of the local garden group member, Pretty Moyo was selected to monitor the site with Miss Lesego Nyathi. At Dongamuzi Mr. Nicholas Sibanda, pump-minder for the community was selected by the meeting with Stephen Mkandla to assist him.

7.1.1. Community Research

Having accepted the need and the potential for the development of abstraction equipment a data collection programme was set up to help with the selection and the design of equipment. Information was gathered on water deterioration patterns and analysis and grading was carried out on river sediment samples. From this and other data collected, tentative experiments were conducted to develop well-points which would be acceptable to disadvantaged communities.

Once the consent of the four rural communities had been obtained to collect data and to conduct experiments within their locality, the two community members selected by each community were given training to undertake work as field research assistants. Feedback was provided to the communities on the activities undertaken by the field assistants and a further link was established when equipment trials commenced. Communities were asked where pump trials should be conducted and were also asked to comment on the perception and suitability of the equipment to be installed. The various communities readily provided feedback on the physical operation and output of the equipment. People's interest and enthusiasm for the equipment was maintained by ensuring their participation during installation and monitoring visits. Community members offered to assist with trial pumping equipment and also identified suitable sites for installation. A general atmosphere of interest and encouragement was provided to research staff.

The participation and interest of local field research staff was guaranteed by continual involvement in all research activities and at orientation workshops when they were able to meet together to share experiences and to report on their interaction with the rural communities that they were a part of. The importance of interaction and acceptability is noted by Dusseldorp and Box (1993) who recommends the involvement of communities in research and feels that to be effective, communication requires empathy, particularly where traditional rationality is likely to be perpetuated by the ingrained habits of the participants. Further to this Marsden (1994) contends that the development of any popular institution will automatically command a degree of local authority that will promote participation and encourage people to be more responsive and ultimately to make some personal commitment or investment to any proposed development activity. He suggests that participants should be involved in all aspects of programme planning and any implementation strategy which is likely to affect their lives and livelihoods. Faulkner and Lenehan (1997) refers to the need to involve people stating that the failure of many water development schemes is due to

the attempted imposition of new technologies and management practices that are alien to indigenous culture and do not involve the local community at an early stage.

7.1.2. Community Involvement with the Development of the Equipment

Selection of the technology level

A realisable balance has to be established between what may be desired and what may be sustainable. An immediate and automatic response of end-users is the assumption that the newest, the latest and possibly the easiest option will provide the best comprehensive solution. The feeling of many rural people is that the most advanced and superior model should be made available to them, but they give little thought to initial costs and ongoing operation, maintenance or replacement costs. Welladvertised high technology solutions are often available on the market offering easy installation and operation. In the face of this it is not always apparent to disadvantaged communities, that what they see as a second rate solution might ultimately be the better option.

Many rural communities have little or no experience of mechanics as they neither own nor have grown up within an atmosphere of mechanical solutions, this is coupled with a wish to increase supply or productivity without increasing the tedium or physical requirement of operation. This possible technical ineptitude is related to a lack of opportunity rather than a lack of ability, but nevertheless poses a severe limitation to successful high technology solutions. At first thought pumps powered by petrol or diesel engines might appear to provide a very positive solution, however there may be severe limitations to successful, long-term engine operation.

It is however not all doom and despondency. Hussey (1996), Naugle (1991) and Owen, Rydzewski et al., (1989) each report on the successful use of handpumps for small-scale irrigation by community groups. The author whilst participating in a demonstration made to rural women on handpump service and maintenance at Esigoveni, Zimbabwe was most pleased to note the tirade which met a local agriculture (AGRITEX) advisor's scepticism of the viability of a handpump. When asked why the women were 'messing around' with a handpump rather than use an engine he was emphatically told that handpumps were cheap to operate, required no outlay on fuel and oil and very little on spare parts and best of all did not require a man to operate them and to interfere in their group - so the AGRITEX officer could take his advice, go back to where he came from and leave the women to get on with their work!

The experience of Dabane Trust with regard to women's participation in pump operation and maintenance has been interesting. Dabane staff maintain that allwomen groups are better able to maintain their pumps than mixed, men and women groups. Ntini (2001) is of the impression that all-women groups are attentive and observant during training and thus between them are better able to work out how to repair a pump. Mixed groups however rely on the men in the group to maintain the pump, but probably they have not worked out the pump operation and are reluctant for this to be seen, consequently they do nothing.

Community gatherings of both women and men felt that the answer to a rural farmer's water problem was the development of suitable abstraction technology and the application of simple handpumps. The research programme was encouraged by

community meeting participants with suggestions of developing well-points and handpumps and increasing the number of installations in suitable rivers where water is retained year round in the sediment.

Community perspective of handpump sand-abstraction systems;

- Savings can be made in time and labour as there is no need to continually deepen a well.
- It is easier to draw water from even a deep well-point than to carry a bucket of water from an open sand-well. In community meetings several women stated that a handpump would significantly reduce the present hardship they experienced when drawing water.
- Handpump operation and maintenance costs are more easily afforded by rural farmers as there are no fuel costs and there are likely to be significant savings on the purchase of lubrication and spares.

7.2. Use and Acceptability of Systems

As a result of vested interests and responsibilities, water use is often divided with women wishing to use water for domestic purposes, food production and income generation and men wishing to use water for livestock. The expectation is thus that the simplified systems now under test will continue with women drawing water to carry home and to irrigate small, stream-side gardens and men drawing water for their livestock. A hollowed out log is often used as a drinking trough for livestock. As a part of the trial programme a number of ferro-cement troughs of the approximate dimensions of a log have been made for use in conjunction with the riverbed handpumps. A mould made of wet river sand is cast on the riverbed and plastered with a ferro-cement concrete mix. A layer of chicken wire netting is then placed over this first layer which is plastered with another cement mortar mix. A simple water trough is made when the casting is inverted and the sand mould removed. Although the concrete 'log' water trough may be lost in the sediment during river flow it is expected that most will be recovered.

Existing scoop-wells are often managed by three or four families of the same kinship and frequently occur some 500 metres apart along a river. Where there is sufficient water a well will often be used to support a brushwood fenced garden of some 100 m². Indications are that the simplified abstraction systems will be used to provide water for such gardens.

7.2.1. Environmental Awareness

A concern of the wider community at Huwana has been the build up of silt and clay in the scoop-wells of a previous season. The community sees that the build up of brushwood and silt within the river sediment restricts the area available for scoopwells in the following dry season. Many people also believe that the build up of sediment in the river channel gives rise to the formation of further islands in an already braided river situation. These concerns have been a motivational point for the community to engage in the research programme in the hope of gaining access to abstraction equipment which will obviate the need to construct scoop-wells each season.

It must be appreciated that whilst private ownership of land might no longer provide a 'social safety net' for poor and impoverished members of society, there are many

limitations to the effectiveness of communal land management. A case in point is the management of livestock within a communal grazing system. Typical stocking rates are 7-8 ha per livestock unit which are generally adhered to by worthy farmers in the commercial farming areas, however due to the density of human population and the social and economic importance of livestock, such a stocking rate is rarely, if ever achieved in the communal areas. The result of this is widespread over-grazing with the consequent result of severe erosion of soil. One farmer, even a group of farmers are unable to improve on the situation. If some farmers agreed to reduce their livestock numbers the herds of those who did not comply would expand biologically to meet the deficit. One hundred, even fifty years ago the *sabhukho*, the chief and his advisors, strictly controlled grazing practises, but now land and grazing is in such short supply that management-planning systems are no longer effected. With the breakdown of such traditions there has been a manifestation of environmental degradation, which in turn has lead to the siltation of river channels.

The depletion of natural timber reserves is a further cause of environmental concern. Timber is required for fuel, for cooking, heating water and space heating. Mature poles are required for home construction and for fencing. Wood is required for furniture, bowls and drums, brushwood is required for fencing, roofing and baskets and finally strips of bark are required for binding purposes and for medicinal use. The importance and need for wood is all pervading. When there was a plentiful supply of wood, whether for firewood, furniture, or as a pesticide, for each purpose there was an appropriate allotted species. Unfortunately the situation is not improving. In August 2003 Nleya (2003) referred to a proliferation of sand-wells (*isiliba*) along the Manzamnyama River, Bulilimamangwe District, Zimbabwe and expressed concern at the ensuing desecration of the environment to fence off these scoop-wells.

Although a community may have an overriding concern for their environment, within a communal land situation this may not necessarily lead to a condemnation of bad environmental practices. In an internal Dabane Trust report, Ntini (2001) expresses concern following a visit to a sand river after an absence of some twenty years. On her return she was horrified to find the river, from which she had once drawn water, now virtually destroyed. With spiralling inflation and an increasingly restricted formal economy in Zimbabwe many people are forced to resort to hitherto untried methods of generating an income. Zimbabwe is a prolific producer of gold and since the early development of the country mining rights have taken precedence over agriculture and property rights. In recent years alluvial gold prospecting has considerably increased with the riverbanks and alluvium in many rivers completely over turned in a quest for traces of gold.

Not only has there been destruction of the environmental through excavation and through the resultant heaps of spoil being washed away during river flow, but mine dump material is now often transported to a suitable river location for reprocessing. Cyanide is used extensively in the gold extraction process and since this reprocessing is essentially a small-scale, informal sector activity, invariably no effort is made to recover the cyanide which then enters the waterway. To worsen the situation the original overburden and mine waste is left in the riverbed or on the riverbank to infiltrate the sediment and to clog the waterway when the river flows. In this way river channels are becoming completely blocked which can only portend future disasters. Although the installation of well-points and handpumps have helped to ease the concern of the Huwana community, typically impoverished communities have few options availably to them to improve their environmental management. A frequent response is likely to be, "we know that we should not be managing our resources in such a way but we have no alternative". A similar sentiment is expressed by Njie and Muir-Leresche (2000) who states that many rural people appear to subscribe to *'kreteminal'*, an Eritrean attitude to the effect that "we should conserve the environment, but never if it means we go hungry". Although difficult to implement in spite of the constraints and the predicament in which many rural communities find themselves, successful conservation programmes are possible

7.3. Suitability and Sustainability of Technology

Several surveys, such as Dube, Ntini et al.,(2001), Gunby, Hussey et al., (1998) and Hussey (1998(c)) indicate the preference of rural people for water from sandabstraction supplies. A realisable potential can thus be identified through the acceptance and preference that people have for sand-abstraction systems.

Although both cheap to implement and effective, basic scoop-well technology is in fact onerous and tedious to construct and to maintain, not made any the more appealing by the fact that a well will be in-filled when the river flows with the first substantial rainfall. The answer, an improved and on-going system, is often perceived by many rural people to require a high technology solution. The most recent and the most advanced technical solution is often the one sought, however it has to be appreciated that many people, especially those in impoverished rural communities have little or no mechanical experience and consequently have only a limited capacity to keep complex mechanical systems operational.

Within the mores of traditional society there was little requirement for maintenance, thus even now rural communities frequently have only a scant concept of maintenance and still exhibit a reluctance to commit limited funds. Amongst the vernacular languages of Southern Africa there is in fact no word for 'maintenance'. As a consequence many rural based end-users simply use equipment whilst it remains operational and then resort to former means, possibly expressing to a development agency a sentiment such as "*your' engine has failed us…………*". Within this concept tools are seldom cherished, to many people a tool is merely a handy, transient appliance that can be used until too worn out and then discarded. Typical traditional tools are instruments for hewing timber such as axes, adzes and knives. Many men are very skilled and adept in the use of these apparently basic tools and together with possibly a pair of pliers, are able to undertake much of the work that is related to livestock management and that is required around a traditional homestead.

The introduction of improved or advanced technology needs to be cognisant of this fact and for equipment to remain operational it must be capable of being maintained with the materials and basic tools that are readily available. However in the so-called, industrially developed world, the general development of technology only continues to become increasingly complex. Hussey (2001(a)) states that the continued trend for conventional engine designs to become increasingly high-tech, exposes the lack of infrastructure and shortcomings in the capacity and availability of service support in third-world countries. Although the service/maintenance intervals of internal combustion engines are being extended and overall reliability improving, simpler power systems are required.

However, particularly in arid and semi-arid regions there remains an urgent need to make water easily available for food production and also to reduce the drudgery of drawing water. Referring to a number of small-scale irrigation schemes in Zimbabwe, Faulkner and Lenehan (1997) reports that the local communities themselves identified a need to upgrade their watering technology from watering can to human powered pumps. From this inception, environmental and socio-economic studies were conducted to establish the feasibility of micro-scale irrigation. Subsequently a simple pumping and irrigation technology was developed and disseminated. Central to the process was a strategy based on close interaction between farmers, fabricators, researchers and extension agents. Farmers were involved in the initial development and fabrication of the pumps so that they considered them to be 'their own' which Faulkner says, contrasts with the conventional approach of presenting farmers with a pump that is produced in a factory and for which they feel little or no responsibility. He makes the point which is also supported by Hussey (1989) that all too often technologists concentrate on research and development and leave diffusion of the results to others, consequently leaving local communities with little sense of ownership.

Simple, small-scale and low-cost technology is by no means the only option available for water abstraction. Whilst it may not be appropriate for impoverished countries of the so-called Third World, affluent Middle Eastern countries often adopt a 'Turnkey' approach to solve their water shortage problems. Gould (2003) describes the installation of a water supply scheme by Black and Veatch Contracting in a process totally removed from any community involvement; from initial surveys and assessment through to installation and training of personnel, to final handover of the project to authorities in Bahrain. Within South Africa, Botha (1999) considers that a principle of BATNEEC (Best Available Technology Not Exceeding Excessive Cost) should be applied and that within this any available method or tool should be utilised. Not dissimilarly Dingle (2003) is of the opinion that the only reason developing countries do not have piped running water is due to underdevelopment and poverty and that NGO aspirations for water delivery are depressingly low. She states that all the water problems in the world could be solved with what was spent on the first war against Iraq. Unfortunately the provision of water cannot be reduced merely to installation costs of high-tech solutions, as continuity, operation and maintenance are the overriding factors required to ensure a sustainable water supply, certainly at an impoverished village level.

7.4. Technical Options

The scoop-well, which is the form of sand-abstraction most commonly utilised, is simple to an extreme. If 'improved' sand-abstraction is to become widely utilised it too must be readily accepted and the technology must be such that rural communities and households are able put effective maintenance and repair systems in place. For this to occur the technology must be at a level that is serviceable with commonplace tools and materials and at a level where local innovations are possible to both composition and structure. For pump technology to be acceptable and functional it must be at a level where local artisans are able to improvise repairs and ideally to fabricate equipment. According to Gordon, Bras et al., (2000) there is no best practice. She maintains that instead of searching for the best available technology, technologies that can be adapted to local circumstances should be utilised. Van der Straaten (1992) is of the opinion that a new technology must allow for innovation if there is to be a successful transfer of technology to disadvantaged communities. He makes the point that independent development and innovation are a significant aspect and a requirement that is frequently overlooked by engineers and technologists if a dynamic application is to take place. He further contends that typically new or appropriate technology is developed in conditions which are conducive to development and then attempts are made to introduce the initiative to targeted groups or institutions instead of development agencies working with developing world institutions in a joint develop exercise. Van der Straaten feels that many development initiatives receive only a slow response through this distanced approach and that invariably many agencies become disappointed at the slow rate of adoption.

Lambert (1992) states that peasant farmers purchase a wide range of agricultural equipment from ox-ploughs to wheelbarrows and are quite ingenious in keeping them operational. The success of farmers in keeping such devices functioning and the existence of an informal repair and maintenance network of village artisans suggests that local maintenance and repair of pumps such as the rope and washer pump are quite possible and thus such pumps are of an appropriate design. Adelsperger and Elson (1999) provides a straightforward list of criteria to which low technology drilling methodologies should subscribe. This list is equally applicable to water abstraction technology which she says must be:

- Socially aware
- Simplistic design
- Robust
- Standardised
- Locally made
- Least cost solution

Development of Well-points, Screens and Caissons

Communities have demonstrated that unless the water abstraction technology is cost effective they will neither accept responsibility, nor will they contribute to its maintenance. Technology which is not utilised, whether it is neglected or rejected, has therefore to be viewed as either unsuitable or inappropriate. Abstraction systems thus have to be either extremely robust or sufficiently simple to encourage and to enable people to effectively undertake maintenance and repair work. In an internal evaluation report conducted for the Dabane Trust by Ntini, Ndlovu et al., (2002), 35% of people felt that they should not have to pay for water services as they considered that water was 'free'. A typical sentiment expressed was *how can we pay for anything that God has given us*? Within this natural reluctance to part with money for the supply or maintenance of water supplies, technical solutions must be of a particular advantage and particularly beneficial if they are to be popularly supported.

Unfortunately, severely negating the success and sustainability of water supplies, water collection is generally considered women's work, probably had men the responsibility for water collection there would be some rapid and radical changes to water supply systems. As can be clearly seen in figure 7.1, the participation of women to men during the construction of Dongamuzi dam was more than 5 to 1. To compound this imbalance, when early rains brought some water to the dam basin, work on the construction of the spillway virtually ceased as it was popularly assumed that the dam was then complete. To overcome this the contractor building the spillway paid some men to mix building mortar. When it then came time to construct

an infiltration well from which women would be able to draw clean, domestic water, the men refused to be involved – unless they were paid.

Free Water?

The Dabane Trust worked with villagers at Dongamuzi, Lupane District, Zimbabwe to construct an earth embankment dam. Almost everyone within the community assisted with loading and unloading trailers with rocks and building materials, in collecting water and consolidating the embankment, digging foundations, mixing building mortar, stone pitching the embankment and any number of support tasks to improve the dam and to keep the equipment operating. When the dam was complete and the first water held in the basin, people brought their few cattle and livestock to drink. One corpulent cattle owner also came with his huge herd. The community queried the right of this person to use the dam as he had not participated in the construction of the dam and had sent no member of his family to assist. His response – he accepted that the dam belonged to the community and not to him, but the water, that was 'God given' and free for the use of everyone.....





In a situation where pump sustainability can only be viewed as suspect, families cannot be dependent on only one source of water, for the sake of security there has to be at least one other supply. In a survey conducted by Ntini, Ndlovu et al. (2002), 36% of respondents stated that they regularly drew water from more than one water source, if only from a seasonal and a more permanent supply. White and Simanowitz (1991) who spent 12 hours a day on several consecutive days in a four month period recording patterns of water collection and use in the Tsholotsho District of Zimbabwe is of a similar opinion.

The need for a number of sources of water is clearly demonstrated by Mabandla (1987) who provided an interesting insight into water collection and pump operation and management. As an inoperative pump was lifted near Mabandla's home in the Tsholotsho District of Zimbabwe, it was found to be full of small stones. Asked why this was, she replied that she and other girls frequently dropped small stones inside the pump because they liked to hear the sound the stones made as they ricocheted down the steel pipe. In response to the obvious statement that that was why the pump had ceased to operate, she responded that was in fact an added advantage as the girls

then had to walk further to fetch water with the result that they had less work to do during the day as they could justifiably stay longer away from home.

To be acceptable, abstraction equipment thus has to be easy to work on, utilise minimal tools and equipment to effect repairs and require low cost spares. The technology must then be effective, efficient, robust, reliable, sustainable, and finally vandal and idiot proof. With these design criteria in mind, consideration should be given to the community perspective of the suitability of point of separation equipment to abstract water from saturated sediment

Well-points

Well-points may be considered to be a suitable technology for use in deep saturated alluvium where they may either be vertically driven or obliquely wriggled with the help of a shovel, into the sediment. Communities are able to exercise a considerable degree of management and control over the installation and operation of well-point technology and possibly over the manufacture of abstraction equipment. Experience is likely to quickly demonstrate that when installed effectively in coarse sediment the technology will provide a satisfactory separation of water from sediment.

Recognition of the need for an effective design and attention to detail in the construction of a well-point will however be critical to success. The well-point will completely clog and become totally useless if it is constructed with apertures which are too large. Conversely, if apertures are too small or too few, the pump will be starved of water. In order to utilise appropriate equipment a correlation is required of aperture size with sediment grade so that excessive sediment is not drawn into the well-point, but rather the development of an effective natural screen will occur within the sediment around the well-point.

Although within the research programme a spreadsheet (appendix 09), has been developed to assist with the calculation of a suitable aperture size to sediment grade, to velocity of flow through a well-point and piping, few if any rural communities will be able to avail themselves of this. However the construction of a steel template or jig to aid the construction of well-points suitable for average or typical conditions would considerably improve the reliability of construction. The actual fabrication of a wellpoint is simple in the extreme and if adequately designed and prevented from clogging should provide many years of trouble-free service. Maintenance should amount to no more than ensuring that couplings remain tight and intact and that the well-point remains in saturated sediment and is not damaged or washed away in an excessive flood situation.

Caissons

A similar situation will be apparent with the construction and installation of a caisson which essentially has the same characteristics as a well-point in that a screen is developed to separate water from sediment, initially with the apertures of the caisson and then with a naturally graded sediment pack around the caisson. A caisson may however be more suited to use in fine sediment than a well-point. In sediment which is too fine for the use of apertures, a caisson which is either wrapped in geotextile or embedded in a gravel pack may be a successful alternative. As large diameter caissons have a much greater surface area exposed to water bearing sediment, the number and even the size of apertures may not be as critical as a well-point. Caissons are installed by excavation and digging-in, undertakings well within the capacity of local communities. Figure 7.2 shows the installation of a geotextile wrapped caisson into the fine alluvial sediment of the Dongamuzi River, Lupane District, Zimbabwe.

Figure 7.2: Installation of a caisson into fine sediment



Infiltration Gallery Screens

Infiltration galleries have a great potential for sustainable water abstraction for communities. A considerable degree of latitude can be tolerated in the design of all aspects of the dimensions of a gallery - the gallery internal diameter and length and even the open surface area percentage. By and large, as long as a gallery extends some 10 metres into a river channel and provided it remains open to an inflow of water it can be expected that there will be a yield of substantial quantities of water. The level of technology is particularly simple and straightforward, at its most basic it is not even necessary to have a piped gallery. A trench leading from the base of the river channel, which is backfilled with coarse sand or aggregate will provide a sufficient conduit for water to flow to an offset-well.

An infiltration gallery is particularly suited in situations of low permeability with fine grade sediment where water may be removed from river sediment by an hydraulic head. Provided the gallery pipe can be installed sufficiently deep, a virtual maintenance free installation can be guaranteed. As installation is by trenching this further ensures a 'popular', sustainable technology. From the position of the technical aspects, an infiltration gallery may be considered an appropriate technology for rural communities.

7.5. Pumps and Power Options

7.5.1. Pumps

Although an efficient well-point is imperative to create effective screening for the successful abstraction of water from river alluvium, the most complex and potentially problematic piece of equipment is the pump. Zimbabwe in particular has both a history of an essentially effective centralised handpump installation and maintenance repair programme and an established industry in support of high performance mechanical water pumps. Thus there is very little understanding at the local community level of the function of a simple, suction handpump. The principle of effectively creating a

vacuum that is then filled with water by atmospheric pressure is largely not recognised. As a consequence, the principle of effective seals and valves is generally not immediately perceived. Due to these limitations there is little chance of guaranteeing the sustained use of a pump that is dependent on complex principles of operation, or maintenance tools that are not generally available.

Pump Serviceability

The less complex and less reliant on sophisticated tools and equipment for maintenance, the greater the chance of regular effective pump performance, particularly when coupled with accessibility and ease of handling. As water is generally available within river sediment at depths within the limits of delivery by atmospheric pressure, a basic suction pump that can be operated and maintained at the village level does offer a suitable solution for drawing water. The U.S. Agency for International Development (1982) reports that there are many compelling reasons for the local manufacture of handpumps so that both repair parts and skills are readily available. The report states that many villages are in need of handpumps but that often the villagers do not have the local resources with which to purchase them. When handpumps are obtained, the repair parts are often not readily available so that many communities have failed to maintain their pumps. The report continues by stating that localised manufacturing options range from the construction of long-lasting and relatively maintenance free pumps that are manufactured at central locations within a country by skilled workers using sophisticated equipment, to full village manufacture of pumps which may be inefficient and have a short life span, but are within the villagers' capability to understand and to construct. A further option is referred to, that of manufacturing the parts of a pump that require accurate machining or casting at a central location within a country, with the balance of the pump constructed and assembled at the village level. The Department considers that such a strategy has been applied with success but qualifies the statement by saying that the choice of options depends on the specific country and village. The author is of the opinion that such a rider is necessary as there is little to be achieved with this strategy if vital parts are not readily available at the local level. With reference to Zimbabwe, which has been committed to a common type handpump since at least the 1920's, (the Murgatroyd in use from 1933 to the mid 1970's, followed by the Model 'A' Bush pump into the 1980's and the model 'B' Bush pump, developed in 1989 until the present, [reference the author and Taylor and Mudege (1996)]), on only one occasion in more than 30 years travelling in the rural areas, has the author found a pump component for sale at a rural store.

According to the U.S. Agency for International Development (1982) handpumps have been installed in many villages throughout the world in a number of different situations but very many quickly become inoperative. Although efforts continue to develop and improve handpumps, in spite of considerable research, development and funding there is still no perfect handpump that will work without proper operation and maintenance although with the introduction of VLOM pumps, down time has been appreciably reduced as demonstrated in table 7.1. According to the Department, all too often a pump will become inoperative due either to a lack of knowledge or to a lack of attention to operation and maintenance. An important opinion expressed is that operation and maintenance procedures should be decided upon and supported so that everyone in the village plays a role that is both understood and agreed.



 Table 7.1: Definitions of reliability, after (Burks 1988)

In an attempt to improve the serviceability of handpumps within the experience and artisanal capacity of a rural community, possibilities may exist for the construction of pumps from alternative materials. In many localities carving has become a home industry and a complete pump might be crafted from wood. A sketch of a carved wooden handpump piston is shown in figure 7.3. Within the research programme, so far unsuccessful attempts have been made to form pump piston plungers from entwined 'eregeni', thin strips of discarded vehicle inner tube and thought has been given to forming pistons from the mastic which exudes from some acacia trees. However it has to be accepted that such 'appropriate technology' is in fact considered very second rate by many rural people and is thus in fact inappropriate. Unless it is utilised by a pump operator as a make shift repair such technology is unlikely to be unacceptable.

Figure 7.3: Carved wooden handpump piston, after Darrow and Saxenian (1986)



Alterations, variations and refinements are continually being made to pump and hand pumping technology in an effort to improve either pump efficiency or service efficiency. Within the broad parameters of positive lift and atmospheric pressure there is a vast array of pumps and pump mechanisms that may be achieved by counterbalance, 'suction', reciprocating rods, rotating shafts, ropes, water jets, forced water or air pressure, or hydraulic oil. Innovation is not limited to pump mechanisms but has also been applied to the way in which a pump may be operated. In South Africa, for instance, where there is a history of innovation, there are available on the market pumps which, may be manually operated by hand or foot pedal power, treadle power or the action of playground swings, roundabouts and seesaws, (Lee 1997) and (Barry 1997). Figure 7.4 shows a pumphead which utilises the principle of a child's see-saw to draw water from a borehole.



Figure 7.4: See-saw pump

For pumps to remain serviceable effective maintenance and repair schedules are required and adhered to. Basic, non-complex pumps provide a good opportunity

Pump Classification

There are several principles and variations which pumps utilise to raise water and even further variation in the terminology used to categorise pumps. (Baumann 2000) who has produced a fact sheet with diagrams of 13 handpumps that are commonly used on rural water supplies is of the opinion that there are five basic principles of raising water:

- 1. Direct lift, where water is lifted in a container. Such pumps are rope and bucket, bailers and Persian wheels.
- 2. Displacement, where water which is physically pushed or displaced from a pump draws more water into the pump. Such pumps are piston pumps, plunger pumps, progressive cavity pumps and diaphragm pumps.
- 3. Velocity, where water is propelled to a high speed so that the momentum produced creates a pressure or flow. Such pumps are centrifugal pumps, propeller pumps, jet pumps and inertia pumps.
- 4. Gas, where a stream of compressed air raises a proportion of water as it flows upwards through the water. Such pumps are air lift pumps
- 5. Gravity, where the energy of downward flowing water is used to lift water. Such pumps are ram pumps and siphons.

Table 7.2: Pump types and characteristics, based on data provided by Hofkes, Huisman et al., (1981)

Type of Pump	Usual Depth Range	Characteristics & Applicability
1. <u>Reciprocating</u> : (Piston or Plunger) a. Suction, shallow wells:	Up to 7 m	Low speed of operation; hand, wind or motor powered; efficiency low (range 25 -
Pitcher, Joggle, Diaphragm	-r ··· · ···	60%)
 b. Direct Lift, deep wells: Rod pumps – Piston & cylinder 	Up to 50 m	Capacity range: 0.6 – 3.0 m ³ /hr; suitable to pump against variable heads; valves and cup seals require maintenance attention.
2. <u>Rotary</u> : (Positive displacement)		Low speed of operation; hand, animal,
a. Low Speed - Chain and bucket, Rope & Washer, Persian Wheels	Up to 10m.	wind powered. Capacity range: 0.3 – 1.8 m ³ /hr. Discharge constant under variable heads.
b. High Speed - Progressive Cavity	Surface use up to 7 m Submerged use 25-150m.	Using gearing; hand, wind or motor powered good efficiency; best suited to low capacity – high lift pumping.
<u>Rotary</u> : (Axial Flow)	5 – 10 m	High capacity – low lift pumping; can pump water containing sand or silt.
3. Rotodynamic		High speed of operation – smooth, even
a. Centrifugal	Up to 7 m	discharge; efficiency (range 50-85%) depends on operating speed and pumping head.
b. Jet	20-35m.	Even discharge; efficiency (range 50- 85%) depending on pump head. Liable to wear with reduced efficiency where water contains abrasive sediment
c. Multi-stage Shaft driven	20-35m	Motor accessible, above ground, alignment and lubrication of shaft critical; capacity range 1.5 - 600 m ³ /hr.
d. Single-stage Submersible	25-30m	Requires skilled maintenance; not suitable for hand operation; powered by engine or electric motor.
e. Multi-stage Submersible	30-120m	As for multi-stage shaft-driven. Smoother operation; maintenance difficult; repair to motor or pump requires pulling unit from well; wide range of capabilities and heads; subject to rapid wear when sandy water is pumped.
4. <u>Air Lift</u>	15-50m	High capacity at low lift; very low efficiency especially at greater lifts; no moving parts in the well; well casing straightness not critical.

Category and Type	Head range (m)	Input power (kW)	Flow range (m³/h)	Efficiency (%)
DIRECT LIFT DEVICES Reciprocating/Cyclic				
Watering can Scoops and bailers Swing-basket Pivoting gutters and 'dhones' Counterpoise or 'shadoof' Rope & bucket and windlass Self-emptying bucket, 'mohte' Reciprocating bucket hoist	0.5-3 1 6 0.3-1 1-3 5-50 .5-10 100+	0.2 0.4 0.6 0.2-0.8 0.2-0.8 0.4-0.8 0.5-0.6 100+	0.5 8 5 2-4 1 5-15 5-15 400+	5-15 40-60 10-15 20-50 30-60 10-40 10-20 70-80
Rotary/Continuous Continuous bucket pump Persian wheel or 'tablia' Improved Persianwheel 'zawaffa' Scoop wheels or 'Sakia' Water-wheels or 'Noria'	5-20 1.5-10 0.75-10 0.2-2 0.5-8	0.2.2 0.2-0.6 0.2-1 0.2-1 0.2-1	10-100 5-25 10-140 15-160 5-50	60-80 40-70 60-80 60-80 20-30
DISPLACEMENT PUMPS				
Reciprocating/Cyclic Piston/Bucket pumps Plunger pumps Diaphragm pump/IRRI pump 'Petropump' Semi-rotary pumps Gas or vapour displacement	5-200+ 40-400 1-2 5-50 1-10 5-20	0.3-50+ 0.5-50+ 0.3-5 0.3-5 0.3-0.1 1-50+	2-100+ 2-50+ 2-20 2-20 1-5 40-400+	40-85 60-85 20-30 50-80 30-60 n/a
Rotary/Continuous Flexible vane pumps Progressive cavity (Mono) Archimedean screw pumps Open screw pumps Coil and spiral pumps Flash-wheels and treadmills Water ladders Chain (or rope) and washer	5-10 10-100 0.2-1 2-6 2-10 0.2-1 5-1 5-20	0.55 0.5-10 0.4 1-50+ 0.33 0.2-20 .02-1 02-1	2-20 2-100+ 15-30 40-400+ 2-10 5-400+ 5-20 5-30	25-50 30-70 30-60 60-80 60-70 20-50 50-70 50-80
VELOCITY PUMPS				
Reciprocating/Cyclic Inertia and 'Joggle' pumps Flap valve pump Resonating joggle pump	2-6 2-6 2-6	.03 .03 .03	1-3 1-3 2-4	20 20 50
Rotary/Continuous Propeller (axial-flow) Mixed-flow pumps Centrifugal pumps Multi-stage mixed flow Multi-stage centrifugal Jet pump centrifugal	5-3 2-10 4-60 6-20 10-300 10-30	10-500 150-500+ 0.1-500 50-500+ 5-500+ 5-500+	100-500+ 1-500+ 10-100 1-100 50-500	50-95 50-90 30-80 50-80 30-80 20-60
BUOYANCY PUMPS				
Air lift	5-20			
IMPULSE PUMPS Hydraulic ram	10-100			
GRAVITY DEVICES Syphons, Qanats or Foggara	1-6			

Table 7.3: Review of pump and water lifting devices, after Fraenkel (1997)

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Table 7.2 shows a categorisation of pumps by basic operating system, together with the salient characteristics of the pumps that might be used on sand-abstraction systems. Pumps, such as reciprocating suction pumps, centrifugal pumps, submersible pumps and above surface progressive cavity pumps which do not utilise a drive shaft between the pump head and the pump body may be used in conjunction with direct coupled well-point systems. Shaft driven pumps such as reciprocating rod pumps and shaft driven progressive cavity pumps may only be used on false-wells in conjunction with infiltration galleries or direct into sub-surface sealed tanks connected to well-point manifold systems. By virtue of their design, ancient pumps such as shadoofs, Persian wheels and paternoster pumps are similarly restricted to drawing from open surface water rather than from any well-point connection. A useful tabled comparison is provided by Fraenkel (1997), table 7.3 indicating the typical efficiency, power requirement, yield and operating head of a comprehensive range of pumps.

In order to keep pumping costs low, the U.S. Agency for International Development (1982) recommends using large bore delivery pipes which will reduces losses to friction and thus reduce energy costs. By the same token this should apply to handpump systems. The Department recommends a delivery pipe velocity of 0.75 m/sec.

The advantage of a progressive cavity pump is its positive displacement characteristic. Indications are that as long as the rotor and stator remain wet, the pump is capable of removing air from a system. Thus priming such a system is easier than priming a centrifugal system and displacement characteristics are better on an inlet pipeline which may have bends, than on a centrifugal system which ideally requires a straight pipe to the pump with no bends. The limitation of a progressive cavity pump is the likelihood of rapid wear to the both the rotor and stator if abrasive sediment is drawn through the pump. Rapid and terminal wear is also likely to occur to the rotor and stator if the pump runs dry whilst pumping for 30 seconds or more.

Suitability of Pumps for Sand-abstraction

Pumps suitable for use with well-points

Although there are several simple suction pumps available on the market, these are in the main complete units, with very few designs available for local manufacture or assembly. The Intermediate Technology Development Group (ITDG), Warwick University, Development Technology Unit (DTU), Appropriate Technology (ApT) and Volunteers In Technical Assistance (VITA) for instance, between them provide a plethora of designs for workshop equipment and carts; hand carts, bicycle carts, donkey carts. Designs are available for the Rope and Washer pump, Lambert (1990) and the Treadle Pump (Lambert 1986), which is in fact a leg operated suction pump, but there has been little development of simple hand operated suction pumps.

The suction pump, also known in various forms as a jack pump, a cistern pump, or in the U.S.A. as a pitcher pump, was probably the most common pump of all time, installed in temperate countries one to two hundred years ago in every farm and stable yard and directly in very many kitchens and out-houses. Both Hasluck (1907) and Vince (1992) have illustrations and designs of 19th Century hand suction pumps, wooden pumps, lead pumps and following the industrial revolution, any number of cast iron pumps. Individual village carpenters and plumbers themselves made many of the earlier wood and lead pumps. Some handpump interest was revived in the 1960's and 70's with reviews in catalogues such as The Whole Earth Catalogue and

magazines such as The Mother Earth News, (Beadles 1978) advocating alternate use of resources and renewable energy but in general, handpump development has been left to the commercial world.

Suction pump technology is however not particularly complex, Hasluck (1907) provides clear diagrams of handpump technology. The Dabane Trust used the same principle as the large steam operated single-acting lift pumps displayed at Kewbridge Steam Museum, London to make the Joma pump, figure 7.5, and appendix 11. The pump uses SWS Rower pump components but could equally well use off the shelf spring-loaded brass non-return valves. A solid piston is attached to a counterbalanced horizontal handle which is moved up and down to draw in water and to discharge to a greater height. The pump cylinder and connecting pipes are all uPVC pipe which are held in place within an angle iron frame. The uPVC pipes are painted to prevent deterioration of the pipes in sunlight and the angle iron also protects the brittle pipes from fracturing. Components required for the pump other than valves and piping are a piston and cup seals which could be made from hardwood or uPVC, and rubber sheeting. Tools required for the manufacture of the pump are a hacksaw, spanners, water pipe pliers and stilson wrenches and a length of threaded rod to connect the piston body with the handle. Welding skill is required in the fabrication and an electric drill or oxy-acetylene equipment is required for making up the pump pivots.

The author has observed a man and his young daughter pumping at a sustained rate of 90×185 mm strokes a minute for more than 20 minutes, drawing water from a depth of 2.4 metres in an infiltration well and discharging at a rate of 2.20 m³/hr, 102 metres distant at a height of 5.75 metres. The girl, about 10 years old was standing on a small pile of bricks to bring her a comfortable height to the handle with the man. The man assured spectators that there was no particular exertion required and that for that reason the output of the pump was acceptable.



Figure 7.5: Joma pump

Although other pumps such as the Treadle and the rotary hand Mono or Orbit Pumps might be ergonomically superior, the Joma conforms to the rapid oscillating stroke action preferred by many pump operators. Many people, particularly women, do not like to utilise pedal power as they feel it is undignified to be astride a saddle and feel very self conscious when working equipment other than by way of the recognised and accepted handle. This also applies in part to a treadle pump as people do not like to expose their legs, although Lambert (1992) states that many people found the pump more acceptable if the pump was sited low so that operators were not raised above the ground. Although rotary pumps have many advantages many people do not like the lunging action of the rotary handle. As an alternative they choose to stand in front of the handle and wind it by hand only, which is both inefficient and tiring. Figure 7.6a indicates the preferred method of rapid, short stroke pumping rather than the long stroke action for which most pumps are designed and figure 7.6b the manner in which a rotary head pump is often misused.

Figure 7.6a: Reciprocating handpump actions









Disliked Action

Preferred Action

Pumps suitable for use with infiltration galleries and false-wells

Rope and Washer Pump

According to Faulkner (1991) the chain and washer pump, also know as a paternoster pump or a yeddle pump, Vince (1992), has been in existence for several centuries and was used widely in Europe before the advent of the steam engine made reciprocating pumps more popular. Watt (1976) indicates the age and origins of the pump by referring to the 'Chinese chain and washer pump'. Watt suggests that producing the washers and the lower pipe section of the pump in a workshop and then distributing them to local areas where the main body of the pump could be completed could achieve extensive pump manufacture. The author first fabricated a chain and washer pump in the early 1970's with a length of 50 mm (2 inch) steel pipe. The pump was installed on a water harvesting tank and was found to be a most effective pump with a high volume output. Since then pumps have been considerable simplified, primarily through the use of nylon rope rather than chain, (Julien and Tijen 1986). Lambert (1986) and Lambert (1990) show how an effective pump can be assembled from a piece of uPVC pipe, a length of rope and recycled materials, such as a discarded car tyre and short lengths of scrap timber and poles.

Treadle Pump

The Treadle Pump is locally manufactured in several countries by local artisans. The original design was developed in Bangladesh by the Rangpur Dinajpur Rehabilitation Service and has since been developed and modified in several centres such as Loughborough University, (Lambert 1990) and the Development Technology Unit of Warwick University, (Thomas 1993), (McGeever and Oram 1997). Detailed instruction plans for a treadle pump, also called a Tapak-Tapak pump, are provided by Ma-Irri Industrial Extension Program for Small Farm Equipment (1987) and also by Hyde (1991) who further makes an assessment of the pump with his design. The treadle pump, figure 7.7 has been used extensively to draw open surface water for the irrigation of small plots in Zimbabwe, (Owen, Rydzewski et al. 1989). The pump is operated by utilising body weight through an up and down walking action on two treadles to move pistons within cylinders. Lambert (1992) in particular extols the ergonomic advantage of powering the pump with large leg muscles rather than the smaller muscles of arm or back. Faulkner (1991) claims that sustainable outputs of at least 3.6 m³ per hr are possible.

Figure 7.7: Treadle pump (Lambert 1992)



Alternate Pumps

Crouch (1983) has edited a VITA manual which provides construction details of six pumps which she maintains are simple pumps that are relatively cheap and easy to build and maintain with local skills and materials. The choice of design for manufacture of a pump should recognise the availability of materials. She contends that the hand-operated pumps each offer a viable alternative to more expensive pumps which require fossil fuel for operation. VITA Pump designs suitable for use with well-points:

- Suction pump fabricated from a short length of 75 mm (3 inch) galvanised water pipe. A pivoted handle moves a wooden piston, which has six holes through it for the passage of water, up and down within the pipe. The valve above the piston and the valve in the base of the pump are both made from vehicle inner tubing.
- Suction or Piston pump depending on whether or not the piston is operating above or within the water level.
- *Inertia pump*, a simple joggle pump with an air tight seal on the pump outlet and no other valve. By repeated raising and lowering of the pump on a simple pivot, water is drawn into the pump body and discharged through atmospheric pressure acting on the surface of the body of water, as the pump is lowered into the water.

VITA Pump designs suitable for use on a false-well:

- *Diaphragm pump* comprised of a rubber sheet which can be drawn up and down within a wooden box by a simple to and fro motion of a handle. Flap seals are made from vehicle inner tube.
- Chain and washer pump or rope and washer pump referred to below
- Archimedes screw

Considerations for Local Manufacture of Pumps

The initial cost of the pump, the spares and operation and maintenance costs are important considerations in the selection of materials and the design of a pump that can be locally manufactured. People are prepared to walk long distances to collect water rather than to expend a significant proportion of their income on operation and maintenance of a pump. Difficulties arise when considering cost versus durability. Materials such as uPVC, wood and recycled rubber are considerably cheaper than steel, brass and neoprene but are less durable. The consumers demand more durable pumps but may not be prepared to pay out the cash required.

Serviceability and even manufacture is a further consideration. Typically a rural community has limited access to specialist tools and skilled personnel so the principles and technology have to be serviceable with basic equipment. Spares need to come from readily available materials such as indigenous hardwood and recycled tubing but again durability may be compromised.

Further considerations are the principles of operation. Many consumers are dismissive of innovative principles and prefer to work with regular oscillating handle actions. Although there may be mechanical advantage in a rotary pump, it may be a significant period of time before people learn to accept a new system. Thought and consideration needs to be given to the acceptability of proposed equipment design.

Simple Handpumps - Commercially Available

Rower Pump

The Rower is a particularly simple suction pump consisting of little more than a piston which is drawn up and down at the end of a uPVC pipe and immediately above an in line foot-valve. The pump was initially developed in Bangladesh by members of the Mennonite community, Darrow and Saxenian (1986) and later refined by SWS Filtration, (Cansdale 1992). Cansdale sells both completely assembled pumps and pump components that may be fitted to locally manufactured uPVC pipes to make up

a pump. Figure 7.8 indicates the operating procedures of four manual pumps, the Treadle pump, Rope and Washer, Rower and Bumi Pump.

Figure 7.8: Stylised representation of the operating procedures of four manually operated pumps, (Faulkner 1991)



The pump has proved to be very popular with the small-scale irrigation groups supported by the Dabane Trust in western and southern Zimbabwe. The pump is particularly uncomplicated and has been seen to be easily maintained and repaired whilst not requiring excessive exertion to operate. Many people have shown a partiality to the smooth 'rowing' nature of pump operation. In tests conducted by Faulkner (1991), table 7.4, the Rower appears out-performed in both yield and efficiency by the Treadle and the Rope and Washer pumps. However irrigators have stated a penchant for the 'light' operation and ease of repair of the pump, which does put it in contention as a suitable and appropriate handpump for use on both well-point and false-well sand-abstraction water supplies.

Table 7.4(a): Comparison of head against discharge of four manually operated pumps, after Faulkner (1991)



Chapter 7

Table 7.4(b): Comparison of efficiency against discharge of four manually operated pumps, after (Faulkner 1991)



Vicanzee Pump

A simple operation joggle type pump invented by Owen Jones has been modified by SWS Filtration Ltd (Undated) and has been installed on an offset-well and infiltration gallery system and also direct fitted to a number of well-points in alluvium beside the Dongamuzi River, Lupane District, Zimbabwe. The well-points were jetted to 6.00 metres and the pumps have proved to be reliable and community operation and maintenance has been more than satisfactory. According to Cansdale (2000) versions of the pumps are effective at depths of up to 12.00 metres which makes them quite suitable for use in conjunction with infiltration galleries and offset- wells. Figure 7.9 shows an SWS Filtration, Vicanzee handpump installed on an offset-well. Cansdale (1994) provides detailed drawings of the pump and accurate installation procedures which are most useful. A review of the efficiency of the pump, including some comparisons with the Blair pump developed in Zimbabwe has been undertaken by Macdonell (1995). On completion of a series of operational tests, Macdonell was of the opinion that by utilising an unusual principle of clearance seals, Cansdale had produced a low maintenance and efficient handpump. Both the Rower and the Vicanzee offer considerable potential for use on both well-point and infiltration gallery sand-abstraction systems.

Figure 7.9: Vicanzee handpump installed on an offset-well



Bucket type pump

Morgan (1990(b)) provides information on the Zimbabwean bucket pump which can be used on wells, tube-wells and shallow boreholes usually to depths of about 15.00 m. This is a very basic, low yielding pump designed to be used by 10 families or some 60 people to draw primary water. It comprises a simple yet effective tube-like bucket that can be lowered by steel rope and windlass into borehole casing. As the bucket is unable to invert to fill, water enters through a poppet valve in the base of the bucket as it enters the water. The full bucket is then drawn to the surface by the windlass, water is released into a container by depressing the poppet valve

Blair Pump

The Blair pump is a simple handpump primarily assembled from standard galvanised steel and uPVC water pipe and regular off-the-shelf steel and ABS pipe fittings. According to Morgan (1984) the pump operates at depths from 2 to 12 metres. Although Kinley (1990) considers the pump to be highly successful, the ball type piston and foot valves are known to be temperamental and the uPVC pipes to be subject to excessive wear. Consequently Macdonell (1995) maintains that the pump is no longer in production. Efforts were made to utilise the simplicity and component construction of the Blair pump by developing the Nsimbi pump, a steel successor to the Blair pump, unfortunately there is little evidence of the continuing use of this pump.

Wavin Direct Action Handpump

Boers (1987) reports on a simple direct action handpump manufactured by Wavin Overseas b.v. The pump uses standard uPVC pipe for both the rising main and, what amounts to a pump rod through which the water rises. The 'pump rod' has a 'ball' valve in the base and a cord seal between the two pipes. Figure 7.10 shows the basic conformation of seals on a joggle type handpump as used on a Wavin direct action handpump. The NIRA AF-85 as described by Burks (1988), operates on similar design principles.





Deep Water Handpumps

Bush Pump

The most common, indeed, almost the only borehole and deep well reciprocating piston handpump in use in Zimbabwe is the Bush Pump. Morgan (1991) provides a detailed explanation and graphic sketches of the pump assembly and installation. This pump, which has been in universal use for more than 70 years, must certainly meet planners and strategists standardisation criteria. However the Bush Pump that is in widespread use can hardly be considered a VLOM pump. In recent years efforts have been made to adapt the pump to VLOM standards but few have been manufactured or installed. The pump is beautiful in its simplicity and in its use of components and materials readily available in Zimbabwe. However, the pump is extremely heavy and cumbersome to operate and requires specialist tools and heavy lifting equipment. Whilst this was quite suitable for a centralised installation, service and maintenance department, it is far from suitable for a localised service but in view of the vast number of pumps in use in Zimbabwe, could be used in conjunction with an offset-well in that country.

Lotus Handpump

Vallally (Undated) has developed a valve principle that he likens to the petal formation of a lotus flower. This valve principle has been incorporated into both the foot valve and the piston of the Lotus pump. Pumping is achieved by raising the piston, which is attached to a nylon rope that passes over a pulley at the top of the pump, by a simple up and down handle action. The pump cylinder and the pump column are threaded and socketed uPVC pipe and thus when removal is required, are both light and easy to lift. The pump is said to work at depths of up to 30 metres but again could be used on a more shallow false-well.

UPM Pump

UPM Pumps (Undated) also produce a handpump head of similar design to the Lotus, with operation also actioned by a rope over a pulley. The pump comprises a series of multiple pistons located within each length of PVC rising main. The rope attaches to the pump rod as it protrudes from the top of the column and is also drawn up and down by a simple handle movement.

Afridev Pump

Baumann and Keen (1991) provides specifications and SKAT drawings for the fabrication of the Afridev deep well handpump. Also included are details on the construction of the pump pedestal and installation instructions and a graphic maintenance manual has been prepared by Waterkeyn (1987). Although the pump could be considerably over-designed for use on an offset-well as specifications indicate that the pump is suitable for lifting water from depths of 10 to 45 metres, due to its popularity as a borehole pump in arid and semi arid areas, it could nevertheless be a suitable handpump.

Flywheel Pumps

Duba Pump

Duba S.A. (Undated) has manufactured a range of handpumps since 1846 and produces in particular, flywheel operated pump heads for use in the Democratic Republic of the Congo, some of which they state have been in use since 1947. These pumps which are primarily for deep water use at depths of up to 60 metres are particularly robust and operate with low wear as the gears are encased in an oil bath. Due to the flywheel effect the pumps are efficient and easy to operate.

Volanta Pump

Venneboer (Undated) reports on the Volanta flywheel handpump which is said to operate at depths up to 100 metres. Although the pump cylinder supplied with the pump is of high performance stainless steel the pump head is in fact of a very simple design comprising a shaft running through two pillow block bearings mounted on a concrete block. On one end of the shaft is a large diameter wheel and handle and at the other a simple cam which is attached to the pump rod to turn rectilinear to reciprocating motion. The principle of this pump could be used when coupled to a simple brass or uPVC cylinder on a false-well.

Progressive Cavity Pumps

Mono Pump

Hand powered progressive cavity borehole pumps are available, (Mono Pumps Zimbabwe Undated) for use on false-wells in conjunction with infiltration galleries. As many of the pump columns are of 40 or even 32 mm O.D. steel pipe it would be quite possible to install such pumps into a well-point system.

Motorised Pumps

Progressive Cavity Pumps

Mono Pump

Of the pumps suitable for mechanical sand-abstraction operation, probably the most suitable is a progressive cavity pump. The concept of a slow spiral stainless steel 'screw', rotating within a static helical rubber stator was first developed by René Moineau in 1933 and manufactured by Mono Pumps Ltd., a company established in 1935. According to a sales brochure, Mono Pumps/Dresser is the successor of this company, now a part of the Halliburton trans-national company, (Mono Pumps 2001). Pumps may be installed on the surface drawing water from a manifold system or may be installed into a well or sealed, sub-surface tank.

Orbit Pump

Orbit Pumps (Undated) also produce a range of progressive cavity pumps suitable for use on the surface or as down-the-hole borehole pumps. Orbit specialises in close-coupled horizontal pumps through a reduction gearbox.

Submersible pumps

There is a wide range of submersible borehole pumps usually powered by electric motors, either from national grids or solar electric but not hand powered. At least

within Zimbabwe little if any use has been made of submersible pumps for community water supplies. However where an appropriate power supply exists use could be made of such pumps to draw water from false-wells or from sealed wellpoint/manifold sand-abstraction systems.

Assessment of pump suitability

Low output suction handpumps such as the Treadle and Rower pumps that may be locally manufactured or assembled, are well suited to drawing water both from wellpoints and from off-set wells. There are also significant possibilities for basic, suction principle piston and bucket handpumps. In all probability commercially manufactured direct action handpumps such as the Vicanzee and Wavin may well be direct coupled to single or multiple well-points and would be particularly suited to off-set wells supplied by infiltration galleries. Handpumps typically used on deepwater wells and borehole have a particularly limited application for sand-abstraction as their use is inevitably limited to off-set wells. Table 7.5 provides an overview of the pumps which might be used on various sand-abstraction systems.

[ype or Trade Name	Replicability	Operation	Appropriate Use	Suitability
Suction pump (Joma)	Artisan workshop	Reciprocating handle	Well-points / Offset-well	Good
Treadle	Artisan workshop	Leg operated treadles	Well-points / Offset-well	Good
Rower	Suitable for local assembly	Rowing action	Well-points / Offset-well	Good
Rope & Washer	Village level construction	Rotary	Offset-well	Limited
Vicanzee	Commercial	Direct action	Well-points / Offset-well	Good
Bucket	Artisan workshop	Windlass	Offset-well	Limited
Blair	Artisan workshop	Direct action	Well-points / Offset-well	Good
Wavin	Commercial	Direct action	Well-points / Offset-well	Good
Bush	Commercial	Reciprocating piston	Deep Well	Limited
Afridev	Commercial	Reciprocating piston	Deep Well	Limited
Lotus	Commercial	Reciprocating piston	Deep Well	Limited
Mono	Commercial	Hand operated rotary	Well-points / Deep Well	Good
Volanta	Commercial	Hand operated rotary	Deep Well	Limited

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7.5.2. Power Options.

An obvious and initial expectation of a community is for a source of power that will provide a maximum output of water for a minimum input of time and finance. However there are many considerations to be made if a satisfactory method of powering a sand-abstraction system is to be identified. Principle factors to be evaluated are:

- The expected daily total volume of water required and the variance in the requirement during the day
- The proximity of the supply to infrastructure such as a mains electricity network and the availability of basic requirements such as fuel and oil from a service station.
- The likely capability of a service/repair facility or local mechanic or artisan to maintain the power source.
- The preparedness of a community to assume responsibility for the operation and management of equipment and their preparedness to contribute financially or physically to the upkeep and maintenance of equipment.
- The energy required to power a system and the age and physical status of the recipient community
- The overall cost effectiveness of a proposed source of power
- Suitability of a power source for a particular application, not all sources of power are suitable for every sand-abstraction water supply.
- Awareness of any vested interests which might impact negatively on the pump operator or the actual equipment

Personal Experience (1)

Working with a community, installing an engine powered pump unit on an infiltration gallery in a sand dam that was under construction. An old man wants to start the engine, I politely point out that there is no water in the system and am told that that is of no matter, by starting the engine the next village will hear it and will then be impressed and aware of the technical superiority of this village.

Sources of power that may be used to energise sand-abstraction water supplies.

- Internal combustion engine
- Electric motor
- Wind-power
- Animal draught power
- Manual power
- Renewable energy engines

Personal experience (2)

Holding forth at a community meeting miles and miles from anywhere, trying to get across the difficulties the remote community would experience in running an engine; citing the failure of a similarly situated community to run an engine – a dear old crone looks up and intercedes with "just bring the engine here and we will show you and that community how *we* can manage an engine;" left me lost for words, swamped by the popular support the statement engendered.

Internal combustion engines

A suitable source of power to operate a pump on either a sand-abstraction well-point or an infiltration gallery system is an internal combustion engine. The typical optimistic view of many depressed rural communities is in fact that one day they will acquire a diesel engine to increase the available volume of water and to reduce the burden of drawing water. As there are so many stationary engines in use in the formal sector of many industrially developing nations, many machine workshops in the urban areas of those countries still carry spares of engines such as Lister and Petter. A surprising number of spares for engines such as Bamford and Ruston are either still available or may be improvised or machined. Cheaper look alikes of these engines such as Dipco and Buffalo from India are also remarkably reliable and the new breed of high speed engines from Honda and Yanmar continue to be particularly reliable. However unless there is sufficient awareness of all that is required to manage such a sophisticated source of power there is little likelihood of an engine being sufficiently maintained to provide a sustainable, ongoing supply of water.

Personal Experience (3)

One young man with no mechanical training prevented a group of 15 women from effectively operating their engine pump unit and garden by insisting that he was the technical expert and the only one competent within the community to operate the engine – with frequent and disastrous results. His virtual highjacking of the technology totally restricted the women and left them completely dependent on him and frequently without irrigation water.

Considerations for the successful operation of an internal combustion engine

- Fuel A regular supply of clean fuel must be identified and maintained. Dirty containers, funnels and hoses that are open to dust or have had contact with dirt on the ground are liable to introduce a surprising amount of abrasive material to an engine. As a result of dirty fuel, filters become clogged, injectors blocked and injector pumps damaged. Very many engines have become inoperative due simply to blocked fuel or oil filters, or blocked or damaged diesel injector nozzles. A further problem may be experienced because of the cost and difficultly of obtaining fuel, many operators run a diesel engine until it runs out of fuel. Either they are then unable to bleed the system or do so with an incorrect size spanner or with a pair of pliers. Consequently the bleed bolt heads are wrung off and cannot be sufficiently tightened to prevent the entry of air into the fuel system and thus the engine becomes inoperative.
- Lubrication It is imperative to store clean engine lubricating oil, to maintain engine oil at the correct level and to change oil, oil filters and fuel filters regularly. These may be too expensive for a community and/or too difficult to acquire. Many rural engine operators over-fill engines with lubricating oil, frequently so much oil is maintained in the sump that it works past the piston rings, to their detriment and is then burnt off with the diesel in clouds of thick black smoke. The remaining ash and tar builds up and deteriorates the cylinder head, piston and injector nozzle.

Personal Experience (4)

Trying to understand why an engine had seized and being told that as there had been no engine oil available, cooking oil had been used as an alternative.... *Point of interest*: sunflower oil and castor oil may be used straight as an alternative fuel oil – not as a lubricating oil.

- Clean operating conditions with adequate ventilation engine operation in a hot or restricted dusty area invariably means inadequate cooling with clogged cooling fins and clogged air and fuel filters. Filters are expensive to replace and it is not always apparent that they may be limiting the efficiency of the engine if not actually causing damage.
- Many rural communities have little or no experience of the implications of operating and maintaining an engine as they have had little opportunity or exposure to practical mechanics and engine technology.

Personal Experience (5)

A brand new 3 cylinder Lister diesel engine that I had installed a few weeks earlier was found with a hole in the side of the block. The local 'bush mechanic' had seen an opportunity to make some extra money and had told the community that the new engine was not working properly and that it required new big end bearings. The community as instructed, despatched one of their members to town to purchase 20 thou bearings from the person who had sold them the engine. Knowing the engine, the supplier refused to sell the bearings so the messenger returned empty handed. The bush mechanic insisted and duly a set of bearings was purchased and delivered to the 'mechanic'. As the crankshaft was still new, still standard, this con man could not torque the bearing caps so left them finger tight. It was not long before a bearing cap came off – through the side of the engine block.

- Organisation and Planning service/maintenance schedules require planning and the acquisition of parts and materials. Funds are required to complete service and maintenance schedules.
- Finance a community-based scheme may not generate sufficient funds for the satisfactory repair or replacement of engine parts, or the engine itself.

Personal Experience (6)

Within five years of helping a 'grassroots organisation' to set up ten engine powered irrigation schemes and twelve grinding mills, not one engine remained in operation. The communities' had neither the resources nor the capacity to provide the running costs and the service and maintenance needed to keep the engines operational.

The author considers that internal combustion engines are not a viable source of power in disadvantaged rural areas. Typically rural communities do not have the infrastructure for the operation and maintenance of an engine that is technically complex and requires additional inputs that may be difficult and expensive to acquire and transport to site. Villagers do not have easy access to service stations for fuel and oil and there are few experienced mechanics with the necessary tools. Spare parts are generally only available in urban centres where there are agents and when available they are often an expensive item for rural communities. Further problems may then arise in transporting fuel and large spare parts either by hiring transport or using public transport.

Electricity

Ostensibly electricity, either mains or photovoltaic, offers a most suitable power supply for a sand-abstraction water pump, that may be either belt driven or direct coupled to an electric motor. The energy required may be supplied from a national grid or, if situated further than 15 kms from a supply line and particularly for smallscale supplies, from a solar energy supply. A supply of electricity is not dependent on inputs such as a liquid fuel that needs to be transported into the community. The breakdown incidence of a simple rotating electric motor is considerably less than a machine which is dependent on a physical action to cause rectilinear motion, which has to be converted to rotary motion and in the process requires considerable lubrication and cooling. Solar voltaic panels are produced by a number of manufactures such as AEG Anlagentechnik (Undated) who provide specifications and installation details on a range of photovoltaic irrigation pumps. B.P. and Neste (Undated) also provides specifications on solar panels which might be used in a variety of applications to power water pumps.

However, in spite of ease and efficient operation, many communities find it less difficult to collect money at their convenience to send someone to fetch diesel for an engine in anticipation of an event, than they do to meet an expenditure for a service which has already been received. Consequently the author is aware of a number of systems that are not always operational as they have been 'cut off' from their mains electricity supply on more than one occasion for non-payment of an account. Not only has the account to be paid before the system can be used, but a reconnection fee has also to be paid before the system is re-energised. Apart from the initial high installation cost of a solar electric scheme, in many rural localities panels are at a premium to charge batteries for the operation of such appliances as D.C. lights, televisions and refrigerators. Solar panels are thus very vulnerable to theft; the author has witnessed a 24 hour guard protecting a large battery of panels with a most formidable array of knives, spears, assegais, batons and knobkerries.

Wind

Although the possibility to drive a water pump by wind energy certainly exists, consideration must be given to several factors. The windmill may well be sited in a river valley which might be sheltered from wind. Unless the energy of the wind is used to drive a generator for an electric motor, a shaft will be required to drive a pump. It may be difficult to find a site for a windmill on a riverbank which is suitable for driving a pump through either a shaft or belts. As a windmill is subject to the vagaries of the wind, although a wind power supply may fill a large tank with sufficient water for a weeks supply of water for livestock, it is unlikely to provide sufficient water to ensure a constant supply of water for irrigation during hot, still periods of the year. To further complicate the use of wind energy it is difficult to ensure a pump.

However the efficiency of windmills has been substantially increased in recent years with a new generation of wind pumps reputed to operate in areas with average wind speeds of 3.0 metres per second, (Polak and Dawson 1995) and (Polak 1998). The Poldaw wind pump is effective in wind speeds of 4.5 m per sec with starting speeds said to be as low as 0.4 m/sec, (AbaChem Engineering Ltd. 1998). Fraenkel, Barlow et al., (1993) provides information on conventional wind pump rotors with a horizontal axis and vertical axis rotors such as the Darrieus and Savonius. Fraenkel also refers to conventional head gearboxes and recent innovations such as the Poldaw nagging-head and the rack-and-pinion, elliptical drive configuration of the ITDG windmill, (IT Power 1990). Fraenkel completes an overview of wind power with manufacturing details of 41 windmills from the conventional to the less than conventional.

Animal Draught Power

Animal draught power has been widely used for centuries on simple pumps such as Persian wheels, shadoofs and Archimedes screws. Draught horsepower was also used extensively over a long period of time to turn appliances such as presses to extract olive oil and apple must for cider and also to turn gins (or ginnies) to power farmyard equipment such as potato riddles and chaff and root cutters, (Major 1985). However as only small volumes of water were ever required in an 18th century farmyard, gins (also known variously as 'horse engines', 'universal power gears' or 'sweeps'), were not commonly used to power pumps and as stated by Lowe (1986) the appliances which converted the slow movement of a rotating beam into rotary shaft power have now disappeared from use. Lowe goes on to state that there is thus no readily available animal-powered appliance that can be utilised to drive a present-day pump, whether it be a pump which has been designed to be powered by an internal combustion engine, an electric motor or a handpump conversion.

In spite of a most apparent dearth of 'engines', (appliances designed to convert animal draught power to shaft power) there nevertheless remains a realisable potential. Animal draught is the power most commonly used for both transport and tillage in marginal arid and semiarid areas. Most peasant farmers are able to harness and to use draught animals and many have direct or indirect access to trained animals. Although communal ownership of draught animals is not typical and although there may be problems associated with ownership, management and feeding, animal-based operational management systems are probably more easily implemented than management systems involving internal combustion engines. Because of the suitability and success of the steam engine, followed by the internal combustion engine for large power requirements, animal draft power has been passed over and is now considered passé, even where it might be appropriate. Much of the foregoing is illustrate in figure 7.11, which shows a borehole pump designed to be operated by a unique sweep arm, however for reasons not apparent the equipment is non-functional.



Figure 7.11: Disused borehole pump with a non-operative sweep arm, (Lowe 1986)

According to Fraenkel (1997) animal-powered irrigation is almost exclusively practised using traditional water lifting techniques that predate the modern industrial era. Fraenkel also states that although in certain areas some attempt was made during this century to produce mechanisms to improve the use of animal power, little if any effort was made to introduce animal-powered water lifting to anywhere where it was not traditionally practised. Although further afield in China he is of the opinion that millions of animal-powered 'liberation pumps' have been produced in an intermediate stage between human pumping and full mechanisation. In spite of such limitations, Fraenkel does consider that animal-powered water lifting could usefully replace human labour for irrigation in many parts of the world where it has not already been used. He considers that there has been little apparent effort to upgrade locally made animal-powered wooden sweeps to manufactured machine gear drives, but rather attempts have been made to improve on human power, or a quantum leap has been made to full mechanisation using engines or mains electricity.

Manual Operation

Although neither cost effective nor particularly efficient, the human operation of pumps is widely utilised, particularly in disadvantaged and depressed areas. The human body requires the input of costly calories to operate and is unable to work at a regular, sustained output for prolonged periods. However for low volume, small-scale pump applications manual pumping is quite effective provided the pump and pump operation are of an efficient design and the pump output is matched to the energy input. The cost of other forms of energising pumps, coupled with inherent problems related to the acquisition of fuel, spare parts and the technical skills that are required for effective sustained operation, frequently makes manual power a realistic and realisable power option. To ensure successful manual pump operation the equipment utilised must be efficient, effective and manageable within an attainable water demand, human power is then a most realisable and sustainable source of power.

Fraenkel (1997) is of the opinion that in many cases human powered devices offer the best means to initiate small-scale lift irrigation because of a comparative low initial cost with more productive pumping technology. According to Lambert (1992) manual pumps have received considerable attention over the last decade for domestic water supply but their potential for garden irrigation has been largely unexplored. He is of the opinion that human powered pumps are able to fill the gap between the watering can and the diesel engine in terms of both output and cost effectiveness as a handpump head is considerably less complicated than an engine and allied pump head, to this sustainability can certainly be added. Faulkner (1991) states that the cost of a diesel powered pump is beyond the means of the vast majority of Africa's individual peasant farmers and that it is also debateable whether or not such a pump is desirable for smallscale water sources, with the possibility of over watering and abstracting much more water than is necessary from shallow, finite aquifers. To be effective, Faulkner considers that a human powered irrigation pump needs to be able to deliver at least 3 m³ per hour over a 15 minute period against a head of 5 metres. Table 7.6 indicates the amount of water that might be delivered by differing systems to a garden using handoperated equipment.

Table 7.6: Potential water supply rates and typical area for irrigation, after Faulkner (1991)

Irrigation System	Flow rate (m ³ /hr)	Average Area of Irrigation (ha)
Watering Can carried to Crop	0.04	0.03
Bucket plus tank with hosepipe	1.08	0.09
Manual Pump	1 - 3	0.25

To ensure efficiency and a minimum of energy loss, an ergonomically suitable pump is essential for successful manual operation. According to Hofkes, Huisman et al., (1981), the power available from human muscle depends on the individual, the environment and the duration of the task but that the power available for work by a healthy man is often estimated at 60 to 70 watts during an 8 hour day. Hofkes points out that this value must be reduced for women, children and the aged and also during periods of high temperature and working environments with high humidity. Of particular significance Hofkes states that where the pump user and the pump are poorly matched, much of the power input is wasted and gives as an example a person operating a pump from a stooped position.

Fraenkel (1997) contends that the daily muscular work capability of a person is in the region of 200-300 Wh/day, which is a 7-11% efficiency of food energy conversion to mechanical energy. During short, strenuous periods Fraenkel maintains that muscle efficiency may be as high as 20-30 % which compares favourably with an internal combustion engine. However it must be appreciated that although commonly used, human muscular energy is not cheap. People with low incomes are often forced to use human power as the actual cash investment is low and power systems are too expensive. Fraenkel maintains that for continuous pumping almost any other source of power will pump water more cheaply, as human work output is only about 250 Wh/day. Thus four days work provides 1 kW, which equates to the output of a small engine in an hour.

Improvements in the application of human power to pumping can however be made through ergonomics and the use of selected muscles in a suitable action at a correct speed through a light but strong mechanism. Hazelton (2000) for instance reports that a human exerts 50% more power by pedalling with legs than pushing a handle with arms. Dynamometer tests have indicated that the average cyclist works at 75 W when cycling at 18 km/hr, if this output could be utilised in pumping, the flow rates in table 7.7 would be achieved. Faulkner (1991) states that conventional analysis typically concentrates on the mechanical efficiency of a machine to convert human energy into useful hydraulic output, whereas in human powered pumps it is the successful utilisation of muscle groups that significantly affect the output of the pump. A pump mechanism that uses a greater number of more powerful muscles is able to facilitate a greater output of energy and a pump which is able to more effectively utilise human energy may have a higher mechanical efficiency than one which uses a smaller and weaker range of muscles.

As they utilise larger leg muscles, foot or leg operated pumps are considered more effective for irrigation than hand or arm operated pumps and as irrigation pumps require operation for several hours a day such efficiency may be crucial. However acceptability and operator's personal preferences for pump action must also be considered as well as the pump application. Hand operated devices may be more convenient to use than leg operated pumps so that lighter and smaller pumps may be more suited to pumping smaller quantities of water. Thus the criteria for defining a good human powered irrigation pump is likely to be significantly different from those for a suitable water supply pump, indicating that consideration of the pump requirement as well as the pumping method is important in the selection of a suitable manually operated pump. Cognisant of this the Dabane Trust has developed a spreadsheet application to determine the position of a counterbalance weight which is able to adjust a pump to individual preferences in the proportion of energy required between drawing water into the pump and discharging, (Hussey 1998).
Head m	0.5	1.0	2.5	5.0	10.0
Flow m ³ /hr	27.5	13.8	5.5	2.2	1.1

 Table 7.7: Theoretical achievable pump rates by pedal power, after Hazelton (2000)

Renewable Energy Engines

Opportunities certainly still exist for engines powered by renewable energy. Hussey (2001(a)) proposed the conversion of an internal combustion engine to that of an Ericsson cycle external combustion engine. In this process heat is applied externally to air which is used as a working medium to provide the required degree of volumetric expansion to produce a motive force. However, whilst Hussey states that the thermodynamic principle of a truncated Ericsson cycle engine was proven and could be developed in a slow moving, large piston application, he considers that due to excessively high internal friction, a fast moving, small capacity engine is unsuitable for conversion.

Dutting (1978) expresses a similar opinion by noting that a modern large piston, slow revving atmospheric engine could be produced with a performance to better the early 500 watt, 1% efficiency machines of 1908. A possible advantage of a large and simple machine is that it requires lower tolerances and is more easily adapted to local foundry and machining capabilities than more precisely finished, high-pressure machines. Takla (1978) considers the application of a low-temperature solar engine with a working fluid evaporating in an evaporator heated with hot water from a solar collector but Parikh (1978) concedes that such engines are essentially only at an experimental stage. Unfortunately it is doubtful if there has been any effective progress at all in the intervening quarter century.

Observations of power options

Systems to power pumps that are suitable for small-scale sand-abstraction use may be electric motors, internal combustion engines or renewable energy engines. However, although the energy output of an engine or motor is generally suitable, due to constraints of limited resources, experience or income it is often beyond the means of rural communities to purchase a power system and then to operate it satisfactorily, sustainably or cost-effectively. Alternative energy systems such as wind or solar power may have a possible application but generally require a very high initial cost, although they may well then have a low operational cost. Since the widespread introduction of the steam engine, followed by the internal combustion engine little use has been made of animal draft power engines and few, if any engines are now commercially available, although they may hold considerable potential.

Small-scale, low output pumps are thus invariably human powered, which often appears to have no apparent cost, but may not be the most efficient. Power may be provided by either arm or leg muscles and may be by way of a reciprocating or rotary action. The most effective manner of manual pumping is often a contentious subject. However, whilst the design of energy efficient manual pumping systems proliferates, so to does a lack of acceptance with instances of a pump designed to be operated through a leisurely seesaw action, in fact operated by hand. Whilst this in itself should not prevent the development of improved handpump systems, it does indicate that the perceptions and expectations of end-users should be taken more into account and that training must invariably accompany any technological intervention.

7.6. User Involvement

In simple, straightforward terms no development initiative will work without the significant involvement of people. It is imperative that potential end-users are involved in all the processes of any development initiative. It is vital to share experiences, ask questions, gain feed-back, seek problem solutions and gain insights into acceptability, limitations, shortcomings and perceptions of usability with the end-users. Only the recipients are able to transfer the technology into the prevailing situation of traditions and traditional knowledge. Henson (1987), former missionary, long time trainer, activist and 'grand old man' of rural development work in Zimbabwe, in his advice to new recruits, in a forthright and uncomplicated manner, would shoot fire and brimstone from his pipe and rant, "Just ask the bloody people"! A similar sentiment to which the author ascribes expresses the importance of the sociological aspect of any technical develop and is encapsulated as, *any fool can produce a technical solution, the difficult part is ensuring sufficient community acceptance to make it work.*

If the introduction of any new technological innovation is to be successful then the sociological aspects of a community must also be fully considered. Marsden (1994) indicates that the knowledge and needs of a rural elite may differ markedly from that of peasant farmers and the knowledge and perceptions of women are different to that of men. He maintains that if indigenous management is about utilising local, folk or vernacular knowledge and organisational methods in the service of more appropriate development strategies, then it is important to investigate how that knowledge is gained and interpreted and how the knowledge might be used most effectively to sustain projects. Matose and Mukamuri (1994) reinforces this perspective with a warning not to underplay the effect that cliques have within rural society. Accordingly he says that the elite, for instance, benefit by being powerful, by being seen to be providing and by manipulating the discourse of religion, conservation and development. Power is particularly reinforced through the control of the most important resources, water, land and trees which obviously impinge at all levels of society.

Batten and Batten (1965) also refers to the factions and rivalries that often occur within a community and draws attention to the need for sensitivity and tact if individuals are to be expected to accept changes in habit or custom. Particular reasoning and diplomacy he says will be required in situations where, for some reason, stakeholders do not initially perceive a need for change. Smillie (1991) comments that although there are often many things that a woman 'should not do', there are very few constraints placed on men, so that when a new technology is introduced which requires upgraded skills or is likely to bring higher returns, men invariably take over.

Davis and Day (1998) expresses a similar sentiment that is also very much the experience of the author. There is no doubt that drawing water is a burden for many women and children, improving practices however is not easy. Any new method of abstracting water has to be acceptable to users and cheaper and easier to use than existing methods. Where new technology is introduced to improve the supply of domestic water there is the distinct likelihood that men will become involved and wish to control and benefit from the new technology. The evaluation and perception of end-users must be acknowledged and respected even though it may differ from that of a technical advisor, as indicated in the cartoon in figure 7.12. Although there may

be an overall advantage to women in the reduction of their work load, there is the disadvantage that women will not then have access to the new technology and as a consequence may lose control over water collection but still be responsible for its use and management in the home. It is quite possible that this is a situation looming at Huwana where well-points and handpumps have been installed as a part of the research programme. There men have become involved in the research programme in the installation of simple pumps which they use and over use to provide water for cattle, meanwhile women do not have access to the pumps and have to dig ever deeper sand-wells as water levels deteriorate.



Fig 7.12: End-user evaluation as portrayed by (Silva 1996)

According to Falkenmark and Morgan (2000) in most cultural settings the capacity and skill of women in water management is not taken into account as the agenda is set by men. Basically women have two predominant roles in relation to water management, the one as users, custodians and local stakeholders of water and the other as professionals in water resource management requiring participation in societal problem analysis and decision-making. Falkenmark also considers that women's mindsets are often different from men's and reflect a preference to peacemaking and sharing, rather than conflict, which is clearly displayed in the manner of water resource utilisation. She maintains that with an increased or improved water supply two main feminisation phases can be distinguished. Following the introduction of new technology, water supply augmentation is the main stratagem with an initial water surplus. A defeminisation of the water supply results as men enjoy new technology and adopt a domineering attitude. This situation continues as long as there remains plenty of water. However when supply no longer meets demand, men abrogate their new-formed responsibilities and a second transition takes place as the community enters a water deficit phase. At this stage a social conscience is required with women needing to assume a major role in order to restructure power relations and to facilitate community water management changes.

The difficulty experienced by women to manoeuvre effectively in the diametrically opposed conditions of marginalisation and the need for arbitration has been shown in research undertaken by Hussey (1997(c)) who states that the experience of women in Africa, whether engaged in informal or formal employment is characterised by dual burdens of inappropriate work-load and sex domination. She maintains that women find it very difficult to cope, experiencing discrimination in the form of traditional cultural expectations, stereotyping, sexual harassment, discriminatory organisational structures and values and double standards for men and women.

The question of ownership of water supplies is central to real community management. Davis and Day (1998) maintains that in the case of a genuinely community managed water supply, the members of the community actually own, operate and maintain the supply. Hussey (1990) reports on a number of communities he has worked with, ascribing improvements to the impact and effectiveness of water development programmes to people who have themselves taken the initiative in construction, management and maintenance. In a similar theme, Oenga (1997) is of the opinion that for any intervention to be successful the community must take the initiative themselves. A balanced involvement from all members of the community is upheld by Kwadzokpo (1997) who states that the more than 50% female composition of the Volta Rural Water Supply and Sanitation Project is the reason for its success.

Both Gubbels (1994) and Fujisaka (1994) maintain that the success of development initiatives is considerably enhanced where there are opportunities for communities to make adaptations. Shah (1994) and Campbell (Undated) also indicate the need for involvement and interaction with rural communities for the success and continuity of any development initiative. Weinrich (1971) reinforces the perspective by reporting on the lack of progress and the ultimate failure of two boreholes to serve a community following the dissatisfaction of kraal heads and village headman and the subsequent alienation of the community due to ad hoc decisions that were made on the selection of water points by chiefs who only purported to represent their people. Haverkort, 'tHooft et al., (2002) is of the opinion that in spite of the globalisation process, indigenous knowledge, values and practices are still widespread amongst rural communities. He considers that the best way to support local people is to understand, test and improve on practices within the local context which he considers to be an 'in situ development of local knowledge'. The process he says implies an ongoing and respectful dialogue between innovators and members of a rural community in which traditions as well as modern practices can be challenged without romanticising indigenous practices or being too prejudiced or sceptical.

Batten and Batten (1965) recommends working with rural communities with sensitivity to feelings and attitudes and being perceptive of the interrelationships that exist between people. Realism, he says, is required in deciding what best to do and which skill is required to achieve acceptance. The following checklist, based on Batten's concepts, provides food for thought for development workers:

- People might seek advice, but it cannot be assumed that is all that is required. People will only accept advice if they think it appropriate. The real work of a development worker is thus to help people find their own acceptable solution.
- Do not assume if people readily agree to a project or resolution that they necessarily want it, or will work to carry it through to a successful conclusion
- Lead discussions and assist people to consider factors that need to be resolved, but which might be overlooked

- Enlist the support of all key and influential people. An understanding of the factions and divisions within a community is important
- Although the advantages of a project or scheme may be stressed, a balanced argument, both for and against an intervention must also be presented. No attempt should be made to 'sell' an innovation, but rather a presentation should be made from the people's viewpoint of both favourable and unfavourable facts
- No attempt should be made to decide for people any matter that they feel they have reason or a right to provide for themselves. Such insensitivity is liable to provoke resentment, a loss of confidence and the ultimate failure of a project.
- When helping a group to choose a project or to plan a programme, there is a need to ensure that every viewpoint and every suggestion from each person is adequately considered
- Proposed changes or interventions should not adversely affect the status of traditional leaders
- Neutrality is important, mediate but do not become embroiled in arguments and quarrels between community factions
- Ensure agreement and understanding before implementation, particularly where there is division or discord, curb any eagerness to get things moving.

Within the research programme community meetings have been held with such considerations in mind. Research activities have been undertaken at sites where people have requested assistance with water abstraction technology. Throughout the data collection phase communities have been informed of intentions and plans to develop appropriate abstraction equipment. Many people have assisted in the installation of well-points and pumps, the equipment has been tested by the end-users who have also provided objective feed-back on its operation and function. In the development of the equipment recognition has been accorded to both appropriate indigenous and exogenous knowledge. In a two-way interaction, whilst groups within the community continued to request trial well-points and pumps, research programme staff identified limitations to operation and management systems within the community. Community leaders were then informed by programme staff of the potential pitfalls to the ultimate success of the initiative and recommendations were made to hold a series of community meetings. Several communities took up the suggestion and went so far as to bar programme staff from attending the meetings, but undertook to provide feedback on the meetings.

7.7. Limitations of Sand-abstraction

Although an effective technical solution is critical to the success of any water development scheme, probably the factor of paramount importance is the need for an effective sociological solution. For any initiative to be a success, it is essential that management systems be established that are acceptable and widely acknowledged, particularly where project or common property is involved. Fear and superstition have an immediate association with both food and water supplies. Water supplies, which are vital for everyone's wellbeing, are particularly vulnerable and therefore to ensure against the possibility of poisoning or contamination must always be seen to be for common use. Freedom of access to water must always be assured; it is imperative that the larger community must always be able to draw water from a source, even though the well may be under the custodianship of a clan or a single family. Often the custodianship is respected and people do not draw water from a family well, however, the right to access must be observed. The converse situation however applies with food supplies where individual families always remain custodians of their own supplies and fiercely protect that right. A family may provide or distribute food within the community but foodstuffs are never community owned.

Prestige, authority and control are important factors within any community, chiefly for social or political gain. In an attempt to influence other people an influential person may not be above attempting to impose their control through threat or fear and unless a water development scheme meets the social norms and the community is resolute in their support of the scheme, a new initiative might well be still-born. Within the research programme a so-called witch, who resented what she perceived as the importance of the field research assistants, did much to intimidate and hinder the data collection activities of the two field research assistants. Following the installation of well-points and handpumps for trial, this person commandeered the pump and refused to allow anyone the use of it. In the same area visits by the author were curtailed following accusations and threats by the local councillor who was disgruntled following the inability of the community to manage a water supply line that Dabane Trust had once been instrumental in refurbishing.

Appiah (1999) points out the importance of a common accord and of reaching agreement not only before any development project is initiated but at all times throughout the life of the project. He states that WATSAN's for instance, need to operate on mutual laws that are agreed on by the whole community. However, as he also indicates and is the experience of Dabane Trust staff, it is one matter to assist a group or community to draw up a list of rules and regulations, but because of relationships, family ties and vested interests, it is another matter for the group to implement those agreements. For any water development scheme to be successful, it is thus vital that it be inculcated into community life. There must be a common understanding of the need for an adequate management of infrastructure as well as a managed water resource, particularly where pump technology is likely to provide an increase in the volume of abstracted water, but where water may be in short supply. Agreements acceptable to the whole community must be made on the sustainable use of both the water resources and the pump as well as an acceptance of community responsibility for maintenance and repair of the infrastructure.

Such concepts may well however be difficult for communities to embrace or to effect, Davis and Day (1998) maintains that the principle that communities should develop and manage their own water supplies may be easier to state than to put into practice. Circumstances and the nature of each community will require a flexible approach to each situation. Fakh (1990) states that a lack of responsibility and acceptance by communities to manage water supplies in parts of Tunisia lead to excessive exploitation of water reserves through the use of motor driven pumps. Over abstraction caused an increase in water and soil salinity with a subsequent reduction in the quantity of water intended for irrigation that ultimately curtailed the success of the programme. Trace and Whiteside (1992) is of the opinion that a number of small projects serving single villages is often easier to operate and maintain than a larger scheme which services several villages, simply because there is a precedent for cooperation within individual communities that does not exist between separate villages.

Limitations of communities to manage their own water development initiatives may be associated with an apparent decay of social structures. Nleya (2003) addressed a community meeting of 244 people (207 women and 37 men). When querying the imbalance, he came to the reluctant conclusion that the men were opting out of any involvement because of what they saw as a gender imbalance. Sentiments expressed were, "women have equal rights now – if they are equal, let them do everything, let them take over.....," accompanied with other inane comments such as, "why should we bother, women can now do everything". The comments show the deep divides, lack of tolerance and lack of understanding that exists, particularly within, traditional conservative societies. At two other community meetings Nleya attended, one at Tshelanyemba and one at Huwana, it became obvious that women were increasingly being held responsible for pumping water for cattle, Nleya, a man of strong traditional principles himself, commented "where are we headed"?

The issue of gender continues to be a most emotive issue that is considerably misunderstood and misrepresented. As demonstrated by Nleya many conservative rural men wish to maintain the imbalance of work and responsibility to their advantage and consequently feel very threatened by 'gender'. However it has to be accepted that women in many ways are the driving force within the family and within the rural areas. Unless there is an automatic, honest, equal and balanced division of both responsibility and labour there can be no sustainable development or improvement of infrastructure.

7.8. Community Management and Sustainability

Not withstanding erroneous perceptions and shortcomings related to responsibilities and gender, the sustainability of a water supply is entirely dependent on the support that is provided by the water consumers within the community. To be sustainable both the operational technology and the operational management of a water abstraction system must be organised and controlled by the community.

It is important in order for it to be sustainable that any technology that is introduced into disadvantaged rural areas must be to an appropriate VLOM (Village Level Operation and Maintenance) standard. The concept of VLOM is in fact most important and must be appreciated as a complete operational system, which to be effective, requires appropriate skills training backed up with suitable operation and management decisions. It is not merely, as is sometimes construed, the identification of a level of technology that can be operated and maintained by a rural community with few skills and minimal equipment.

Staff of the Dabane Trust, an NGO with which the author is involved, have developed a programme of support to a community based group which extends for a period of three years. The first several months, even a year is devoted to exploring the dynamics of the group and assisting with led discussions and awareness raising of the issues which are likely to relate to water supply management. Issues considered are those of responsibility and operational management, water use and ownership of the water source and abstraction equipment. Sessions are planned to increase awareness around issues such as effective leadership and to draw attention to the need for effective interaction within the community. Sociological capacity building as well as analysis of practical issues such as identification of the technology to be used, maintenance and repair regimes are other issues dealt with. This period is followed by the actual development of the water source, together with pump installation and technical training in maintenance and repair. The training period is a sliding involvement, with a strong initial association that decreases to little and finally to no tangible assistance to the group. In further support of this concept Jespersen (1995) considers that the full range of local support structures must be inculcated into the VLOM concept in order to ensure that a sustainable water supply may be created. He also points out that VLOM is not purely a technical concept but in fact more a socio-economic concept that has a large amount of community development attached to its introduction and function. Once introduced, he says, VLOM is a dynamic process that requires constant development and refinement to cater for the increasing skills that communities acquire and if followed through, increases the users degree of responsibility and ultimately to their taking complete charge.

To ensure an acceptable level of understanding and sustainability Ravenscroft and Cain (1997) maintains that adequate training is vital to the success of any project but that training should not be general. He contends that training should be project specific so that trainees are able to apply their skills directly to the project and that training should not relate only to practical skills, but also to committee and management skills. In this manner the technical, operation and management, organisational and financial aspects of the project are equally appreciated. Subsequent to the research programme the author is of a similar persuasion and further, to the realisation of the advantage of making training available to anyone who is involved in the project or pump operation. In this manner everyone is made aware of potential problems and remedies and are also in a position to support each other when repairs are required.

Webster, Dejachew et al., (1999) is of the opinion that local sustainability cannot be quickly achieved and states that it is a commonly held myth that local sustainability can be achieved in 3 to 5 years. He queries whether the concept of VLOM is in fact achievable at all as he maintains that there are always some pump repairs which will remain beyond the capabilities of most villages. Thus Webster proposes that to ensure sustainability a degree of backstopping will be required, whether it be physical such as in the repair of pumps or non-physical such as the re-motivation of pump caretakers who may have lost their interest. With the VLOM concept in mind he does point out that the easier and simpler a scheme, the more sustainable it will be and that locally available and replaceable materials should be used wherever possible and appropriate.

Referring to the importance of an effective pump committee within the VLOM concept, Connolly (1990) is of the opinion that they are vital to successful, continuous operation of a pump and lists the responsibilities which should be entrusted to pump committee members.

- Ensure no misuse of the pump
- Keep the pump and surrounds neat and clean
- Check the surroundings of the pump and repair any surface erosion
- Check and repair any damage to the fence around the pump
- Check and provide any repairs to the headworks to ensure that waste water drains away
- Report pump wear or breakages to the pump minder for immediate attention and repair

Indicating the need for VLOM to extend beyond the purely technical, Mukhwana and Hukka (1995) reports on a variety of problems that had to be faced by a water supply programme that was established with a 'Supply Driven Approach' in the Western Province of Kenya. Many of the problems faced are those common to many schemes: i. Financial Problems

Inadequate revenue collected

Misappropriation of revenue collected

- Poor record keeping
- Unsuitable tariffs
- ii. Management Problems

Unsuitable committee members – either under or over qualified, resulting in poor planning

Inadequately qualified staff – due to poor training and/or remuneration

Inadequate/inappropriate supply of parts and spares Lack of service/maintenance programmes Inability to adhere to a constitution or by-laws

iii. Technical Problems

Inappropriate technology used Inadequate tools and equipment Lack of routine and corrective maintenance

Poor quality of works

iv. Socio/political Problems

Interference by politicians and other influential people in decision-making Inter clan rivalry Inability and/or unwillingness to pay

7.9. Controls

Cost Effectiveness

The chance of success is essentially dependent on cost effectiveness. Disadvantaged rural communities with little involvement or dependence on so-called modern technology and probably a legacy of failed development projects are unlikely to expend money on anything that is seen to be unnecessary or unsustainable. Income that is available after the purchase of basic food requirements is generally used for school fees or to purchase commodities such as school books or a radio battery and not to improve a water system that may not work and which one might not be able to control. Certainly, as long as there remains an option to access water by merely digging a hole, unless there are substantial benefits to be obtained by installing a pump, the situation is likely to continue.

The situation at Huwana during field trials of new equipment epitomises the need for proven and dependable technology and the need to provide a definite and positive advantage. Through community meetings people stated that it was becoming difficult for them to dig such deep sand-wells each year and they were concerned that the brushwood fences were in-filling the sand-wells when the river ran. This in turn was clogging the river channel, preventing the digging of a well at a suitable site in the following year. The community had thus been very keen to test the new well-point and pump technology. However, although the community made full use of the pumps, they had little faith in the unproven technology and also continued to dig sand-wells.

When the technology is proven, accepted and in regular use, increases in the supply of water are likely to be translated into income through increased food production and

improvements in livestock husbandry. The development of such enterprises also provides for a cash income that can be used for the operation, maintenance and repair of the pump. In this way sustainability is ensured and through the additional income to families, cost effectiveness is achieved.

Understanding the Technology

In any culture to be appropriate, useful and sustainable, technology requires understanding. Although the basic concept of priming a pump can be appreciated, the principles of valves and 'suction', air exclusion and atmospheric pressure are more difficult perceptions. Even after practical training where everyone works on a pump there appears to be a reluctance to undertake pump maintenance and a latent '*fear of the unknown*' by both men and women. Dabane Trust programme staff talk of giving people the *confidence* to dismantle a pump. The disinclination of men would appear to stem from a fear of not succeeding and of being seen to be incompetent and women an unwillingness to put themselves forward. However, in a needs-must situation women will successfully wrest with a technical problem, particularly when encouraged to do so and if not hampered by men. In conjunction with any intervention and installation, practical demonstrations and training are essential, people will not make adequate use of the technology unless they can be persuaded to understand the basic principles and systems employed and acquire the self-assurance to embrace the technology.

For any intervention to be acceptable and successful it is imperative that it be understood. It is not sufficient to dump the technology in the lap of the community, but the pros and cons of the intervention must also be simultaneously introduced. If the technology is to be utilised it has to be assimilated into community structures and into everyday life. Significant planning is required, agreement on the use of the resource, use of the technology, ownership, custodianship, contributions and membership and user fees, maintenance and repair, use and volume of water that can be abstracted, number and catchment area of users, constitutions, bye laws and rights of appeal, safeguards and protective measures are all issues that require considerable consideration.

Easy Operation & Low Maintenance

Experience has shown that if something is unreliable the tendency is for it to be abandoned and a return made to the original system, even if that is more laborious and time consuming. The realisation must be made in Zimbabwe and many other African countries that when a new technology is introduced to a community that society has its own culture, philosophy and values that to an outsider may appear to be offhand or to encompass a certain fatalistic attitude to life. All too often this is not taken fully into account and charities and development agencies instigate their own development strategies based on western concepts and values. When the technology ceases to be used these agencies then either blame the community, or more likely themselves for the failure.

In the past communities had little need for maintenance and this impacts badly on present-day technology. Consequently if a recently introduced technology ceases to work, there is often an automatic reversion to a former technology. Unless the technology is appropriate and sufficiently user-friendly for people to be able to quickly and effectively make repairs, the technology will soon be abandoned. A value must be given to maintenance and to ensure an acceptance and sustainability, end-users must be equipped with both the skills and the tools to take control of the technology for themselves and to make it their own. Responsibility and a working out of management systems are imperative for the successful uptake of a new technology or intervention.

Demonstration of Effectiveness

Technology has to be seen to be effective. A well-point and pump must demonstrate clearly that it is easier to install and operate than it is to undertake the daily drudge of digging and maintaining a sand-well and then dipping out limited amounts of water with a gourd or small enamel dish. Ideally the technology must be sufficiently acceptable for it to be able to take off on its own and for the informal sector to develop and adapt it as necessary.

Acceptance of a technology only occurs with the right conditions and a suitable opportunity. A clear example of this was the introduction of a simple wireinterlocking machine to Zimbabwe. Noble Moyo and the author fabricated a machine in the early 1970's from a design prepared by Merlin Bishop, the World Neighbour's representative at the time. The machine was easily constructed and was simple to use to produce diamond mesh security fencing. However at that time a completed roll of mesh wire was available from a developed and competitive formal industry sector for the same financial outlay as the wire required to make up the mesh. Consequently there was no uptake of these machines at all. Ten years later however, the economy had changed from a limited, low volume market, based on centralised highly mechanised industry, to one with higher volume sales and a greater involvement of the informal sector. As a result there was a rapid proliferation of interlocking machines with probably several hundred churning out rolls of wire mesh under every second tree in both urban and rural areas. The machines themselves were made in the informal sector and were constructed from any available material, incorporating whatever was seen to be suitable, from lengths of pipe to bits of car tyre and car steering wheels. The technology was seen to be both financially and technically effective and the equipment simple, effective and sustainable.

7.10.Advantages and Disadvantages of Sand Abstraction to Communities

Improved sand-abstraction provides several significant opportunities for rural communities to upgrade their water supplies. However there are limitations which must be considered. Although there are many technical advantages, in order for these to be successful, the several sociological disadvantages should not be overlooked.

Advantages

- Ease of drawing water it is easier and safer to pump water than to climb in and out of a sand-well. As wells increase in depth so accidents occur, particularly when a women attempts to climb a steep incline with 20 litres of water on her head and a baby on her back.
- Ease of installation it is easier to drive in a well-point than to dig a deep sand-well
- Clean, potable water is drawn from a well-point, unlike open-surface water there is little fear of contamination
- More water can be drawn through a pump than can be scooped from a sandwell

- A well-point is a one-off installation whereas a sand-well needs continual excavation
- Less environmental damage from cutting of timber and brushwood and clogging of river channel
- Less time devoted to collecting water
- New skills and confidence for women
- Reduced carrying of water

Disadvantages

- Danger of over abstraction of water, in the extreme, severely depriving a community of water
- Acceptable management systems have to be developed and adhered to by the community in both the management of the resource and of the pump
- More costly than simply digging a sand-well
- Tools, materials and skills training is required
- Possible divisions within the community over the use of water and volumes of water which may be drawn by an individual or a family. There are frequent divisions between those (more often than not, women) who wish to grow food and those, (exclusively men) who wish to use water to maintain their cattle herds for reasons of culture and prestige.

7.11.Additional Inputs Required

As already stated, it is a straightforward exercise to design the technology but it is the sociological aspect that proves the success or the failure of a system. The new or the improved technology has to be acceptable to the entire community and the community has to be sufficiently mobilised to manage not only the abstraction technology but also, most importantly the management of the water resource. The research programme indicated that:

- There is a need to break down any divisions associated with technology within the community. This may well require sensitisation of the community to issues of gender and the division of labour. Community meetings and capacity building workshops may well be required to raise awareness on issues such as role sharing, responsibility and decision making within the family and the community.
- Community agreement must be reached on management and use of the water resource. Inevitably when new technology is introduced it becomes dominated by men who tend to use the improved and additional water indiscriminately, thus largely negating the benefits of the technology. It was this perception that gave rise to the development of small, low-cost pumps for cattle watering.
- Discussion groups and training sessions will be required to motivate people to take control of the technology and to convince people that it is in fact worthwhile to persevere with the technology, to understand it and to commit time and money to maintenance and repair.
- Community leaders will need to be encouraged to hold meetings for the entire community to consider and monitor the use of the water resource.

- Women have to be enabled to manage the pump technology. They have to be convinced that they are capable of operating and maintaining equipment themselves and do not have to be dependent on the leadership of men.
- Members of the community may require specific training in the use and maintenance of the pumps and care of the immediate environment of the pump to safeguard both the equipment and the land.
- Training will be required in the use of tools and equipment to operate and maintain upgraded water systems.
- The community will be required to put in place measures of control to prevent people from outside the community travelling long distances with water carts or herding cattle from far afield to an efficient water point, consequently over abstracting water to the detriment of both the supply and the land as grazing becomes concentrated and the livestock form paths, which form water runs, which causes soil erosion.

7.12.Potential

Improved sand-abstraction has the potential to provide more water for more communities. Many rural people in areas where an insufficient or inadequate supply of water is experienced consider that water is the precursor of all benefits and improvements, people have been heard to say, *with water comes development*. An augmented, improved and safe water supply will automatically generate a number of benefits for society. According to Lovell (2000) any water related activities have a high economic value and can play an important role in household income and livelihood strategies and through diversification have the potential to avoid over reliance on single production activities such as rain-fed cropping of marginal lands. Thus people will utilise clean and additional water in a number of ways:

Figure 7.13: Community members, Dongamuzi collecting fetid water from a temporary infiltration well in the silt of a dry dam basin.



Figure 7.14: Water supply from a sand-abstraction source



Health

- An improved and better standard of cleanliness can be expected from a pumped water supply than from an open-surface water supply. A source of 'safe' water will reduce water borne diseases and improve the overall and general health of the family. In areas where open water is commonly used for domestic water there is frequently a high incidence of diarrhoea, the potential for which can be seen in figure 7.13 in comparison with the clean water supplied to the tank in figure 7.14.
- Fewer visits to open-surface water and less use of such water will reduce contact with mosquito breeding areas with a consequential reduction in malaria.
- In arid and semi-arid areas frequently people do not drink enough water despite long hours spent working in the full sun. If more water is carried home for domestic consumption more water will be available for drinking.

Food security

An increase in available water generally results in the development of small-scale irrigated gardens which contribute considerably to the nutrition of a family. According to Bijlsma (1996) a healthy and improved diet including the consumption of more vegetables is an important recommendation for people who are HIV/Aids positive.

Additional Income

Once additional water is available there tends to be a proliferation of income generating projects. Additional water is typically put to a multitude of uses in smallscale enterprises such as burnt brick and concrete block making, small livestock rearing, irrigated gardens and, sometimes not as beneficial, beer brewing. Along with home improvement activities such as the re-plastering of adobe walls and the smearing of earth floors such small-scale, individual projects provide ready cash for women who are then able to make payments on school fees, uniforms, books and clothes for the family. Many women will carefully garner small incomes and put money aside to deal with the inevitable sickness and funerals that occur within the family and on important occasions she may even be able to make the odd trip to town on the bus.

Sustainability

The ability to master the skills and equipment necessary to maintain the operation of pump equipment will not only provide a regular clean supply of water but also the ability to engage in other activities for the betterment of the family. Successful management of a water supply and pump equipment requires logistical and financial management and record keeping that can be translated into family level financial recording and budgeting and may spread to the maintenance and repair of household articles and equipment.

Community Development

A regular, sustained water supply provides a reliable income to enable a family to educate their children and with education comes enlightenment. This in turn encourages the ability to challenge and query biased decisions and the confidence to stand up for ones legal and constitutional rights and not to be brow beaten and demoralised by an over-bearing partner or community leader. Water gives women the chance to hold their heads high within their communities, to demonstrate their ability and to lead their families from fear and impoverishment to open and rewarding lives.

7.13.Summary

A research programme alongside four sand rivers was engaged in with the involvement of people in different communities. Following initial contact with these communities and subsequent community meetings, a total of eight people were identified to maintain a contact between the research programme and the community and also to assist with the collection of data from field research sites. The selection of these field research assistants was made following meetings which were held between staff members of Dabane Trust and leaders in each community and finally meetings to which the entire communities were invited. Requests were made at the meetings and agreed to by the communities to engage in a programme of data collection. At each community meeting people were informed of the need to engage in research activities to assess water use and water losses from the sand rivers. Through the inception of these meetings, the research initiative was involved with the communities in a two-way exchange of information. On the one hand it was possible to explain how the research programme was envisaged and at the same time to gather the perceptions of the four communities on the use of the water resource and together to consider the use of data for the subsequent development of equipment and how that might possibly be translated into improved water management and supply systems.

The field assistants continually relayed back to interested members of the community the progress of the data collection and linked this with possible options for the development of equipment and abstraction systems. In this manner an association was maintained with the communities throughout a four-year data collection period. As the programme moved to more practical applications the communities were informed of new technology during the development and testing phases and particularly when equipment was introduced into the areas around the research sites for field testing. Efforts were also made through the field research assistants to gauge people's understanding and the perceptions that they were likely to have of the equipment that was in the process of development and thus the chance of acceptability and success. The interchange also provided a forum for an overview of community management systems. Consideration was also given to the technology that is available and a review undertaken of the methods and equipment that could be used for water abstraction and sources of energy that would be suitable to power them. Discussions were held around the various options the communities had to improve their water supplies and assessments were made of what would be required to implement acceptable and sustainable systems of operation and management. A prime consideration during the study was the identification of problems that were likely to be encountered and possible practices that would ensure the successful and sustainable operation of equipment. During the research programme ongoing discussions were held to identify such things as the possibility of divisions and vested interests within the community and the likelihood of a reluctance on the part of the communities to assume responsibility for any corporate responsibility and management of water supplies and water abstraction equipment. Whilst the introduction of new technology may well be welcomed with jubilation, often little thought is given to systems of operation and management. It is quite logical to assume that any shortcoming to the success of improved water abstraction systems will lie not with any limitation associated with technology but with sociology. How the technology will be made to work will be at least as important as how the technology will work, although an understanding of one may well lead to the other.

Without effective management systems that are acceptable to the entire community successful operation and management will not be achieved. Communities have indicated preferences for technology to be primarily cost effective, require low maintenance and to be 'user friendly'. Unless a technical intervention conforms to these strictures and is seen to have considerable advantage it is most unlikely that there will be any acceptance by a community of an 'improved' technology.

Limitations exist with some of the equipment that might be available to abstract water from sand-abstraction systems, particularly some forms of pump and power systems that might be used to energise them. Although many forms of pump, including ancient lifting devices, are generally suitable for use with infiltration gallery and false-well systems, in the main only suction pumps are suitable for use on small-scale well-point systems. To help overcome this, continuing development of suitable low cost pumps that can be fabricated and repaired without the use of complex tools and a demystification of pump technology is required. In order to maximise adoption of new technology and new concepts, communities will be required to reconsider both technical and sociological paradigms and to confront sensitive issues such as traditional roles of responsibility, decision-making, maintenance of abstraction systems and the management and use of water resources. Without at least consideration of the contentious issues of responsibility and use of water no effective, sustainable development initiative is likely to take root. Without a preparedness to tackle these issues and demonstrate a genuine and honest acknowledgement of the predominating role that is accorded to women without concomitant responsibility, no 'development' or 'improvement' can be expected to succeed. It has to be appreciated that improved technology cannot work in isolation and that that is a difficult concept for traditional and conservative societies to accept.

The advantages of new technology can be seen to outweigh the disadvantages as long as people have an understanding, preparedness and an acceptance of the new systems and a preparedness to make them work. New systems will not be acceptable if people do not feel involved or are not prepared to take control. To this end people will be required to engage in a comprehensive evaluation of responsibilities and management systems, a willingness to develop new skills and to expend resources on the maintenance of equipment. When these issues have been resolved the potential certainly exists for the popular uptake of new technology that will change lives in depressed areas and help marginalised communities to adapt to the changing needs of the modern world.

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Chapter 8

Social Research Applications

8. Sociological Constraints

The sociological perspective of communities or community members who are interested in utilising new methods of sand-abstraction is likely to have a considerable impact on the final adoption or rejection of improved sand-abstraction technology. Although the equipment may perform satisfactorily, popular uptake of the technology cannot be assured unless there is an equally effective sociological acceptance. Correct identification and awareness of the constraints that are likely to influence the success of introduced technology is essential. The principle factors that are likely to affect the success and final outcome of an improved technology are:

Cost

The technology must be cost effective. There is little surplus cash available in most remote arid and semi-arid areas and people have their own priorities and interests. The alleviation of drudgery, which has been borne by financially impoverished societies from time immemorial may not be a priority, at least not sufficient to commit hard won cash. Traditionally people are expected to cope with hardship and drudgery. Undue operation and maintenance costs may thus preclude sustained use of technology, as people will simply revert to the use of excavated scoop-wells.

Jealousy

As much as possible the community must be unified and cohesive. The wider society must accept the improved water source so that it is appreciated as a community asset. Without widespread acceptance some members of society may well become inclined to work against the success of the project and the use of improved equipment. Members of the community have probably long been working together and such a concept must be perpetuated as, for example, people enjoy the contact, the social outing to collect water and to gossip at the water-point. Water is a communal asset under community management; it is imperative to success that this condition be continued. It is also important to appreciate the full impact of communal status and the importance of maintaining the status quo where no one person is seen to advance without the rest of the community. A situation of all or none is likely to prevail and considerable resentment is likely to occur if the precedent is not maintained. If societal parameters are not upheld, fear and superstition are likely to propagate and the community is likely to query how a person advanced, was, for instance witchcraft used? This could lead to the ostracism of a person, the lack of acceptance of a technology and the collapse of an improved water supply.

Vested Interests

Acceptance of the use of water is essential. Without this acceptance new technology is unlikely to be successful. Generation after generation of men have drawn water for

livestock, with the use of water for food production a very recent innovation accorded to women. There is still significantly more status accorded to a person with a large herd of cattle and little income, than to a person with a small irrigated garden and a regular income. Status and importance continue to be accorded traditional values. Particularly in water deficit areas it may not be possible for everyone to have access to or to use the water in the way that they wish. Decisions will have to be made or the supply of water may prove to be insufficient.

Maintenance

As explored in the previous chapter maintenance is likely to be accorded a low priority and at best should probably be considered *'crisis maintenance'*. New technology is likely to be used with zest as long as it remains working, thereafter will be the true test of its suitability and acceptability.

Thus opportunities must be created and developed if new concepts and new technological approaches are to be accepted and utilised at a rural community level. Practical design criteria can be developed but in order for the technology to be utilised successfully it must be returned to the people who must feel sufficiently confident to accept it and to adapt it to their own criteria and validation.

Awareness of the implications and effects that new technology will have on society is a crucial factor that must be considered by a community if the technology is to be effective. Answers must be found with regard to satisfactory management, responsibility and the maintenance of equipment. Improved technology might also pose problems through easier abstraction of water leading to an immediate oversupply and over abstraction; these issues can only be resolved through open and honest discussion, effective leadership, local personal capacity building and technical training. Community leaders must encourage people to invest time to learn about the technology and be prepared to finance maintenance of the technology.

If technology is to be operated independently at the rural community level it must be at a level that is both acceptable and understandable. A simple technology is thus the most likely to succeed, even if this requires more frequent repairs. Equipment must be easily maintained and repaired with basic tools and readily available materials. Factors likely to influence success are:

Community Discussion

Awareness building and decisions on the use of water, the quantities which may be abstracted and by whom, the custodianship and the responsibility, undertaking and cost of maintenance of equipment are all issues that require resolving through community meetings.

<u>Usefulness</u>

Many people are of the opinion that an increase in the availability of water will make life easier. There will be more water for personal use, for home improvement and maintenance, for additional livestock and most importantly for the generation of financial income.

Value

Particularly in difficult or water deficit areas there is an additional value to an improved water supply where there is no open sand-well. At Huwana the community wished to use handpumps to draw water to avoid the entrapment of brushwood and silt which occurred in scoop-wells. At Makhulela pumps provided an obvious advantage where

people experienced problems with elephants defecating in scoop-wells and filling in the wells as they bathed and played in the loose sand around the wells.

<u>Training</u>

Both technical and sociological training are likely to assist in the acceptance and sustainability of new technology. People who have the knowledge of operation and the skills and equipment to operate and maintain abstraction equipment are likely to make it succeed.

Perception

Understanding both the limitations and the benefits of the technology are likely to improve the success of the technology.

8.1. Community Perspective

8.1.1. Community Meetings

Throughout the research period meetings have been conducted with communities. Initially meetings were held to explain to communities the purpose of a sandabstraction research programme and to seek local approval to undertake field research activities. Particularly in areas of severe water deficit, communities were most keen to be involved and were at pains to encourage and to participate in the research programme.

The meetings orchestrated by the research programme were requested by Dabane Trust and organised through the Local Government Councillors who had been elected by the community. Meetings ranged from the participation of a few people, such as a water-point pump committee, typically held under a tree in the vicinity of a proposed source of water, to meetings to which the entire community was invited, involving a hundred and fifty or more people held at the local school. In general there was a lot of interest and good participation of both women and men at the meetings with women frequently involved, even though many communities still consider that a woman should only reflect the opinions of her husband.

Such involvement was gratifying in view of the frequency of community meetings, which is a constraint to popular participation. Community members are frequently called to meetings, which are used as a method of briefing rural communities and soliciting support. People are expected to attend meetings called by their chiefs, local government councillors, village development workers, village health workers, school head teachers and NGOs. Through community meetings appeals are made to people to build or extend a school or a clinic, choose a pump management committee, a dam management committee, suffer a political harangue, be cajoled into participating in 'public works programmes' in order to receive, food, seed or some other political handout and generally be appraised of what is expected of them. Figure 8.1 shows a community meeting held at Dongamuzi, Lupane District, Zimbabwe to discuss methods of developing sand-abstraction and better utilisation of the technology.

Figure 8.1: Community meeting



8.1.2. Indigenous Knowledge

To be acceptable and sustainable technology must fit within the bounds and structure of society and in order for it to be fully utilised, must be understood and adaptable. Many researchers such as Ramprasad (1999) and Scoones and Thompson (1994) have noted the importance and relevance of community, or 'indigenous' knowledge to technology. In order to gain a full insight and an understanding of the technologies and techniques in common use, discussions have been undertaken with a number of communities to provide background information and a better appreciation from an end-users perspective, of the potential, the advantages and disadvantages of sand-abstraction. Such an approach and understanding will help to foster a better appreciation of low-level technology water source development schemes, that according to IT Publications (1990) will ultimately guarantee sustainability.

In order to better appreciate and to develop appropriate systems of abstraction, discussion and research was conducted which built on the typical traditional knowledge and the concepts that rural communities have of sand-abstraction. Such an interaction prepared the way for new ideas and an increase in the understanding required for an improved sand-abstraction technology to succeed. The involvement of rural practitioners throughout the research programme enabled the enhancement of latent technical expertise to support the development of equipment. As indicated by Agarwal and Narain (2000), such joint research activities make new concepts more widely appreciated and eventually better utilised.

Traditional Family Roles

By tradition, responsibility for the family and the division of family labour was such that men were the physical protectors of the family and responsible for its wealth. Within a largely pastoral society wealth was essentially related to the ownership of livestock. Thus men were primarily involved in the management of livestock, leaving responsibility for everyday family routine and chores to the women of the household. In rural society this custom is largely perpetuated today, but as many men make a living not in the rural areas, but in the urban areas or out of the country and only remit money to their families in the rural areas this places an even greater workload on women. Unfortunately remitted money is often received sporadically, which places a yet greater responsibility on rural women. Consequently women now have to manage the home, provide food through dryland cropping or irrigation in season and generate an income to clothe children and send them to school, as well as tend livestock for their husbands. The men who do remain in the rural areas often continue to concentrate their activities around livestock which generally only feature in the family economy during the most dire of circumstances. A typical further limitation is that women managing family affairs are unable to sell or slaughter livestock or to sell any dryland crop produce that they have grown without the consent of the male head of the family, wherever he may be. With a rather different perspective the Rev. Bozongwana (1983) states that subordination on the part of a wife is not intended in any way to imply servitude but merely to sustain and enhance the marriage bond through good rapport. He does also indicate that there are very few taboos placed on men and that even these are limited as men wish to have more freedom than the other members of the family or community.

Personal Experience (1)

Working with a large group of men and women of Mazwi, Matobo District, Zimbabwe. The men decide that we should eat and instruct the women who are waiting patiently for any instruction, to prepare food. The women reply that they did not bring food as they have no surplus. The men insist and the women query, where are they to get food; the response – you are women, you know such things.

Responsibilities and family division of labour continues to be all important. Smout and Parry-Jones (1999) states that gender issues are particularly important in water and sanitation projects as it is often the women who are the providers, users and managers of domestic water. It is also usually women who have responsibility for family health and hygiene. Men often have differing needs and priorities with regard to water such as for livestock watering which may conflict with the needs of women. It is therefore essential that the needs of both women and men are equally addressed, particularly in the planning stages when most of the important planning decisions are made. Generalisations and convenient assumptions also cannot be made, Botchway (1993) for instance reports on failed development initiatives in Ghana because of the alienation of women and children following incorrect assumptions of pooled family labour.

8.1.3. Management of Water Supplies

Community Perceptions

Discussions on various aspects of sand-abstraction were undertaken through a variety of community meetings ranging from formal gatherings which included community leaders and teachers, to structured interviews and questionnaires at the household level, to small gatherings of interested participants working in conjunction with researchers. Thus a broad perspective was gathered from a wide cross section of representative rural communities. This perspective was considered to be most important. As is widely accepted and referred to in works such as, 'Dying Wisdom' by Agarwal and Narain (2000) and 'Voices from the Rocks', Ranger (1999), local people can be expected to have an in-depth understanding of sand rivers and methods of sand-abstraction which they are able to relate to history, traditions and culture. Through dialogue, appreciation of ownership, management, methodologies and any taboos associated with sandabstraction were explored and provided a base from which to develop appropriate, efficient and cost effective water supplies. Together with communities, reliable sources of water were identified and information gained on annual and seasonal river flow. A record of changing river patterns and sediment water retention periods was made and utilised to increase general knowledge.

The discussions that were held enabled researchers to learn about community perception of water that is retained in river sediment and the traditional water management systems that have been employed. Each meeting was adamant that sandabstraction contributed considerably to the health and well being of their society.

Each of the four communities described the typical present-day method of temporary well construction, which is based around a section of open-ended drum. Reports indicate that a one third length of 100 litre drum, some 30 to 40 cm long, should be dug into the surface dry sediment until the water level is reached. Part of a 100 litre drum is considered ideal, but a 200 litre or even 20 litre drum section is also considered adequate. Recharge to the well occurs by water flowing through the sediment through the open lower end. To maintain a well, sediment requires continual removal from within the drum, however due to falling sides and a welling up of saturated sediment within the well, water depth can rarely be maintained at more than 75 mm.

As the water level drops so the drum requires further lowering. The alluvium from the excavation is thrown onto the sides of the well which is in turn fenced off with temporary brushwood fencing to prevent livestock from contaminating the water and collapsing the sides of the well in their search for water. Typically a piece of sheet metal is placed over the top of the drum to reduce contamination from foreign matter and to reduce the ingress of sand. However, because of the unstable nature of the dry sediment and the continual deepening of the wells which is required, it is frequently difficult to prevent the movement of sediment into the drum from the unstable sides. Furthermore, as the water source becomes deeper in the sediment so it also becomes more difficult for people to reach the well and to draw water. Several people expressed concern at the difficulty and even danger of climbing out of these temporary wells when balancing a full 20 litre drum of water on their heads. Particularly when water sources become deep in compacted sediment people either cut steps or lash together make-shift ladders, however many respondents felt that these were particularly unsafe.

Researchers were also informed that in past years similar methods of abstraction had been carried out in vleis. Although it was commonly accepted that many vleis had dried up in recent years, people stated that the practice was still undertaken when water was plentiful. A popular notion expressed, was that the drying of traditional water sources together with increased populations in communal areas due to the earlier forced removal of people from commercial farming land, had necessitated well digging and borehole drilling programmes. Figure 8.2 shows how precarious it can be to draw water from seasonal supplies. This photograph was taken at Gwampa Vlei, Nkayi District, Zimbabwe.

Frequently discussions reverted to the advantages of sand-abstraction systems where the water was seen to be 'sweet', clean and filtered with little discolouration, little turbidity and no 'germs'. However, a general summing up of the prevailing situation with sand-abstraction scoop-wells brought out the following negative points -

- Animals quickly destroyed and contaminated open wells if they gained access. As animals sensed such water supplies, unless well protected they frequently destroyed or damaged the wells in their efforts to reach water.
- It was hard work to dig down to the water level and to then maintain a scoop-well.

- It was a laborious process drawing water, particularly when water was deep in the sediment as the infiltration rate would then be slow. It took time to draw water and sometimes meant that a person did not wait long enough for the infiltrating water to settle and clear sufficiently.
- Wells were often deep, particularly late in the season and then became difficult to climb in and out of with a full bucket of water. This also gave rise to the possibility of injury to people and livestock. If considered too deep towards the end of the dryseason, children were often not allowed to draw water for fear of accident.
- There was no knowledge of when a river might flow and thus no precautions could be taken to safeguard a well. Consequently brushwood fences would be washed into the wells making it difficult to construct a well at the same spot in the next season, particularly as the brushwood frequently allowed for the build up of silt and fine sediment. Furthermore, the drum halves that allowed access to water were lost when the river flowed and had to be replaced in the following season. As almost all sound drums are commercially recycled they are not easily found and are costly to replace. As it was often not possible to re-dig a scoop-well in the same site, optimum sites were frequently lost, which reduced the availability of sites and possibly affected the overall availability of water.
- It was noted that a number of wells in a river could have a detrimental effect and that a small number of wells was preferable. It was thought that many wells led to high losses of water through evaporation and general damage to the river system.

Respondents felt that well-points and hand-pumps were a way of overcoming these problems. It was also noted that well-points allowed for the drawing of clean, filtered water without sediment at any time in the season, whether or not the river was flowing.



Figure 8.2: Deep open well

Management of Water Supplies

The general understanding in each community was that a water source that has been dug in the river by a family or a small group of people could in fact be used by anyone from the larger community. It was stated that people preferred to draw their water from one particular well and that although anyone could use a well, all users must secure the protection of the well after use.

Community use of a well was cited as being preferable because of the risk of poisoning from people who might have been excluded. Thus community ownership of one well maintained well was seen as being preferable and that a number of wells gave rise to a lower standard of general management. However, it was generally recognised by the group that with the increasing need for water, there was an increasing number of wells being constructed.

It was also very clear that at least the men in the community were very keen indeed to utilise the sand-abstraction hand pump systems for drawing water to give to cattle. It was however an understanding that villagers who did not co-operate in the digging of wells should not be able to water their livestock at a sand well.

Points of Management from Various Meetings:-

- Typically 4 to 7 families dig, fence and manage one well. Frequently these are families that have a close relationship, often members of the same clan.
- During a drought when water is particularly deep in the river sediment, four or more people typically go to a well together and can then pass buckets from one person to the next to obviate the need for everyone to climb in and out of the well.
- The placing of an open-ended drum in a scoop-well allows for easy maintenance and makes for satisfactory management of a source of water.

Continuing Knowledge

Following a request by the author to establish a research site to monitor the river and the water in the sediment one group acknowledged that this was part of a learning process which might further benefit them and other communities. They stated that they had already worked with Dabane Trust programme staff to set up a small-scale sandabstraction pump system for a group garden and that they too wished to expand their knowledge of sand-abstraction systems and thus were pleased to participate in a research programme.

At one meeting a number of older members of the community reminisced on water supplies and traditional wells in past years when the situation of general water supply was said to have been more plentiful. The points raised were that:

- Scoop-wells had been well managed and were particularly useful during the 'old days'
- River based wells had become more prolific in the early 1960's as the population had increased following a policy of 'Land Apportionment' and widespread resettlement of people from commercial to communal land during the 1940's and 1950's.
- Frequently the water from scoop-wells was used to water livestock. This was done by carrying buckets of water from an open well to a hollowed out tree trunk on the riverbank.
- Properly constructed scoop-wells sited in riverbeds were used particularly from August to the onset of the next season's rains. Up until this time water was available

either in open pools in the river or in shallow surface excavations where a person had only to scoop the sand to one side. It was also said that in the past, water was sometimes available in shallow, rain filled wells in people's arable fields away from the river.

• The first technology step had been the introduction of open-ended drums into the wells as these had helped to maintain a greater depth of standing water. Prior to this introduction, larger, more open wells had been required which the community thought had contributed to increased water losses from the river through evaporation although it is more likely that the diminished depth of water was due to an ingress of sediment from the sides of the scoop-well.

Disadvantages of sand wells:

- There was a perceived danger in dug wells as it was a daunting task to clamber out of a well with a full bucket of water on one's head. This could lead to personal accident or to a broken container.
- It was hard work and difficult to maintain an adequate depth of water as sand had to be excavated everyday in order to be able to draw sufficient water. As the water level dropped a well had also to be increased in size and deepened every week. Several women referred to this limitation.
- It was difficult to assess the available long-term water supply. If a well was badly sited and dried up another, completely new well had to be dug.
- No technology was readily available to select suitable sand-well sites. A person could only adopt a random approach based on intuition and the experience of previous seasons to identify a possible deep site that might be capable of maintaining a regular, steady supply of water.
- Sand scoop-wells were now considered so numerous that they had contributed to environmental degradation and to a general deterioration of the river and its water bearing capacity.

Expectations of a Sand River Water Supply:

It is quite apparent from discussion and observation that rural communities have a bias towards sand-abstraction water supplies. There would appear to be a cultural security with scoop-wells which are steeped with traditions of operation and management practices that have all helped to ensure successful use over a long period of time. Sandabstraction water supplies are especially valued in areas where groundwater sources are particularly inadequate such as in extensive areas of gneiss or granite which are generally poorly fractured and thus have only a limited groundwater supply. Deep groundwater supplies are also often limiting, due either to contamination by mineral salts or simply to the physical limitations of drawing sufficient water from a great depth.

The record of groundwater handpump reliability is also often a dismal chronicle, Taylor and Mudege (1996) refers to 8,814 reported breakdowns on 14,028 Zimbabwean Bush Pumps during the year 1995/96. Average downtime was apparently 15 days with 24 days in Matabeleland South where there is a great potential for sand-abstraction development. Taylor also comments that the focus of the last few decades has been on the development of new infrastructure with decreasing allocations for the maintenance of existing infrastructure. He says experience has shown the seriousness of this mistake across Africa, with new facilities often broken down after only a few years and never repaired. In such situations people are only too keenly aware of the benefits of sandabstraction but they also acknowledge the shortcomings of transient wells which have to be reconstructed each year. Many people have thus expressed a need for more sustainable abstraction systems and have shown a willingness and an interest in working towards establishing more permanent solutions.

8.2. Practical Use and Suitability

8.2.1. Community Management

With the breakdown and abandonment of centralised services for the maintenance and repair of water delivery equipment, it is commonly accepted that adequate levels of community involvement, responsibility and management are required to ensure effective and sustainable water supplies. Indeed many researchers and writers refer repeatedly to the need to ensure comprehensive involvement of consumers in all aspects of water supply delivery. Hartung (1990) for instance states that community participation should involve joint planning and decision-making and as such will be a determining factor in the success of any water project, especially with regard to its continuing operation and maintenance. Singh (2002) refers to a large number of water resource development and watershed management projects, which have been initiated for poverty alleviation and social development, but few of these he says have ever achieved their intended goals because the recipients were not involved in the identification and implementation of the projects. Singh maintains that the participation of recipients is a key element that will determine the success or failure of a project and that to ensure success it is imperative that local institutions are functioning correctly and that suitable aspects of indigenous knowledge are incorporated into project design.

To instil effective levels of community management Thompson (1991) considers that ultimate responsibility should lie with those who are involved and who have to continuously make decisions concerning resource allocation, farming practices and conservation. However, he is also aware that powers of decision-making alone will not lead to successful project implementation as the resources that are generally available to rural communities, together with their technical knowledge and skills are likely to be insufficient. The success of rural development programmes, he maintains, depends largely on the participation and willingness of peasant farmers together with the ability of the State or development agencies to recognise the limitations and the potential of local socio-economic and agro-ecological factors and to encourage and support local initiatives. Tchawa (2000) contends that a link can be established between technology and innovation as he considers that new technology is also able to lead to social innovation. He refers to a community in Cameroon which successfully utilised a new source of water by setting up a management committee to arrange the distribution of water. Distribution was carried out under strict rules which had been set by the farmers themselves, which Tchawa reports they both respected and implemented.

Scoones and Toulmin (1996) contends that the distinction between indigenous and introduced technology may in many cases be artificial. He considers that it is the ability of a community to deal with the process of technological change rather than the technology per se, which will be the determining factor to success. However, he does continue with the idea that when introduced technologies are imposed on people the prospects for the transition and for local adaptation of the technology are constrained and problems are likely to arise. Scoones considers that off-the-shelf technical packages appeal to development planners and project administrators as such archetypal approaches ensure predictability. He is of the opinion that standard administrative procedures for delivery, equipment needs, labour demands and cost calculation, together with set schedules for implementation and pre-determined physical targets, monitoring and evaluation procedures ease project implementation. Further, when confronted with an operational problem it is likely that a straightforward diagnosis and a standard solution can be implemented over a wide area. Scoones conclusion is that driven by the logic of internal planning frameworks, such projects have been and will continue to be implemented on a large scale.

Peabody and Yusuf (1999) points out that community participation has progressed from an initial concept of community members providing free unskilled labour, to participation in the planning, design and execution of projects, to responsibility for the ultimate organisational support and management structure. According to Whyte and Burton (1977) the mode of decision-making is important. In most traditional communities decisions are made with widespread community participation in a process of seeking opinion through general discussion and consensus of agreement before the leader enunciates a decision. The choices and trade-offs between conflicting goals of factions within the community thus become presented as an array rather than as an ordered series and proponents of each particular view actively ensure that their criteria or trade-off stays within the form of the debate. Mbugua, Githendu et al., (Undated) realises that many problems related to water development are fundamentally linked to community participation. Participation in a community he says, is never homogenous as there will always be differences of opinion between members involving any conflicts of interest that are likely to occur as well as issues of gender, culture and political constraints which are likely to segregate people.

Ownership and Responsibility

Within the constraints and possible limitations with the involvement of the user community, 'ownership', or custodianship and ultimate responsibility must be clearly demarcated for there to be a successful utilisation of technology. To engender a community responsibility both the water source and the technology that is utilised to abstract the water must be acceptable and conform to the conventions of society. Cleaver (1998) makes a point that local principles of water use and management are not necessarily explicit rules or regulations, but rather customs and conventions; perceptions of what people consider to be the 'right way of doing things'. These norms are based on the need, or the right to access to water within a dryland area and generally 'pre-date' by many decades the establishment of more recent water sources and water-point committees. Cleaver also brings out the point that people prefer to maintain access to a number of different water sources over a wide area, not just to the local one that they 'own'. The reasons provided are that certain sources are preferred for particular purposes and insurance, if one source dries up, breaks down or access to it is restricted, the users need to be sure of being able to draw water elsewhere. This situation does not of course educe the commitment that is required to maintain a water supply in a constant state of operation.

Sutton (1999(c)) considers that a carefully designed programme with an appropriate selection of the technology and sensible training will bring about cost-effective and sustainable water solutions. She is of the opinion that responsibility for infrastructure is more likely to be achieved through involvement in decision making than though

any amount of physical work. In a comprehensive analysis of the water supply situation in Zimbabwe post Independence, Stene-Johansen (1985) states that boreholes were considered by the population to be operated and owned by the District Development Fund (DDF), a function of Local Government and that protected wells and in some cases boreholes, were looked upon as the property of the district council. It was only unprotected sources of water and surface water that were considered the property of the community. The report, a proposed National Water Plan, goes on to state that the installation of primary water supplies using handpumps will not be a success on a national scale, unless an effective appropriate maintenance programme is developed and that the main emphasis of the programme should be on preventative maintenance. The Water Plan stipulates that in order to ensure that the pumps are checked regularly and that the time between breakdown and repair is minimal, maintenance should be carried out by people who live in the vicinity of the pumps. Further recommendations are that each handpump should be maintained by a Water Committee of 2-4 people with at least two of the members, being women.

Stene-Johansen recommends that the village level pump committee should:

- Ensure the pump is not misused
- Keep the pump surrounds clean and neat and attend to any erosion
- Repair fences
- Ensure that all waste water is free to drain away and to maintain the spillway channel
- Check nuts and bolts for tightness and grease parts of the pumps when required
- Contact the pump minder to repair faults
- Assist the pump minder to undertake repairs

The legacy of centralised maintenance, at least in Zimbabwe, is not conducive to community involvement in water development schemes. Boydell (1990) maintains that prior to Independence, no effort was made by the authorities of the time to motivate the rural majority to participate in the country's development needs, which did little to instil a concept of community participation. The reason for this he feels was that such motivation would have made the rural population even more aware of their underprivileged status and would have raised expectations which the then Government was not prepared to satisfy. A cavalier attitude is indeed conveyed in the Water Act of the Government of Zimbabwe (1976), which provided extensive legislation on the use of water by the formal and commercial sectors, generally upstream of the communal areas, but merely ascribed the rights of the occupants of those areas to water, with a need to provide *due regard to the interests of the occupants of 'Tribal Trust Land'*.

More recently the Zimbabwe National Water Authority (1996), (ZINWA), recommends the development and rapid implementation of innovative approaches that go beyond the usual and traditionally expensive drought-susceptible approaches involving large dam construction. ZINWA suggests a more comprehensive water management and development programme including groundwater development from boreholes, shallow wells, sand-abstraction and collector wells, as well as surface water by utilising various types of dams and rainwater harvesting and catchment protection such as terracing and tree and vetiver grass planting. It maintains that particular emphasis should be placed on drought proofing. It is imperative that responsibility and ownership for water source management and technology be inculcated into community perceptions, since without it pump technology will not be successful and neither established or new, innovative technology will be controlled by the consumers. For the technology to be beneficial in the long-term the people must be prepared to take responsibility and to assume a sense of ownership.

Application of the Technology

For new approaches to sand-abstraction to be effective and successful, a basic level of technology is required, so simple that consumers will have the confidence, the tools and the ability to dismantle, effect innovative repairs, reassemble and refit the necessary equipment. The technology must be capable of being undertaken at the village community level with acceptable agreements on use, operation, management and maintenance in place. The possibility may also exist at a family or clan level where individuals are responsible for management and maintenance, in this way there is likely to be an improvement at the technical level, but nevertheless to be acceptable and sustainable there must still be agreement with the wider community on the use and quantities of water which may be abstracted from the resource.

Whyte and Burton (1977) supports the introduction of appropriate, low cost technology so that the scope of the technology and the technical components are within the decision making compass of small communities. She believes that the technology will then be understandable, capable of modification at the local level and will be seen to be flexible. Provided a simple technology is utilised, Whyte also maintains that it is not necessarily a limitation of the technology if the community has to import materials for the operation and maintenance of equipment, as there will still be sufficient cognisance of the design and the repair needs to ensure sustainability.

The correct level of technology is all too important, Howsam (1990) states that the lack of success with maintenance or rehabilitation projects often stems from the introduction of an inappropriate technique or an inappropriate application of a potentially suitable technology. He maintains that the technology level to be adopted must be serviceable and in his own words states that a 'suck-it-and-see' approach where a simplified technical solution is provided to a community for them to experiment with is all too common in groundwater engineering. Even at this level Howsam considers that without sufficient preparation the initiative may be doomed to failure. At the other end of the scale, Knight (2001) warns against 'transplanting' technology. She states that it should not be assumed that technical answers that work satisfactorily in North America or Europe will necessarily be suitable or successful in so-called developing countries where different conditions or circumstances may well render a technology or high-tech equipment, a disaster.

Recognising the problems that exist with the sustainability of handpumps in many parts of the industrially developing world a team based at WEDC is investigating the social, institutional, financial and technical factors seen to promote sustainability. The intention is to synthesise data from a variety of sources and produce guidelines for designing sustainable handpump projects, (Skinner and Reed 2001).

Manufacture and Installation

Simplified rule-of-thumb principles as in table 8.1 may well assist community members, consumers, artisans and entrepreneurs in the acceptance and understanding

of new or adapted appropriate sand-abstraction technology. A step-by-step approach will assist in the formulation of quick and ready solutions for a given set of circumstances. The assembly of guides, gimmicks and gadgets, such as the fabrication jig, figure 8.3 and the sediment gauge, figure 4.36 are more than likely to assist in the successful introduction, fabrication and installation of the technology. The table below, provides an assessment chart with a sequence of procedures to assist in site and equipment selection. Assessments are made from information that can be gathered on the depth of riverbed sediment, the depth of water available in the sediment, the grade of sediment and finally the nature of the river channel. The chart indicates the water abstraction options that are then available in differing conditions and provides an overview of how to proceed where the depth of sediment or the depth of water available within the sediment is to a particular depth.

Table 8.1: Site and equipment selection chart



Well-points

Construction of a uPVC driven well-point can be made considerably easier by using a steel jig to obviate the need for individual measurements and marking-out. Construction with the aid of a jig will also improve the accuracy and uniformity of the fabricated equipment. A suitable jig constructed from 50 mm (2 inch) steel water pipe can be used to ensure the correct number and position of apertures as well as help to determine a satisfactory size of aperture on a uPVC well-point. The construction of such jigs as seen in figure 8.3 could form the basis of training workshops for groups or local artisans conducted by interested NGOs.



Figure 8.3: Fabrication of uPVC well-point using a jig

Caissons

A similar manufacturing approach can be made with the construction of a caisson. The design and operation of a caisson differs little from that of a well-point but does provide the flexibility for use in finer, 'medium' grade sediment and there may be a further advantage in some conditions of requiring installation by digging into sediment rather than by driving-in. A caisson offers further flexibility in that abstraction points have been successfully fabricated from a range of materials including plastic basins and no-fines concrete and in many situations allow considerable latitude in the size and formation of a pertures. Less critical attention to optimum design is possible in the fabrication of a caisson with a better than average chance of success, generally making it possible for a less than perfect fabrication to function adequately and thus allowing local artisans considerably more opportunity for improvisation.

Infiltration Galleries and False-Wells

Infiltration galleries of either finely slotted pipes or pipes that are covered with synthetic textile are likely to form a more suitable solution to water abstraction in shallow or fine sediment than well-points. Where suitable slotted pipe is not readily available on the market this is likely to provide something of a problem as invariably only ultra fine slots of >1.00 mm are suitable for use in fine sediment that will not allow the ingress and subsequent clogging of the gallery with silt and fines. Such fine slots will inevitably be difficult to manufacture without specialist equipment. It can be general assumed that a slot formed with a hand hacksaw blade will not be sufficiently fine. An alternative to a slotted pipe is a pipe with large apertures that is covered with a fabric, however, although the apertures may be easily formed in

pipework it is more than likely that a suitable synthetic material will not be readily available in low-income communities.

One solution to this problem is for an organisation or an NGO to acquire a suitable fine, circular saw blade that can be used to slot uPVC pipe. However this in itself is not easy. Although a web search conducted in August 2003 revealed a number of manufacturers and suppliers of uPVC saws, further enquiries revealed that each was a hand saw for use in cutting sections of pipe rather than slotting. A subsequent query elicited several responses, but no blade suitable for slotting uPVC pipe.

Where infiltration galleries are utilised, offset or false-wells are also required. The opportunity for independent community participation, planning and general involvement is considerably higher in the construction of a well than in the fabrication of an infiltration gallery. The digging of a well-shaft into riverbank alluvium alongside a suitable abstraction site requires little more than the ability to dig deep enough into the bank to ensure that the base of the well will be at least a metre lower than the infiltration gallery in the river sediment. The well shaft then requires lining and the infiltration pipe to be joined into the well. Lining is a relatively straightforward procedure of stacking well-rings within the well shaft and back-filling to the surface. Provided suitable moulds, reinforcing, cement and building materials are available, the construction of well rings is a relatively simple undertaking by a group or community as indicated in figure 8.4.

Figure 8.4: False-well mould and rings



Related Technologies

In some situations there is a potential for water abstraction which can be met through the installation of tube-wells in alluvial, non-river channel sand or gravel beds. Due to the probability of a greater degree of compaction of these beds than river channel alluvium, the possibility of driving a well-point to a sufficient depth may not exist. However Dungan (2001) and de-Vries (1999) have both described their approaches to driving wells in such conditions and Maclear (1997) has provided information on jetting wells. Their descriptions indicate the similarity with well-point sandabstraction systems and thus the potential for community involvement in the installation and management of the techniques in sand or gravel beds. Other allied possibilities also exist for community improvisation and development of sand-abstraction related technology through the manufacture of well-rings and the construction of an infiltration well in alluvial saturated sediment. Such a well might either be fed directly from seepage from a river channel or from a dam basin. Where flow is likely to be excessively low, a further possibility that a community might tap which will improve the transmission of water is the utilisation of a false-well with a trench that has been dug to depth from a vlei or dam basin and back-filled with a coarse grade material rather than an expensive and probably difficult to obtain infiltration pipe.

Systems of Pumping

Community acceptance and uptake of handpump technology is likely to be more difficult than the acknowledgement and appreciation of well-point abstraction technology. Whilst the basic concept of hand pumping is one of simplified construction to ensure low-cost and ease of serviceability and possible improvisation and whilst the various components can be fabricated from a variety of low-cost materials, both assembly and durability pose significant problems.

Pistons and valves can both be made with a combination of hardwood and sections of discarded vehicle inner tube. However:

- Accuracy is required in the cutting and forming of the piston and valve bodies, suitable tools and retaining devices may not be readily available
- Assembly of the components requires threaded rod, nuts and spanners which are also not readily available within an impoverished rural community
- The piston body and seals are subject to excessive wear, particularly during the development of a natural screen in the sediment around the well-point when water with a high proportion of fines is abstracted through the pump.
- Similarly, the pump cylinder, in this instance only the interior surface of a standard uPVC pipe, is also subjected to excessive wear
- Stripping and reassembly of the pump requires understanding and care if the piston of a suction pump is not reassembled to allow a free passage of water through the piston body, the pump simply will not work

For successful and widespread uptake and utilisation of the technology it is imperative that such factors be identified and planned for, and that both appropriate tools and training is provided.

8.2.2. Capacity Building and Training

If new approaches to technology are to be taken up, communities need to be in a state of psychological readiness and will most likely require both suitable technical training and sociological scrutiny. The experience of the Dabane Trust is that dialogue, interactive community discussion as well as practical training, provides a suitable basis for such intervention, (Ntini 2001). The importance of this approach cannot be overestimated, van Walsum (2002) for instance considers that any knowledge and thus any appropriate training will lead to greater self-respect and the respect of others which enables both women and men to improve the quality of decision making which impacts well on the likely success of a project.

In an overview of the prevailing situation in Zimbabwe's rural areas Taylor, Woelk et al., (Undated) ascribes the reluctance of rural communities to assume responsibility for local infrastructure to the degree of authority and control exercised by the State.

He contends that at Independence, countries in Africa have understandably endeavoured to improve the conditions that existed in their rural, marginalised areas. However the efforts that were made have been dictated by a centralised authority and directed at areas that were traditionally the preserves of local custom and control. Such centralised planning serves to weaken local capacity and as most national governments usually seriously overestimate their ability to manage national resources, attempts to modernise and rationalise resource management and to draw communities into larger national and global systems of development have generally not materialised. At the same time this demand on national treasuries has meant that they have become overburdened and unable to deliver the expected services to the communities. This has unfortunately resulted in a largely weakened local capacity and a transfer of resources and power from local authorities to a national elite. Thus, rather than stimulate development, the process has created a dependency on outside interventions and has stifled local initiative.

In a further reference to the need for comprehensive community involvement, Good (1996) draws attention to the fact that 'community consultation' is almost always far too vague, since the term inevitably groups together disparate stakeholder groups such as those both with and without power or influence, livestock owners and non owners of livestock and not the least, men and women. The danger Good says is that the ostensible voice of the community may in fact be only the voice of certain members of the local male elite and that the most beneficial outcomes for the largest number of people may therefore not be achieved. His concern is that powerful families and those with vested interests may seek to appropriate or dominate community meetings and training sessions for their own convenience. Thus a particular sensitivity must be demonstrated if indeed all the necessary support is to be educed from the entire community. As a reminder of the need for popular participation in all aspects of planning Rizvi (2003) reports on the failure of a series of water development projects in the Punjab because of a continuance of top down planning amid, as he puts it, 'much hullabaloo around the need for a decentralisation of power and bottom up planning'.

Local Skills, Infrastructure and Responsibility

Some recognition of the local skills and the infrastructure that is available and from which a water development initiative can be built is thus required. Local leadership capacity building including practical skills training programmes should enhance the concept of responsibility and ownership. Whyte and Burton (1977) is at pains to recommend an evaluation of the perceptions and the needs of a community and households and to encourage any effort towards assisting the community to understand the dynamics of water supply for the provision of sustenance, livelihood and income. From the inception of a water source development project the community should thus be developing systems of infrastructure and management to ensure optimum and sustainable use of the water supply and the new technology. The establishment and acceptance of widespread and popularly supported management systems will help to ensure accord in the allocation and distribution of water, the payment of dues, the handling of disputes and the provision of co-opted but willing labour to deal with breakdowns. Systems of management designed at the village level should encourage understanding and flexibility and should be used to promote the development of components of management that can be selected and combined to provide the choice and introduction of a suitable technology and a management system that is fitted to individual communities or groups of communities.

Munyira and Nhunhama (1998) focuses on the need for community mobilisation which he says should provide communities with the necessary education, managerial and technical skills that will empower them to be able to plan, implement, manage, operate and maintain their water supply systems. In addition the mobilisation strategy should particularly convey the concept of community ownership of projects and enhance participatory approaches. Ockelford (1996) indicates that it should be particularly borne in mind with any mobilisation strategy that women are not merely a water interest group, but are the users, managers and providers of domestic water for the family and are responsible for domestic hygiene thus they should not just be consulted but should be fully involved in the complete conceptualisation, planning and design of a water supply.

Referring to the decentralised three-tier water source maintenance programme adopted within Zimbabwe, Mpamhanga (1997) states that the programme is required to have a well defined social mobilisation structure in place from community to national level. He does however add that a limitation to community mobilisation is ensuring community empowerment, management, ownership and sustainability rather than a mere concept of community participation and involvement. He continues by unambiguously stating that currently communities do not perceive constructed water and sanitation facilities as theirs but link them to the financiers which has led to problems of operation and maintenance as the communities then expect the financiers to take care of the facilities.

Community Operation, Maintenance and Management

Sutton and Sutton (1990) makes the point that the primary objective of a rural water supply is to provide a source of water that is reliable, adequate in yield and acceptable in quality and site to consumers. She then refers to Narayan-Parker who states that consumers are increasingly required to play a part in maintaining the water supplies that they use, particularly where central governments do not themselves have the infrastructure or finance to bear the responsibility. Where the source fails in any one or more of these attributes the consumer soon becomes disillusioned and efforts by the community to maintain or improve the supply soon decrease and the benefits of a new supply or technology are likely to be lost. Sutton considers that there may even be a negative effect if health problems are exacerbated due to a return to traditional, contaminated sources after a period of access to safe water. To compound this loss of interest Sutton has also noted a resistance to continuing to pay for repair and maintenance costs where supplies repeatedly break down, particularly where an alternate source is available within 1 - 1.5 kms of a home.

In a further reference to maintenance, Sutton (1999(c)) contends that there is more attention given to equipment and infrastructure to which a community can relate, than to a lifting device for which the community have little comprehension. She is of the opinion that communities are quite prepared to raise funds for new buckets or chains and to attend to the maintenance of the well head and surrounds and to organise rotas for women to clean around the well which they can largely do for themselves, but not to pay someone to purchase pumps parts or to repair a pump. The reason that she provides, is that technical education is usually carried out as a fixed programme designed without reference to the problems encountered or identified by the communities themselves, which contrasts to management training when communities are often encouraged to identify problems and to think up solutions relevant to their social structure and environment.
With particular reference to Village Level Operation and Management, de Melo (2000) picks up on the VLOM concept which she says was encompassed because of a realisation that expensive equipment was frequently inoperative, perhaps simply for the want of a cheap seal. To this end the World Bank promoted the development of appropriate handpump technology with the intention of utilising localised maintenance solutions. A policy of pump standardisation was also introduced in many countries in an attempt to improve the availability of spares, with maintenance undertaken by consumers. de Melo also states that the reliability of a pump is not only measured by the number of times it breaks down but also by the time that it takes to effect repairs and as the availability of spares helps to reduce the down-time of a handpump this directly impacts on the reliability of the pump. Ockelford (1996) reports that the VLOM concept has now evolved to form the basis of most water and sanitation projects. Although the focus is at the village level, for it to operate successfully a national or regional framework is required. Thus, Okelford points out that implementing agencies need to define their involvement and to determine exactly what, and how much can be achieved at the VLOM level.

Local input and the development of an innovative, user-oriented approach to rural water supply can best be achieved by providing encouragement and practical support to communities to conduct suitable research, experimentation and evaluation during the planning of a water development programme. At the same time we should be wary of the delivery of a soc-fix approach to parallel the tech-fix one. User choice must allow for the rejection of externally promoted choices.

The National Coordinating Committee (2000) states that decentralisation has been adopted as official Zimbabwean Government policy in rural development. As a result the role of Central Government has changed from that of being a provider of infrastructural development to a more streamlined role of facilitating the process of development of community initiatives and priorities. This has lead to devolution of both responsibilities and authority to the lowest community based VIDCO level, (Village Development Committee).

8.3. Technology Transfer

The shortcoming with many water development projects is that they do not become embedded in the everyday life of the community but are simply exploited as long as they remain operational and are left to moulder when they break-down. Thus a popular transfer of technology from research and development to ownership and utilisation is imperative. With this in mind, within the research programme and before any installation was undertaken and before communities were involved in field testing equipment, they were challenged to develop water use and equipment operation and maintenance systems.

However it is also appreciated that there is nothing like experience gained first hand and thus whilst discussions continue at a community level some four installations have so far been undertaken at each research site. These installations have been undertaken by participants in the research programme together with interested members of the community. Research personnel have offered advice on the development of improved water abstraction systems and the members of the community who have involved themselves have been free to query the technology.

The installations have evinced much interest and a lot of participation from at least male members of the community particularly where there is severe water shortage and

where it is not easy for people to regularly provide water for livestock. However whilst it might be disappointing not to have a significant involvement of women in the development of the technology, it must be appreciated that the initial requests for improved water supplies emanated from male members of the community who wished to ease their livestock watering system and as has already been indicated men are likely to revel in any new technology. The reality is also that whilst women might be involved in the management of a water point, it is unfortunately men who control the technology so that realistically women remain pragmatic, making use of any opportunity when it is available, but moving to another when it is not. Divisions and utilisation of equipment by gender will only be dispensed with following a mind-set change and a thorough appreciation of the technology to the entire community.

Within this limitation, so far there has been appreciable use made of the well-points and handpumps that have been installed. Disappointment has been expressed by members of the community when the technology has not been available, as for instance when well-points were removed due to clogging. Interest and a willingness to keep the equipment operational has been demonstrated. Questions have been asked on the technology and interest shown in the opportunity for personal, unremunerated involvement to maintain the equipment. It is encouraging to note that discussion during the installations have indicated an attitude of, *this is great, I now have more water for my cattle*, but also one of, *how does it work and how can I fix it*?

8.4. Promotion of the Technology

During the research period systems have been developed that will abstract water from sand rivers without constructing deep, insecure sand-wells. The systems are simple and basic and technically functional but will only be acceptable and operational as long as people have recognised their water sources as being inadequate in either quantity or quality and wish to work together to better the supply. If people are prepared to confront the problem together, improvements will ensue, provided:

- People feel that the new technology will be advantageous
- There will be value for money the advantages gained will, in the community valuation, outweigh the costs that will be incurred.
- People accept the technology and 'make it their own' the level of technology and understanding will encourage people to feel free to operate install and maintain and hopefully ultimately to manufacture the technology themselves. The acceptance of ownership and responsibility for operation and maintenance is imperative, the equipment must be seen as an asset of, and belong to the community and not to an implementing agency.
- There is sociological agreement within the community on the operation and management of the technology consensus must be reached within the community, either through independent meetings called by community leaders or through meetings orchestrated by an implementing agency. Issues to be resolved are the:
 - o use of the water
 - o volume of water to be abstracted by a particular family
 - custodianship of equipment, technical operation and maintenance, who may and who may not operate and attend to the pump and equipment.
- There is a technical capacity within the community to maintain and repair the equipment, either through inherent skills or specific skills training

A number of implementation strategies are required to facilitate the introduction of the technology and the sociology that is required to ensure the successful installation and acceptance of improved sources of water. An assessment of the potential of sandabstraction to provide sustainable improved supplies of water is required, initiatives to this end include an evaluation of the technology through extensive dialogue with both consumers and implementers, as well as publicity to promote and disseminate information on the technology. To this end initiatives have been made to focus attention on sand-abstraction through documentation, colloquy, assessment and training.

Field Manual

A most useful promotional tool will be the development of a comprehensive field manual which will provide information on the potential for sand-abstraction and the technology and equipment that is available. A simple how-to-do-it manual produced in straightforward easily understood terms, a basic fabrication and installation manual which includes the sociological aspects which should be anticipated is more than likely to be of considerable benefit as an explanatory and promotional tool to both the professional water fraternity and practical, hands-on NGO personnel.

The launch of a technical and promotional manual would be best undertaken in conjunction with a practical peer review of successful sand-abstraction installations within Zimbabwe. Such a forum involving practical site visits would provide a useful insight into the implication and operations of sand-abstraction and could also act as an interesting launch for a sand-abstraction field manual.

Peer Review - Seminar

Plans are in hand to hold an international conference in Zimbabwe to generate awareness of the potential and the suitability of the water resource potential of sandabstraction. Discussion and working groups will review opportunities and traditional practices and report on the status of sand-abstraction within their own countries. It is intended that a presentation will be made of the technical and the sociological intervention that Dabane Trust utilises in its sand-abstraction programme and visits will be made to a number of productive gardens to meet with community groups to learn first hand of the impression that end users have of the sand-abstraction technology. A critical analysis of the technology will then made by the conference participants who will also provide an overview of the possibility and suitability of the new technology within their own countries.

It is anticipated that some 30 to 36 people will be invited to attend the conference. Donor and partner organisations will be invited to send participants from organisations with which they have contact and which they consider might benefit from exposure to the technology. It is also hoped that professional water engineers from the academic and commercial field will also participate. Plans are that whilst the main language will be English, facilities will also be provided for members of organisations from Francophone and if there is sufficient interest, from Lusophone countries to also attend.

Participants will consider the potential and the appropriateness of sand-abstraction and engage in issues such as:

- Group development and community meeting dynamics
- Fabrication of suitable abstraction equipment

- Sand-abstraction site identification
- Installation of equipment and construction of infrastructure
- Pump and equipment operation and maintenance
- Water resource utilisation

During this seminar an inventory will be compiled of organisations that are interested in exploring the possibility of sand-abstraction water source development. The intention will then be to undertake visits to the organisations that appear to be the more promising.

A sequence of events intended to both assess and promote sand-abstraction as a basis for a community based water source development programme might well comprise:

• Identification

Identification of country areas and regions where it is likely that sandabstraction will have a useful potential. This process is already part of an ongoing exercise

- Identification will be undertaken by personal contact, desk studies and web site reviews
- Organisation Inventory

Development of an inventory of donor agencies, NGOs, PVO's and Grass Roots Organisations working within areas where there is the likelihood of a good potential for sand-abstraction.

- Achieved primarily by personal contact and through contact and subsequent recommendations from so-called First World partner organisations who might be supporting organisations working in suitable sand-abstraction areas
- Colloquium

A colloquium of interested organisations and professionals will review the Dabane Trust sand-abstraction technology and group support strategies

- Participants will review the Dabane Trust methodology technology and sociology and provide feed-back to a wide forum of interested organisations which will be further developed during the colloquium
- Interested organisations will be invited to indicate the suitability of the development strategy to their own circumstances and working environment
- Visits

A schedule of visits will be made to organisations that express an interest in participating in a sand-abstraction programme. Due to cost and personnel constraints this undertaking may well be carried out in collaboration with other NGOs and donor/partner organisations

- Visits will be made to organisations by people with experience in group development and small-scale sand-abstraction technology to assess the suitability of the organisation and its operational area for participation in a sand-abstraction development programme.
- As it is the experience of Dabane Trust that the introduction of suitable technology is not the sole basis of a development programme, a particular effort will be made to identify organisations which engage in development initiatives with strong community development and capacity building methodologies

• In-service Training

Organisations that maintain an interest and appear to have both the interest and the capacity to successfully entertain a sand-abstraction development programme will be invited to send two or three of their personnel for inservice training for some three months to work practically with Dabane Trust staff to gain experience of the implementation of a sand-abstraction programme

- Programme development Staff of participating organisations will return to their own organisations to implement their own sand-abstraction programme
- Adaptation of technology As the technology is primarily based on a small-scale, low cost, user friendly technology aimed at a very high degree of local independence and sustainability, the very simple handpump technology may be used to develop other appropriate water sources.

Institutional Support – Sustainable Water Extraction Technology Trust (WETT)

A number of charities and donor organisations have provided considerable financial and logistical support to the sand-abstraction research programme that has been undertaken by the author and Dabane Trust since 1998. Several foundations and institutions have expressed a wish to see a greater utilisation of the technology developed during the research programme and of that employed by Dabane Trust. The Trust acknowledges that it has developed a successful a niche role in the development of sand-abstraction water supplies within western and southern Zimbabwe and that it is well set-up and well equipped to undertake both technical and sociological intervention. However it is also quite aware that it would not be possible for the Trust to step outside this function and to extend its involvement beyond its present sphere of influence.

The possibility thus exists for other institutional involvement and to this end the author has been instrumental in setting-up a British registered charity, the Sustainable Water Extraction Technology Trust (WETT), registration number 1087667. The trustees of this charity have between them extensive knowledge of effective low-level technology pumping devices, project development and monitoring, the development of effective training packages and strategies, academic research programmes, publicity and institutional development. The charity is intending to compile an inventory of organisations interested in participating in an extensive sand-abstraction development programme in at least suitable regions of Africa. It is intended that WETT will be able to act as a conduit and financing organisations.

Dabane Trust has expressed a wish to offer training to NGO field workers from interested organisations. By working alongside Dabane Trust staff and engaging in both the sociological and the technological aspects of sand-abstraction development it is hoped that staff of other organisations in Africa will be able to relate the technology to their own situations and to assist rural communities in their own countries to develop appropriate water abstraction systems.

Interest Sharing Network Group - Amanzi

Interest and goodwill in the development of sustainable water supplies is surprisingly widespread internationally. A group of interested people in Malvern in the United Kingdom used their local newspaper to draw attention to poor water supplies in the Matshetshe area of Gwanda District, Zimbabwe and as a result were able to assist four communities to construct weirs to improve their water supplies. According to (Tomlinson 1991) the Malvern community was kept informed of activities of the Matshetshe communities through the newspaper.

Particularly with the introduction of the internet the possibility certainly exists for a more personalised involvement of people in the 'technically developed world' with those involved in water development projects in the 'technically developing world'. Although many online interest groups already exist, the Amanzi Project as it was called, (based on the isiNdebele word for water), focussed on the needs of a specific group of people and was able to establish an interest and to build up a link between the two communities. The possibility of using such an innovation to generate an interest in sand-abstraction, community links and so-called developing world issues will be explored.

Advertising

Various tee-shirts, golf shirts, caps, bandanas and wraps that depict sand-abstraction have been designed and sold within Zimbabwe.

8.5. Acceptability by End Users

The principle of sand-abstraction is recognised through widespread use of traditional scoop-wells and has been proved to be feasible through the few commercial applications which draw water for irrigation, ranching and domestic water supply. Although the technology has been proven to be effective, to be utilised and acceptable it must also be sustainable as an everyday working technology.

The introduction of any developed technology is a welcome addition to impoverished areas that are largely bereft of any technological development. There is a likelihood that many people from disadvantaged areas will consider that the acquisition of any technology will be of advantage to the locality and will be likely to provide benefits and possibly increased wealth. Men in particular appear quite prepared to experiment with new technology, without necessarily relating the technology to any form of continuity or sustainability, even to the extent of indiscriminate use of the technology and of water. Women as the main providers, draw and use water more rationally and appear more prepared to work with the technology, to understand it and to keep it operational. Whereas many men are quite prepared to utilise any technology as and when it is available, women will approach the technology with a more positive attitude towards making it work. In general terms, women will make every effort to sort out the use and sociology aspects related to water and, provided the technology is acceptable, will doggedly persevere at mastering it. Women will more readily espouse a process of accepting and establishing a successful technological intervention. The introduction and acceptability of new technology is a process where initial, immediate interest has to be transferred to acceptance and acceptance to commitment by all members of a community.

In an internal report prepared for the Dabane Trust by Dube (2003), she states that initial indications are that the people who have had access to the new sand-abstraction

technology have appreciated the equipment. Participants at a workshop held in the Victoria Falls made statements to the effect that appreciable time was saved by using the new well-point and pump technology. The pump technology enabled people to fill a typical 20 litre container faster than from a scoop-well and further, that pumps obviated the tedious and time consuming task of digging and maintaining a scoop-well. There was a further advantage in the quality of water which was cleaner than that drawn from a scoop-well. The level of technology was also considered suitable as people stated that they felt prepared to undertake maintenance and repairs to the equipment themselves, provided they receive appropriate training. A level of technology where no specialist tools were required was also appreciated. The initial cost and cost of service/maintenance was identified as a crucial factor, whilst people stated that they would prefer a solid and durable 'steel' pump, they nevertheless accepted a pump which was comprised of cheaper materials and spares, even though they acknowledged that service, maintenance and repair intervals would more than likely be more frequent. Fraenkel (1997) also acknowledges the preference of many farmers to purchase cheaper systems with higher running costs, even though they may result in inefficient and sometimes uneconomic systems.

In all probability the actual uptake and success of the technology will be dependent on the situation associated with the water supply. Trials are initially conducted in the vicinities of the four field research sites at Dongamuzi, Huwana, Tshelanyemba and Wenlock. Although requests have been made for more pumps and for pumps which can be permanently installed, early indications are that there is appreciably more interest and capacity shown within the communities of Dongamuzi and Huwana where water is considerably more transient being deep within the river sediment and generally in short supply, than at Wenlock and Tshelanyemba where water is more available and much easier to access.

A report of the acceptability and the local capacity of rural communities to operate and maintain abstraction equipment has been prepared by Ntini, Ndlovu et al.,(2002) in conjunction with staff members of the Dabane Trust and the eight field research assistants. The survey set out to establish how much control the communities' felt that they exercised over their water supply systems and reviewed the tools and equipment together with the skills required to operate and maintain various water supply systems. The general response was that communities considered that they were not, and should not have to be responsible for the upkeep of pump equipment and that maintenance and repair services at a local level were in the main inadequate. Typical sentiments were that:

- Centralised maintenance/repair systems had been effective, that communities were generally satisfied with that service, there was little that had been wrong with the system and therefore there was no need for change
- Communities felt that they did not own the infrastructure and therefore they should not be responsible for maintenance and repair
- There was a stated preparedness to pay for services provided there was an efficient delivery. When challenged with the obvious reluctance shown by people to pay for services, it was made clear that as they did not see regular maintenance being undertaken they were therefore not prepared to pay. Many respondents stated that they would be prepared to pay, in cash or kind, for the repair of breakdowns if this was undertaken with expediency
- Localised maintenance/repair services and facilities were unable to cope as they were poorly equipped and poorly supplied

• Although the use of readily available and make-shift materials were a definite advantage, the durability of pump and abstraction equipment should not be compromised. In the light of the above points, the issue of long-wearing and costly, against frequent replacement and cheap short term repairs remained unresolved.

Such issues will only begin to be resolved following continuing trials and dialogue with and between communities that will lead to experience and increasing competence as well as a more apparent preparedness to pay, probably following an overall increase in the disposable income of a community. Such sentiments need to be put to a practical test to establish which, or even whether or not, either level of technology will be maintained. Unfortunately the 'durable' option may be a symptom of the 'dependency syndrome' and only ascribed in the hope that outside intervention will continue to provide maintenance for the equipment rather than any readiness to expended cash and undertake maintenance and repairs for oneself.

Although the collection of field data has ceased, meetings continue with the four communities that reside in the proximity of the research sites. These meetings are held in order to gauge community acceptance of the well-point and pump technology and the possibility of continuing to work with the field research assistants to monitor pump performance, initiatives by the communities to undertake maintenance and repair and the community perception of the pumps is under consideration.

8.6. Acceptability by the Water Fraternity

Although there is an extensive range of equipment suitable for sand-abstraction use it is probable that the technology is under utilised and is considered more an innovation with a dubious potential than a serious, main stream water supply option. In view of the considerable development of borehole screen technology and the extensive range of self-jetting well-points which is available, this does seem surprising. Tube-well screen technology is utilised extensively in parts of Pakistan, Northern India and Bangladesh and although there is considerable use made of Ranney cum collector wells throughout the American mid-west and parts of Europe and Asia as well as significant use of de-watering well-points to control water levels along the Dutch coastline and Berlin, (Senate Department of Urban Development 2003), there are few effective water abstraction programmes that utilise sand-abstraction per se.

Dungan (2003) operates a help line web site where queries relating to the use and installation of well-points are posted. However the calibre of question gives the impression of some kind of bizarre water abstraction option for use by the fringe community. Other obscure references come from an American Army web site, (U.S. Army 2003) which maintains that at the turn of the century the U.S. Army developed a fast and effective method of providing bivouacking troops on the move with water. The system did not involve a lot of expensive and cumbersome equipment as *soldiers simply drove a pipe into the ground with a sledgehammer until the aquifer was reached*. Dungan (2003) states much the same and continues that well-point technology has subsequently been proven to be ideal for supplying water to homesteads, second homes and to remote villages in developing nations. Although a number of well-screen manufacturing companies advertise extensively, the general impression is that sand-abstraction is only used by a-typical enthusiasts.

Well and borehole technology appears to have been unequivocally embraced by the water community to provide all solutions to groundwater supply even if this be

alongside a river suitable for sand-abstraction. Combrink (1988) stated that as he was adept at drilling boreholes he found it easier to abandon a well-point system in the Shangani River at Gwayi River, Zimbabwe and to drill and gravel-pack boreholes in alluvial, collapsing sands alongside the river. Hussey (2000) indicates that there is a domination of borehole technology to provide solutions to groundwater abstraction. A one-off option that can be used to draw water from depths of 30 to 300 metres in almost any situation appears to appeal to planners and engineers alike, regardless of the technology or sustainability of the water abstraction system then required.

Some specialist use has been made of sand-abstraction but unfortunately this has not proved to be a good legacy as commercial schemes appear to have been frequently overused with subsequent disastrous consequences to the source. Nottingham Estate in the Beitbridge District of Zimbabwe for instance pumped water from the sediment of the Limpopo River round the clock for eighteen months, abstracting so much water that according to the co-owner, Ambler-Smith (1999) a salts build up was precipitated to such a degree that the site had to be abandoned. In a further instance of over abstraction, the townspeople of Swartkopmund, Namibia over abstracted water from the sand of the Swartkop River with similar results and have consequently had to resort to de-salination of seawater, (Heyns 1999). Certainly overuse up-stream in the catchment is more than likely to causes dryland rivers to significantly dry up so that users downstream, such as the town of Swartkopmund do not receive sufficient for their needs. The prime example of this is the Rio Grande where water no longer reaches its mouth in Mexico because of the overuse of Los Angeles and southern California.

Whilst such situations continue there is little likelihood that sustainable use patterns will be developed by the international water fraternity. Such overuse consequently causes a loss of the entire water reserve. The technology has proved to be adequate but non-sustainable use has lead to the collapse and abandonment of the technology, which has in turn given sand-abstraction a bad name, so that it is no longer considered a viable community water supply option. Until these perceptions change and sustainable abstraction programmes are devised and adhered to it is probable that the potential for sand-abstraction will not be realised.

8.7. Conclusion

Rural communities have indicated that often the perception of planners and engineers are not necessarily their own perceptions. The rural people with whom the research programme has had contact have shown that for an introduced technology to be successful, technologists must be more aware of the concepts and values that they experience. People concerned have indicated that unless they are fully involved in the development process little is likely to be achieved, particularly where involvement is limited simply to technology selection and decision making, or worse just to the provision of installation labour. Through on-going discussion and observation it is also clear that unless and until people are prepared to take complete responsibility for the technology and are prepared to set up abstraction and management systems themselves, for themselves, sustainable abstraction technology is unlikely to be achieved.

Existing management and concomitant discussions undertaken by various communities have shown that the adoption of a recommended or introduced technology to improve a water supply is dependent on the acceptance of both a satisfactory technological solution and the development of an acceptable sociological solution; between the two

there is an inextricable link. Interested individuals in informal discussion have stated that they consider that a technical solution can best be developed by an agency in collaboration with community members and requires acceptance and feed-back from the community and although an agency or NGO is able to focus attention on issues of management, the sociological aspect regulating the use and the controls of the technology can only be developed within the community.

Through meetings and discussion, several factors have been identified as crucial to the ultimate success of a technological intervention. Prime consideration was given to cost with people stating that unless the technology is considered cost effective, it is unlikely that it will be maintained in the long-term. People have stated that to be acceptable they need to be convinced that the advantages of a new technology or solution will considerably outweigh the expenditure that they will inevitably incur. A sociological dynamic that was identified and manifests itself particularly within many disadvantaged communities is jealousy, referred to variously as envy, covetousness, resentment, protectiveness, suspicion and distrust. However the consensus is that local society has to overcome such disagreement and constraints if the technology is to be used and acceptable. Divided communities in particular thus have to learn to get along and to work together for the common good, which in many instances may be easier said than done. Without complete acceptance by the entire community some members act either overtly or covertly against new concepts and technology. Recognition of the existing local authority or controlling interests of a water source has also been acknowledged as of importance as without the acceptance of those prominently involved there may be little opportunity for either an increase or an improvement to water source technology. A contentious issue, particularly where there is water shortage has proved to be the possibility that not everyone in the community may have the use of as much water was they might like. Communities are having to grapple with 'best-fit' decisions that will be acceptable to the greater part of the community and will in the main be easily implemented to ensure adequate water and sustainability of the water source.

A further difficult issue is the significance of adequate and regular maintenance to the success of any new technology. Wherever possible people have stated a preference for training to be given to all users of the technology, rather than to a few representatives. In this manner people feel that they are able to support and assist each other with maintenance and repair procedures by analysing the problem and then encouraging each other to tackle it. Such a concept indicates that it is basic level equipment that is required so that people with little technological sophistication are able to relate to equipment, to understand it and to be prepared to strip and repair it, ideally with materials that are available but if necessary through adaptation and innovation. People have requested appropriate technical training and have identified a need for sociological capacity building as key to the acceptance and workability of new technology. The perspective is that a community of people who have the technical knowledge of operation, the skill and tools to maintain abstraction equipment together with the sociological ability to work through individual problems will be likely to achieve the long-term use of equipment.

The perspective of the implication of new technology on society is a crucial factor that requires considerable deliberation by a community. The communities in the research area are seeking solutions to satisfactory management, responsibility and the use and maintenance of equipment. An issue to be resolved is the inherent difficulty that an improved technology might cause through the easier withdrawal and possible over abstraction of water that can only be resolved through open and frank discussion,

technical training, personal capacity building and effective leadership. Community members are expecting their leaders to provide leadership, rather than hindrance, towards a satisfactory resolution of the issues that surround the introduction of new technology and management in order to make the technology acceptable and sustainable.

Personal Experience (2)

Installing a pump and engine beside a dam near Mtshabezi, Gwanda District, Zimbabwe, two school boys come to see what is going on, peering through the doorway they point and whisper trying to figure out the installation and pipework. A local man assisting with the installation snaps at the boys, "get away from here you boys, this is men's work". The boys leave disconsolately, little the wiser.

To facilitate community decision-making and awareness building, community meetings have been encouraged at each field site throughout the research period. At these meetings, some of which research personnel have been free to attend and some to which they have not, traditional work and management roles have been explored together with discussion around issues and values that could be broadly understood as indigenous knowledge. At these meetings community perceptions have been explored, particularly those associated with the management of existing water supplies. Issues such as the need for ultimate local responsibility for the technology have also been discussed as all too often individuals and even communities accept new technology or technical improvement as impermanent. Discussion has been provoked around issues such as the typical short-term use to which equipment is sometimes subjected, used only whilst it is available as ownership and responsibility for equipment are seldom understood or accepted. Efforts have been made within the research programme to point out the fallacy of this attitude and to indicate an alternative where communities become fully responsible for the technology. Discussions have attempted to establish the fact that abandoning a technical solution until the next one comes along is not necessarily the best solution nor is such a solution likely to perpetuate.

Feedback from interaction with communities is that there is a preference for sandabstraction water, particularly where a convenient choice can be made. The principle of well-point abstraction and simple hand pumps has largely been accepted as technologically suitable, fixable and sustainable. Suggestions have been received from individuals and the options are being explored together. Issues for deliberation are the implication of expending more on the pumps to make them more durable but then evaluating the extra costs which will be incurred in more expensive construction, installation, maintenance and repair costs. Whilst still working through these concepts indications are that there can and will be a successful technology transfer that will be acceptable through installation and field testing with feedback from communities. Perceptions are that the technology will be acceptable, workable and sustainable as long as adequate capacity building and VLOM training is undertaken.

Chapter 9

Achievements

9. Achievements of the Study

A study was conducted with the principle intention of assessing the possibility and the suitability of sand rivers to provide clean water in useable quantities to disadvantaged rural communities. The concept was one of assessing the potential reserve of water and if appropriate to develop a simple, basic technology that might be used to abstract water. The hope was that research would provide sufficient data and incentive for work to proceed on the development of an abstraction technology that would be acceptable, sustainably and affordably, and at a level which would be easily maintained and cheap enough for impoverished communities to be prepared to commit funds. The idea was that the technology should use, basic, low cost, readily available equipment that required few tools and no specialist tools and at the same time be simple enough for people to embrace and to operate the technology themselves at the community or household level.

Significant data was in fact acquired both from a study of sand rivers and from the development of equipment that was used in the rivers and to abstract water from river alluvium. However, as field trails commenced with simple, practical equipment, of particular significance was the reminder that technology is not the sole factor limiting reliable abstraction systems. Indications were that sociological factors relating to the wider community must also be understood and potentially contentious issues resolved in order for technology to be accepted and successful. Without attention to factors such as ownership and responsibility for a technological intervention, maintenance and repair will not be undertaken and the technology will not be useable, effective or acceptable and certainly not sustainable in the long term.

Crucial to a successful intervention was the realisation of the need to involve all key players and to ensure that sociological as well as technical requirements and shortcomings are answered. Access to the technology, training in maintenance and the use of water are further factors that must be faced and resolved before success can be assured. When everything, and only everything, is in place can a technology be expected to work. A not insignificant achievement has thus been the considerable insight that has been gained into the idiosyncrasies of the four rural communities with which the author was privileged to have an interaction. Whilst significant data has been gathered on dryland rivers and the resource of water available, the study has also demonstrated the incontrovertible link of river, technology and people.

9.1. Analysis of Field Research

9.1.1. Suitability and Success of Research Sites

Through the research programme experiments were conducted in four sand rivers in western and southern Zimbabwe in localities with differing topographical and

hydrogeological conditions. Water supply conditions within the sand rivers vary from extreme and perpetual water shortage, where the communities have to make regular adjustments and controls over water use, to conditions where water is relatively plentiful. Differences also exist both between and within the sociological composition of the communities that live in the vicinity of each of the research sites. Although each site was encompassed within a sand river, significant variations were evident, as indicated in table 9.1 with the rivers and the sites particularly chosen for these differences.

Equipment was placed at each site to provide data that would lead to a more accurate understanding of the general evolution and particularly the characteristics of flow and the potential for water storage of sand rivers. Two local residents within the vicinity of each of the four sites were contracted to monitor the equipment, to gather data and equally importantly, to provide feedback to their communities on the progress of the research and data collection. Although the equipment and subsequent data collection were essentially devised to gather information that could be used beneficially to develop appropriate low-cost equipment at a level of low-technology, the researchers were also able to benefit directly from the data that they gathered.

Criteria	Dongamuzi	Huwana	Tshelanyemba	Wenlock
Type of River	Meandering sand	Braided sand river	Plateau sand river	Watershed sand
	river – small,	– moderate, width	– wide, width	river – moderate,
	width 15m	61m	132m	width 33m
Catchment	58 km²	2,300 km ²	1,500 km ²	320 km ²
Area	Forest &	Flat, dry, few	Mixed Commercial	National Park &
	Communal land	contributory stream	& Communal land	Communal land
Flow of River	Intermittent	Intermittent	Intermittent	Intermittent
Rainfall – 18	620 mm	533 mm	450 mm	428 mm
year av.				
Regional	Kalahari sand &	Kalahari sands,	Older gneiss	Granite, gneiss
Geology	mudstone	gneiss, alluvial		
		deposits		
Other Water	None. Poor dam	Reasonable.	Reasonable.	Poor.
Options	potential.	Deep boreholes	Low yielding	Low yielding
	Contaminated		boreholes in rock	boreholes
	boreholes			
Riverbed	Mudrock	Clay	Rock & Clay	Rock
Sediment	Fine æolian	Coarse	Coarse gneiss	Coarse granite
	Kalahari sand	granite/gneiss		
Depth of	1 - 2 m	2 - 3 m	1.5 - 2.5 m	1.5 – 3 m
Sediment				
River Environ:	Mopane, Acacia,	Acacia,	Mopane scrub,	Tree savanna,
- Vegetation	Combretum	Softwoods,	Terminalia,	Combretum scrub,
		Combretum	Combretum	Acacia
Community	Cropping	Livestock	Livestock	Tourism
Livelihood	Livestock	Cropping	Cropping	Cropping
				Livestock
Commitment	High because of	Good because of	Moderate – poor	Low – divided
of Community	water shortage	water shortage	leadership	community
Use of Water	Domestic	Domestic	Livestock	Gardens
		Gardens	Gardens	Livestock
		Livestock		

Table 9.1 Tabulated overview of conditions pertinent to the four research sites.

Whilst quite aware of general seasonal climatic variance the researchers were able to discern a direct link and application for the information they gathered. Through the daily readings and interpretation of data the research assistants were able to assist the community to learn more about their local environment. The rainfall readings taken from the rain gauges provided an accurate record of when most rain fell, the total amount and the intensity of rainfall. The evaporation pans provided an understanding of the relationship between the hottest months and the farming calendar and thus a better appreciation of when to plant dry-land crops was evident. Through the research activities the community was better able to appreciate the likely effect of planting in a specific month and the possible effect of the weather on the various stages of crop development.

A further advantage to many people in the various communities was a greater understanding of the effect of inadequate and drought rainfall years. Through the variance in the deterioration of water levels in the river sediment, communities were able to develop a more accurate perception of the volume of the water reserve. With that information the communities, particularly in the disadvantaged areas of Dongamuzi and Huwana, were better able to make adjustments to their water demand.

9.1.2. Suitability and Success of Data Collection

The selection of the conditions and location of the sites proved to be appropriate as a useful and suitable range of data became available. Annual climatic conditions were also fortuitously advantageous as over the four years of collection, data was gathered in two seasons of poor to moderate rainfall and two seasons of fairly good to high rainfall. During 2000, mid-way through the research period, extreme cyclonic conditions conducive to prolonged periods of heavy precipitation prevailed throughout the entire research area. Thus a wide overall range of conditions was experienced during the data collection period.

Data was collected throughout a four-year period from 1999 to 2003. The sites were set up during an approximate twelve-month period with each piece of equipment devised, designed, fabricated, installed and tested in turn. Thus the first year was much of a learning period both in the testing of the equipment and the training of the field research assistants. Once the field assistants understood the whys and the wherefores of what was required they achieved a most satisfactory level of input. Overall research activities were completed with few changes of personnel; there was a regular collection of data which appeared to be reliable, although unfortunately a batch from one site was inadvertently lost.

Regular visits were made to check on the sites and on the research assistants to verify their readings of gauges and equipment. Initially site readings were restricted to total water loss from the sediment through water level readings with the piezometer tubes. The readings taken by the field research assistants were checked whenever site visits were made and also by comparative readings taken with a dumpy level to water levels in trial pits.

Although it took most of a year to complete site set up and for the assistants to settle in and fully understand what was required, this in fact proved to be a useful training period. The research assistants also attended ongoing training and experience-sharing workshops throughout the five years, which provided the opportunity for check ups and updates. A total of five workshops were held with the field personnel which provided an opportunity for visits of the full complement of research assistants to each site with a final cumulating workshop held in Victoria Falls where the field assistants from dry, interior areas had their first sight of a perennial river and enjoyed a number of the tourist spectacles.

The research assistants devised management and data collection schedules for their convenience. Although individual approaches and idiosyncrasies emerged these were each dealt with and ultimately a balanced methodology was achieved and each assistant proved to be capable and competent. The two assistants at Wenlock seemed completely disinterested but won an informal competition devised to test their knowledge of the required research and when reviewing their data it became apparent that they had just quietly been going about their work. An old lady at Huwana who had demanded to be included in the data collection and caused some worry with regard to her ability to take measurements sent her granddaughters who were in their GCE 'O' level year at school to take measurements and consequently produced regular, accurate readings. A summary of the purpose, the equipment or method employed and the frequency of data collection is provided in table 9.2.

Research Undertaken	Method of Data Collection	Frequency	Suitability
Total water loss from sediment	Piezometer tubes & water level dippers	Weekly	Appropriate
Rainfall	Rain gauge	Daily	Appropriate
Evaporation (2 sites)	Standard Evaporation pan	Daily	Appropriate
Velocity of water through sediment	Water surface slope decay, Dilution tests	Weekly readings × 4 in one season	Appropriate
Flood crest flow level	Height of flow gauge – calibrated chalked measure	Daily during river flow	Accurate readings, Gauge vulnerable to flood damage
Depth of flow in sediment	Chain secured in river sediment	One reading at end of season	Poor, limited data
Sediment accretion/degradation	Same spot dumpy level readings	One reading at end of rainy season	Appropriate

Table 9.2: Research activities undertaken by field research assistants,

9.1.3. Suitability and Success of Equipment

The data recording equipment used at each site was designed and fabricated within the research programme. This was done partly because suitable equipment was not readily available to purchase or to hire, but primarily because it was considered that manufacture would provide a better understanding and 'feel' for the equipment and be more appropriate for the use of the local research assistants. Some shortcomings and breakdown of equipment was experienced such as with the calliper gauges which were adapted for use on the evaporation pans. Regular damage occurred to the crest level gauges at two sites due to debris carried in the floodwater building up on the gauges sufficient for the gauges to be washed over in the current. Some difficulty was also experienced in early efforts to trace the depth of flow tell-tale chains, however they were eventually found through extensive excavation and five or six location measurements, rather than just two measurements were taken for subsequent installations.

Table 9.3: Summary of equipment and suitability of experiments conducted at research sites.

Test	Equipment used	Successes/Limitations	Corrections	
Field Testing				
Loss of water from	Slotted piezometer	Flow of water downstream	Put in tubes wrapped	
sediment	tubes into sediment to	blocked tubes with fine	in geotextile to	
	measure water level	sediment.	prevent inflow of	
			fines. Electric water	
			level dippers were	
			more successful	
Accretion of sediment	Dumpy level	Successful. Established		
within river channels		level of sediment in river		
		channels is in equilibrium		
Crest flow height - to	Calibrated chalked	Clogged up with debris,	A sloping leading	
establish link between	gauges installed in	sometimes washed away	edge fitted to the	
heights and depths of	tubes set in riverbank	with heavy rains	tubes to allow debris	
flow and safety of well-			to be washed over the	
points and pumps			top of the tubes	
Depth of flow- to see the	Aluminium tubes	Difficult to trace tubes	Used anchored chain	
depth in the sediment at	placed through horizon		instead of tubing	
which water flowed	of sediment			
Rain – daily record of	Rain gauges set up at	Initial inaccurate readings	Training workshops	
rainfall	field workers homes		held	
Evaporation levels –	Evaporation pans set up	Animals drinking and	Covered pans with	
read every day to	at 2 sites only because	birds drowning in pans	netting	
establish water loss	of shortage of water to			
through evaporation	top up pans at other 2			
	sites			
Control Testing				
Sand tank for testing	Concrete tank filled	Good set up, constant flow		
well-points and pumps	with sediment collected	and satisfactory test of		
	from sand river	well-points under different		
		flow rates by changing		
		size of driving or driven		
NT7 11	No. inter Committee inter	Quality dealised		
Well-points – to assess	Variety of well-points	Could not duplicate exact		
suitable types of well-	tested in sand tank.	same conditions for each	1 1	
point for differing river		well-point		
Conditions	Erected coeffeld towns	Mainritz of trating dans in		
Handpumps - to test	Effected scattold lower	field	· · · ·	
yield at 5.5 and om	pumped water from	Inela		
Field Testing	Sanu micu talik	· · · · · · · · · · · · · · · · · · ·	· · · · · · · · · · · · · · · · · · ·	
Well-points - to assess	Well-points being	First well-points blocked	Smaller anertures	
wen-points - to assess	tested at research sites	in field testing Field	were put in and have	
conditions	and further along rivers	testing ongoing	now been made	
conditions	and further along rivers	testing ongoing.	standard	
Handnumns - to assess	Pumps tested in variety	Some numns hard work	Continuing	
suitability durability	of conditions	because of limitations of	observations and	
operation, ease of repair		material and complexity	alterations	
and maintenance		Ongoing field testing		
Sand dams & sub-	Artificially building up	No significant feedback or	· · · · · · · · · · · · · · · · · · ·	
surface dams -to assess	sediment for water	data vet. Testing ongoing		
their suitability for use	storage using gabions			
at less than optimum	sand dams and sub-			
sites	surface dams			

The greatest problem was associated with the piezometer tube readings which suffered a slow ingress of fine sediment. Initially this affected the readings that were taken from a rod dipped into the tube and finally when some of the tubes were so filled with sediment that they maintained a water level higher than the level in the sediment. The inaccuracies incurred with a dipping rod were resolved with an electronic water level dipper and the silt accumulation by installing new tubes wrapped in synthetic geotextile. Table 9.3: Indicates the suitability and success of the equipment and the experiments, together with some of the corrective measures, conducted at the research sites.

9.2. Research Undertaken

9.2.1. Community Involvement

Community meetings were held to discuss local perceptions and indigenous knowledge relating to sand-abstraction systems. A basic component of the research was to recognise people's observation of sand-abstraction systems and the various related positive and negative factors. Discussion with rural communities was undertaken in an air of informality and consideration was given to traditional and seasonal water supplies, the characteristics of local rivers and the general availability of water, suitability and sustainability of water supplies. Opinion on the optimum and desired form of water supply was sought and those to which people were accustomed. Discussions and deductions were documented as a record of historical and background information. They also helped to provide an understanding and give feedback, which was used to identify the water-abstraction systems which people consider are an improvement on existing systems and which are considered to constitute useful, low cost and sustainable water supplies.

System and Methodology:

- The principle of Participatory Rural Appraisal (PRA) based study, as exemplified by Nabasa, Rutwara et al. (1995) was developed to obtain introductory and background information and data relating to community perception on the application and suitability of low-cost sand-abstraction. The intention was to gauge the interest of end-users in sand-abstraction water supplies and if positive to then develop low-cost sustainable systems that could be used to provide safe water and water for small-scale agro/industrial purposes. Through PRA it was expected that community interest and individual perception of possibilities for the development of sand-abstraction technology would be identified.
- Surveys were conducted to assess preferences and the reliability of existing water supplies as well as the suitability of rivers and river sites for traditional sand-wells and the potential for the technical development of equipment suitable for sand-abstraction.
 - During community meetings participants were assisted to provide an appraisal of traditional management systems of sand-abstraction water supplies. The general feeling was that the water from sand-abstraction had a better taste and a better colour than deep groundwater. That sand-abstraction systems, whilst not difficult or expensive to maintain, constitute a lot of work in continued excavation and thorn fence management. Deep sand-wells were also considered a potential danger to

users either from collapse or from accident when scaling the sides with a full bucket of water.

- A household survey was undertaken to assess the use and sustainability of sand-abstraction systems in relation to other water supplies. Community representatives subsequently continued a dialogue within the community to assess the possibility of developing small-scale sustainable systems.
- Assessments of the sustainable use of sand rivers and environmental conservation or degradational practices were noted by members of the communities where field research sites were situated. Efforts were made to develop local environmental awareness and good conservation practices such as a record of streambank damage and visible river load. The incidence of brushwood fences which surround traditional sand-wells and which are likely to be washed into the wells were also noted. A record was also maintained of sand-wells and sand-abstraction systems and used to indicate general conditions and when water levels became too low for pumping or traditional collection.
- A further survey was conducted by a student of the Midlands University, Zimbabwe, in conjunction with community members to provide a relatively accurate indication of the volume and use of water required and abstracted by selected households in the vicinity of a sand river.
- Field research sites were set up to provide information and data on the nature and stability of four rivers and data was collected on water loss and recharge. Eight field research assistants, members of the respective communities were chosen through the communities to assist in the data collection programme. The author and other members of the Dabane Trust staff monitored the activities of the field assistant as they collected data over a four-year period.
- On-going evaluation of data and discussions were conducted by the author, Dabane Trust staff, field research assistants and members of the communities. Each year evaluation workshops were conducted and a final culminating workshop was undertaken to assess community perceptions, the success and achievements of the research programme.

9.2.2. Experiments Conducted

A total of seven experiments were undertaken during a four-year data collection period. Essentially the intention was to monitor the river and to establish factors related to the overall rate of water loss from river alluvium during each dry season. An overview of the research is contained in table 9.3. Study and experimentation also led to a process whereby the suitability of river sites could be assessed to lead to the setting up of successful sand-abstraction schemes.

Development of a Site Assessment Procedure

To indicate the likely suitability of a site in a sand river for sand-abstraction development the following initial assessments are recommended:

- 1. Undertake a Hydrological Survey of the River:
 - Local community identification of parts of the river with the most reliable, year round supply of water

- Visual appraisal of river length, width, depth. Depth of sediment may be determined with a metal probe driven to the base of the river channel. During this process the riverbed can also be assessed; if the probe meets solid resistance and vibrates when driven further the base of the riverbed is likely to be rock and if resistance is 'sticky', the base is likely to be fine sediment or clay
- Assessment of river sediment. Assessing the 'feel' of a handful of sediment will establish whether or not a sample is gritty and then by allowing the sample to trickle to the ground an indication can be made of the texture of sediment. If particles fall straight it can be considered coarse and thus to have a high porosity. If it appears fine or dusty the sample is likely to have a low porosity and low permeability and thus may be unsuitable for development as a site for a sand-abstraction installation. Other simple field assessments may be made with use of the sediment grading gauge, figure 4.36 and the hand held sieve, figure 4.34. Further, more accurate grading tests may be required.
- 2. Establish the Demand for Water

If the hydrological survey is conducive to the development of a sandabstraction system, determine the water requirements of the community:

- Domestic requirement
- Irrigation requirement
- Livestock watering requirement
- Other available sources of water (dams, boreholes, wells)
- Possible sources of power, unless a handpump option already chosen

3. Sociological Survey

Undertake discussions on

- Responsibility and ownership of equipment
- Management operational and maintenance/repair systems
- Sociological problems within the community that may impact negatively on the success of a scheme
- 4. Off-site Testing
 - Sieving of a sample of sediment to establish the grading and permeability and to provide an informed estimate of the porosity
 - Analysis of a water sample through field equipment or at a laboratory
- 5. Selection of Equipment
 - Selection of suitable well-point and abstraction equipment based on an assessment of river sediment or graded sediment sample

9.2.3. Achievements of the Research Programme:

Data Collection

- Development and installation of research site equipment which provided verifiable data.
- Data collection from field research sites on four rivers.
- Data from the research sites assisted in the development of suitable low cost equipment.

- Trust of four rural communities gained, particularly those in serious water deficit areas.
- Input from communities on sand rivers and scoop-wells, identification of good potential water sites and community assessment of traditional use and management of sand-abstraction.
- Better appreciation of local water resources by the community regarding vulnerability and factors relating to recharge and loss of water. Information from data gathered has enabled the community to have access to additional information on the climate and environment that can be applied to land husbandry and cropping practices.
- Basic low-cost abstraction equipment has been developed and installed and is presently undergoing practical testing in the field.

Development of Equipment

Equipment has been developed in conjunction with information from the field research. The equipment has been designed and developed through testing in a control tank and is presently undergoing field testing. Three field sites have been equipped with well-points and handpumps for extensive on-site testing.

- <u>Wenlock</u>, 3 well-points and simple handpumps have been installed in the river channel south of the research site
- <u>Tshelanyemba</u>, 3 well-points and simple handpumps have been installed in the river channel south of the research site
- <u>Huwana</u>, 4 well-points and basic handpumps have also been installed in the river channel. 2 close to the test site area and a further 2 at Ndutshwa 7 kms to the southeast
- <u>Dongamuzi</u>, attempts to install well-points without modification have failed due to the fine river sediment. Installation of handpumps and well-points and/or the installation of infiltration galleries modified with a covering of synthetic material is under consideration.

Development of Less than Optimum Sites

The improvement of inferior sites has become an important aspect of the research programme. Where the potential for well-point abstraction is poor, particularly in areas where there are few other options for water supply, attention is being focused on ways of developing sand-abstraction sites through infiltration galleries, sub-surface dams or sediment accumulation schemes such as sand dams or gabion schemes. Tube-wells with shrouded points and infiltration galleries discharging water to offsetwells are under trial at Dongamuzi which has been identified as a water deficit area with contaminated groundwater and a low potential for surface dams. Plans are also in hand to construct a sand dam on the Dongamuzi River. A sub-surface dam is under construction at Hingwe where the sediment is 3 to 4 metres deep but the land is too flat for a dam basin. Water from boreholes in such areas is generally contaminated with minerals salts and thus where conditions may be improved or increased sand-abstraction has a good potential.

9.3. Development of Equipment

Research has indicated that extensive use is made of the water retained in sand rivers and substantial quantities of water are drawn for both primary and secondary purposes. Traditional methods of abstraction are easily applied as they are low technology and low cost. However dialogue and further research has also indicated that the management of traditional systems is laborious and time-consuming. Traditional scoop-well technology may also be no longer sustainable due to the vast quantities of brushwood that are required for fencing and the subsequent build up of silt and brushwood that is deposited within the river alluvium when the river channel floods.

Approaches have been made to development organisations by rural communities for assistance with abstraction systems that will provide an easier and more sustainable method of drawing an optimum supply of water at a level of technology that is convenient, acceptable and supportable.

Assessment of the technology available

To date the commercial technology that is available for abstracting water from sand rivers is based primarily on borehole screen technology and is consequently overdesigned and over-priced for small-scale application. Screens suitable for abstracting large volumes of water are available as either well-point and manifold systems or as infiltration galleries discharging to collector or offset-wells. Small-scale, low yield equipment is available but is typically used for specific purposes such as de-watering building sites and has little application beyond this. In some cases limited use is made of suitable equipment but it is little known beyond a particular district or locality. Trial use has been made of the relatively complex collector well technology, which due to its high capital investment in drilling technology cannot be considered an appropriate solution for a community wishing to take control of their own water supplies.

Assessment of requirements

Criteria were determined for the development of equipment that would be likely to ease and improve the abstraction of water from river sediment in a 'popular' and sustainable manner.

<u>The SMAARTS Test</u> Checklist of Sociological and Technological Requirements for a Successful Adoption of Sand-abstraction Sustainability Maintainability Acceptability Affordability

Reliability Transferability Suitability

- <u>Sustainability</u>: the technology must be such that end-users are able to understand and operate it for themselves and to supply their own solutions to keep equipment operational
- <u>Maintainability</u>: only basic procedures of installation, maintenance and repair should be utilised so that users are prepared to undertake maintenance work and to respond to breakdowns

- <u>Acceptability</u>: a level of technology to which people are able to relate that ideally becomes a 'popular' technology where there is a sense of identity, ownership and responsibility
- <u>Affordability</u>: Parts and ideally the equipment itself should be fabricated from locally available or recycled materials which are unlikely to command great expense
- <u>Reliability</u>: The equipment should be durable, ideally sturdy and consequently long-lasting
- <u>Transferability</u>: Ideally manufacture should be possible with only basic tools and without specialist equipment. People should be able to associate with the technology, if necessary with appropriate technical training and sociological capacity building so that the technology is successfully adopted in other localities
- <u>Suitability</u>: Effective technology with advantages which are clearly apparent in ease of abstraction, quantity or quality of water

9.4. Review of Equipment now Available

9.4.1. Well-points and Caissons

A specialist range of abstraction equipment that can be adjusted to a range of installation conditions has been developed as summarised in table 9.4.

Type of Well-point	Installation Method	<u>Suitability</u>	Performance
uPVC, round apertures	Driven	Good – easy manufacture, adaptable, durable	Good
uPVC slot apertures	Driven	Poor – prone to breakage during installation, likelihood of slots clogging with fines	Acceptable
Steel, round apertures	Driven	Moderate – expensive materials, adaptable, durable	Good
No fines concrete sheath	Digging	Good – easy manufacture, adaptable, durable	Not fully appraised
Type of Caisson			
uPVC, round apertures	Digging	Good – easy manufacture, adaptable, durable	Good
Two basins	Digging	Moderate – easy manufacture, adaptable	Not fully appraised

Table 9.4: Appraisal of developed well-points and caissons

• Well-points with numerous round apertures have provided the best overall potential to date. Such well-points as shown in figure 9.1 have shown that they can be used in a broad spectrum of conditions and are straightforward to fabricate and install.

Figure 9.1: uPVC round aperture well-point



• Concrete encased well-points as shown in figure 9.2 have shown a potential in control tank testing but are yet to be field tested.

Figure 9.2: No-fines concrete sheath well-point



Table 9.5 ranks the design of six well-points and caissons on their suitability for use by disadvantaged communities, the likelihood of the acceptability by rural communities and the chance of continuing and further use. Assessments were based on the ease and cost of acquiring materials and ease of fabrication together with the control and field testing undertaken.

Well-points and Caissons	Sustainability	Maintainability	Acceptability	Affordability	Reliability	Transferability	Suitability
uPVC round aperture well-point	* * *	****	****	* * *	* * * * *	****	****
uPVC slot aperture well-point	* * *	* * *	***	* * *	* * *	* * *	* *
Steel, round aperture well-point	**	* * *	* * *	*	****	* * * *	****
No fines concrete well-point	***	****	***	* * *	***	* * *	Not fully tested
uPVC round aperture caisson	***	****	****	* * *	* * * *	****	* * * * *
Two basins caisson	****	****	****	**	***	**	****

Table 9.5:	SMAARTS	ranking o	f well-	points and	caissons
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9.4.2. Handpumps

Four handpump variants have been worked on during the research programme. Objectives of production have been:

- Simplicity, easily understood design and operation
- Low cost manufacture and assembly, minimal use of specialist tools or equipment
- Manufacture from readily available materials
- Ease of maintenance, readily procured materials for replacement parts, easily manufactured and easy fitment of parts with no specialist tools
- Reliability
- Durability
- User acceptability

Writers such as Fraenkel (1997), Hasluck (1907) and Hofkes, Huisman et al., (1981) apply differing descriptions to basic handpump principles. The terminology used by

Fraenkel (1997) appears to best determine the variations and has been applied accordingly with some refinement in the description of the following pumps.

Reciprocating Displacement Pumps

Bucket pump:

A simple suction pump fabricated from uPVC pipe and ABS pipe fittings, comprising a single flap inlet valve, with a further flap valve above a piston, figure 9.3. Pump attaches at sediment surface level to the column of a driven well-point with a flap valve at the top. The pump is positioned vertically and the hand operated piston pumped up and down. Valve and piston bodies have been constructed from 12 mm uPVC sheet and from locally available hardwoods such as Zimbabwean Teak (Baikiaea Plurijuga), which although serviceable and durable is prone to crack if subjected to periods of wetting followed by drying. The piston comprises three wooden discs which sandwich seals of rubber sheet from an inner tube with a flap valve, which is also cut from an inner tube, above. Ports through the discs and seals allow the passage of water. However this assembly complicates the unit as it necessitates a threaded rod with hex nuts to secure the components and also requires spanners to assemble and dismantle. Problems were also experienced when local artisans found difficultly in assembling the piston so that the ports remained open.

Figure 9.3: Bucket pump



• Piston pumps:

o Mafu

A very simple suction pump fabricated from uPVC pipe with two flap valves and a solid piston with no ports, figure 9.4. Valve bodies are made from local hardwood with an inner tube flap valve above. A single, solid hardwood piston is being experimented with. A local carpenter with average or slightly above average skills is able to make both the valve bodies and the piston. The pump body is made from uPVC pipe and does not require ABS pipe fittings. On the one hand this reduces costs, but as there are no fittings that can be used to join sections of the pump, this requires the use of ABS solvent cement rather than PVC cement. ABS solvent cement is not readily available and cannot be transported as air cargo.

Figure 9.4: Piston pump



o Joma

A simple but effective pump, figure 9.5, can be fabricated from off-the-shelf components. Spring-loaded non-return valves may be used as in line valves and piston bodies may be made up from plastic bodies with rubber 'O' rings or cup seals or from brass and leather. These components may be assembled in uPVC pipe and the unit fitted into a welded angle-iron frame with a handle, pivot and fulcrum.

Figure 9.5: Joma pump



Reciprocating Inertia Pump

Joggle pump

An extremely simple handpump variant as shown in figure 9.6. A single flap in the base of a 40 mm O.D uPVC pipe pump column operating within an open-ended 50 mm O.D uPVC pipe. Atmospheric pressure together with the water seal that is created between the two pipes is sufficient to pump water to a height of 3.00 metres at 1.23 m³/hr. Overall tolerance between the pipes is 5.20 mm creating an approximate average gap of 2.60 mm around the internal pipe. To keep costs to an absolute minimum no pipe fittings have been used and in order to discharge water the interior pump column pipe is looped over. However, although the pump is both effective and easy to maintain the creation of a close, neat bend in a 40 mm uPVC is not easily achieved and requires further attention.

Figure 9.6: Joggle pump



9.4.3. Summary of Handpumps

- Bucket pump. A handpump fabricated from readily available materials has worked satisfactorily at a height of 6 metres. However, reliability may be questionable. The pump however is still under review and it is expected that adaptations will be made as required.
- Piston pump. Development is continuing with a simple pump comprised of little more than sections of uPVC pipe, suitable hardwood, inner tubing, screws and mastic.
- Joma pumps have proved to be quite suitable for sand-abstraction use. Almost 100 have been manufactured and installed by Dabane Trust in southern and western Zimbabwe and are in regular use lifting water from sumps situated on riverbanks to garden reservoirs situated beyond and above the river flood level.
- Joggle pump. A very simple and basic pump for low lifts of 3.00 metres or less. The pump operates directly in the water inside a well-point. Excellent for simplicity but limited efficiency. With no piston, no seals and just one valve a pump cannot realistically be any simpler.

Table 9.6: SMAARTS ranking of handpumps

Handpumps	Sustainability	Maintainability	Acceptability	Affordability	Reliability	Transferability	Suitability
Bucket	***	***	***	***	****	***	****
Piston	****	****	****	****	***	****	*****
Joma	***	***	**	*	****	*	*****
Joggle	****	****	****	****	****	****	* *

9.4.4. Data Collection Equipment

Whilst neither a primary intention of the research programme nor in fact essential to the success of the programme, two pieces of research equipment were developed that proved to be eminently suitable.

- A sieve shaker was developed for grading sediment. The appliance allowed a stack of sieves to be shaken by a slowly rotating cam. The mechanism was powered by an electric motor that was geared down by a belt drive to the wheel rim of a child's bicycle and a chain drive from a sprocket on the bicycle wheel to a chain wheel on a bicycle bottom bracket shaft to which the cam was connected.
- A permeameter and stand was developed for on-site constant head permeability readings. The permeameter was based on a model used by Wipplinger (1958) during his research on the storativity of sand dams in Namibia. The open-ended permeameter enabled accurate readings as an undisturbed sample of river sediment could be collected as a single core, the permeameter then sealed with minimum disturbance and readings taken within a few metres of the sampling site.

9.5. Conclusion

Field research sites provided data and a significant insight into the nature of sand rivers and the water resource contained therein. Four field research assistants appointed by their various communities undertook regular data collection and provided vital feed back on the research programme to their respective community that was much appreciated and in fact used to the greater benefit of the communities.

Criteria have been developed to assist in an assessment of rivers that might be suitable for sand-abstraction purposes and also for an assessment of the merits and final selection of an appropriate abstraction site. A check list of criteria has similarly been developed to consider and review the requirements for an appropriate technology selection. In a further effort to ensure the success and sustainability of an introduced technology, four communities have been challenged to review not only their technological capacity but also their sociological acuity. The design and manufacture of equipment that was used as a source of data from the rivers and that developed for abstraction purposes was carried out as a component of the research programme. An initial selection of equipment was made from a study of materials available, fabrication requirements and controlled tests. The more promising equipment was then installed for field testing amongst the four communities. Initial indications have been that useful equipment has indeed been developed and that is acceptable to the respective communities.

Chapter 10

Summary and Conclusions

10. The Intention of the Study and Further Recommendations

Water is invariably a scarce commodity in dryland arid and semiarid areas. Although water may be considered a diminishing resource, demands for it continue to grow as populations increase and marginal land is subjected to increasingly intensive agricultural practices. Demands are also made on water for food production, for poverty alleviation and for general sustenance and well-being. Water is in fact required for all aspects of human health, welfare and recreation. There is a need for water for everything from an adequate supply of drinking water for humans, to livestock and food production, income generation and to home construction and maintenance.

New and innovative ways are required to ensure that water is used wisely and that maximum use is made of the water available. The potential of previously untapped reserves of water requires examination and improved methods of sustainable water management must be assessed. Sustainability of water abstraction systems must also be examined so that resource poor communities are in fact able to operate and maintain and become responsible for their own, reliable supplies of water.

Due to little exposure to technical training and often only limited powers of decision making, many people, women in particular, are often subjected to considerable hardship and disadvantage in the daily search for water. Their ability, however to manage the resource is often far superior to that of men who have little regard for judicious utilisation or for conservation. Henson (2003) reported to the author instances of women in the dry interior of Mozambique walking to 12 hours in one direction to fetch water in remote areas where pumps had broken down. A simple technology with which women were conversant might well alleviate such hardships.

10.1. Aims and Objectives

Many dryland, sand rivers, contain a little utilised water resource. Particularly as water is in acutely short supply in such regions it was imperative to undertake a realistic assessment of the resource and potential of dryland rivers to augment clean water supplies. The intention of this study has been to assess the suitability of sand rivers to retain useable and abstractable quantities of water that could be managed sustainably by rural communities. In order to achieve an accurate assessment of a sand river water resource it was necessary to:

• Undertake a hydrogeological study of sand rivers under differing conditions. This involved investigating the characteristics of sand rivers to assess their potential to retain useable quantities of water and to consider the nature of water loss and the implication of that loss. Criteria had to be established for the selection of

preferred sites and consideration given to what equipment installed for abstraction might be subjected to during flood.

- Establish the needs and requirements of typical user communities. The resources, skills, capacity and capability of communities required ascertaining at both a technological and a sociological level so that disadvantaged communities might be assisted to set up long-term sustainable water supply systems that they are able to operate and maintain themselves, ideally from resources within the community.
- Identify a suitable and correct level of technology. Design, manufacture, test and develop a range of simple equipment that can be assembled from readily available materials using basic tools and fabrication techniques. Ideally people with little technical aptitude and recourse to only limited tools should be able to fabricate, install, operate and maintain suitable equipment in the long-term.
- Establish an accurate perception of the sociological dynamic of a community. The sociological factors that are conducive to the use, operation, maintenance, repair and general long-term sustainability of equipment require an in-depth assessment.

This study and research programme has been established and developed with the objective of gaining an insight into the foregoing issues and with an aim of developing options that might improve water supplies in dryland areas and make more water available.

10.2.The Hypothesis

The hypothesis of this study contends that

- Sand rivers constitute a viable source of groundwater
- Sand-abstraction is a technology that can be utilised by rural communities
- Sand-abstraction can be a sustainable technology
- Strategies can be developed to assist with the establishment of the technology

10.2.1. Verification of the hypothesis

Sand rivers are a viable source of groundwater

Research has shown that water held in the alluvium of sand river channels constitutes as viable a source of water as any unconfined aquifer within a dryland area. But, as with any other potential source of water, surveys, tests and care are required in the identification and selection of suitable sites for development. The identification of usable rivers and suitable sites requires particular care, as considerable variation can be expected in the yield of the aquifer, which is particularly vulnerable to seasonal fluctuation and water loss.

Data collected from sand river channels during four seasons of study has shown that water may be retained year-round, although the reserves within the same aquifer will fluctuate depending on the season and the recharge of previous seasons. Interviews, conducted with both users of commercial sand-abstraction schemes, (appendix 01) and small-scale, subsistence farmers, (appendix 03) indicate that considerable reserves may be available.

Sand-abstraction is a technology suitable for utilisation by rural communities

Well-screen technology has been primarily developed and utilised for borehole water abstraction and for dewatering or groundwater level control and not for the abstraction of water from sand river aquifers for productive purposes. The technology has been utilised in large-scale commercial sand-abstraction schemes but there has been extremely limited use made of the technology at a small-scale individual or community level although some use has been made in schemes instigated by national governments and NGOs for domestic water or irrigation use by isolated communities.

Development during the period of research has however shown that the technology can be adapted for use at a basic, grassroots level. Well-points, caissons and simple handpumps have been developed and satisfactorily performance tested under control conditions. On completion of the data collection period, twelve simplified abstraction systems that have been developed for operation and maintenance by rural communities were under going field trials at five sites with promising results. Further test installations are planned.

Indications from the communities utilising the abstraction equipment are that less time is now spent in collecting domestic water and that increased volumes of water are being made available for livestock and the development of irrigated microgardens. With the introduction of a sustainable abstraction technology and simplified handpumps, work has been made easier at these gardens and more people have the opportunity to establish income-generating projects.

Sand-abstraction is a sustainable technology

Research has shown that sand-abstraction may be utilised in a manner at least as sustainable as any other potential dryland water supply. A simple, straightforward installation and abstraction technology has been developed during the research programme and has been utilised by rural communities. Results have shown that people have both an interest and the inclination to attempt repairs for themselves and are able to accomplish basic maintenance and repairs, demonstrating that the technology is sustainable.

Practical criteria can be developed to assist with the establishment of the technology

Dialogue with community members, field research assistants and water consumers as well as records and observations on the use and management of water supplies and the operation and treatment of equipment has indicated a likely need for an assessment of technical aptitude and sociological parameters in the use and management of both the water source and the equipment. As a result of such assessment, technical training and sociological capacity building may be required.

Practical involvement, research and discussion have also indicated that the development of guidelines can assist with issues such as site assessment, installation design and the fabrication, maintenance and repair of abstraction equipment.

An essential realisation during the equipment trial period was the importance of sociological development. To ensure ultimate success of any technical development an assessment of the community should be undertaken by any implementing agency.

10.3.Evaluation

Research has demonstrated that water is available in the sediment of sand rivers and that where suitable conditions prevail this water will remain year round. Study, design, fabrication and development have also shown that water may be abstracted from saturated sediment and as such sand-abstraction may be considered a viable source of groundwater.

A simplified mechanised technology of water abstraction from sediment has been developed and has been installed for field testing with encouraging, early results. However, study has also indicated that successful technology development cannot be conducted in isolation, that a strong, effective sociological dynamic must be developed if not already in place. There is a need for communities to extend their conventional roles and perceptions of traditional water management into responsibility for new technology and systems of management that cater for an increased use of water. This study has discerned that invariably there is no easy solution, that little can be achieved in isolation, that there can be no quick-fix, rather, that comprehensive solutions and persistence is required.

10.3.1. Availability of the Resource

Research at four typical sand river sites in dryland areas has shown that depending on physical and climatic conditions water is retained within the sediment of the river channel. Data has been gathered to demonstrate that the volume of water reduces over time but that a proportion is likely to remain and be available for abstraction throughout a prolonged dry-season and until recharge occurs in the river channel during flood intervals. Such volumes of water are able to constitute an important water resource in dryland, arid and semiarid areas where the potential for both deep groundwater and surface water development may be limited.

Study and assessment have also revealed, both at the research sites and at a number of other similar sand river sites and dry dam basins that water retained in sand river alluvium and the water within the aquifer underlying the riverbed remain linked so that as water within river alluvium lowers, water may still be available within the underlying levels of the riverbed. There is thus a potential to artificially increase the storage capacity of sub-optimum sites by increasing the depth and volume of sediment available for water storage within a suitable river channel.

10.3.2. Development of Technology

Abstraction technology has been developed that has demonstrated a potential to improve the ease and the volume of water that can be drawn from sand rivers. Indications are that the technology is usable, sustainable and replicable and is presently being field tested, with promising early results. Modifications such as reducing the aperture size of the driven well-points and the development of equipment to assist maintenance and repair procedures have been made as required. Difficulties experienced and general shortcomings have been noted and design and installation procedures adapted as required. Consequent design alterations have been made to some of the components such as the piston and valves.

In spite of the introduction of new installation and abstraction technology, community members have been able to keep the equipment serviceable. Installations undertaken to date have been carried out by the staff of Dabane Trust and the author, in conjunction with members of the surrounding community. As installations have progressed so explanations of principles and procedures have been made and a number of people have demonstrated an interest in and aptitude for the new equipment.

10.3.3. Acceptability

Initial indications are that community members have demonstrated an interest in the low-level technology and have been able to affect basic maintenance and repair work. Equipment development is, however, still at an early, even exploratory stage and requests and recommendations to continue the research and development aspect of pump technology continue to be received. Older women (and children) in particular have expressed a need for 'lighter' pumps and men request 'stronger' more durable pumps and pump components, which overall demonstrates a basic appreciation and acceptance. Whilst further design and possible improvements to abstraction technology can be entertained, consideration must be applied to all aspects of development. If, for instance, people are to be able to maintain the technology themselves and possibly to undertake fabrication and installations, the technology cannot be out priced.

An analysis of opportunity and acceptability provided by Dube (2003) at a workshop held with field research assistants included the following suggestions for a successful implementation:

- People considered to have suitable skills or aptitude should be identified by the greater community for training in the manufacture and installation of abstraction equipment.
- The selection of those wishing to make and install pumps should be made at village meetings so that everyone might have an input into the decisions made and so that sociological discussion might ensue with regard to site selection, use of water and responsibility for the infrastructure
- The possibility of setting up a small manufacturing initiative for abstraction equipment at a District level (within Zimbabwe) was proposed and considered suitable by some participants. The training of a small number of skilled artisans who would be able to manufacture pumps for sale to surrounding communities was thought to be particularly appropriate
- The need for training of local artisans in pump maintenance and repair by persons qualified in sand-abstraction technology was generally agreed as a way of ensuring the sustainability of the pumps

10.3.4. Responsibility

New technology will not be successful or sustainable if there is no concomitant responsibility. Indications are that technological interventions have only succeeded where communities have accepted ownership and responsibility for the technology, or at least that the technology has failed to take off where there has been little or no effective responsibility. Without an acceptance of responsibility technological development is transient and unsustainable.

An indication of acceptance of ownership of this technology application is contained in a report by Dube (2003) who states that members of the Huwana community set times for use of newly introduced sand-abstraction technology. Water could be drawn for domestic use from 6 to 10 am and from then until 4 pm for livestock watering when domestic water could again be drawn. The decision and agreement, which was binding for all households in the community, was made at a ward meeting where the whole community had a chance to be present.

10.4. Achievements

Subsequent to this research programme the potential of sand-abstraction as a water resource has been better appreciated. Experimentation has provided data on water recharge and loss patterns within a river channel and the effect of the vagaries of weather and seasonal variance. Research, interview and study have increased awareness of the necessary requirements, the established technology and the equipment that is available for abstracting water. More is known of the possibilities and options that are required for the operation and maintenance of small-scale, basic sand-abstraction technology and the capacity and capabilities of rural communities to operate and maintain such systems. Insight has been acquired into the technical training and sociological capacity building that is likely to be required for systems to be sustainable.

A research and development programme has enabled the design and fabrication of efficient abstraction equipment from material that is generally available in industrially developing countries using uncomplicated production techniques, basic tools and skills. As much as possible the materials utilised have been those that were comparatively cheap, readily available and easily worked. To ensure sustainable development, other selection and design criteria were ease of maintenance and repair. A realisation during the period of study has been that recipients of an intervention or technology must be adequately prepared to ensure effectiveness and sustainability. On-going discussions have been held with rural community members in an attempt to instil the need for sociological acceptance and development in order ultimately to ensure sustainability of equipment

Sociological advances have also been achieved, at least in the realisation of what is required in order to ensure sustainable development of technological systems. Although research and development has advanced a simplified sand-abstraction technology, interaction with communities has demonstrated that in order to bring the technology into everyday use, social parameters must be set and agreements made on water use, equipment operation and maintenance. It has been appreciated that people have to accept responsibility for the technology and to understand the importance of regular maintenance and repair.

10.4.1. Research programme analysis of requirements for a satisfactory development of water supply infrastructure.

Research has shown that in order for an introduced technology to be successful at a village level there has to be:

- Adequate appreciation of the extent and limitation of the water source
- A satisfactory level of technology that is:
 - Cost effective, essentially the equipment will require a low initial capital cost and have low operational and maintenance costs
 - Largely constructed from locally available materials with little or no dependence on imported materials or technology
 - Quickly and easily understood so that there is an appreciation of the principles of operation and maintenance

- Simple and straightforward to construct, duplicate and repair with no specialist tools required at any stage
- Functional and efficient within the limitations of available low-cost materials and village level skills
- Time saving, the technology should be more quickly and more easily operated and maintained than a traditional open sand-well
- Successful implementation of a village level technology must be accompanied by sufficient sociological preparation. Community meetings are likely to identify the implications and sociological requirements of a technology, particularly for a new technology to be acceptable and to be utilised in a sustainable manner. Guidelines are required to assist understanding, acceptance and ultimate responsibility for equipment. Decisions that are acceptable to all consumers are required in order to ensure the continuing operation, maintenance and repair of equipment
- Adequate training in operation and maintenance is imperative. People need to understand the components of the equipment, the working principles and to establish satisfactory principles of management. Skills training is required in installation and maintenance techniques, an adequate number of suitable tools are required, together with advice in the use and care of tools, repair and maintenance equipment.
- Consideration must also be given to all sociological aspects that affect consumers or the community. There is considerable implication in the fact that in many communities men will not have been traditional custodians of sources of water but with a new technology will likely wish to be involved in abstraction, to experiment with and even to control the technology. There is a likelihood of new users increasing the demand for water for both primary and secondary use with possible over abstraction of water and depletion of the resource. It has been seen that women have a better understanding and aptitude for the conservation of water and are better able to appreciate the constraints and to stretch minimal resources. It is therefore important that both men and women are equally involved in any water source development programme.

10.5.Conclusion

Water is available in sand rivers

Water is retained in the sediment of dry, sand river channels and in many situations will provide a source of water that is acceptable to consumers. Following the cessation of a rainy period it can be expected that the water level will be at or near the surface of the sediment. During the ensuing dry season the water level will drop in the aquifer due to evaporation from the sediment, from continuing downstream drainage, from seepage through the bed of the river channel to the underlying aquifer and through abstraction. In suitable conditions, essentially larger river channels that are able to retain extensive reserves of water, water will be retained in river channel alluvium throughout a dry season until adequate recharge in the next, subsequent rainy season and possibly, if an inadequate recharge, through a further dry season.

The supply of water is not an unlimited resource but requires careful site identification and management. Procedures and precedents must be set if it is to be utilised in a sustainable manner.
Abstraction technology can be developed

Technology has been developed to mechanically abstract water from saturated river alluvium. Much of the equipment available is based on that required for deep groundwater abstraction. A part brief of this study has been an assessment of the equipment that is available for abstraction together with consideration and possible development of equipment suitable for small-scale use by rural communities or individuals. The assessment of data gained from field research and from a review of available equipment led to the development of a range of trial abstraction equipment which is presently undergoing field tests within four communities.

With the intention that that the technology should be acceptable, understandable and easily maintained by remote, disadvantaged communities, materials that were found to be readily available were utilised in the fabrication of equipment. A particularly low level of technology was selected for manufacture, installation and maintenance. Initial indications are that the equipment has proved to be sociologically acceptable to water consumers and is technologically satisfactory. Modifications have been made to the equipment and further modifications and installations have been planned. Thus far however there has been insufficient time to establish whether or not the technology will be maintained as a viable community water supply, although some positive indications have been received.

Sustainable use can be made of abstraction technology

The sustainability of traditional sand-abstraction systems has been subjected to a punishing sequence of tests over at least the last one hundred years and has in the main been seen to be reliable in that many people have continued to draw water, even if in minute quantities, when virtually all other sources of water have dried up. With regard to technology that has been introduced during this research and study programme, abstraction equipment has been installed and is in use. It appears to be appreciated and understood, however now is perhaps the most crucial time when the sustainability of the equipment will be put to the test by the various communities.

Dialogue on sustainability continues with questions posed to consumers on the availability and suitability of materials, technical skills and tools that are available within the community and not the least their preparedness to shoulder the initial cost and maintenance of equipment.

Technological and sociological criteria will assist implementation of the technology

Technical training and sociological capacity building are factors that are key to assisting water consumers to appreciate and develop a measure of acceptability, responsibility and sustainability for a technology. Criteria and procedures can be identified and established through practical involvement, which, as it develops and is refined, can be demonstrated through a variety of media.

Through such media information may be displayed on hydrogeological criteria for site assessment; from identification of a river suitable for sand-abstraction, site selection for the installation of equipment and the likelihood of disruption or damage to abstraction equipment and safeguards that may be taken to reduce the possibility of damage to equipment. Technological criteria, design and guidelines that are suitable for fabrication, installation and maintenance and repair of equipment are particularly suited to demonstration through a manual or video. Sociological aspects, such as the need for responsible custodianship and use of water, agreements and management of water supplies, acceptance of responsibility for operation and maintenance are also issues that may be presented in a variety of media to stimulate awareness and discussion that can lead to important and supportive decision-making.

Whilst the precedent for water utilisation through sand-abstraction and technological innovation might be established and even shown to be sustainable on a test or trial basis, little will ultimately be achieved unless the technology is accepted and brought into the realm of independent village-based technology. Initiatives are required that are able to quickly and accurately demonstrate and convince end-users of the importance of the various issues that are necessary to successfully use the technology of sandabstraction.

10.6.Recommendations

10.6.1. Use and Development of the Technology

Use and Development at a Local Level

In order for sand-abstraction systems to be used regularly and sustainably it is imperative that abstraction equipment be seen primarily to provide a creditable solution to a genuine need. It is essential that end-users be prepared to accept total responsibility for any infrastructure and to be in agreement as to the manner of operation, management of systems and the use of water. Without such an agreement an improved system cannot be expected to be practicable. In some situations, these requirements will automatically be in place; in others there will be a need to develop capacity in order to ensure sustainability.

Individuals or communities may require assistance to adequately identify their options. Consideration must be given to issues such as local hydrogeological and socio-economic opportunities, local resources and the capacity and ability of the recipients. The most suitable level of technology, together with the accessibility of tools, equipment, spares and materials and the available income of the community to operate and maintain equipment are further factors to be considered. An assessment will be required of the availability of water, water demand and the use of water. It will also be necessary to assess what the end-users are able to do for themselves and the support and backup that are available. At least in the initial stages of contact with end-users, a site appraisal survey may well be required, as well as sociological capacity building, management training and operation and maintenance training.

Although there is a likelihood of the need for such assessments and appraisals, there is in fact only so much that can be prepared or can reasonably be expected to be undertaken. Ultimately the relevant decisions are with the end-users who must accept and adapt an initiative and develop procedures and systems that will lead to a satisfactory conclusion. The technology level must be such that people are prepared to make innovations, to experiment and to work together in an effort to make the most of the technology. Ultimately the community must agree or disagree to accept the intervention and the technology must then be subjected to the foibles and constraints of community operation and management. On-going monitoring will be required and support for community problem solving, training and skills may also be required as long as the commitment to the technology remains apparent and the intervention is not receiving just casual interest. Where and when these initiatives come together, a

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successful use and continuing development of the technological opportunity can be expected.

Use and Development by the Water Profession

Although large-scale schemes are quite feasible on rivers with large catchment areas where there is a considerable reservoir of water, the technology probably has a greater application and potential with small-scale schemes on smaller rivers, for community or individual use. The development of small-scale schemes is generally left to the responsible authorities of so-called Third World Nations and national and international NGOs. Realistically the best avenue to an increase in the use of lowtechnology sand-abstraction systems is awareness building within the NGO world.

The technology that has been developed within this research programme is at a level that many NGOs operating in areas that are suitable for sand-abstraction development, will be able to utilise with a minimum of resourcefulness. NGOs that are involved in water development programmes are also often in a position to provide the initial impetus and assistance to communities that is often required when starting up projects. Many NGOs are involved in integrated programmes that could easily embrace the practical installation and training that is required for the satisfactory operation and management of a low-level technology intervention. Opportunities for increased use are seen to rest with NGOs and will constitute the focus of attention for further development initiatives.

10.7.Promotion of the Technology

The need to extensively and accurately impart information gained from research is a fundamental concern. According to Saywell (1999) undue emphasis is still placed on the production of a single report strategy that consequently fails to reach a widespread audience. Saywell makes the point that research cannot be utilised unless it is made available to those who might best use it, at the time that it is required and in an easily interpreted format, providing findings that are comprehensible and adaptable to local circumstances. Without a multifaceted approach to dissemination, new opportunities and research will remain unutilised and unrealised.

Promotion within Communities

Opportunities to promote the use of well-point technology at a 'popular' or community level exist through inviting the media to visit development projects. In this way they can view and be made aware of the opportunities offered by sandabstraction. National and regional media, particularly radio, generally have a wide coverage and presenters often have a penchant for interviewing local community members and are quite likely to provide a balanced report of a successful technology.

Local promotion can also be achieved through informing local government and rural traditional leaders of the potential for well-point technology. Many meetings occur within rural communities where a broad spectrum of issues is often discussed. Where local leaders have experience or understanding of the possibilities and opportunities there will be a greater acceptability and more accurate explanations of systems and the potential will be better portrayed to the water consumers within a community.

Further opportunities for presentation and promotion amongst people with a direct interest in the technology may be achieved through participation in local and regional agriculture and technology shows. Practical displays, dioramas, photo displays and

the distribution of fliers, brochures and reports all serve to advance the presentation of facts and to draw attention to new interventions. Often a successful promotional tool is word-of-mouth reports, particularly where inter-visitation is possible with organised exchanges between community groups for one-on-one exposure and fact finding.

Promotion within the Water Profession

Although the interest and acceptance of end-users in improved sand-abstraction technology is of paramount importance, the rate of uptake through localised initiatives can only expect to be slow. It is the water profession, those who are actively and regularly engaged in efforts to improve rural water supplies, who are most likely to cause the greatest change and who are probably best targeted. It is intended that efforts be made to persuade water engineers, from the staff of NGOs and small-scale operators through to the planners and designers of large-scale schemes, to take an interest in and to consider the possibilities and potential of sand-abstraction. Initiatives to promote sand-abstraction technology have been broadly presented in chapter 8, some of which are already in hand.

The identification of NGOs, PVOs and grassroots organisations that operate in areas where sand-abstraction is either known or thought to have a potential is already underway. The particular focus for identification is on countries that are likely to utilise low-level technology applications where there is no easy access to high tech equipment and fuel.

Plans are in hand to host an international conference in Zimbabwe for water engineers and planners from countries where there is a potential for sand-abstraction. Participants from practical, hands-on NGOs and from academic research and planning centres will be invited to review the initiatives and work of the programme to date, to evaluate the technology and to express opinions on the possibility for its use in other parts of Africa. In this manner it is hoped water professionals will become more aware of available technology and the possibilities of sand-abstraction. Efforts need to be made to encourage those with a vested interest in water development projects and initiatives, particularly in arid and semiarid areas to consider, or reconsider, the possibilities of utilising sand-abstraction schemes, especially when designing VLOM schemes that will require full community operation and management.

It is intended that the conference will organise a series of visits to small-scale sandabstraction schemes so that the technology will be seen as it is, and a channel of direct contact will be established for interested parties with end-users. The intention is not to organise a lectured, how-to-do-it seminar, as much as to facilitate an approach that will provide an opportunity to discuss opinions, perceptions and personal experience of sand-abstraction. The conference will provide an opportunity to establish the opportunities that exist to utilise sand-abstraction, particularly where conditions are considered conducive, but also where presently there is little use; whether the choice be a low-tech or a high-tech option.

If, following the planned conference and the identification of NGOs with an interest in sand-abstraction, it is reasonably clear that opportunities do exist to extend the use of sand-abstraction further identification and assessment of potential areas should be undertaken. Having established interested parties and possible areas for sandabstraction the possibility exists for in-service training of NGO staff at centres such as Dabane Trust where there is an active low-tech sand-abstraction programme.

10.8.Recommendations and Future Work

10.8.1. Development of the Technology

Hands-on Development by Users

Use of well-point and handpump equipment by end-users will provide a rapid and effective selection process of technological development. The installation of well-points and handpumps with the agreement and active participation of communities should be continued. The subsequent use, function, dysfunction and innovation that is required to ensure continuing operation, or possible rejection, is the ultimate test to which the technology should be subjected. If the technology is considered worthwhile, suitable and appropriate, end-users will quickly accommodate and develop procedures to ensure adequate maintenance, repair and management. An extension of the use of the technology into new areas with different situations will provide a more broad-based application that is more likely to encourage an appropriate development of the technology. Where there has been a successful installation there is a likelihood of experimentation in the knowledge that there is a fallback position to an already successful installation.

Responsibility, sustainable use and the innovation that will be required to ensure a satisfactory conclusion will only take place when practical maintenance and management skills training have been provided. Regular monitoring of the use of the technology is a further worthwhile undertaking where lessons learnt can be followed up and the experience used in other areas to ensure success.

Reports received by the author from the field research assistants based at each of the four research sites are that the communities wish to continue their association with the research initiative and with Dabane Trust in order to continue the development, installation and test of abstraction equipment. Recommendations recorded by Dube (2003) at a workshop held with the research assistants as an evaluation of the field research programme indicated that:

- Installation and development of low-technology, community owned well-points and handpumps should continue and efforts should be made to have the technology accepted as an integral part of the community water supply
- Community management and responsibility of pumps should be encouraged
- Local leadership should be encouraged to participate more in the development activities of a community
- Pump committees should be set up for each handpump to oversee the use and maintenance of equipment. The communities should be encouraged to assist the committees to undertake their responsibilities.
- Efforts should be made to demonstrate the importance of the research programme in the development of water supplies and irrigated gardens to everyone within the community.
- Efforts to disseminate the information and data that was gained during the research programme should continue. The sharing of research information between those of the Dabane Trust staff who were involved in the research programme, the research assistants and the community at large and also between members within the community was thus seen as important.

• Research and trial programmes undertaken should be reported and discussed at community and local government ward meetings which village leaders attend so that everyone was always aware of developments

Field Manual and Handbooks

Widespread adoption of sand-abstraction cannot be anticipated if continuing efforts are not made to promote and to further develop the technology. A comprehensive booklet explaining the technology and incorporating topics such as site selection, choice of equipment, installation and sociological guidelines would constitute a useful promotional tool that could be expected to increase the understanding and acceptability of sand-abstraction.

A suitable handbook offers the opportunity of an explanation of sand-abstraction from site identification and abstraction options to the sociological and technical requirements, management and maintenance systems. A comprehensive field manual can be a technical resource document that demonstrates a logical and straightforward procedure and is an accurate reference document for explanation of either a complete sequence or for aspects of sand-abstraction installation, operation and maintenance. A manual provides step-by-step procedures that if followed, considerably increase the possibilities of a successful installation. Examples of comprehensive manuals relating to topics such as 'well construction' have been designed by Mann (1992) and Laver (1968); and Naugle (1991) and Deverill (1999(b)) have prepared detailed manuals on successful tube-well programmes as a way of disseminating information. In a more extensive work Visscher (1985) uses the approach and format of a manual to convey the salient facts of a slow sand-filtration system.

Field manuals for the use of project members need not be sophisticated, the author with Dabane Trust has produced a range of explanatory and practical skills training manuals on subjects such as money management, environmental conservation, gardening and handpump operation and maintenance such as the Rower pump manual, Moyo and Woodhouse (Undated), (appendix 12).

Online Presentation

Ever-increasing use is made of the Internet, which offers an immense opportunity for promotion, development and feedback. With so many websites and so much information available, it is however imperative that information should be presented in an interesting, appealing and professional manner that is completely accurate and accessible. The design and layout of a website should be such that it is able to catch the attention of water professionals as well as small-scale operators in countries where download speeds will be slow due to modem baud speeds operating at below optimum performance through inadequate or poorly maintained phone services.

Publication of Professional Papers

The publication of technical, select and peer reviewed papers in authoritative journals as well as more basic, descriptive articles in hands-on periodicals is likely to reach a wide audience and has the potential to interest and to promote the technology. The annual WEDC Conference is guaranteed to reach a remarkably wide audience both through direct contact with participants and the subsequent online publication of papers. WEDC is a renowned and well-respected institution with whom further links are likely to be explored. The relevant sections of this thesis combined with the experience of the author and Dabane Trust staff might well be developed into a field manual or handbook with the publication of a complete book a further possibility.

10.8.2. Recommendations of the Study

The research programme undertook data collection and gathered impressions from people, which lead to a more comprehensive characterisation and understanding of sand rivers that has been documented in this thesis. The research provided a basis for the development of appropriate low-technology well-point abstraction and handpump equipment and an overview of the requirements to make the technology successful and sustainable. The study should now turn to verification of this information and the subsequent technology development and thus:

- Undertake trials of the recommended procedure of site selection and appraisal
- Continue to conduct extensive field tests of the equipment that has been developed during the research programme and modify it as necessary, to improve reliability and durability and to ensure a potential for local manufacture and increased use
- Undertake a promotion and publicity campaign to disseminate the results of the study and, more importantly, the technology and development procedures that have been implemented
- Conduct physical assessments of the suitability of areas that have been identified as possible sand-abstraction areas
- Set up an identification and selection process of organisations that are likely to have a socio-technical capacity and consider the possibility of establishing an in-service training programme for NGO personnel with a view to extending the manufacture and installation of appropriate low-tech sand-abstraction equipment within a sociologically acceptable context

10.8.3. Opportunities for Further Study

Although the research activities were substantially completed, subsequently some aspects of study would benefit from further attention and more detailed data and analysis.

Sub-optimum Sites

The potential to improve sub-optimum sites became quite apparent during the research period. During the study period activities were limited to investigations at two possible sand dam sites, one sub-surface dam site and one sediment accretion scheme. Of the sand dams, one dam is in the second year of construction with survey work continuing at a second possible site. At the time of completion of the study construction of the sub-surface dam was about to commence and a survey had been undertaken of a stretch of river to assess the potential to trap sediment but the scheme was itself not undertaken. However, the surveys captured the interest of some members of each community and thus opportunities to adequately study the possibilities of improving a range of sites should ideally be engaged in. The possibility of increasing the storage capacity of sub-optimum sites through sand dams, sub-surface dams and gabions or other mechanisms to cause an increase in the volume of sediment within a water channel does appear to hold both interest and potential.

Abstraction Equipment

Well-points and handpumps have evolved during the period of study. The prospects appear promising, however insufficient time was available during the research programme to adequately and fully test and monitor all the equipment. Further testing and monitoring of equipment is imperative for at least a further two or three years with modifications and adjustments undertaken as necessary.

Water Loss from Sediment

The initial concept of field study work was primarily the characterisation of a sand river involving local people from the nearby community and using rudimentary equipment that was considered suitable for the use of a layperson. The research programme set out to involve the local communities and to gain their interest, in fact to gain their trust, so that honest and accurate assessments could be expected when the time came for an assessment of the worth of sand-abstraction and the possibilities of developing basic low-cost, low-tech abstraction equipment. From this aspect the research programme was both useful and beneficial, particularly as data was gathered in a range of conditions over five seasons, from low rainfall to considerably above average rainfall. Unfortunately however, the opportunity to undertake research into riverbed losses due to seepage did not materialise. A comparative check of data using high-tech self-recording or signal transmitting equipment set up from the outset to establish the proportion of each loss of water from sediment would be of great interest and benefit

Study of Environmental Factors

Degradation of the environment is a primary cause of surface erosion that in turn has caused heavy sedimentation of river channels and thus has given rise to conditions in which sand-abstraction is possible. However, many sand rivers are now in equilibrium and are no longer dependent on continuing excessively heavy sediment loads for further accretion of sediment in order to retain water. Consequently watershed management and environmental conservation programmes are required to ensure the continued stability of sand river channels.

Socio-technical Studies

This study has been at pains to indicate the indubitable requirement of an effective sociological dimension to a technological intervention. Unless society and technology are in accord it is most unlikely that sustainable development will occur. Further studies to consider the symbiosis that is required for successful implementation can only be to an overall advantage.

Conclusion

The research work undertaken has thus proven that there is definitely a window of opportunity for sand-abstraction. It has been shown that there is a water resource available in dryland sand rivers which may be abstracted in a sustainable manner at a basic level of technology that can be operated and maintained by rural communities and that this technology may be linked to traditional systems of water management. Now that the assumptions have been confirmed the real challenge is to disseminate the information to get it more widely accepted and to motivate people to put the technology into practice.

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THE FEASIBILITY OF SAND-ABSTRACTION AS A VIABLE METHOD OF GROUNDWATER ABSTRACTION

APPENDICES

Stephen W Hussey

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APPENDIX 01

SAND-ABSTRACTION SCHEME SITE VISITS

ZIMBABWE - March 1999

1. Chisumbanje, Save River (South-east Zimbabwe)

This is probably the largest sand-abstraction irrigation system in the world where up to 2,500 hectares can be irrigated from the Save River. The Save River has a catchment area of some 38,140 km² and in the vicinity of the abstraction site is approximately 600 m wide with some 15 m to 17 m or more depth of sediment. The initial scheme was set up in the early 1970's and consisted of 150×100 mm (6×4 inch) slotted steel pipes which were direct coupled to a pump. However this did not meet the full potential for irrigation and in 1983 the scheme was enlarged to pump 1,200 m³/hr. It was enlarged again in 1991/92, during the devastating drought in southern Africa. The new scheme delivered 1,440 m³/hr and provided water for the full 2,500 hectares of irrigation, essentially for sugar cane, cotton and winter wheat. However there is still a potential for a further 2,000 hectares to be added. According to Dube, (1999), even in the dry season and following the extremely severe 1992 drought, the pumps were still able to deliver 1,440 m³/hr. continuously, 24 hours per day.

The abstraction system comprises 4 pumps in a false well on the riverbank. Two \times 450 mm diameter pipes extend from the well 170 m into the Save River, where they turn parallel with the riverbank, each then extends for a further 108 m. From each of these there are twelve tee offs which extend a further 6 m and at the end of these, 150 mm Ø stainless steel Johnson Screens extend between 8 and 9 m deep into the sediment. All connecting piping is steel pipe which is rubberised inside and out to minimise rusting, (Broderick, (2000). Caterpillar D8's assisted during installation to remove some 2 m of surface sand down to the water bearing level. Self-jetting well-points were jetted in so that the base of each screen was some 12.5 m deep in the sediment, Mpofu, (1997).



Fig A1: Design of sand abstraction installation at Chisumbanje, Save River, Manicaland, Zimbabwe.

2. Chikwarakwara, Limpopo River (South-east Zimbabwe)

Refurbishment of the water supply system which abstracts water from the Limpopo River to irrigate 25 hectares was completed in 1998. Presently abstraction is from boreholes in the alluvium, some 20-30 m from the river channel. However, the original scheme, installed in the 1950's, comprised 50 mm (2 inch) well-points connected to a 150 mm (6 inch)infiltration gallery which was connected to a progressive cavity pump. Well-points were fabricated from 2 inch galvanised steel pipe with longitudinal slots cut with a fine set oxy-acetylene torch and high tensile steel galvanised wire wound around the pipes over the entire length of the slotted section. Wrapping of the wire was undertaken on a slow moving lathe and the ends of the wire were welded in place to keep it tight. However, since the wire surfaces were in contact with each other the resulting apertures were very narrow and quickly became closed, either through rusting or the accumulation of fine sediment and salts, (Esterhuizen, 1987).

Plans are to extend the scheme to 65 hectares by using two 150 mm manifold systems in the river connected to artificial boreholes on the riverbank. The intention is to utilise six or eight 200 to 250 mm diameter Johnson screens per manifold placed 6 m apart. Pumping will either be by a progressive cavity pump in each of the artificial boreholes for a fully automated system delivering 80 m³ per hour or a single 120 m³ per hour centrifugal pump and vacuum tank to provide a semi automatic priming system, (Makwangudze, 1999).

3. Nottingham Estates, Limpopo River (South-east Zimbabwe)

Over several years Charles Ambler-Smith has designed and installed a number of sandabstraction irrigation schemes in the Limpopo River. The most recent is designed to yield some 300 m³ per hour from 200 well-points, (1.5 m³ per hour per well-point). Design velocity is for 0.30 m/sec through the slots into the well-point and for 1.50 m/sec through the pipe system. Ambler-Smith says that he generally uses steel well-points which can be driven into the sediment but has also used flexible poly-pipe well-points which can be jetted in. He also says that he is a firm believer in developing the sediment to remove fines and to effectively create a gravel pack around each well-point. Development is carried out either by hand surging the well-points or by back-washing with both water and compressed air.

The scheme irrigates a citrus orchard and date plantation and comprises two submersible pumps in $2 \times 150 \text{ mm} \times 5.00 \text{ m}$ deep tube-wells on the riverbank. The tube-wells are connected to a 75 mm galvanised steel manifold configured in a wide-spreading zigzag formation in the river bed. Some 200 well-points are directly attached to the manifold. The well-points have been fabricated from 40 mm galvanised steel pipe with slots cut with an angle grinder disc. Experience has shown that the further the well-point from the pump, the greater the slot area required. This particular system is considered to be approximately 25% over designed due to the propensity of well-points to block through a slow build up of silt, salts and rust. The system has also intentionally been designed to operate at low abstraction velocities in order to prevent pump cavitation, but has nevertheless been found to draw an approximate one third greater power requirement than the pump specification. This has been attributed to excessive drawdown and a subsequent high suction head due to a slow recharge rate through the sediment. To reduce drawdown around a well-point Ambler-Smith prefers to use several widely spaced, relatively small-bore well-points rather than a single large diameter well-point and in a further attempt to reduce overall drawdown within the river he has spread this system in a 'W' configuration over some 200 metres along the river channel. The wellpoints have been installed to approximately a depth of 6m, but even at this depth have been known to be washed away. Where necessary well-points are tied to concrete beams or stakes which are driven into the riverbed, although even these have been known to move. Ideally well-points are secured to bedrock.

Ambler-Smith maintains that he has operated well-point schemes similar to this one continuously, day and night for up to twelve months, barring mechanical breakdowns. After a year of continuous pumping however he reports a build up of fines in the system which has required clearing by backwashing. Although this temporarily clears the system within a month or so there is again a significant build up of fines.

Other systems that Ambler-Smith has tried are 75 mm steel well-points installed to about 9m depth (there is a 10-11m depth of sediment in the Limpopo River). Seven of these 75 mm well-points were installed per scheme but in a drought season the drawdown was found to be excessive and consequently the suction head was too great for reliable pumping. Nottingham Estates have also used caissons to abstract water but in the conditions of the Limpopo River they were found to be unsuitable due to the ingress of considerable amounts of fines which blocked the caissons with a jelly like substance.

Ambler-Smith by preference has used centrifugal pumps to progressive cavity pumps in spite of a greater possibility of cavitation and vulnerability to river flood.

Conversation: Ambler Smith, Owner/Manager Nottingham Estate, Beitbridge; March 1999, (Ambler-Smith, 1999).

4. Shashe Irrigation Scheme, Shashe River (South-west Zimbabwe)

The present irrigation scheme draws water from six separate well-point systems with diesel engines along a 3 km section of the Shashe River. 3,330 m³ water is used per day to irrigate 65 hectares. Makwangudze, (1999) states that the well-point systems are either 150 mm Johnson screens or 50 mm (2") slotted steel pipes connected to 150 mm manifolds direct coupled to progressive cavity pumps. Water is pumped directly into a main supply which discharges into stilling boxes and supply canals. The original scheme irrigated 80 ha from 8 well-point systems.

5. Tshelanyemba Hospital Scheme, Shashane River (South-west Zimbabwe)

The system provides 15 m^3 of water per hour to a hospital, residences and an irrigation plot. The abstraction system comprises an 18 m by 150 mm galvanised steel manifold with tee-offs 4 m apart staggered on each side with one at the end, giving off sets to ten 50 mm galvanised steel well-points. The well-points used are 1.5 m long, and slotted over the lower 1.00 metre with a with a finely set oxy-acetylene torch. The lower end was drawn to a point and the top fitted with a type D threaded flange.

At installation river sediment was excavated by hand down to the water bearing level, (approximately 1m at the time of installation) and the manifold placed at this level. A wooden block was placed over the pipe flange and the well-point driven diagonally into the sediment to its full depth with hefty blows from a sledge hammer. At the required depth the well-point was connected to a second D type flange by way of a flexible helical suction tube and flanges on $1m \times 50$ mm diameter off sets from the manifold. The manifold was connected by a 75 mm Class 10 uPVC pipe to the top of a vacuum tank on the river bank.

The vacuum tank has a capacity of 2½ times the combined volume of the suction pipe, the manifold and the off sets. The bottom of this tank is connected to the top of a progressive cavity pump. By opening a valve on the supply line to by-pass the pump the vacuum tank can be filled with water draining back from the supply line. A vacuum tank was installed in order to obviate the need for non-return valves on the inlet side of the system as this can render a system inoperative if they become clogged with sediment. Experience has shown that it is sometimes difficult to ensure a satisfactory seal and to prime a sand-abstraction system that uses non-return valves. When a vacuum tank is full, the pump can be started with sufficient water to lubricate the pump and to create a vacuum on the inlet, suction side of the system.

This system was designed and installed by the author in 1991 and has kept the Salvation Army Hospital at Tshelanyemba in water ever since, even during the severe drought of 1992 when the Shashane River did not flow. The original scheme provided for water purification tanks before the water was used in the hospital, however, after a series of tests conducted by the Bulawayo Municipal Water Works in their Criterion Laboratory, this was considered to be unnecessary and the water is used straight from the river.

6. Tshelanyemba Primary School, Shashane River (South-west Zimbabwe)

The scheme delivers 4.5 m^3 of water per hour from a B50 Mono progressive cavity borehole pump to a school and garden. The system is comprised of a 150 mm × 3 m galvanised steel manifold with three tee-offs for well-points, one on each side and one at the end. The well-points and manifold installation procedure was undertaken in the same manner as the Tshelanyemba hospital site. However, in this system water is gravity fed from the manifold into a sub-surface tank which is dug into the riverbank below the level of the manifold.

Although below ground and below the level of the manifold this tank is also a vacuum tank which can be primed from the delivery line by by-passing the pump. The tank has a section of 150 mm borehole casing welded to it that extends to the ground surface. The top of this casing is sealed and the borehole pump head fitted to it. The pump's stator and rotor are placed within the vacuum tank and the whole unit sealed, thus even when the water level drops in the river sediment and water no longer flows by gravity into the vacuum tank, the system can be primed and remains operational. The installation was designed and undertaken by the author in 1987 and has been operational since then.

7. Tshelanyemba-Nyashongwe Pipeline, Shashane River (South-west Zimbabwe)

According to Tshuma, (1992) who has been the pump minder since the inception of the system, the installation was carried out in 1952 to provide water along a 15 km pipeline for livestock use. However over the years the pumps had broken down and the abstraction system had become totally clogged with sediment. The Dabane Trust in 1992 installed a new system similar to that used at the Tshelanyemba hospital.

The original system comprised five 50 mm diameter well-points which were slotted and bound with high tensile steel wire. The well-points were some 20 m apart and 10 m each side of a centrally connecting 50 mm galvanised steel pipe. Although the system gravity fed to a pump at a lower point of discharge, the top of each well-point was fitted with a non-return valve. To keep them in place, the well-points were attached to steel fence standards which had been driven into the riverbed. The 50 mm galvanised steel central connecting pipe extended 250 m down the river channel to a shaft within a pump house. At this point the pipes were direct coupled to 2 piston pumps which supplied water to drinking troughs along the pipeline to a tank at the end of the line at a height of 50 m above the pumps. This original system was typical of some 10 or more systems installed in Zimbabwe at that time.

8. Mambale Irrigation Scheme, Shashe River (South-west Zimbabwe)

Water is drawn from the Shashe River, the border between Zimbabwe and Botswana for irrigation. The original system installed in the 1950's comprised a well-point system very similar to the original Tshelanyemba – Nyashongwe system. A well-point and manifold system gravity discharged water into a sump on the riverbank from where a diesel engine pumped water into a canal to irrigate 14 hectares. The system fell into

disuse in the 1970's during the Zimbabwe Liberation War and was refurbished by a consortium of five Bulawayo-based NGOs in the mid 1980's with a system similar to the Tshelanyemba Primary School scheme. A new manifold with well-points was installed and direct coupled to a progressive cavity borehole pump. These new well-points were drilled with 6.00 mm apertures. The original well-points had been wire-wound and during the period of disuse the wires had broken down and the well-points filled with sand.

During refurbishment the irrigated area was reconstructed with new canals but due to the remoteness of the area the farmers experienced considerable difficulty in obtaining diesel and operating the pump. Consequently little use was made of the scheme in spite of considerable demand for food in this low rainfall and drought stricken region and in spite of the considerable volume of water available in the river sediment. Presently the scheme is in the process of being refurbished once again as the farmers have found a new donor who has installed new centrifugal pumps and also extended the scheme by a further 10 hectares.

SOUTH AFRICA - KWAZULU-NATAL, - April 1999

The Kwazulu-Natal sites are either in perennial river systems or systems with only short periods of no-flow, thus the rivers are primarily riverbed/gravel bed intake systems with characteristics dissimilar to the characteristics of sand-abstraction systems in ephemeral rivers. However the principles and largely the equipment remain of interest to this research. Almost all sites in the perennial rivers at some time have experienced blockage problems, chiefly from iron-based algae that develops inside the well-points at the interface between the sediment and water. Several of the systems were also reported to be prone to a build up of fines.

The actual purpose of the site visits was to establish the propensity and extent of black algae growth in the abstraction systems. The author, together with Stewart Helm a former WEDC student and chemical engineer, was able to accompany Michelle Clanahan of Mensi Water Engineers who was collecting water and sediment samples and conducting research in an attempt to establish both the cause and a cure for this biofouling, (Clanahan, 1999). Unfortunately after more than two months work and many thousands of kilometres visiting schemes and obtaining samples from Cape Town to Jotsholo not far from Victoria Falls, Clanahan's samples were inextricably mixed up by the laboratory and the work was never completed.

1. Ifafa, Mtwalume River,

The scheme on the perennial Mtwalume River is a part of the extensive Umgeni Water supply which provides water throughout the Natal South Coast. The abstraction site is at a point on the river about 5 km from the Indian Ocean where it is some 25-30m wide. The depth of river flow varies between about 1 m and a few centimetres although floods of up to 3m have been experienced. Sand bags had been placed diagonally across the river to direct the river flow over the well-points. The scheme comprises six 150 mm Johnson screen well-points placed horizontally about a metre deep in the river sediment some 3-4 m out from the river bank. Each well-point is connected by 150 mm flexible helical hose to a similar hose dug into the river bank at approximately the water surface level. This manifold leads directly into a pump station. If pumped continuously the system will yield 25 m³ of water per day. However this is not typical as the pump system is controlled by liquid level controls on the supply tank and is only operational when the tank level drops.

However, the system generally pumps considerably below capacity due to an excessive build up of iron-based bacteria which develops inside the well screens and clogs the slots. As the supply tank is some 20 m above the well-points a charge of water from the supply tanks can be used to backwash the well screens in an attempt to clear the bacteria. To keep the system operational backwashing is required some 4 times a week. The water is used by Umgeni Water in the south Kwazulu-Natal urban water supply system. (Pillay, 1999).

2. Sand Dam, Umzinto River

This system also provides water for Umgeni Water and also experiences considerable problems with bio-fouling. Sediment had been excavated in a sand dam so that 10×2.4 m sections of 150 mm Johnson screen could be placed horizontally on the sediment with approximately 500 mm of water above each. This depth of water is maintained over the screens by water flowing over a weir. Each well-point is connected to a manifold running along the bank and at each junction there is a uPVC inspection cap above ground level which gives access to a gate valve to close off the line to the well-point.

The well-points had not been covered with sediment because the continual growth of black algae required regular monitoring and frequent blockages of the screens sometimes required their removal for cleaning. The system was regularly backwashed with some 50m head of pressure from the storage tanks in an effort to remove the growth.

3. Fairview Community Scheme, Mkomazi River

Two systems have been installed. The first by a local cane farmer for his own use, was thought to comprise a Johnson screen which delivered water to a false borehole in the river bank. However apart from observing a borehole pump this could not be verified. Following the success of this scheme the local farmer had assisted the local community to abstract water from the river for their use and to pump it 7 kms into the hills above the river where a piped water scheme was intended. However, the community were dissatisfied with the scheme which they said had not provided the water required and as the farmer was demanding payment for the water abstracted, the matter had been placed with courts for litigation. The community claimed that the scheme as advised by the farmer had not provided them with the designed supply of water and that the water had had an unpleasant taste when the scheme was first used. Clanahan, (1999) considers this to be due probably to a build up of iron-based algae. As a result the community had no interest in the scheme and had refused to pay either the water or electricity charges required.

Although the Mkomazi River was perennial, the abstraction scheme had been sited in a surface dry section where water was found at 1.6m below surface.

4. Community Scheme, Phungashe River

Water for a community, gravity reticulation scheme is drawn from a gabion abstraction box situated in a pool between two rock shelves. The pool has been deepened with a back-hoe to the rock base and the back-hoe used to place the gabion baskets onto the rock base. The outer gabion box measures $3 \times 5 \times 1.2$ metres deep with a second box inside. The abstraction box is thus comprised of two baskets, one inside the other with a 750 mm wide cavity between which is filled with large football-sized rocks on the outer side, progressing to smaller tennis ball sized rocks on the inside. This loose stonewall creates an interior cavity of free water, $1.5 \text{ m} \times 3.5 \text{ m}$ with 900 mm of standing water. The structure has a concrete slab over the entire surface with access through a tight fitting manhole to prevent the ingress of silt when the river is in flood. The gabion is held in place with eight 50 mm steel pipes at the corners and along the sides, which have been driven into the riverbed and then filled with concrete. The exterior surface of the gabion in the river is covered with geotextile to prevent excessive silt entering the free water abstraction area. However there is concern that the geotextile will block with either fine sediment or algae and thus diminish the water flow. Consequently more than 30×50 mm slotted uPVC pipes have been placed from the outer sides of the box, horizontally through the open cavity between. The intention is, if the geotextile blocks, to break the geotextile over the ends of these pipes to allow water to flow into the sump through the slotted pipes.

Within the sump are two submersible pumps supplying $1.8m^3$ water per hour to a nearby reservoir. At this reservoir are two progressive cavity pumps which pump to a supply tank 300 m higher up the hillside to the community above. From these tanks it is planned to have some 60 km of supply line. The Phungashe River is a mountain torrent with a 40 km² catchment with a high seasonal variation in flow, hence the need for such a secure form of abstraction system.

5. Umkomaas River Abstraction Site, Umgeni River

This system is also a part of the Umgeni Water supply system providing water to the urban and holiday areas along the Natal South Coast, south of Durban. The design of the scheme is similar to that of the Ntwalume water abstraction system, with six \times 150 mm \times 2.4 m Johnson screens placed in the sediment of the perennial river. The well-points are in turn connected to a manifold on the bank and connected to pumps in a secure pump house above the river bank. The river has been known to flood 4.5 m high, but can also virtually dry up. Consequently the South African Pulp & Paper Industry mill (SAPPI) some 250 m up stream from this abstraction point had constructed a sand bag weir for their own off take purposes and had undertaken to provide water to the Umgeni plant.

The well-point abstraction scheme is only now used if water from the diversion weir is excessively turbid when abstracting through the well-points significantly lowers treatment costs. When in use backwashing is carried out not more than once a week as the black iron based algae deposits are not as severe as with the Ntwalume scheme

6. St Faith's Boarding School, Mtwalume River

This scheme provides water to a 750 pupil secondary school overlooking the Mtwalume River. The site is high in the hills where the river is still very fast flowing and where the riverbed is predominantly comprised of rocks and cobbles with very little sand. The abstraction point is a sump with two submersible pumps 2 m from the edge of the river. The off-take for the sump is a $3.5 \text{ m} \times 15 \text{ m}$ long gabion which extends 7 m into the river. The rock-filled gabion extends to the bedrock of the river approximately 1m deep. An outer rock-fill wall 1.25 m wide creates a hollow centre to the gabion to the riverbed and allows water to enter from the gravel of the riverbed. Within this cavity there are two \times 250 mm diameter, class 10 uPVC pipes which have been slotted with an angle grinder and discharge into the sump. The exterior surface of the gabion is covered with woven geofabric (with the appearance of polypropylene sacking), which keeps sediment out of the pipes and the rock filled gabions are expected to keep the pipes in place. The gabion was constructed on the upstream side of a rock bar with the surface of the gabion barely above water level so that when the river is in flood the water merely flows over without damage.

The pumps deliver 7.2 m³/hr to a supply tank 60 m above the river to supply the boarding school. The intake system was designed by Simon Osborne of Silk, Kisch, Peralter Engineers, Newcastle, Kwazulu-Natal.

7. Ilovo Sugar Refinery, Stanger, Mvoti River

The system once supplied water to the entire sugar refinery plant, centre of an extensive sugar cane growing area around Stanger, north of Durban. The abstraction system had been set up in the 1950's but was apparently now considerably blocked with algae growth to the extent that the scheme had not been in use for over a year. The water abstracted from the system was also said to cause frequent blockages in the plants boilers. As an alternative system, a back channel had been constructed from the river to the plant from which water for the boilers was currently abstracted directly.

Unfortunately pump and installation details were sketchy. Three pumps of approximately 10 m³ per hour were housed in a solid subsurface structure with each connected to infiltration galleries which radiated under some 60m of marsh land reed beds into the perennial Mvoti river.

8. Umgeni Water Scheme, Umhlati River

The scheme also provides water to the Umgeni Water supply area. The abstraction point is sited some 15 m below a causeway and 100 m above a bend in the river where there was deep sediment below a steep rock cliff. However, sediment in the riverbed at the abstraction site was only 70-150 mm deep and comprised cobbles and coarse sand. Abstraction was through a gabion box 1 m deep and 6 m long which was placed laterally on the bed of the river. The gabion box was fitted with 3×100 mm Class 10 uPVC pipes which had been slotted with an angle grinder. The slotted pipes were installed at 1 m centres through the centre of the gabion box and were thus 50 mm from the bed of the river. Each infiltration gallery had a 45° uPVC bend with a rodding eye some 150 mm above the surface of the water. Access could thus be gained to the infiltration gallery for inspection and/or flushing out. These bends and rodding eyes were set in concrete which anchored the pipes to the river bed. The infiltration galleries were joined at the other end by a connecting manifold running across the river and straight to a pump house against the riverbank, 2 m in diameter and 5 m high. Entry was gained to the pump house from bank level where there were 2 electric motors which were shaft driving 2 centrifugal pumps at manifold level. Although this scheme was only 15 months old, swabs taken from inside the infiltration galleries through the rodding eyes already showed traces of algae growth.

9. Sindisi Abstraction system, Mona River

This system provides water to a rural community near the royal Zulu town of Nongoma. It also is a gabion system but unlike the earlier visited systems is not placed on rock but is 'floating' on sand sediment above a rock outcrop. The gabion box is constructed in a manner similar to other gabion abstraction systems and is 6 m long, 4 m wide and 1 m deep. Inside the sump of the gabion box are 2 slotted flexible drainage pipes of 100 mm diameter. A submersible pump is installed into each of the pipes and pumps directly to a community supply tank in the hills. The system was designed by Peter Glover of Glover Development Engineers (see attached design) but was unfortunately washed away during the 1999/2000 rainy season, (Glover, 1999).

10. Ngutu Abstraction scheme, Buffels River

The scheme provides the town of Nqutu with water from the Buffels River. It is comprised of 4 offset wells situated on the riverbank in a bend of the river. Each well has 4×150 mm diameter galleries of Johnson screening radiating at a depth of 2.70 m into the river sediment. The installation was carried out in 1974 and it is not clear how the installation was carried out. As the wells have an internal diameter of 3.5 m it is assumed that the screens were jetted in horizontally in 3 m section from inside the wells with one section added to another. The final length of each of the 16 galleries is not known. The false wells are however 6m deep and the galleries are 1.8 m from the floor of the wells. Each of the wells is connected with a 300 mm manifold which runs behind it, gravity supplying a large underground tank at the base of a 15 m high pump station. Pumps 3 m above the water level are shaft driven from the surface.

On the day of the visit attempts were being made to clean out the galleries due to considerable blockage of fine sediment and a slimy black algae resulting in the system only delivering approximately 20% of design. Each false well was emptied with a dewatering pump so that entry could be made into the well, this should not of course have been possible if the system was fully operational. The cleaning crew were intending to attempt to clean out the galleries using a 500 m³ per hour compressor. However they stated that in the past this had had very little effect. A visual inspection of the galleries with a high-powered torch, to a distance of about 10 m, revealed a pendulous growth of a black slimy, graphite like precipitation or growth. A decision not to use the compressor was taken, but at a later date to use hydrogen peroxide to dislodge the growth. This was in fact carried out in May 1999 and proved to be considerably more effective in the increase in water supply than the use of compressed air.

11. Makhosini Scheme, White Mfolozi River

This abstraction system provides water to a large rural boarding school and a nearby community. The system comprises a stainless steel box measuring $1.6 \text{ m} \times 1 \text{ m} \times 1 \text{ m}$ with series of 3.5 mm apertures around the sides and base. Although the site is beside a perennial mountain river, this caisson has been installed in deep sand sediment on the inside of a bend to reduce its vulnerability to flood damage. The caisson gravity discharges to false tube-wells with submersible pumps on the riverbank. The volume of water which can be abstracted was unfortunately not known.

12. Ulundi Water scheme, White Mfolozi River

This scheme was prime reason for the visits and the research which was being conducted at some 27 sites. The scheme was designed to supply water to 60,000 people in the town of Ulundi through an infiltration gallery system installed in the sediment of a balancing weir on the Wit Umfolozi River. The scheme was designed by Michelle Clanahan who at that time was with Chunnett, Fourie & Partners Consulting Engineers.

The scheme comprises 3 balancing gates in a weir across the river at a point where it is some 200 m wide. The actual barrage was built on rock but the basin had quickly become silted to a depth of several metres. The abstraction system was planned to utilise the draw off gallery of an earlier weir which ran transversely into the river channel. A new covered concrete gallery, 1.50 m high and 1.00m wide was constructed for 60 m in the base of the weir approximately in the centre of the river and at 90° from this original gallery. Each side of this new main gallery a series of 12 by 50 m × 150 mm Soloflo screens, now 2.5 m deep in the present sediment and comprising a total a length of 1,200 m had been installed some 50 m back from the present weir.

As with the Nqutu scheme only some 20% of abstracted design could be drawn on the date of site visit. By draining the weir, entrance was gained to the gallery with immediate access to the infiltration galleries. The floor of the gallery contained some 150 mm of fines and the infiltration galleries were seen to be clogged with the same black, graphite like slime as well as with a 'flaky' bright orange growth. On a visit almost a year earlier, Clanahan had placed boxes of equipment in 3 galleries where this growth might develop. One set contained small sections of 75 mm by 50 mm Soloflo screen and two sets contained sections of screen and 10 microscope slides for analysis. Unfortunately as this research was not completed, no data is available.

13. Ophazana Abstraction system, Sinceme River

This abstraction system was a further system installed in a mountain torrent for a rural community. This scheme was basically a 20 m concrete gallery placed longitudinally in the river with a right angle offset 20 m to the riverbank and a further right angle into a 60 m gallery along the riverbank to a sump. The sump contained 2 submersible pumps which supplied a reservoir. From the reservoir water was pumped to a supply tank in the hills from where a distribution pipeline supplied water to some 2,000 people.

The actual abstraction system was a 1 m wide, 1.5 m high concrete gallery constructed on the rock of the riverbed. The river had been temporarily diverted and the sediment excavated down to the rock base with a back-hoe. A 20 m long vee-shaped base to the

gallery was cast on the rock and from this shuttering was erected to cast the sides of the gallery. Open apertures 1 to 1.5 m long and 0.5 m high were left along the sides of the gallery near the base, with 1 m of concrete wall between. A screen was made for each aperture with a stainless steel plate perforated with 3.175 mm (1/8") holes and bolted over the apertures with stainless steel rawl bolts. The gallery was then filled with sand and covered with a plastic sheet so that a concrete slab could be cast on the top to form a cover. The stainless steel screens were then removed, the sand shovelled out, the gallery swept clean and the screens replaced. 19mm stone was then heaped against the gallery which was then covered with fist sized rocks and then with sand. The river was then returned to its original course and had covered the gallery with rock, cobbles and sand. However the far bank had continued to erode so that, in fact the river no longer flowed over the gallery but to one side of it. Despite this the system had been in place and working regularly for 18 months with no problems.

14. Denny Dalton Weir, White Mfolozi River

The scheme comprised a shallow concrete weir which effectively formed a subsurface dam. The river was some 25 m wide with predominantly coarse-grained sand both sides of the subsurface dam. The scheme was designed to supply 39 m^3 per hour to a rural community but it is quite likely that the yield would be considerably more than this.

In the weir basin three 25 m lengths of 250 mm slotted pipe had been installed. These galleries were placed at 6m centres longitudinally in the river. Raised concrete bases had been cast in the weir basin to support the galleries and inverted stainless steel U bolts also cast into the concrete to keep the screens in place. The screens also ran through the middle of galvanised mesh gabion baskets 4.75 m wide by 1.60 m high, filled with 6.00 mm stone. The gabions had in turn been covered with more rocks for protection and further filtering of the system. This construction then connected into a main gallery which was also slotted and ran along the inside edge of the weir wall. This lead to a pump which again delivered water to a hilltop from which a gravity distribution system served the surrounding community.

SOUTH AFRICA – CAPE TOWN – September 1998

Tube Well Jetting on the Cape Flats

The Cape Flats are comprised of water saturated gravel bed with water some 1-1.5 m below surface. This can be abstracted through jetted tube wells. This particular site was a suburban garden in Blouberg and the source of water for jetting was a swimming pool, but it could equally have been from a series of 200 litre drums and/or a return line to a settling tank. Jetting was through sections of 50 mm steel pipe, the first with serrations cut on the leading edge. At the top of this was a right angled bend and a short length of steel pipe. This was coupled to a flexible suction hose to a 50 mm centrifugal pump drawing water from the pool. In order to make a start through the ground surface a 75 mm uPVC pipe was hammered into the sandy ground to a depth of about 1m.

The jetting with the 50 mm steel pipe was started through this 75 mm pipe, simply by surging the pipe up and down to dislodge the underlying sand which was then washed out

of the top of the uPVC pipe. This continued down with sections of 50 mm pipe being added as required. Care was taken to ensure that penetration was slow and surging continuous in order to ensure that the water washed back up the outside of the jetting pipe and did not just blow into the surrounding sand. In this way a tube-well was formed in the sediment, without casing, and a depth of 7m was reached. A 1m length of 32 mm Soloflo slotted uPVC pipe with an aperture width of 0.25 mm and a sealed end was inserted into the bore and a 19 mm centrifugal pump attached to the top through a temporary flexible hose. With the pump in use the well-point was adjusted within the tube well to a point which provided the greatest flow of water. The tube well was set at this position and left. There was natural slumping of the unlined tube-well which resulted in a permanently placed well-point.

KEYNSHAM, SOMERSET, ENGLAND - July 1999

Ranney Well, Cadbury-Fry Chocolate Factory, River Avon

The Ranney well was sited 10 m back from the River Avon which was some 17m wide at this point. Five laterals radiated from the well, one of which went directly under the Avon. Four others, basically three on one side and one on the other, extended into the gravel bed of the riverbank. Unfortunately there was no record of the length of these infiltration galleries. The Works Engineer, Mr Dave Tilley, stated that the scheme was set up in the 1950's and that he remembered the lateral under the river bed as not being very deep into the river bed. At one stage, to increase infiltration, the riverbed had been raked of leaves and fine sediment but this had not been done since 1960 and the system had not been backwashed since about 1980. He also stated that the water was of a quality comparable to that of the town supply and that the water from the Ranney well had been used directly in the boilers of the factory. Although the system had been used for some 45 years it was no longer in use as all the water that was required by the factory was now being obtained from on site boreholes.

NAMIBIA - SWAKOPMUND - November, 1999

Subsurface Dam, Swakop River

It was apparent that this system was no longer in use. The river at this site was some 55 - 60 m wide with a sheer rock cliff which had been considerably eroded through the abrasive action of wind borne sand. On the other side of the sand-river was a natural sand dune, approximately 40-50 m high, encroaching into the river on the south side. Between these two, steel piling had been driven down to a depth of 17 m to the riverbed. According to Hayns, (1999), prior to installation the riverbed had been probe and the piling cut to lengths to conform to the riverbed profile. The lengths had then been driven in the river sediment with a steam hammer. The piling consisted of W section lengths and had individual locking rods to secure the sections. Initially the top of the piling was 1m below the sediment surface in order to prevent turbulence and damage when the river was in flow. However, it could be seen that the piling was now level with the upstream sediment and there was a ± 3 m drop to the sediment on the lower side.

In order to meet the demand of the coastal town of Swakopmund the system had been over abstracted and was now defunct. Although the concrete storage tanks, pumps and inlet pipes were still in situ, details of the abstraction system, well-point or infiltration gallery is unknown. An older, smaller pump system was also evident on the cliff which appeared to have a direct off take from the river. Swakopmund, which is surrounded by desert, now obtains its water from a blend of borehole water from along the coast and desalinated seawater, (Gould, 2001).

Palmenhorst Oasis, Swakop River

The site is on the Swakop River which crosses the Namib Desert, average rainfall 50 mm per annum. The scheme had been used to grow irrigated fodder crops for sheep on a desert farm. There were three, now vintage, pumps and stationary engines at the site, which had at various times abstracted water from the river sand. However, presently the irrigation scheme is unused and is in fact badly eroded and becoming covered with drifting sand. Water for the farmstead is presently abstracted from an open sump dug into the riverbank that contained water of dubious quality. In former days however Wipplinger, (1958) had conducted extensive research into the sand river water source of the irrigation scheme.

Map of Riverbed and Sand-abstraction Sites Visited in KwaZulu-Natal, (Map Studio, Struik Publishing Group, Durban, South Africa.



APPENDIX 02

Rainfall Readings from Zimbabwe Meterological Office Sites within +/- 25 kms of Field Research Sites

Tsholotsho - Huwana Field Research Site

Tsholotsho

Latitude 19 45S Longitude 27 46E

Season	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Annual	Season
80/81	0.0	0.0	1.0	6.0	163.9	64.2	203.6	137.3	114.7	33.7	2.5	0.0	726.9	80/81
81/82	0.0	0.0	0.0	16.7	140.6	63.2	15.8	19.4	0.5	37.4	0.0	0.0	293.6	81/82
82/83	10.8	0.0	1.0	135.7	73.9	63.7	97.9	76.3	42.9	91.2	14.7	0.2	608.3	82/83
83/84	10.5	0.0	0.0	27.9	79.3	87.8	22.0	73.5	76.0	5.0	0.0	8.0	390.0	83/84
84/85	8.5	0.0	9.5	61.0	63.6	102.5	166.5	120.5	2.0	17.5	0.0	0.0	551.6	84/85
85/86	0.0	0.0	0.0	3.0	12.6	203.0	109.7	51.9	64.1	181.5	0.0	0.0	625.8	85/86
86/87	0.0	0.0	35.5	36.5	63.3	79.7	48.7	69.7	25.6	0.0	0.0	0.0	359.0	86/87
87/88	0.0	0.0	0.0	14.4	64.0	179.7	76.8	118.0	111.4	22.4	0.0	27.3	614.0	87/88
88/89	0.0	0.0	0.0	62.5	34.4	75.5	130.9	183.1	5.2	40.2	0.0	0.0	531.8	88/89
89/90	0.0	0.0	0.0	39.3	45.0	32.7	118.5	66.7	21.0	40.3	14.5	0.0	378.0	89/90
90/91	0.0	0.0	0.0	12.0	32.6	98.7	119.2	191.0	142.2	0.0	0.0	0.0	595.7	90/91
91/92	0.0	0.0	0.4	30.4	38.1	98.8	35.9	35.0	46.0	0.6	0.8	0.0	286.0	91/92
92/93	0.0	0.0	0.0	52.0	141.0	136.7	90.7	97.9	67.6	25.8	5.2	0.0	616.9	92/93
93/94	0.8	0.0	40.4	12.5	208.6	87.9	189.6	63.0	21.1	0.0	15.7	0.0	639.6	93/94
94/95	0.0	0.0	0.0	27.8	29.4	80.2	50.6	16.5	20.6	6.6	22.8	0.0	254.5	94/95
95/96	0.0	0.0	0.0	56.6	63.2	212.0	223.2	194.4	30.9	31.0	37.6	0.0	848.9	95/96
96/97	0.0	0.0	0.0	51.3	117.2	158.9	192.9	34.6	118.7	27.8	0.0	0.0	701.4	96/97
97/98	0.0	0.0	87.2	7.7	68.5	93.5	212.8	36.5	60.7	3.0	0.0	0.0	569.9	97/98
98/99	nr	nr	nr	nr	nr	262.3	136.2	nr	65.6	nr	nr	nr	464.1	98/99
99/00	nr	nr	nr	nr	56.0	108.0	264.0	138.0	99.0	12.0	8.0	0.0	685.0	99/00
00/01	0.0	0.0	0.0	31.0	77.2	67.2	35.3	217.1	101.0	11.0	0.0	2.0	541.8	00/01
01/02	0.0	0.0	0.0	5.0	65.1	57.0	42.5	5.9	24.2	151.9	7.0	0.0	358.6	01/02
02/03	2.0	0.0	3.0	34.0	27.6	76.0	33.0	55.0	13.0					02/03
												Total	11,641.40	
										Low	254.5			
										High	848.9	22 yrs	529.2	Av

Kezi - Tshelanyemba Field Research Site

Kezi

Latitude 20 55S Longitude 28 27E

Season	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Annual	Season
80/81	0.00	2.20	12.20	29.10	187.60	53.10	157.80	166.70	116.20	18.90	13.60	0.00	757.40	80/81
81/82	0.00	0.20	9.70	39.50	123.90	48.00	22.30	21.70	13.70	29.70	5.10	0.00	313.80	81/82
82/83	7.00	12.20	0.00	94.10	42.30	32.20	16.20	67.90	50.00	49.00	0.00	0.00	370.90	82/83
83/84	3.00	10.90	0.00	10.00	87.40	48.00	14.20	6.00	101.00	23.00	0.00	0.00	303.50	83/84
84/85	0.00	0.00	23.00	35.00	69.70	102.60	133.80	98.70	3.60	1.00	1.00	0.00	468.40	84/85
85/86	4.10	0.00	1.40	60.00	2.00	72.60	9.50	29.00	7.00	105.10	0.00	0.00	290.70	85/86
86/87	0.00	0.00	1.00	67.50	149.10	83.80	26.80	13.00	7.00	0.00	0.00	0.00	348.20	86/87
87/88	0.00	0.00	3.00	7.10	32.00	230.90	40.60	219.90	174.40	12.20	5.50	14.90	740.50	87/88
88/89	0.00	3.60	1.00	51.00	48.00	29.70	85.30	85.40	9.10	26.10	0.00	6.20	345.40	88/89
89/90	0.00	2.00	0.00	23.10	89.70	30.10	102.50	51.40	28.00	17.50	2.70	0.00	347.00	89/90
90/91	0.00	0.00	0.00	8.90	23.40	144.90	144.80	115.40	157.60	0.00	0.10	0.10	595.20	90/91
91/92	0.00	0.00	0.00	1.50	38.60	36.50	70.60	14.80	29.90	1.00	39.00	1.50	233.40	91/92
92/93	0.00	0.00	0.00	40.00	25.70	188.10	62.50	108.00	1.00	25.70	0.00	0.00	451.00	92/93
93/94	18.00	0.00	6.60	5.20	214.80	111.50	33.00	109.00	0.00	0.00	0.20	0.00	498.30	93/94
94/95	0.00	0.20	1.10	60.20	41.90	47.40	39.50	169.80	164.10	9.50	19.90	0.00	553.60	94/95
95/96	0.00	0.00	0.00	0.30	91.10	108.40	318.80	117.70	31.20	0.20	13.00	0.00	680.70	95/96
96/97	22.90	0.00	0.00	10.30	157.60	28.70	140.70	40.30	51.10	19.80	8.20	0.00	479.60	96/97
97/98	0.00	0.00	36.00	38.30	77.90	11.20	202.20	14.00	4.20	0.00	0.00	0.00	383.80	97/98
98/99	0.00	0.00	0.80	29.00	64.00	133.40	107.50	79.20	47.50	7.50	0.00	0.00	468.90	98/99
99/00	0.00	0.00	1.30	16.20	103.60	92.20	288.50	326.30	149.70	12.90	13.70	77.60	1,082.00	99/00
00/01	0.00	0.00	0.00	3.50	65.30	68.10	30.30	214.30	45.40	2.90	3.00	0.00	432.80	00/01
01/02	3.50	0.00	7.00	31.60	137.10	57.90	47.90	15.30	0.20	33.80	0.00	10.80	345.10	01/02
02/03	2.70	0.00	13.80	60.00	15.20	32.00	19.00	100.00	79.00	nr	nr	nr	321.70	02/03
			25.2									Total	10,811.90	
										Low	233.4			
										High	1,082.0	22 yrs	491.5	

Matopos Sandveld - Wenlock Field Research Site

Matopos Sandveld

Latitude 20 24S Longitude 28 28E

Season	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Annual	Season
80/81	3.3	0.0	12.8	7.6	212.0	35.4	270.0	150.4	32.0	20.8	9.9	0.0	754.2	80/81
81/82	0.0	0.0	0.2	37.7	175.5	48.7	29.3	37.6	32.8	14.6	4.0	0.8	381.2	81/82
82/83	20.3	9.5	3.4	119.2	67.3	9.8	46.4	7.3	19.5	59.9	17.3	0.9	380.8	82/83
83/84	10.4	4.2	0.0	17.4	78.2	62.3	43.2	25.6	87.1	16.0	0.0	3.6	348.0	83/84
84/85	4.5	0.0	34.7	58.7	122.2	118.7	151.6	40.6	6.3	0.5	8.7	0.0	546.5	84/85
85/86	0.0	0.0	6.1	46.7	50.1	118.2	57.0	31.8	41.1	153.8	0.0	0.0	504.8	85/86
86/87	0.0	0.0	0.0	50.4	59.7	78.5	75.0	42.3	21.2	0.0	0.0	0.0	327.1	86/87
87/88	0.0	0.0	0.3	15.0	120.4	255.5	56.7	281.9	121.2	3.3	4.8	21.9	881.0	87/88
88/89	0.0	4.1	0.0	20.1	75.2	76.1	98.9	118.5	26.3	24.9	6.6	0.0	450.7	88/89
89/90	0.0	0.0	0.0	59.8	48.1	70.8	128.3	115.7	23.0	0.0	nr	0.0	445.7	89/90
90/91	0.0	0.0	0.0	20.2	30.7	98.0	108.7	65.9	nr	nr	nr	nr	323.5	90/91
91/92	nr	nr	0.0	5.2	86.8	43.8	75.6	2.8	68.1	0.0	0.0	0.0	282.3	91/92
92/93	0.0	0.0	0.0	11.2	56.1	173.7	128.6	110.3	48.7	19.8	0.0	0.0	548.4	92/93
93/94	9.2	0.0	39.1	7.5	118.4	128.4	88.2	23.1	2.0	0.2	0.0	0.0	416.1	93/94
94/95	0.0	0.0	0.0	59.5	68.9	91.5	110.6	122.6	118.3	40.4	0.0	0.0	611.8	94/95
95/96	0.0	nr	nr	68.9	96.1	162.8	293.9	164.4	6.5	1.0	0.0	0.0	793.6	95/96
96/97	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	0.0	96/97
97/98	1.6	0.0	49.7	23.0	72.1	48.0	230.1	25.9	29.6	2.0	0.0	0.0	482.0	97/98
98/99	0.0	0.0	0.0	8.0	103.1	114.0	101.6	54.9	38.0	3.0	0.0	0.0	422.6	98/99
99/00	0.0	1.5	0.0	23.1	161.7	149.3	160.6	303.8	170.0	13.1	13.8	65.0	1061.9	99/00
00/01	1.3	0.0	0.4	16.9	100.4	32.8	62.5	185.8	56.5	7.8	6.0	1.4	471.8	00/01
01/02	3.4	0.0	22.5	80.2	110.0	161.6	51.8	5.2	2.2	74.6	0.0	16.8	528.3	01/02
02/03	19.0	0.0	10.5	19.3	20.8	nr	nr	nr	nr	nr	nr	nr	69.6	02/03
	1							1115				Total	10,962.3	
										Low	282.3	1		
										High	1061.9	21 yrs	522.0	Av

Gwanda Rail - Wenlock Field Research Site

Gwanda Rail

Latitude 20 57S Longitude 29 01E Altitude 990M

Season	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Annual	Season
80/81	0.0	0.0	18.8	12.7	165.1	51.4	144.1	101.0	63.6	4.0	32.4	0.0	593.1	80/81
81/82	0.0	0.7	0.0	67.3	82.5	0.0	33.8	33.7	4.5	27.0	12.0	1.9	263.4	81/82
82/83	10.4	18.2	0.0	61.0	66.7	47.0	2.4	76.5	33.0	32.7	2.0	0.5	350.4	82/83
83/84	5.5	6.8	0.0	23.4	61.2	55.0	28.9	21.0	65.5	16.4	0.0	0.0	283.7	83/84
84/85	1.5	0.8	25.5	28.7	105.3	67.1	230.5	62.1	15.9	2.8	9.4	0.0	549.6	84/85
85/86	1.0	0.0	3.3	20.3	8.0	112.5	47.0	17.3	26.3	73.4	0.4	0.0	309.5	85/86
86/87	0.0	0.0	13.4	113.1	73.0	62.6	29.8	24.0	10.5	0.0	0.0	0.0	326.4	86/87
87/88	0.0	0.0	0.0	1.3	53.0	247.3	3.6	224.0	128.4	3.0	3.0	30.2	693.8	87/88
88/89	0.0	4.5	1.3	56.5	39.3	40.9	26.6	127.6	23.3	28.1	0.3	3.2	351.6	88/89
89/90	0.8	0.5	0.1	25.2	87.4	35.6	212.4	39.7	6.8	34.2	2.1	0.0	444.8	89/90
90/91	0.0	0.0	0.0	38.5	26.4	74.4	63.8	91.6	181.6	0.0	0.0	0.0	476.3	90/91
91/92	0.0	0.0	0.0	0.0	56.0	20.5	54.4	16.0	25.9	3.3	0.0	0.0	176.1	91/92
92/93	0.0	0.0	0.0	11.2	72.3	152.4	90.5	78.4	1.0	15.2	0.0	1.1	422.1	92/93
93/94	22.3	0.0	8.2	2.0	176.3	129.4	21.1	43.1	0.0	0.0	0.0	0.0	402.4	93/94
94/95	0.0	0.0	0.0	53.0	30.1	97.8	57.8	126.2	155.8	1.3	19.5	0.0	541.5	94/95
95/96	0.0	0.0	0.0	31.2	154.3	45.6	186.1	176.8	11.1	5.4	25.1	0.0	635.6	95/96
96/97	30.6	0.0	0.3	73.1	39.2	81.7	201.5	25.0	95.1	93.2	6.3	0.0	646.0	96/97
97/98	0.0	0.0	19.2	10.2	79.0	14.8	131.8	53.9	21.5	0.0	0.0	0.0	330.4	97/98
98/99	0.0	0.0	0.0	4.3	57.1	85.9	44.8	136.5	0.0	0.0	0.0	0.0	328.6	98/99
99/00	0.0	0.0	0.0	46.0	15.0	95.0	177.0	400.8	0.0	3.0	19.0	49.0	804.8	99/00
00/01	2.0	0.0	0.0	18.0	51.0	52.0	44.0	353.0	69.0	0.0	0.0	0.0	589.0	00/01
01/02	0.0	0.0	0.0	12.0	100.0	101.0	99.0	16.0	34.0	0.0	0.0	0.0	362.0	01/02
02/03	0.0	0.0	0.0	0.0	0.0	64.0	40.0	31.0	112.0	nr	nr	nr	247.0	02/03
												Total	9881.1	
										Low	176.1	6.00		
										High	804.8	22 yrs	449.1	Av



23 Year Rainfall at Sites in the Proximity of the Field Research Sites



98/99

00101

06197



45 Year Rainfall - Burnside, Bulawayo, Zimbabwe



Zimbabwe 100 year National Rainfall Average; 1901/02 - 2000/01

APPENDIX 03

DONGAMUZI FIELD RESEARCH SITE

Dongamuzi River

Overall runs north to south a	and at this point east to west
15,00m wide at this point	

Piezomenter Tubes & Core Samples; 4th	June '99
Bench Mark, Tell-tales & Height of Flow Meters + Rain Gauges; 4th	Nov '99
Bench Mark reading 25th	n Oct '00
Bench Mark, Slope of River 9th	April '01
Tell-tales & Height of Flow Meters 31s	t Oct '01
Profile probing, Bench Mark reading, Tell Tale investigation 11th	April '02
Tell-tales & Height of Flow Meters 27th	Sept '02
Sub-surface velocity readings 19th	May '03
Water surface reading, Bench Mark reading, Tell Tale investigation 2nd	July '03

1 Riverbed Gradient

•			
500	metres ea	ach side of piezometer tube line	
	1	500 m above	1.17

	Gradient	1 in	350		0.29	%
	1000					-2.87
11	<u>100</u>	500 m belo	w	1.97		-0.34
10	100	400 m belo	w	1.63		-0.27
9	100	300 m belo	W	1.36	1.95	-0.30
8	100	200 m belo	w		1.65	-0.29
7	100	100 m belo	w	1.99	1.36	-0.34
6	100	Piezometer	line	1.65	1.56	-0.13
5	100	100 m abov	/0	1.51	1.43	-0.16
4	100	200 m abov	/0	1.35	1.54	-0.35
3	100	300 m abov	/8	1.86	1.19	-0.45
2	100	400 m abov	/8	1.41		-0.24
Dongamuzi River

2 Sediment Surface & Water Surface Slope

	Water		Surface		Water		Surface	
22-May-03								
100 m East	0.000		1.395	0.000	0.000		1.282	0.000
50 m East	2.548	0.000	1.614	-0.219	2.574	0.000	1.600	-0.318
Piezometers	2.728	-0.180	1.747	-0.133	2.724	-0.150	1.742	-0.142
Piezometers	2.640		1.459		2.570		1.502	
50 m West	3.065	-0.425	1.910	-0.451	2.995	-0.425	1.935	-0.433
50 m West					2.775		1.715	
100 m West	0.000	0.000		0.000	2.922	-0.147	1.835	<u>-0.120</u>
		-0.605		-0.803		-0.722		-1.013
Water surface level over 1	00 m			Water sur	face level or	/er 150 m		
		-0.605 (m		-0.722 n	n		
Water surface slope is 1 in	ı			Water sur	face slope is	s 1 in		
		165	0.61	%	207	0.48 9	б	
Surface level over 100 m		-0.803 ו	m	Surface le	vel over 200) m	-1.013 ı	n
Surface slope is 1 in				Surface sl	ope is 1 in			
		187	0.53	%	197	0.51 9	6	

Water was not obtained in each hole and water depth from surface varied depending on consistency of sediment, depth/proximity of mudrock

Dongamuzi River

2 Sediment Surface & Water Surface Slope

	Water	:	Surface		Water		Surface	
22-May-03								
100 m East	0.000		1.395	0.000	0.000		1.282	0.000
50 m East	2.548	0.000	1.614	-0.219	2.574	0.000	1.600	-0.318
Piezometers	2.728	-0.180	1.747	-0.133	2.724	-0.150	1.742	-0.142
Piezometera	2.640		1.459		2.570		1.502	
50 m West	3.065	-0.425	1.910	-0.451	2.995	-0.425	1.935	-0.433
50 m West					2.775		1.715	
100 m West	0.000	0.000		0.000	2.922	-0.147	1.835	<u>-0.120</u>
		-0.605		-0.803		-0.722		-1.013
Water surface level over 1	100 m			Water sur	face level or	ver 150 m		
		-0.605 n	n		-0.722 n	n		
Water surface slope is 1 in	n			Water sur	face slope is	s 1 in		
		165	0.61	%	207	0.48 9	6	
Surface level over 100 m		-0.803 n	n	Surface le	vel over 200	0 m	-1.013 m	I
Surface slope is 1 In				Surface sl	ope is 1 in			
		187	0.53	%	197	0.51 9	6	

Water was not obtained in each hole and water depth from surface varied depending on consistency of sediment, depth/proximity of mudrock

,

Dongamuzi River

2 Sediment Surface & Water Surface Slope

	Water		Surface		Water		Surface	
22-May-03								
100 m East	0.000		1.395	0.000	0.000		1.282	0.000
50 m East	2.548	0.000	1.614	-0.219	2.574	0.000	1.600	-0.318
Plezometers	2.728	-0.180	1.747	-0.133	2.724	-0.150	1.742	-0.142
Plezometers	2.640		1.459		2.570		1.502	
50 m West	3.065	-0.425	1.910	-0.451	2.995	-0.425	1.935	-0.433
50 m West					2.775		1.715	
100 m West	0.000	0.000		0.000	2.922	-0,147	1.835	<u>-0.120</u>
		-0.605		-0.803		-0.722		-1.013
Water surface level over 1	00 m			Water sur	face level ov	/er 150 m		
		-0.605 (m		-0.722 m	1		
Water surface slope is 1 in	1			Water sur	face slope is	s 1 in		
		165	0.61	%	207	0.48 9	6	
Surface level over 100 m		-0.803 (m	Surface le	ivel over 200) m	-1.013	m
Surface slope is 1 in				Surface sl	lope is 1 in			
		187	0.53	%	197	0.51 9	6	

Water was not obtained in each hole and water depth from surface varied depending on consistency of sediment, depth/proximity of mudrock

Dongamuzi River

2 Sediment Surface & Water Surface Slope

	Water		Surface		Water		Surface	
22-May-03								
100 m East	0.000		1.395	0.000	0.000		1.282	0.000
50 m East	2.548	0.000	1.614	-0.219	2.574	0.000	1.600	-0.318
Piezometers	2.728	-0.180	1.747	-0.133	2.724	-0,150	1.742	-0.142
Plezometers	2.640		1.459		2.570		1.502	
50 m West	3.065	-0.425	1.910	-0.451	2.995	-0.425	1.935	-0.433
50 m West					2.775		1.715	
100 m West	0.000	0.000		0.000	2.922	<u>-0,147</u>	1.835	-0.120
		-0.605		-0.803		-0.722		-1.013
Water surface level over 1	00 m			Water sur	face level o	ver 150 m		
		-0.605 r	n		-0.722 n	n		
Water surface slope is 1 in	1			Water sur	face slope la	a 1 in		
		165	0.61	%	207	0.48 9	6	
Surface level over 100 m		-0.803 r	n	Surface le	vel over 20	m C	•1.013 r	n
Surface slope is 1 in				Surface s	lope is 1 ln			
		187	0.53	%	197	0.51 9	6	

Water was not obtained in each hole and water depth from surface varied depending on consistency of sediment, depth/proximity of mudrock

Manzamnyama River,

Overall runs east to west and at this point south-east to north-west 61,00m wide at this point

Piezomenter Tubes & Core Samples;	20th May '99
Bench Mark, Tell-tales & Height of Flow Meters + Rain Gauges;	11th November '99
Bench Mark readings;	14th September 00
Tell-tale Investigations	19th October '00
Chain tell-tale, cleared plezometer tubes & well-point trials	2nd November '00
Core sediment samples (attempt), Tell-tale chains	22nd March '01
Core sediment samples	25th April '01
Evaporation pan, New tell-tales jetted, Bench-mark to sediment readings	18th May '01
New piezometer tubes. Driven tell-tale chain	9th November '01
Site checked, Evaporation pan moved	4th April '02
Riverbed profile	13th Nov '03

1 <u>Riverbed Gradient</u> 500 metres each side of piez

0 metres	each side of	piezometer tube lin	8				W	idth of Riv	er	North bani S	outh bank
							С	hannel wi 1	Total width	height	height
1		500 m above		1.35				24.50	99.50	1.75	1.00
2	100	400 m above		1.41		-0.06		29.00	121.50	2.00	0.50
3	100	300 m above		1.67	1.37	-0.26		44.50	110.00	2.00	0.50
4	100	200 m above			1.42	-0.05		44.50	92.00	2.00	0.25
5	100	100 m above		1.48	1.66	-0.24		26.60	62.00	2.00	1.25
6	100	Piezometer lin	e	1.64		-0.16		27.00	61.00	1.25	2.25
7	100	100 m below		1,78	1.34	-0.14		47.00	85.00	0.75	2.50
8	100	200 m below			1.58	-0.24		28.00	71.50	0.80	2.75
9	100	300 m below		1.36	1.55	0.03		44.00	61.00	1.50	3.00
10	100	400 m below		1.62		-0.26		33.00	64.50	1.50	2.50
11	<u>100</u>	500 m below		1.75		-0.13		44.00	63.50	1.50	1.50
	1000					-1.51					
		Slope is	1 in	660	-	662.25	0.15 %				

.

Manzamnyama River,

2 Sediment Surface & Water_Surface Slopes

		0	6/12/2003		15/06/	03	22/06/	/03	29/06/	03	07/01/2	003	07/06/2003		13/7/2003		20/7/2003	3
		Surface	Water		Water		Water		Water		Water		Water		Water		Water	
1	50 m NW	1.555	1.74	-0.24	1.75	0.02	1.80	0.04	1.86	0.02	1.87	0.03	1.90	0.05	1.93	0.07	1.995	0.059
2	50 Piezomete	1.558	1.50	0.11	1.77	-0.15	1.84	-0.15	1.88	-0.11	1.90	-0.13	1.95	-0.155	2.00	-0.18	2.054	-0.164
3	<u>50</u> 50 m SE	1.529	1.61		1.62		1.69		1.77		1.77		1.795		1.82		1.890	
	100			-0.13		-0.13		-0.110		-0.090		-0.100		-0.105		-0.110		-0.105
	Slope is 1 in		-769		-769		-909		-1111		-1000		-952		-909		-952	
			0.13 %		0.13 9	ж.	0.11 9	*	0.09 %		0.10 %		0.11 %		0.11 %		0.15 %	

Manzamnyama River,

3 River Channel Profiles

3

Riverbed Profile

Length of Probe

Readings across the river	2	10	20	30	40	50	60	70	80	90	100	110	120
500 m NW	1.46	1.56	1.63	1.48	2.35	1.07	1.15						river width 63 m - last reading at 60 m
400 m NW	1.42	1.79	1.52	2.43	2.39	2.30	0.86						river width 65 m - last reading at 60 m
300 m NW	0.13	2.25	2.76	2.42	2.07	2.78	1.88						river width 64 m - last reading at 60 m
200 m NW	0.90	1.50	2.03	1.35	2.03	2.20	1.90	2.30	1.76	0.48			river width 90 m - last reading at 90 m
100 m NW	2.85	2.90	3.30	3.30	2.40	2.34	2.26	1.65	1.95	1.70			river width 89 m - last reading at 85 m
Piezometer line	0.90	2.82	2.65	3.30	2.06	2.75	2.02						river width 65 m - last reading at 55 m
100 m SE	1.45	2.70	1.43	0.00	2.67	0.94	0.86	1.80	0.53				river width 74.7m - last reading at 73 m
200 m SE	1.23	1.72	2.25	2.24	2.07	1.09	0.00	1.14	1.34	0.98			total river width 90.5m - last reading at 87 m island from 59.2 to 64.3
300 m SE	1.54	2.33	1.39	0.70	0.78	0.90	1.17	1.23	1.10	1.10	1.10		river width 99.5m - last reading at 97.5 m - sand bank .35m high at 50m mark
400 m SE	1.30	1.27	0.95	1.58	1.65	1.00	0.74	1.75	0.90	1.10	1.13	1.74	1.52 river width 123.7m - sand bank between 40 and 50m marks
500 m SE	1.00	1.26	1.10	2.62	1.34	2.54		0.63	0.63	0.78	0.66		river width 99.3m - last reading at 97 m - island forming from debris collected at old well at 30m mark, island at 60m



Manzamnyama River,

Riverbank & Sediment Surface Profiles

	Riverbed	Bank	Distance		Riverbed	Bank	Distance								
100m SE	2.7	0.88	12.7		3.33	0.97	2.5								
200m SE	2.15	1.33	32.0		3.08	0.88	2.2								
300m SE	1.4	0.78	21.0		2.65	0.37	1.5								
300m SE		0.67	7.0												
400m SE	2.84	1.54	7.9		2.35	0.02	2.0								
500m SE	2.88	1.62	7.2		2.37	0.52	1.0								
4 <u>Aqqrada</u> /Degradatio	ation_ on of Sedir	nent	11/11/1999	14/09/00	Annual Los	18/05/01	Annual Los	Fotal Los	12/08/02	Annual Los	rotal Los	01/07/03	Annual Los	Fotal Loss Gain	Lo Date
Bench Mark			0.98	0.69		1.48			1.65			1.61			
Sediment	Site		2.99	2.76	0.06	3.63	0.08	0.14	3.68	-0.02	0.12	3.60	-0.14	-0.02	
	East Peg:		18.88m									1.45			
	West Peg:		19.42m												
Sediment	Site		3.05	2.79	0.03	3.67	0.09	0.12	3.65	-0.09	0.03	3.51	-0.20	-0.17	
	East Peg:		28.28m												
	West Peg:		28.77m												
Sediment	Site		2.96	2.77	0.10	3.57	0.01	0.11	3.63	-0.01	0.10	3.56	-0.13	-0.03	
	East Peg;		38.79m												
	West Peg;		38.93m												
Sediment	Site		3.10	2.81	0.00	3.65	0.05	0.05	3.7	-0.02	0.03	3.65	-0.11	-0.08	
	East Peg;		53.77m												
	West Peg;		53.58m												

Manzamnyama River,

5 Porosity		
Sediment	248.6	gms
	218.9	
	237.2	
	271.3	
	279.6	
	280.0	
	256.8	
	1,792.4	
Water	681.0	ml
Total	2,473.4	
Porosity	27.5	%

6 Permeability

Length of sample (I)	10	cm	10	cm	10	çm
Cross sectional area of sample (A)	177	cm2	177	cm2	177	cm2
Volume of water (q)	100	ml	100	ml	100	mi
Duration of test (t)	9.34	5905	9.33	59CS	9,26	80CS
Head difference (h)	3.00	cm	2.80	cm	2.90	cm
Permeability	0.202	cm/sec	0.217	cm/sec	0.211	cm/sec
	7.27	m/hr	7.80	m/hr	7.59	m/hr

7 Core Sample Sites

1 Depth	1.85m	East Peg;	28.60m	Between 1st & 2nd Peizometer Tubes
		West Peg;	28.40m	
2 Depth	2.00m	East Peg;	40.40m	Between 2nd & 3rd Peizometer Tubes
		West Peg;	40.50m	
3 Depth	1.95m	East Peg;	52.50m	Between 3rd & 4th Peizometer Tubes
		West Peg;	52.50m	

Manzamnyama River,

25/04/01	2 succes	2 successful samples drawn											
	1 Depth	4.075m	East Peg	29.15m 28.51m									
			West Peg										
	2 Depth	4.100m	East Peg	46.50m									
			West Peg	46.61m									

8 Peizometer Tube Positions 4 Peizometer tubes, in line with the bench mark across the river

				New tubes in	stalled 0	9/11/01
1	Depth of Tube	2.00m			2.00	Not to bottom of sediment
South	East Peg;	22.65m			22.76	
side	West Peg;	22.60m			22.55	
2	Depth of Tube	4.00m			4.00	To bottom of sediment
Centre	East Peg;	34.35m			34.55	Replaced - covered with geotextile & jetted in 2nd Nov '00
South	West Peg;	34,35m			34.44	
3	Depth of Tube	4.00m	To bot	tom of sed	4.00	•
Centre	East Peg;	46.30m	46.47	Replaced	46.40	
North	West Peg;	46.20m	46.40	with a 2,{	46.38	
				filled with 6	i00mm se	ediment
4	Depth of Tube	2.00m			2.00	Not to bottom of sediment
North	East Peg;	58.20m			58.27	
side	West Peg;	58.35m			58.22	

Manzamnyama River,

9 Tell-Tale

<u>Chains</u> Placement 1, South Side of River Installed 11th Nov '99 chain jetted to 1.75 m - cut 100mm below surface East Peg; 29.90m 19th Oct '00 chain found at depth of 1.07m - Maximum depth of flow 1.07 m West Peg 27.70m Placement 2, North Side of River Between 3rd and 4th Pelzometer Tubes East Peg; 49.17m West Peg 49.10m Chain Installed 8th June '00 chain jetted to 1.40 m - chain cut 100mm below surface Placement 1, South Side of River East Peg; 2nd Nov '01 chain found at depth of 31 cm - Maximum depth of flow 0.31 m 30.38 West Peg 30.92 <u>Chain</u> Installed 9th Nov '01 chain driven to 2.80m - chain cut 100mm below surface Placement 2, North Side of River 21st Oct '02 chain found at depth of 34 cm - Maximum depth of flow 0.34 m 49.70 East Peg; West Peg 50.10 Check marker peg driven in 0.30m SE of tell tale chain East Peg; 49.52 West Peg 49,96 <u>Chain</u> Installed 18th May '02 chain driven to 2.87m - chain cut 100mm below surface East Peg; 38.00 1st July '03 chain found at depth of 17 cm - Maximum depth of flow 0.17 m West Peg 39.30 Aluminium Tubes 31 x 100mm AI Tubes placed from River Bed to Surface in a continuous line Placement 2, West Side of River Between 1st & 2nd Peizometer Tubes East Peg; 28.38m

	West Peg	28.48m	09/11/01 Not1	found
	Depth of Pk	cement	De	opth of Placement
1	3.20		17	1.60
2	3.10		18	1.50
3	3.00		19	1.40
- 4	2.90		20	1.30
5	2.80		21	1.20
6	2.70		22	1.10
7	2.60		23	1.00
8	2.50		24	0,90
9	2.40		25	0.80
10	2.30		26	0.70
-11	2,20		27	0.60
12	2.10		28	0.50
13	2,00		29	0.40
-14	1.90		30	0.30
15	1,80		31	0.20
16	1.70		Surface	

Manzamnyama River,

Aluminium Tubes 21 x 100mm Al Tubes placed from River Bed to Surface in a continuous line Placement 2, West Side of River Between 3rd & 4th Peizom Between 3rd & 4th Peizometer Tubes

.,					
	Eas	st F	'eg;	52	.10m

West Peg 52.22m

D	epth of Placement	Depth of P	lacement
1	2.20	12 1.10	
2	2.10	13 1.00	
3	2.00	14 0.90	
4	1.90	15 0.80	
5	1.80	16 0.70	
6	1.70	17 0.60	
7	1.60	18 0.50	
8	1.50	19 0.40	
9	1.40	20 0.30	
10	1.30	21 0.20	
11	1.20	Surface	

Water flowed 2,50m - 3,00m deep during the 99-00 rains

19th Oct '00 - Dug to 1,48m (to water level) and probed another 300 - 350mm but found no tell-tales

Zinc Disks

Placement 1, V	Vest Side o	f River		Between Rive	r Bank &	1st Peizometer Tubes
	East Peg;		16.12m			
	West Peg	:	16.22m			
			Incremental Rise of	Depth to Sed	iment	Amount of
	Depth of F	Placement	Tell-tale Placement Pi	ipe After Each Ri	ise in Pip	Sediment added
1	1.75	In Water	River Bed	2.70	-	2.70
2	1.50	In Water	0.25	2.63	0.07	2.56
3	1.25	In Water	0.25	2.85	0.17	2.68
4	1.00	In Water	0.25	2.98	0.30	2.68
5	0.75	In Water	0.25	2.93	0.27	2.66
6	0.50	In Water	0.25	2.90	0.22	2.68
7	0.25	In Water	0.25	2.98	0.30	2.68
Surface	-	Damp	0.25	-	-	-

Water flowed 2,50m - 3,00m deep during the 99-00 rains

19th Oct '00 - Dug to 1,55m (to water level) and probed another 300 - 350mm but found no tell-tales

Placement 3, C	entre of Ri	ver		Between 2nd & 3rd F	eizometer Tub	es
	East Peg;		40.13m			
	West Peg	;	40.22m			
			Incremental Rise of	Depth to Sediment	Amount of	
	Depth of F	lacement	Tell-tale Placement P	pe After Each Rise in Pi	p Sediment ad	bet
1	1.75	In Water	River Bed	2.50	0.27	2.23
2	1.60	In Water	0.25	2.17	•	2.17
3	1.25	In Water	0.25	2.27	0.10	2.17
4	1.00	In Water	0.25	2.30	0.13	2.17
5	0.75	In Water	0.25	2.28	0.11	2.17
6	0.50	In Water	0.25	2.29	0.12	2.17
7	0.25	In Water	0.25	2.40	0.24	2.16
Surface	•	Damp	0.25	-	-	-

Shashane River,

Overall runs north to south and at this point north to south 132,00m wide at this point

Site Visits

Piezomenter Tubes & Core Samples;19th May '99Bench Mark, Tell-tales & Height of Flow Meters + Rain Gauges;28th Oct. '99Bench Mark readings, Height of Flow Gauges, Checking - Piezometer Tubes (No. 4 be 7th Nov '00Core samples, Evaporation Pan set upCore samples, Evaporation Pan set up16th May '01Bench Mark readings, River slope, Replaced 4 Piezometer Tubes25th Oct. '01Bench Mark readings, River bed profile (south)9th April '02

1 River Gradient

Measurements taken 500 metres each side of piezometer tube line

1		500 m ab	ove	1.90		
2	100	400 m ab	ove	1.74		0.16
3	100	300 m ab	ove	1.54	1.09	0.20
4	100	200 m ab	ove		1.42	-0.33
5	100	100 m ab	ove	1.26	1.86	-0.44
6	100	Piezomet	er line	1.66		-0.40
7	100	100 m be	low	1.65	1.04	0.01
8	100	200 m be	low		1.49	-0.45
9	100	300 m be	low	1.80	1.83	-0.34
10	100	400 m be	low	1.56		0.24
11	<u>100</u>	500 m be	low	2,22		-0.66
	1000					-2.01
	Slope is	1 in	500		0.20	%

2 Sediment Surface & Water Surface Slope

100m north Piezometer Line 100m south	Water 1.825 2.115 2.515	-0.290 <u>-0.400</u> -0.690	Surface 2.655 2.785 3.185	-0.130 <u>-0.400</u> -0.530
Slope is	1 in	290 0.34	1 in	377 0.27 %

Shashane River,

3 River Chann	nel Prot	files																			
Riverbed Profile	e																				
		Length	of probe		3.10	metres								Last rea	ding 2.00	m before	e river ba	ank			
	Probe in	ntervals a	cross the	river bed	d - west	to east													river		
Distance from to last rea	river bank ading	80	70	60	50	40	30	20	10	Centre	10	20	30	40	50	60	70	80	from river bank to last	m	
																					m width of river, last
500m North	1.00				1.46	2.23	2.56	2.37	1.59	2.45	1.73	2.50	1.00	1.64	1.99				1.00	100.00	reading 98m
																					m width of river, last
400m North	1.00	1.50	2.24	2.14	2.14	2.53	2.63	1.58	2.39	2.42	2.49	1.73	1.52	1.42	1.14	0.96	1.45	1.15	1.00	147.10	reading 145.1
																					m width of river,f last
																					reading at 152.7, island
300m North	1.00	0.50	1.02	1.04	1.66	2.72	2.82	3.10	2.35	2.40	2.16	1.15	1.65	1.97	1.43	0.20	1.36	1.29	1.00	154.70	with grass at 140m
200m North	1.00		0.89	0.87	1.75	2.09	3.02	2.52	2.97	2.47	2.68	2.79	1.60	1.99	1.75	1.85	1.18		1.00	136.60	m width of river
																					m width of river, last
																					reading 138.1, silt layer at
100m North	1.00		0.57	1.67	2.37	2.32	2.22	2.82	1.52	2.31	1.95	2.05	2.48	1.28	1.58	1.71	1.04		1.00	140.10	60m and at 1.02 at 70m
Piezometer Tubes	1.00		1.10	1.60	2,15	2.85	3.10	2.30	1.72	1.84	1.87	2.42	1.45	1.80	2.44	1.87	0		1.00	132.10	m width of river
100m South	1.00	1.50	2.10	2.83	2.90	2.63	1.40	2.70	1.10	1.75	1.83	2.05	1.87	2.20	2.24	1.59	1.55	0	1.00	148.70	m width of river
200m South	1.40		2.90	2.93	2.47	2.97	2.52	2.27	1.57	1.26	2.05	2.65	2.69	1.87	1.95	1.10	0		1.40	142.80	m width of river
300m South	4.00	2.50	2.22	2.23	2.58	2.85	2.58	2.08	3.10	2.76	2.57	1.33	1.80	0.08	0.35	0.27	0.96	1.03	4.00	168.00	m width of river



Appendix 03

Field Research Site Data

Shashane River,

River Ba	ank & S	edime	ent Surfa	ace Prot	file																		
-	-10 Ba	ank	River	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	River Ec I	River Ban	10	River Edge
500m	1.79	3.76	3.57	3.35	3.28	3.26	3.33	3.41	3.49	3.56	3.41	3.32	3.29								2.68	2.51	100.00
400m	2.28	3.39	3.76	3.65	3.62	3.41	3.28	3.29	3.41	3.56	3.6	3.62	3.64	3.88	3.71	3.78	3.66	3.28	3.27		2.01	2.06	145.10
300m	1.52	2.71	2.48	3.41	3.37	3.21	2.93	2.91	2.84	3.16	3.51	3.49	3.40	3.38	3.39	3.23	3.20	3.21	3.26	2.76	2.12	2.13	152.70
200m	1.69	2.37	3.03			3.03	3.02	2.93	2.82	2.69	2.53	2.49	2.46	2.57	3.10	3.12	3.43			3.34	2.98	1.00	134.60
100m	1.54	2.29	3.68	3.59	3.46	3.44	3.45	3.49	3.47	3.39	3.48	3.45	3.55	3.59	3.79	3.77	3.70			3.73	2.51	1.43	138.10
										.0			×0			Cale							
						<i>D</i> ;		<i>D</i> 2	°0	p.	<i>D</i> .	.0	,0 ²	0.		SS ¹							
						-ElGan		el Gall	Gaint		- ElGan	Gain		-slGan	Gain								
						0 5	alor	ै ्र	5	Ň	0 ⁵ 0	551	N.	ون رو	55								
4 <u>Aggr</u>	adation	/ Dec	radatior	<u>n of</u>	mia		nuo	a) v		milo	NO.		nuia	tal									
<u>Sedime</u>	<u>nt</u>				67.		b7.	X 0		62.	X 0		b.	X 0									
			29/10/99	7/7/00		25/10/01			9/4/02			30/06/03											
Bench Ma	ark		1.20	1.97		1.58			0.67			1.42											
Sedim Site	e		2.56	3.25	-0.08	2.92	0.06	-0.02	2.02	0.01	-0.01	2.78	0.01	0.00									
NO	rth Peg;		17.60m																				
So	uth Peg;		17.76m																				
Sedim Site	e		2.43	3.26	0.06	2.79	-0.08	-0.02	1.92	0.04	0.02	2.72	0.05	0.07									
No	rth Peg;		43.20m																				
So	uth Peg;		43.10m																				
Sedim Site	0		2.48	3.24	-0.01	3.00	0.15	0.14	2.04	-0.05	0.09	2.62	-0.17	-0.08									
No	rth Peg;		65.58m																				

•

South Peg; 65.37m

.

Shashane River,

5 Porosit	Υ.				
Sediment					
	360.9				
	361.7				
	324.4				
	187.0				
	1,608.4				
Water	<u> </u>				
	2,379.4				
Porosity	32.4 %				
6 Permea	ibility				
Length of san	nple (i)	10	cm	10	cm
Cross section	al area of sample (A)	177	cm2	177	cm2
Volume of wa	ter (q)	100	ml	100	ml
Duration of te	st (t)	9.40	Secs	8.80	Secs
Head differen	ce (h)	5.40	cm	5.60	cm
Permeability		0.111	cm/sec	0.115	cm/sec
		4.01	m/hr	4.13	m/hr

7 Core Sample Sites

16/05/01

1 Depth	1.950m North Pe 19.47m	
	South Pe 17.58m	Probed to 2.05m - to clay of river bed
2 Depth	2.14m North Pe 39.00m	
	South Pe 37.20m	Probed to 2.80m - may have been well into clay of river bed
3 Depth	1,68m North Pe 73.48m	
	South P∉ 72.49m	Probed to 1.73m - to clay of river bed (failed to draw clay sample)
		Stone +/- 52x38x27mm wedged in bottom of coring auger - prevented 130mm entering
4 Depth	1.665m North Pe108.00m	
	South Pe108.63m	

8 Peizometer Tube Positions

		Depth offiezometeliezometelezometer						
4 Peizomel	ter tubes, in line with		New Tub	Tubes	Tubes	Tubes	Tubes	
		m	m	m	m	m	mm	mm
1	Depth of Tube	2,20m	1.60	1.41	1.71	-	800	0
	North Peg;	31.84m From west bank	32.67					
	South Peg;	32.47m From west bank	32.15					
2	Depth of Tube	2.95m	2.80	2.59	1.70	- 0.01	540	260
	North Peg;	58.92m From west bank	59.40					
	South Peg;	59.30m From west bank	59.05					
3	Depth of Tube	3.45m	2.80	2.53	1.69	- 0.02	820	-20
	North Peg;	85.00m From west bank	86.25					
	South Peg;	86.18m From west bank	86.00					
4	Depth of Tube	3.10m Readings from East bank (not west bank)	2.15	2.07	1.84	0.13	570	230
	North Peg;	29.80m To bolt at base of Umpafa tree on East bank	30.13					
	South Peg;	29.93m To bolt at base of Mdubi tree on East bank	29.95					

Shashane River,

9 Tell-tales

Chains

.

				Installed 16th May '00 chain jetted to 1,75 m - cut 100mm below surface
1 Depth	1.33m	North Pe 4	16.60m	30th June '01 chain found at depth of 85 cm - Maximum depth of flow 0.85 m
		South P€ 4	19.97m	
2 Depth	2.30m	North Pe 9	97.50m	13th July '02 chain found at depth of 23 cm - Maximum depth of flow 0.23 m
		South Pe 9	97.60m	
				30th Sept '03 chain found at depth of 25 cm - Maximum depth of flow 0.25 m

<u>Aluminium Tubes</u> 17 x 100mm Al Tubes placed from River Bed to Surface in a continuous line North Peg; 12.93m Installed 28th Oct '99

	South Peg; 13.46m
	Depth of Placement
1	1.80
2	1.70
3	1.60
4	1.50
5	1.40
6	1.30
7	1.20
8	1.10
9	1.00
10	0.90
11	0.80
12	0.70
13	0.60
14	0.50
15	0.40
16	0.30
17	0.20
•••	

Surface

25/10/00

Efforts to locate tell-tales - Excavated site to water level at 0.87 m, no tell-tales located.

Continued +/- 300 mm below water level, still no tell-tales

Observed layer of cobbles at 1,00 m which would be the effective river bed in the previous (2000 - 2001) season Dimension of cobbles excavated mm.

296x65x60	270x180x30	160x160 100x100x25
120x80x70	117x112x75	110x80x 100x85x25

Zinc_disks

Placement	1, West Side	of River		Between River bank & 1st Peizometer Tubes
	North Peg;		19.40m	13.35 m from each
	South Peg;		19.34m	
			Incremental Ris	eof
	Depth of Pla	cement	Tell-tale Placen	nent Pipe
1	1.67	Wet	River Bed	
2	1.25	Dry	0.37	
3	1.00	Dry	0.25	
4	0.75	Dry	0.25	
5	0.50	Dry	0.25	
6	0.25	Dry	0.25	
Surface	•	Dry	0.25	

Shashane River,

Placement 2, Centre west of River					Between 1st & 2nd Peizometer Tubes				
North	Peg;		45.76m		13.50m from each				
South	outh Peg; 45.62m								
			Incremental F	lise of					
Depth	of Pla	cement	Tell-tale Place	ement Pipe					
2	1.50	In Water			Initially placed a	it 2.25m depth but 0,75r	n		
3	1.25	Dry	0.25		sediment drawn	into placement tube wh	nen		
4	1.00	Dry	0.25		measuring gaug	je withdrawn			
5	0.75	Dry	0.25						
6	0.50	Dry	0.25						
7	0.25	Dry	0.25						
Surface	-	Dry	0.25						
Placement 3, Cent	tre of F	River			Between 2nd &	3rd Peizometer Tubes			
North	Peg;		72.70m		13.50m from ea	ch			
South	Peg;		72.50m						
			Incremental F	lise a Depth to	Sediment	Amount of			
Depth	of Pla	cement	Tell-tale Place	emen After Eac	h Rise in Pipe	Sediment added			
. 1	1.75	In Wate	River Bed	3.00	Some sediment	drawn into placement t	ube		
2	1.50	In Wate	0.25	3.00	when core tube	removed			
3	1.25	Dry	0.25	3.00		•	3.00		
4	1.00	Dry	0.25	3.00		•	3.00		
5	0.75	Dry	0.25	3.20		0.20	3.00		
6	0.50	Dry	0.25	3.18		0.18	3.00		
7	0.25	Dry	0.25	3.20		0.20	3.00		
Surface	-	Dry	0.25	•			•		
	-	4 . 4			Dobuoon Jrd P				
Placement 4, Cen	tre eas	st of River	•		Dermeen and or	4th Pelzometer Tubes			
Placement 4, Cen North	tre eas Peg;	it of River	99.60m		13.50m from ea	4th Peizometer Tubes Ich			
Placement 4, Cen North South	tre eas Peg; Peg;	at of River	99.60m 99.45m		13.50m from ea	4th Peizometer Tubes Ich			
Placement 4, Cen North South	tre eas Peg; Peg;	at of River	99.60m 99.45m Incremental F	Rise o Depth to	13.50m from ea	Ath Peizometer Tubes ich Amount of			
Placement 4, Cen North South Depth	tre eas Peg; Peg; of Pla	t of River	99.60m 99.45m Incremental F Tell-tale Place	Rise o Depth to emen After Eac	13.50m from ea Sediment h Rise in Pipe	Ath Pelzometer Tubes ich Amount of Sediment added			
Placement 4, Cen North South Depth 1	tre eas Peg; Peg; of Pla 1.67	cement	99.60m 99.45m Incremental F Tell-tale Plac River Bed	Rise o Depth to emen After Eac 3.00	13.50m from ea Sediment h Rise in Pipe	Ath Pelzometer Tubes ich Amount of Sediment added			
Placement 4, Cen North South Depth 1 2	tre eas Peg; Peg; of Pla 1.67 1.50	cement In Wate In Wate	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25	Rise o Depth to emen After Eac 3.00 3.00	13.50m from ea Sediment h Rise in Pipe	Ath Pelzometer Tubes ich Amount of Sediment added			
Placement 4, Cen North South Depth 1 2 3	tre eas Peg; Peg; of Pla 1.67 1.50 1.25	cement In Wate In Wate Dry	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.00 3.00	13.50m from ea Sediment h Rise in Pipe	Ath Pelzometer Tubes ich Amount of Sediment added -	3.00		
Placement 4, Cen North South Depth 1 2 3 4	tre eas Peg; Peg; of Pla 1.67 1.50 1.25 1.00	icement In Wate Dry Dry	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.00 3.19	13.50m from ea Sediment h Rise in Pipe	Ath Peizometer Tubes ich Amount of Sediment added - - 0.19	3.00 3.00		
Placement 4, Cen North South Depth 1 2 3 4 5	tre eas Peg; Peg; 1.67 1.50 1.25 1.00 0.75	icement In Wate In Wate Dry Dry Dry	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.00 3.19 3.25	13.50m from ea Sediment h Rise in Pipe	Ath Peizometer Tubes ich Amount of Sediment added - - 0.19 0.23	3.00 3.00 3.02		
Placement 4, Cen North South Depth 1 2 3 4 5 6	tre eas Peg; Peg; of Pla 1.67 1.50 1.25 1.00 0.75 0.50	icement In Wate In Wate Dry Dry Dry Dry	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.00 3.19 3.25 3.23	13.50m from ea	Ath Peizometer Tubes ich Amount of Sediment added - - 0.19 0.23 0.23	3.00 3.00 3.02 3.00		
Placement 4, Cen North South 1 2 3 4 5 6 7	tre eas Peg; Peg; 1.67 1.50 1.25 1.00 0.75 0.50 0.25	icement In Wate In Wate Dry Dry Dry Dry Dry Dry	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.19 3.25 3.23 3.23 3.25	13.50m from ea	Amount of Sediment added 	3.00 3.00 3.02 3.00 3.01		
Placement 4, Cen North South 1 2 3 4 5 6 7 Surface	tre eas Peg; Peg; 1.67 1.50 1.25 1.00 0.75 0.50 0.25	icement In Wate In Wate Dry Dry Dry Dry Dry Dry Dry	99.60m 99.45m Incremental F Tell-tale Place River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.00 3.19 3.25 3.23 3.23	13.50m from ea	Amount of Sediment added - 0.19 0.23 0.24	3.00 3.00 3.02 3.00 3.01		
Placement 4, Cen North South 1 2 3 4 5 6 7 Surface	tre eas Peg; Peg; of Pla 1.67 1.50 1.25 1.00 0.75 0.50 0.25	cement In Wate In Wate Dry Dry Dry Dry Dry Dry Dry	99.60m 99.45m Incremental F Tell-tale Place River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.00 3.19 3.25 3.23 3.25	13.50m from ea	Ath Peizometer Tubes ich Amount of Sediment added - 0.19 0.23 0.23 0.24	3.00 3.00 3.02 3.00 3.01		
Placement 4, Cen North South Depth 1 2 3 4 5 6 7 Surface Placement 5, East	tre eas Peg; Peg; of Pla 1.67 1.50 1.25 1.00 0.75 0.50 0.25	icement In Wate In Wate Dry Dry Dry Dry Dry Dry Dry Pry Pry	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.19 3.25 3.23 3.25	13.50m from ea Sediment h Rise in Pipe Between 4th Pe	Amount of Sediment added - 0.19 0.23 0.24	3.00 3.00 3.02 3.00 3.01 - -		
Placement 4, Cen North South 1 2 3 4 5 6 7 Surface Placement 5, East Umpa	tre eas Peg; Peg; 1.67 1.50 1.25 1.00 0.75 0.50 0.25 - -	icement In Wate In Wate Dry Dry Dry Dry Dry Dry rer	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.19 3.25 3.23 3.23 -	13.50m from ea Sediment h Rise in Pipe Between 4th Pe 12.70m from ea	Amount of Sediment added 0.19 0.23 0.23 0.24	3.00 3.00 3.02 3.00 3.01 -		
Placement 4, Cen North South Depth 1 2 3 4 5 6 7 Surface Placement 5, East Umpa Mdub	tre eas Peg; Peg; 1.67 1.50 1.25 1.00 0.75 0.50 0.25 - - - - - - - - -	icement In Wate In Wate Dry Dry Dry Dry Dry Dry Pry rer (north) south)	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.19 3.25 3.23 3.25 -	13.50m from ea Sediment h Rise in Pipe Between 4th Pe 12.70m from ea	Amount of Sediment added 	3.00 3.00 3.02 3.00 3.01 - bank		
Placement 4, Cen North South Depth 1 2 3 4 5 6 7 Surface Placement 5, East Umpa Mdub	tre eas Peg; Peg; 1.67 1.50 1.25 1.00 0.75 0.50 0.25 - t of Riv fa tree t tree (icement In Wate In Wate Dry Dry Dry Dry Dry Dry Pry er (north) south)	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.19 3.25 3.23 3.25 - Rise o Depth to	13.50m from ea Sediment h Rise in Pipe Between 4th Pe 12.70m from ea Sediment	Amount of Sediment added 0.19 0.23 0.24 bizometer Tube & River ch	3.00 3.00 3.02 3.00 3.01 - bank		
Placement 4, Cen North South Depth 1 2 3 4 5 6 7 Surface Placement 5, East Umpa Mdub	tre eas Peg: Peg: Peg: 1.67 1.50 1.25 1.00 0.75 0.50 0.25 c of Riv fa tree t tree (t of Pla	icement In Wate In Wate Dry Dry Dry Dry Dry Dry Dry cory corth) south)	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to emen After Eac 3.00 3.00 3.19 3.25 3.23 3.25 - Rise o Depth to emen After Eac	13.50m from ea Sediment h Rise in Pipe Between 4th Pe 12.70m from ea Sediment h Rise in Pipe	Amount of Sediment added 0.19 0.23 0.24 Amount of Sediment added	3.00 3.00 3.02 3.00 3.01 - bank		
Placement 4, Cen North South Depth 1 2 3 4 5 6 7 Surface Placement 5, East Umpa Mdub	tre eas Peg; Peg; 1.67 1.50 1.25 1.00 0.75 0.50 0.25 c of Riv fa tree t tree (0 of Pla	icement In Wate In Wate Dry Dry Dry Dry Dry Pry er (north) south)	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to amen After Eac 3.00 3.00 3.19 3.25 3.23 3.25 - Rise o Depth to emen After Eac ally placed at 1.	Between 4th Pe 12.70m from ea Sediment h Rise in Pipe 12.70m from ea Sediment h Rise in Pipe 75m, there was	Ath Peizometer Tubes Amount of Sediment added - 0.19 0.23 0.23 0.24 sizometer Tube & River ch Amount of Sediment added an in-flow of 0.62m whe	3.00 3.00 3.02 3.00 3.01 - bank		
Placement 4, Cen North South Depth 1 2 3 4 5 6 7 Surface Placement 5, East Umpa Mdub Depth	tre eas Peg; Peg; 1.67 1.50 1.25 1.00 0.75 0.50 0.25 c of Riv fa tree t tree (icement In Wate In Wate Dry Dry Dry Dry Dry Pry er (north) south)	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to amen After Eac 3.00 3.00 3.19 3.25 3.23 3.25 - Rise o Depth to emen After Eac ally placed at 1. a tube removed	Between 4th Pe 12.70m from ea Sediment h Rise in Pipe 12.70m from ea Sediment h Rise in Pipe 75m, there was	Ath Peizometer Tubes Amount of Sediment added - 0.19 0.23 0.23 0.24 bizometer Tube & River ch Amount of Sediment added an in-flow of 0.62m whe	3.00 3.00 3.02 3.00 3.01 - bank		
Placement 4, Cen North South Depth 1 2 3 4 5 6 7 Surface Placement 5, East Umpa Mdub Depth	tre eas Peg: Peg; 1.67 1.50 1.25 1.00 0.75 0.50 0.25 - - - - - - - - - - - - - - - - - - -	icement In Wate In Wate Dry Dry Dry Dry Dry rer (north) south) icement	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to amen After Eac 3.00 3.00 3.19 3.25 3.23 3.25 - Rise o Depth to emen After Eac ally placed at 1. a tube removed 2.00	Between 4th Pe 12.70m from ea Sediment h Rise in Pipe 12.70m from ea Sediment h Rise in Pipe 75m, there was	Ath Peizometer Tubes Amount of Sediment added 0.19 0.23 0.23 0.24 Nizometer Tube & River ch Amount of Sediment added an in-flow of 0.62m whe	3.00 3.02 3.00 3.01 - bank		
Placement 4, Cen North South Depth 1 2 3 4 5 6 7 Surface Placement 5, East Umpa Mdub Depth	tre eas Peg; Peg; 1.67 1.50 1.25 1.00 0.75 0.50 0.25 - t of Riv fa tree t tree (0 of Pla	icement In Wate In Wate Dry Dry Dry Dry Dry rer (north) south) icement In Wate Dry	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to amen After Eac 3.00 3.00 3.19 3.25 3.23 3.25 - Rise o Depth to emen After Eac ally placed at 1. a tube removed 2.00 2.10	Between 4th Pe 12.70m from ea Sediment h Rise in Pipe 12.70m from ea Sediment h Rise in Pipe 75m, there was	Ath Peizometer Tubes Amount of Sediment added - 0.19 0.23 0.23 0.24 bizometer Tube & River ch Amount of Sediment added an in-flow of 0.62m whe - 0.10	3.00 3.02 3.00 3.01 - bank n 2.00 2.00		
Placement 4, Cen North South Depth 1 2 3 4 5 6 7 Surface Placement 5, East Umpa Mdub Depth	tre eas Peg: Peg: 1.67 1.50 1.25 1.00 0.75 0.50 0.25 - - - - - - - - - - - - - - - - - - -	icement In Wate In Wate Dry Dry Dry Dry Dry dry er (north) south) icement In Wate Dry Dry Dry	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to amen After Eac 3.00 3.00 3.19 3.25 3.23 3.25 - Rise o Depth to emen After Eac ally placed at 1. a tube removed 2.00 2.10 2.25	13.50m from ea Sediment h Rise in Pipe Between 4th Pe 12.70m from ea Sediment h Rise in Pipe 75m, there was	Amount of Sediment added 0.19 0.23 0.23 0.24 Amount of Sediment added an in-flow of 0.62m when 0.10 0.24	3.00 3.02 3.00 3.01 		
Placement 4, Cen North South Depth 1 2 3 4 5 6 7 Surface Placement 5, East Umpa Mdub Depth 1 2 3 4	tre eas Peg: Peg: 1.67 1.50 1.25 1.00 0.75 0.50 0.25 - - - - - - - - - - - - - - - - - - -	icement In Wate In Wate Dry Dry Dry Dry Dry dry er (north) south) icement In Wate Dry Dry Dry Dry Dry Dry Dry Dry Dry Dry	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to amen After Eac 3.00 3.00 3.19 3.25 3.23 3.25 - Rise o Depth to emen After Eac ally placed at 1. a tube removed 2.00 2.10 2.25 2.25	13.50m from ea Sediment h Rise in Pipe Between 4th Pe 12.70m from ea Sediment h Rise in Pipe 75m, there was	Amount of Sediment added - 0.19 0.23 0.23 0.24 Hzometer Tube & River ch Amount of Sediment added an in-flow of 0.62m whe	3.00 3.02 3.00 3.01 		
Placement 4, Cen North South Depth 1 2 3 4 5 6 7 Surface Placement 5, East Umpa Mdub Depth 1 2 3 4 5 5	tre eas Peg: Peg: 1.67 1.50 1.25 1.00 0.75 0.50 0.25 - t of Riv fa tree t tree (0 of Pla 1.25 1.00 0.75 0.50 0.25 1.00 0.75 0.50 0.25	icement In Wate In Wate Dry Dry Dry Dry Dry dry er (north) south) icement In Wate Dry Dry Dry Dry Dry Dry Dry Dry Dry Dry	99.60m 99.45m Incremental F Tell-tale Plac River Bed 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25	Rise o Depth to amen After Eac 3.00 3.00 3.19 3.25 3.23 3.25 - Rise o Depth to emen After Eac ally placed at 1. a tube removed 2.00 2.10 2.25 2.25 2.22	Between 4th Per 13.50m from ea Sediment h Rise in Pipe 12.70m from ea Sediment h Rise in Pipe 75m, there was	Amount of Sediment added - 0.19 0.23 0.23 0.24 Hizometer Tube & River ch Amount of Sediment added an in-flow of 0.62m when - 0.10 0.24 0.25 0.21	3.00 3.02 3.00 3.01 		

Mtshelele River,

Overall runs north to south and at this point north to south 27.30 m wide at this point

Site Visits

Piezomenter Tubes & Core Samples; Bench Mark, Tell-tales & Height of Flow Meters + Rain Gauges; Observation - River still flowing +/- 200mm deep Replacement of lower height of flow meter Core samples taken, Searched for Tell-tales Replaced Piezometer Tubes, Lower Height of Flow Meter River surface slope & Profile probing Water surface level & sub-surface velocity tests 19th May '99 27th October '99 17th May '00 23rd Nov '00

6th Nov '01 16th April '02 19th & 21st May '03

1 Riverbed Gradient

500 metres each side of piezometer tube line

		COO		4.00		
1		500 m above		1.33		
2	100	400 m above		1.51		-0.18
3	100	300 m above		1.68	1.33	-0.17
4	100	200 m above			1.52	-0.19
5	100	100 m above		1.34	1.70	-0.18
6	100	Piezometer lir	e	1.53		-0.19
7	100	100 m below		1.67	1.28	-0.14
8	100	200 m below			1.55	-0.27
9	100	300 m below		1.28	1.72	-0.17
10	100	400 m below		1.49		-0.21
11	<u>100</u>	500 m below		1.67		-0.18
	1000					-1.88
	Gradient	1 in	530.00			- 531.91

Mtshelele River,

2 Sediment Surface & Water Surface Level

250 metres each side of piezometer tube line

1		20 m				30m						
21-May-03	Water		Surface		Water		Surface		Water	S	urface	
250 m North	1.887		1.513		1.855		1.425					
200 m North	1.985	-0.098	1.588	-0.075	1.968	-0.113	1.129	0.296				
	1.807		1.410		1.790		0.951					
150 m North	1.967	-0.160	1.536	-0.126	1.970	-0.180	1.255	-0.304				
100 m North	2.075	-0.108	1.639	-0.103	2.083	-0.113	1.576	-0.321	2.070		1.440	
	1.998		1.562		2.006		1.499					
50 m North	2.121	-0.123	1.516	0.046	2.114	-0.108	1.608	-0.109				
Piezometer line	2.173	-0.052	1.692	-0.176	2.188	-0.074	1.720	-0.112				
	1.833		1.352		1.848		1.380					
50 m South	1.922	-0.089	1.531	-0.179	1.917	-0.069	1.455	-0.075				
100 m South	1.983	-0.061	1.588	-0.057	1.982	-0.065	1.712	-0.257	1.984		1.681	
	2.018		1.623		2.017		1.747		2.019		1.716	
150 m South	2.134	-0.116	1.799	-0.176	2.124	-0.107	1.781	-0.034	2.119	-0.100	1.794	-0.078
200 m South	- '		0.549	0.000	2.238	-0.114	1.916	-0.135	2.238	-0.119	1.840	-0.046
			0.228		1.917		1.595		1.917		1.519	
250 m South	-	0.000	1.672	<u>0.000</u>	2.021	<u>-0.104</u>	1.672	<u>0.000</u>	2.024	<u>-0.107</u>	1.568	<u>-0.049</u>
		-0.807		-0.846		-1.047		-1.051		-0.326		-0.173
Drop in water level in	400	-0.807 m			500	-1.047 m	1		150	-0.326 m		
Slope 1 in	•	496	0.20	%		478	0.21	6		460	0.22 %	
Drop in surface level in	n m		400	-0.846 r	n		450	-1.051 m			150	-0.173 m
Slope 1 in				473				428				867

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Mtshelele River,

Water Surface Gradient

50 metres each side of piezometer tube line

		Surface	%	21/05/03 Water	Water Gradient	%	6/11/03 Water	Water Gradient	%	18/06/03 Water	Water Gradient	%
	Surface	Gradient	slope	level	1 in	slope	level	1 in	slope	level	1 in	slope
North	1.516			2.121			2.266			2.366		
P'line	1.692	284	0.35	2.173	962	0.10						
South	1.732	463	0.22	2.330	478	0.21	2.476	476	0.21	2.570	490	0.20

3 River Channel Profiles

Riverbed Profile

Length of Probe	3.30 1	n								Width of
21-May-03	1m	5m	10m	15m	20m	25m	30m	35m	40m	River
250 m North	1.30	?	1.90	?	2.07	?	0.41			33m
200 m North	1.28	1.540	1.84	1.730	2.13		0.67		0.24	47m
150 m North	1.33	1.740	2.27	2.170	2.67	1.330	0.69		0.74	50m
100 m North	2.74	2.780	2.70	2.490	2.21	1.820	1.78			33m
50 m North	2.37	2.820	2.80	2.640	2.75					28.5m
Piezometer line	1.06	1.890	3.10	2.800	2.77	2.350				27.3m
50 m South	2.08	2.330	2.72	2.810	2.90	2.240				29.6m
100 m South	1.80	2.170	2.64	2.750	2.50	2.040	1.39	reading @	29m	30m
150 m South	2.13	2.400	1.70	2.340	2.33	1.910	1.88	0.820		36.3m
200 m South	1.80	2.890	0.18	2.040	2.20	2.130	2.01	1.610		38.7m
250 m South	0.20	2.640	2.02	1.950	1.98	1.700	1.74	1.300		36.2m



Width of	Depth of
river (m)	River (m)
0.0	0.00
1.0	-1.06
5.0	-1.89
10.0	-3.10
15.0	-2.80
20.0	-2.77
25.0	-2.35
27.3	0.00



Mtshelele River,

								.0		.0		ALC .
4 Aggradation /Degradation of Sediment			Annual	ossiGain	Annual Loss	Cain Total Lose	GaintoD	Armallos	Total Lossi Ga	nto Date Minual Los	Totalloss	GaintoDe
			Annual	44/00/04	Annual	Total	4.010/00	Annual	Total		Total	
Der als March	19/05/99	23/11/00	Loss/Gair	11/06/01	Loss/Gain	Loss/Gain	16/9/02	Loss/Gain	Loss/Gain ###	## Loss/Gain	Loss/Gain	
Bench Mark	0.73	0.99	0.00	0.20	0.00	0.00	0.82	0.40	1.0)5 1 0.02	0.04	
Sediment Site	2.00	2.20	Ų.UZ	1.55	0.06	0.00	2.05	- 0.12	- 0.04 2.	51 0.03	- 0.01	
North Pet 17.00m												
Site	1 98	2.28	0.04	1.52	0.03	0.07	2.05	- 0.09	- 0.02 23	30 0.02	0.00	
North Per 27 01m	1.50	2.20	0.04	1.02	0.00	0.07	2.00	- 0.03	- 0.02 2.	0.02	0.00	
South Pe 27.95m												
000.010 20000												
5 <u>Porosity</u> Sediment 362.6 gms 373.9 365.4 365.8 <u>189.9</u> 1,657.6												
Water <u>736.0</u> ml												
Total 2,393.6												
Porosity 30.7 %												
6 Permeshility												
l oneth of sample (l)		10	cm		10	c m		10	c m	10	cm	
Cross sectional area of sample	(4)	10	cm2		10	cm2		177	cm2	10	cm2	
Volume of water (n)	V 7V	100	mi		100	ml		100	mi	100	mi	
Duration of test (t)		8.69	secs		8.95	secs		8,86	secs	8.95	secs	
Head difference (h)		4.10	cm		4,10	cm		3.80	cm	4.00	cm	
Permeabliity		0.1588 5.72	cm/sec m/hr		0.1542 5.55	cm/sec m/hr		0.1681 6.05	cm/sec m/hr	0.1580 5.69	cm/sec m/hr	

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Mtshelele River,

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				Gain		Sain	in io v		Gain	in to	`	Gain	ain to b
4 Aggradation				0550	Loss	e e	Go	N ⁶⁵		BCO	105	NO ASE	Go.
/Degradation of			rual.		Jual	ALC.		nual	, all		ual.	-allo	
<u>Sediment</u>			bui		bui	10 ¹		bru	1012		bui	LOR	
			Annual	44/00/04	Annual	Total	1010100	Annual	Total		Annual	Total	
Booch Mark	19/05/99 23/1 0.73	1/00 I 0.00	Loss/Gair	11/06/01	Loss/Gain	Loss/Gain	16/9/02	Loss/Gain	Loss/Gain	1.05	Loss/Gain	Loss/Gain	
Sediment Site	2.00	2 28	0.02	1.55	0.06	0.08	2.05	- 0.12	- 0.04	2.31	0.03	- 0.01	
North Per 17.60m	2.00	2.20	0.02	1.00	0.00	0.00	2.00	- 0.12	- 0.04	2.01	0.00	- 0.01	
South Pe 18.20m													
Site	1.98	2.28	0.04	1.52	0.03	0.07	2.05	- 0.09	- 0.02	2.30	0.02	0.00	
North Peç 27.01m													
South Pe 27.95m													
5 Porosity													
Sediment 362.6 gms													
373.9													
365.4													
365.8													
189.9													
Water 736.0 ml													
Total 2,393.6													
Porosity 30.7 %													
C. Dormochility													
6 <u>Permeability</u>		40			10			40			10		
Cross sectional area of sample		177	cm2		177	cm2		10	cm2		10	cm2	
Volume of water (a)		100	ml		100	ml		100	mi		100	mi	
Duration of test (t)		8.69	secs		8.95	secs		8.86	secs		8.95	secs	
Head difference (h)		4.10	cm		4.10	cm		3.80	cm		4.00	cm	
Permeability		0.1588	cm/sec		0.1542	cm/sec		0.1681	cm/sec		0.1580	cm/sec	
		5.72	m/hr		5.55	m/hr		6.05	m/hr		5.69	m/hr	

Mtshelele River,

7 Core Sample Sites

1 Depth	1.65m	South Pe	15.30m	Between 1st & 2nd Peizometer Tubes
		North Peç	15.20m	
2 Depth	2.00m	South Pe	20.35m	Between 2nd & 3rd Peizometer Tubes
		North Pec	20.30m	
3 Depth	1.95m	South Pe	25.35m	Between 3rd & 4th Peizometer Tubes
·		North Pec	25.30m	

8 Peizometer Tube Positions

4 Peizor	meter tubes, installed	d in line with the be	nch mark across the rive	r	New Tubes
			23/11/00		11/06/01
1	Depth of Tube	2,20m			2.10
West	North Peg;	12.30m			12.80
side	South Peg;	12.40m			12.20
2	Depth of Tube	2.95m	Missing	Found	2.00
Centre	North Peg;	17.70m Probe	d to 3,30m		18.10
West	South Peg;	17.76m Clean,	, coarse sediment, no silt	to full depth	17.65
3	Depth of Tube	3.45m	Missing	Found	3.00
Centre	North Peg;	22.92m Probe	d to 3,10m		23.40
East	South Peg;	22.99m Clean,	, coarse sediment, no silf	to full depth	22.80
4	Depth of Tube	3.10m	Missing	Found	2.90
East	North Peg;	28.25m Probe	d to 2,85 & 3,10m		28.50
side	South Peg;	28.35m Clean,	, coarse sediment, no silf	to full depth	28.00

Saturated sediment in October '99 was either heavily silted or compacted in the base 400 - 500mm. Probing in Nov '00 indicated clean, coarse sediment to the rock of the river bed which could be easily felt. 3 piezometer tubes were lost at these points giving rise to the speculation that the river flowed to the full depth - either completely replacing the sediment or at least washing it through.

9 Tell-tales

<u>Chains</u>					
1 Placement, West	side of river	Installed	Installed Checked		
Between 1st & 2nd	Peizometer	Tubes	19/06/01	23/10/02	25/06/03
North Pe	eg;	13.60m	0.10	0.45	0.15
South Pe	eg;	13.45m			
Length o	of chain 1,70	m with anchor o	driven into sedime	nt	

Aluminium Tubes

17 x 100mm Al Tubes placed from River Bed to Surface in a continuous line

North Peg; 13.46m South Peg: 12.93m

Depth of Placement

1	1.80	10	0.90
2	1.70	11	0.80
3	1.60	12	0.70
4	1.50	13	0.60
5	1.40	14	0.50
6	1.30	15	0.40
7	1.20	16	0.30
8	1.10	17	0.20
9	1.00	Surface	

Mtshelele River,

Zinc disk	<u>s</u>					
Placeme	nt 1, We	st Side of I	River	Between 1st & 2nd Pe	izometer `	Tubes
	North P	eg;	14.75m			
	South P	eg;	14.80m			
	11 tell-ta	ales were p	placed. However the	wet sediment blocked t	the tell-tal	e placement pipe and
	all 11 w	rere remov	ed with the pipe, no	ne were initially placed i	in the sed	iment.
	Eventua	ully 3 tell-ta	les were placed			
	Depth o	f Placeme	Tell-tale Placement I	Pipe - Incremetal rise		
1	0.65	Dry	0.25			
2	0.40	Dry	0.25			
Surface	0.02	Dry	0.25			
Placeme	nt 2, Cer	ntre of Rive	er	Between 2nd & 3rd Pe	izometer	Tubes
	North Pe	eg;	20.28m			
	South P	eg;	20.38m			
		I	ncremental Rise of			
	Depth o	f Placeme	Tell-tale Placement F	Pipe		
1	1.75	In Water F	River Bed			
2	1.50	In Water	0.25			
3	1.25	Dry	0.25			
4	1.00	Dry	0.25			
5	0.75	Dry	0.25			
6	0.50	Dry	0.25			
7	0.25	Dry	0.25			
Surface	-	Dry	0.25			
Placeme	nt 3, Cer	ntre of Rive	er	Between 3rd & 4th Pei	zometer 1	Tubes
	North P	eg;	25.54m			
	South P	eg;	25.63m			
		1	ncremental Rise of	Depth to Sedimer Amo	unt of	
	Depth o	f Placeme	Tell-tale Placement I	PAfter Each Rise i Sedi	ment add	ed
1	1.75	In Watei	River Bed	2.00		2.00
2	1.50	In Water	0.25	2.00	-	2.00
3	1.25	Dry	0.25	2.00	•	2.00
4	1.00	Dry	0.25	2.25	0.25	2.00
5	0.75	Dry	0.25	2.23	0.25	1.98
6	0.50	Dry	0.25	2.27	0.32	1.95
7	0.25	Dry	0.25	2.18	0.18	2.00
Surface	-	Dry	0.25	-		~



Dongamuzi - River Flow & Water Loss 1999

Loss

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Dongamuzi - River Flow & Water Loss 2000



Dongamuzi - Rainfall 2000





80 75 70 65 60 55 50 45 40 35 30 8 ainfall (mm) 25 20 15 10 5 0 Evaporation (mm) 1-Jan-01 1-Feb-01 1-Mar-01 1-Apr-01 1-May-01 1-Jun-01 1-Aug-01 1-Sep-01 1-Oct-01 1-Nov-01 1-Dec-01 1-Jul-01

2.4 2.2 2.0 1.8 1.6 Ê 1.4 Maximum Height of Flow Height of Flow 1.2 1.0 0.8 0.6 0.4 0.2 Maximum Sediment 0.0 -0.2 an-02 1-Feb-02 1-Mar-02 1-Apr-02 1-May-02 1-Jun-02 1-Jul-02 1-Aug-02-1-Sep-02 1-Oct-02 1-Nov-02 1-Dec-Minimum Gediment Leve -0.4 0.0 -0.2 -0.4 -0.6 -0.8 Ê -1.0 E -1.2 ຮູ -1.4 ງ -1.6 -1.8 -2.0 -2.2

Dongamuzi - River Flow & Water Loss 2002

-2.4



Dongamuzi - Rainfall 2002

Huwana - River Flow & Water Loss 1999

								<u></u>		
	Maximum Height	of Flow								
	Maximum Sedimer	nt								
-99	1-Feb-99 1-Mar-99	1-Apr-99 1-N	lay-99 1-Jun	99 1-Jul	-99 1-Au	g-99 1-S	 	Oct-99	1-Nov-99	1-Dec-99
							- · ·			· · · · · · · · · · · · · · · · · · ·
										1
	· · · · · ·					┨═┨╌┨╶╂ ┨╼┨╶┧╌┨ ┨╶┨╶┨╶┨	<mark>╋╋╋┙┙ ╺╺╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴╴</mark>			· · · · · · · · · · · · · · · · · · ·
				<u> </u>	╏╌┠╌┠╶┠	╏╏╏╎	┨╼┨╼╂╶┠			

Loss (m)

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Huwana - Rainfall 2000

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Huwana - River Flow & Water Loss 2001
- 50 45 40 35 Rainfall (mm) 30 25 20 - 15 - 10 5 0 Evaporation (mm) 1 3 1-10 -0 1-Jan-01 1-Feb-01 1-Mar-01 1-Apr-01 1-May-01 1-Jun-01 1-Sep-01 1-Oct-01 1-Nov-01 1-Jul-01 1-Aug-01 1-Dec-01

Huwana - Rainfall & Evaporation 2001



Huwana - River Flow & Water Loss 2002

50 45 40 35 **(mm)** 30 **[mm]** 25 **2** 20 15 10 5 0 Evaporation (mm) 10 2.5 0 1-Jan-02 1-Apr-02 1-May-02 1-Jun-02 1-Jul-02 1-Aug-02 1-Sep-02 1-Oct-02 1-Nov-02 1-Dec-02 1-Feb-02 1-Mar-02

Huwana - Rainfall & Evaporation 2002

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Huwana - River Flow & Water Loss 2003





Tshelanyemba - River Flow & Water Loss 2000







Tshelanyemba - River Flow & Water Loss 2001



Tshelanyemba - Rainfall & Evaporation 2001



Tshelanyemba - River Flow & Water Loss 2002



Tshelanyemba - Rainfall & Evaporation 2002



Wenlock - River Flow & Water Loss 1999

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Wenlock - River Flow & Water Loss 2000

Loss

Wenlock - Rainfall 2000









Wenlock - Rainfall 2001

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Wenlock - River Flow & Water Loss 2002

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Loss



Wenlock - Rainfall 2002

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Wenlock - River Flow & Water Loss 2003





Comparison of Evaporation Losses 2002

Evaporation from Surface Water
Evaporation from Sediment

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Comparison of Evaporation Losses 2003

Evaporation from Surface Water
Evaporation from Sediment

APPENDIX 04

DONGAMUZI FIELD RESEARCH SITE

Dongamuzi River,

SEDIMENT GRAIN ANALYSIS

6/27/2001

Dongamusi - Centre of River, Centre of Sediment

20 random grains, ommitting largest and smallest Quartz and Feldspar 0.02 grams

No.	Length	Width	Breadth	Sphericity	
1	2.50	2.00	1.75	0.82	
2	1.25	1.00	1.00	0.86	
3	1.25	1.00	0.75	0.78	
4	1.00	0.75	0.75	0.83	
5	1.00	0.75	0.75	0.83	
6	1.25	1.00	0.75	0.78	
7	1.50	1.25	1.25	0.89	
8	1.50	1.20	1.00	0.81	
9	1.00	0.75	0.75	0.83	
10	2.50	1.75	1.50	0.75	
11	1.00	0.75	0.50	0.72	
12	0.75	0.50	0.50	0.76	
13	0.50	0.50	0.50	1.00	
14	0.75	0.75	0.50	0.87	
15	0.50	0.50	0.25	0.79	
16	0.75	0.75	0.50	0.87	
17	0.66	0.66	0.50	0.91	
18	0.66	0.50	0.33	0.72	
19	0.75	0.66	0.50	0.84	
20	0.75	0.75	0.66	0.93	
				0.83 Av.	

DONGAMUZI FIELD RESEARCH SITE

Dongamuzi River,

SIEVE ANALYSIS

South s	side of Riv	er				
Sieve	Upper		%	Lower		%
mm	Sample 1	%age	passing	Sample 2	%age	passing
5	0.0	0.0	100.0	0.0	0.0	100.0
2	1.3	0.2	99.8	8.2	1.3	98.7
1	7.2	1.2	98.6	19.4	3.0	95.7
0.5	243.7	40.6	58.0	379.8	58.7	37.0
0.25	276.7	46.1	11.9	207.0	32.0	5.0
0.125	54.9	9.1	2.8	24.2	3.7	1.3
0.063	6.9	1.1	1.6	2.8	0.4	0.9
0	9.9	1.6	0.0	5.6	0.9	0.0
	600.6			647.0		



DONGAMUZI FIELD RESEARCH SITE

Dongamuzi River,

SIEVE ANALYSIS

Centre	OI KIVEI								
Sieve	Upper		%	Centre		%	Lower		%
mm	Sample 1	%age	passing	Sample 2	%age	passing	Sample 3	%age	passing
5	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0
2	28.3	3.9	96.1	51.8	6.4	93.6	11.8	1.7	98.3
1	22.9	3.1	93.0	33.2	4.1	89.5	75.5	11.1	87.2
0.5	298.8	41.1	51.9	287.3	35.5	54.0	304.7	44.6	42.6
0.25	272.6	37.5	14.4	329.0	40.7	13.3	238.3	34.9	7.7
0.125	83.3	11.5	2.9	72.5	9.0	4.3	35.6	5.2	2.5
0.063	5.8	0.8	2.1	20.9	2.6	1.8	0.8	0.1	2.4
0	15.4	2.1	0.0	14.2	1.8	0.0	16.1	2.4	0.0
	727.1			808.9			682.8		



DONGAMUZI FIELD RESEARCH SITE

Dongamuzi River,

SIEVE ANALYSIS

North side of River

Sieve	Upper		%	Lower		%	
mm	Sample 1	%age	passing	Sample 2	%age	passing	
5	0.0	0.0	100.0	0.0	0.0	100.0	
2	114.2	22.8	77.2	31.0	5.7	94.3	
1	87.8	17.5	59.7	55.5	10.3	84.0	
0.5	199.1	39.7	20.0	304.5	56.3	27.6	
0.25	65.3	13.0	7.0	116.1	21.5	6.2	
0.125	21.2	4.2	2.7	22.3	4.1	2.0	
0.063	9.3	1.9	0.9	2.3	0.4	1.6	
0	4.4	0.9	0.0	8.7	1.6	0.0	
	501.3			540.4			



HUWANA FIELD RESEARCH SITE

Manzamnyama River,

SEDIMENT GRAIN ANALYSIS

6/27/2001

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Huwana - Centre of River, Centre of Sediment

15 random grains, ommitting largest and smallest Quartz and Feldspar 0.62 grams

	Material	Sphericity	Breadth	Width	Length	No.
	quartz	0.91	1.50	2.00	2.00	1
	quartz	0.72	1.00	1.50	2.00	2
quartz	feldspar &	0.72	2.00	2.00	3.25	3
1000	quartz	0.76	1.00	1.75	2.00	4
	feldspar	0.87	2.33	2.50	3.00	5
	quartz	0.83	1.75	2.33	2.66	6
	quartz	0.96	2.00	2.25	2.25	7
	feldspar	0.84	3.25	4.00	4.66	8
quartz	feldspar &	0.90	2.00	2.00	2.33	9
	quartz	0.78	1.00	1.33	1.66	10
	quartz	0.90	1.50	1.50	1.75	11
	feldspar	0.69	1.00	1.75	2.33	12
quartz	feldspar &	0.98	2.25	2.25	2.33	13
	quartz	0.73	1.33	1.50	2.25	14
	feldspar	0.85	1.75	2.66	2.75	15
	Av	0.83				

HUWANA FIELD RESEARCH SITE

Manzamnyama River,

SIEVE ANALYSIS

South side of River

Sieve	Upper		%	Centre		%	Lower		%
mm	Sample 1	%age	passing	Sample 2	%age	passing	Sample 3	%age	passing
5	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0
2	70.3	10.4	89.6	50.3	6.4	93.6	107.4	13.8	86.2
1	264.7	39.1	50.6	291.8	37.0	56.7	268.4	34.4	51.9
0.5	245.0	36.1	14.4	260.8	33.0	23.6	251.0	32.1	19.7
0.25	80.6	11.9	2.5	146.6	18.6	5.1	119.2	15.3	4.5
0.125	9.3	1.4	1.2	31.4	4.0	1.1	30.5	3.9	0.6
0.063	7.1	1.0	0.1	6.1	0.8	0.3	1.9	0.2	0.3
0	0.8	0.1	0.0	2.6	0.3	0.0	2.5	0.3	0.0
	677.8			789.6			780.9		



HUWANA FIELD RESEARCH SITE

Manzamnyama River,

SIEVE ANALYSIS

Centre o	of River			Upper					
Sieve	Upper		%	Centre		%	Centre		%
mm	Sample 1	%age	passing	Sample 2	%age	passing	Sample 3	%age	passing
5	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0
2	90.4	12.9	87.1	179.0	21.5	78.5	111.2	15.2	84.8
1	292.2	41.8	45.2	348.7	41.9	36.6	325.6	44.6	40.2
0.5	187.7	26.9	18.3	206.8	24.8	11.8	201.7	27.6	12.6
0.25	105.2	15.1	3.3	61.5	7.4	4.4	70.2	9.6	3.0
0.125	20.1	2.9	0.4	24.2	2.9	1.5	15.0	2.1	0.9
0.063	0.7	0.1	0.3	2.6	0.3	1.2	1.2	0.2	0.8
0	2.1	0.3	0.0	9.6	1.2	0.0	5.7	0.8	0.0
	698.4			832.4			730.6		
	Lower								

Sieve	Centre			Lower			
mm	Sample 4	Sample 5					
5	0.0	0.0	100.0	0.0	0.0	100.0	
2	114.0	15.3	84.7	114.6	14.6	85.4	
1	361.5	48.4	36.3	291.0	37.2	48.2	
0.5	219.7	29.4	6.8	249.6	31.9	16.2	
0.25	42.0	5.6	1.2	92.0	11.8	4.5	
0.125	4.9	0.7	0.6	24.7	3.2	1.3	
0.063	0.3	0.0	0.5	9.0	1.2	0.2	
0	3.9	0.5	0.0	1.4	0.2	0.0	
	746.3			782.3			



Shashane River,

SEDIMENT GRAIN ANALYSIS

6/27/2001

Tshelanyemba - Centre of River, Centre of Sediment

60 random grains, ommitting largest and smallest Quartz and Feldspar 0.71 grams

No.	Length	Width	Breadth	Sphericity	1
1	2.50	2.25			feldspar & quartz
2	3.50	2.00	1.50	0.63	quartz
3	3.25	2.00	1.50	0.66	feldspar & quartz
4	3.25	3.00	2.50	0.89	feldspar
5	2.50	2.00	2.00	0.86	quartz
6	3.00	2.00	1.50	0.69	quartz
7	1.50	1.50	1.00	0.87	quartz
8	3.50	2.00	1.50	0.63	quartz
9	3.50	2.50	2.25	0.77	feldspar & quartz
10	3.50	2.00	1.50	0.63	quartz
11	2.00	1.25	1.00	0.68	feldspar
12	3.25	2.50	2.00	0.78	quartz
13	3.50	2.50	2.00	0.74	quartz
14	4.50	3.00	2.00	0.67	feldspar
15	3.00	2.00	1.50	0.69	quartz
16	4.00	2.75	2.00	0.70	quartz
17	2.00	1.50	1.00	0.72	quartz
18	3.50	2.50	2.50	0.80	feldspar & quartz
19	3.50	3.00	2.00	0.79	quartz
20	3.00	2.00	2.00	0.76	feldspar
21	2.25	1.75	1.50	0.80	quartz
22	3.25	2.75	1.75	0.77	quartz
23	3.50	3.00	1.25	0.67	quartz
24	5.00	3.75	3.25	0.79	feldspar
25	2.00	2.00	1.25	0.85	quartz
26	2.75	2.50	1.75	0.83	quartz
27	3.00	2.50	1.75	0.65	feldspar
28	2.25	1.75	1.00	0.70	feldspar & quartz
29	2.50	2.00	1.50	0.78	quartz
30	4.25	2.75	2.75	0.75	feldspar
31	1.50	1.25			quartz
32	4.50	2.50	2.50	0.68	quartz
33	2.00	2.00	2.00	1.00	quartz
34	2.00	1.50	1.25	0.78	quartz
35	3.75	3.25	1.00	0.61	quartz
36	2.50	1.25	1.00	0.58	feldspar & quartz
37	2.25	2.00	1.75	0.88	feldspar
38	2.50	2.25	2.00	0.90	quartz
39	3.50	3.00	1.25	0.67	quartz
40	3.25	2.50	1.50	0.71	feldspar

No.	Length	Width	Breadth	Sphericity	
41	2.00	1.50	1.00	0.72	feldspar
42	2.50	1.75	1.25	0.70	quartz
43	2.50	2.00	2.00	0.86	quartz
44	3.00	3.00	2.50	0.94	feldspar
45	3.75	2.75	2.50	0.79	feldspar & quartz
46	2.75	1.75	1.75	0.74	quartz
47	3.25	2.75	1.75	0.77	feldspar & quartz
48	2.25	1.75	1.25	0.76	feldspar
49	2.50	2.00	2.00	0.86	quartz
50	3.00	2.00	2.00	0.76	quartz
51	2.50	2.25	1.75	0.86	feldspar & quartz
52	2.25	2.50	1.75	0.86	quartz
53	3.50	2.00	1.50	0.63	feldspar
54	1.50	1.50	1.25	0.94	feldspar & quartz
55	2.25	2.00	1.75	0.88	quartz
56	2.25	2.00	1.00	0.73	quartz
57	2.00	1.25	1.00	0.68	feldspar
58	2.25	1.75	1.25	0.76	quartz
59	2.50	2.25	2.00	0.90	quartz
60	3.50	2.50	3.50	0.80	feldspar
				0.76	Av.

Shashane River,

SIEVE ANALYSIS

West side of River

-			10	Lower		%
mm	Sample 1	%age	passing	Sample 2	%age	passing
5	0.0	0.0	100.0	0.0	0.0	100.0
2	138.3	17.3	82.7	162.7	20.5	79.5
1	287.7	36.1	46.6	320.3	40.3	39.2
0.5	249.7	31.3	15.3	222.3	28.0	11.2
0.25	102.6	12.9	2.5	71.9	9.1	2.1
0.125	12.9	1.6	0.9	10.5	1.3	0.8
0.063	0.7	0.1	0.8	1.7	0.2	0.6
0	6.1	0.8	0.0	4.7	0.6	0.0
	798.0			794.1		



Shashane River,

SIEVE ANALYSIS

West Centre of River

Sieve	Upper		%	Centre		%	Lower		%
mm	Sample 1	%age	passing	Sample 2	%age	passing	Sample 3	%age	passing
5	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0
2	100.5	11.5	88.5	232.8	29.3	70.7	168.5	24.8	75.2
1	309.8	35.6	52.8	259.7	32.6	38.1	278.0	41.0	34.2
0.5	297.7	34.2	18.6	196.4	24.7	13.4	157.6	23.2	11.0
0.25	126.1	14.5	4.1	78.6	9.9	3.5	40.8	6.0	5.0
0.125	23.0	2.6	1.5	18.2	2.3	1.2	15.6	2.3	2.7
0.063	1.0	0.1	1.4	4.7	0.6	0.7	11.3	1.7	1.0
0	12.1	1.4	0.0	5.2	0.7	0.0	6.9	1.0	0.0
	870.2			795.6			678.7		



Shashane River,

SIEVE ANALYSIS

East Centre of River

Sieve	Upper		%	Centre		%	Lower		%
mm	Sample 1	%age	passing	Sample 2	%age	passing	Sample 3	%age	passing
5	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0
2	118.6	20.2	79.8	146.2	22.1	77.9	52.7	32.3	67.7
1	203.9	34.7	45.1	311.3	47.1	30.8	52.4	32.1	35.5
0.5	164.2	27.9	17.2	163.1	24.7	6.1	44.3	27.2	8.3
0.25	79.4	13.5	3.6	21.6	3.3	2.8	6.2	3.8	4.5
0.125	12.6	2.1	1.5	13.8	2.1	0.8	4.7	2.9	1.7
0.063	7.3	1.2	0.3	0.6	0.1	0.7	0.2	0.1	1.5
0	1.5	0.3	0.0	4.4	0.7	0.0	2.5	1.5	0.0
	587.5			661.0			163.0		



Shashane River,

SIEVE ANALYSIS

ast Sid	e of River						
Sieve	Upper		%	Lower		%	
mm	Sample 1	%age	passing	Sample 2	%age	passing	
5	0.0	0.0	100.0	0.0	0.0	100.0	0.0
2	137.2	11.9	88.1	254.7	27.4	72.6	27.4
1	321.0	27.9	60.1	403.1	43.3	29.3	70.7
0.5	434.9	37.9	22.3	213.2	22.9	6.4	93.6
0.25	186.1	16.2	6.1	29.9	3.2	3.2	96.8
0.125	52.5	4.6	1.5	23.1	2.5	0.7	99.3
0.063	1.8	0.2	1.3	1.5	0.2	0.5	99.5
0	15.2	1.3	0.0	5.1	0.5	0.0	100.0
	1,148,7			930.6			



WENLOCK FIELD RESEARCH SITE

Mtshelele River,

SEDIMENT GRAIN ANALYSIS

6/27/2001

Wenlock - Centre of River, Centre of Sediment

15 random grains, ommitting largest and smallest Quartz and Feldspar 0.66 grams

No.	Length	Width	Breadth	Sphericity	
1	2.50	2.25	1.00	0.71	quartz
2	2.50	2.00	1.75	0.82	quartz
3	1.50	1.50	0.66	0.76	feldspar
4	2.50	1.75	1.50	0.75	feldspar & quartz
5	2.50	2.00	1.75	0.82	feldspar
6	4.50	3.50	2.75	0.76	quartz
7	3.25	2.25	2.00	0.75	quartz
8	1.50	1.50	1.25	0.87	feldspar & quartz
9	3.50	3.25	3.25	0.95	feldspar & quartz
10	4.00	3.50	2.50	0.82	quartz
11	1.75	1.50	1.25	0.90	quartz
12	3.00	1.75	1.50	0.66	quartz
13	1.75	1.50	1.50	0.90	feldspar & quartz
14	2.50	2.25	1.75	0.86	quartz
15	1.25	0.75	0.75	0.71	quartz
				0.80	Av.

WENLOCK FIELD RESEARCH SITE

Mtshelele River,

SIEVE ANALYSIS

Centre o	of River								
Sieve	Upper		%	Centre		%	Lower		%
mm	Sample 1	%age	passing	Sample 2	%age	passing	Sample 3	%age	passing
5	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0
2	146.1	24.1	75.9	244.5	29.4	70.6	273.5	28.2	71.8
1	224.4	37.0	38.9	295.9	35.6	35.0	377.4	38.9	33.0
0.5	160.8	26.5	12.4	189.7	22.8	12.2	238.8	24.6	8.4
0.25	51.1	8.4	4.0	61.2	7.4	4.8	62.2	6.4	2.0
0.125	15.6	2.6	1.4	8.9	1.1	3.8	11.7	1.2	0.8
0.063	7.1	1.2	0.2	10.4	1.3	2.5	6.1	0.6	0.1
0	1.5	0.2	0.0	21.0	2.5	0.0	1.3	0.1	0.0
	606.6			831.6			971.0		



WENLOCK FIELD RESEARCH SITE

Mtshelele River,

SIEVE ANALYSIS

Centre o	fRiver								
Sieve	Upper		%	Centre		%	Lower		%
mm	Sample 1	%age	passing	Sample 2	%age	passing	Sample 3	%age	passing
5	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0
2	146.1	24.1	75.9	244.5	29.4	70.6	273.5	28.2	71.8
1	224.4	37.0	38.9	295.9	35.6	35.0	377.4	38.9	33.0
0.5	160.8	26.5	12.4	189.7	22.8	12.2	238.8	24.6	8.4
0.25	51.1	8.4	4.0	61.2	7.4	4.8	62.2	6.4	2.0
0.125	15.6	2.6	1.4	8.9	1.1	3.8	11.7	1.2	0.8
0.063	7.1	1.2	0.2	10.4	1.3	2.5	6.1	0.6	0.1
0	1.5	0.2	0.0	21.0	2.5	0.0	1.3	0.1	0.0
	606.6			831.6			971.0		


WENLOCK FIELD RESEARCH SITE

Mtshelele River,

SIEVE ANALYSIS

East Sid	e of River			Upper			Lower		
Sieve	Upper		%	Centre		%	Centre		%
mm	Sample 1	%age	passing	Sample 2	%age	passing	Sample 3	%age	passing
5	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0
2	106.7	18.5	81.5	151.0	18.7	81.3	90.7	12.2	87.8
1	225.8	39.1	42.4	330.0	40.8	40.6	337.7	45.2	42.6
0.5	171.5	29.7	12.7	253.2	31.3	9.3	240.8	32.3	10.4
0.25	52.1	9.0	3.7	56.4	7.0	2.3	61.9	8.3	2.1
0.125	17.5	3.0	0.7	14.5	1.8	0.6	8.2	1.1	1.0
0.063	3.5	0.6	0.1	4.1	0.5	0.0	6.1	0.8	0.1
0	0.3	0.1	0.0	0.4	0.0	0.0	<u>1.1</u>	0.1	0.0
	577.4			809.6			746.5		
Sieve	Lower								
mm	Sample 4								
5	0.0	0.0	100.0						
2	259.0	30.0	70.0						
1	315.1	36.5	33.5						
0.5	204.9	23.7	9.8						
0.25	66.0	7.6	2.1						
0.125	10.6	1.2	0.9						
0.063	6.0	0.7	0.2						
0	1.8	0.2	0.0						
	863.4								



SEDIMENT CHARACTERISTICS

So	urce: D	ONGAMU	JZI			Magnificat	tion: 6.4	Date: 28 th June '99
No	Position in Sediment	Description	%	Angularity	Shape	Surface Texture	Orientation	Comment
1	South	Quartz	97				Disturbed Sample – unable to establish	Well sorted Decaying Feldspar
	Тор	Feldspar	3	Sub- rounded	Equant	Smooth		
		Other					S	
2	South	Quartz	97				Disturbed Sample – unable to establish	Well sorted Decaying Feldspar
	Centre	Feldspar	3	Sub- rounded	Equant	Smooth		
	1. C.L.	Other			11 2		1	
3	South	Quartz	85		Equant to	Rough to	Disturbed Sample – unable to establish	Well sorted Decaying Feldspar Fossilised
	Bottom	Feldspar	15	Sub- rounded	Elongated	Smooth		Monuses
		Other			1			
4	North	Quartz	98				Disturbed Sample – unable to establish	Well sorted
	Тор	Feldspar	2	Sub- rounded	Equant	Smooth		
		Other						
5	North	Quartz	98				Disturbed Sample – unable to establish	Well sorted
	Centre	Feldspar	2	Sub- rounded	Equant	Smooth		
		Other						
6	North	Quartz	98				Disturbed Sample – unable to establish	Well sorted
	Bottom	Feldspar	2	Sub- rounded	Equant	Smooth		
		Other						

So	urce: D	ONGAMU	JZI			Magnifica	tion: 6.4	Date: 28 th June '99
No	Position in Sediment	Description	%	Angularity	Shape	Surface Texture	Orientation	Comment
1	South	Quartz	98				Disturbed Sample – unable to establish	Well Sorted
	Тор	Feldspar	2	Sub- rounded	Equant	Smooth		
		Other						
2	South	Quartz	95				Disturbed Sample – unable to establish	Well Sorted Indication of decaying Feldspar
	Centre	Feldspar	5	Sub- rounded	Equant	Smooth		
		Other						
3	South	Quartz	95				Disturbed Sample – unable to establish	Well Sorted
3	Bottom	Feldspar	5	Sub- rounded	Equant	Smooth	comonisii	
		Other						
4	North	Quartz	99				Disturbed Sample – unable to establish	Well Sorted
	Centre	Feldspar	1	Sub- rounded	Equant	Smooth		
		Other						
5	North	Quartz	99				Disturbed Sample – unable to establish	Well Sorted
	Bottom	Feldspar	1	Sub- rounded	Equant	Smooth		
		Other					1	

So	urce: H	UWANA				Magnifica	tion: 6.4	Date: 28 th June '99
No	Position in Sediment	Description	%	Angularity	Shape	Surface Texture	Orientation	Comment
1	South west	Quartz	95	Angular to	Equant to		Disturbed Sample – unable to establish	Immature sample Rose quartz present
	Surface	Feldspar	5	Sub- angular	Elongated	Rough		
		Other	Fe					
2	South west	Quartz	95	Angular to	Equant to		Disturbed Sample – unable to establish	Large particles of Non-decaying Feldspar
	Upper	Feldspar	5	Sub- angular	Elongated	Rough		
		Other						
3	South west	Quartz	95	Angular to	Equant to		Disturbed Sample – unable to establish	Large particles of Non-decaying Feldspar
	Centre	Feldspar	5	Sub- angular	Elongated	Rough		
		Other						
4	South west	Quartz	95	Angular to	Equant to		Disturbed Sample – unable to establish	Large particles of Non-decaying Feldspar
	Lower	Feldspar	5	Sub- angular	Elongated	Rough	1.000.0000	
		Other						

So	urce: H	UWANA				Magnifica	tion: 6.4	Date: 28 th June '99
No	Position in Sediment	Description	%	Angularity	Shape	Surface Texture	Orientation	Comment
1	North East	Quartz	95	Angular to	Equant	Rough	Disturbed Sample – unable to establish	Immature Sample Fairly well Sorted
	Centre	Feldspar	5	Sub- angular				
	Surface	Other						
2	North East	Quartz	97	North East	Equant to	Rough	Disturbed Sample – unable to establish	Immature Sample Fairly well Sorted
	Centre	Feldspar	3	Centre	Elongated			
	Upper	Other						
3	North East	Quartz	97	North East	Equant	Rough	Disturbed Sample – unable to establish	Immature Sample Fairly well Sorted
	Centre	Feldspar	3	Centre				
	Centre	Other						
4	North East	Quartz	97	North East	Equant	Rough	Disturbed Sample – unable to establish	Immature Sample Fairly well Sorted
	Centre	Feldspar	3	Centre				
	Bottom	Other						

So	urce: H	UWANA				Magnifica	tion: 6.4	Date: 28 th June '99
No	Position in Sediment	Descriptio n	%	Angularity	Shape	Surface Texture	Orientation	Comment
1	North West	Quartz	60				Disturbed Sample – unable to establish	Poorly sorted Large Feldspar particles
	Тор	Feldspar	40	Sub angular	Equant	Rough		
		Other						
2	North West	Quartz	85				Disturbed Sample – unable to establish	Fairly well sorted
	Centre	Feldspar	15	Sub angular	Equant	Rough		
		Other						
3	North West	Quartz	95				Disturbed Sample – unable to establish	Fairly well sorted
	Bottom	Feldspar	5	Sub	Equant	Rough		
		Other		Barra				

So	urce: TS	SHELAN	YEN	1BA		Magnifica	tion: 6.4	Date: 28 th June '99
No	Position in Sediment	Description	%	Angularity	Shape	Surface Texture	Orientation	Comment
1	West	Quartz	95				Disturbed Sample – unable to establish	Quite well sorted Longer Feldspar particles Indications of Iron
	Surface	Feldspar	5	Sub- angular	Equant	Rough		
		Other	Fe					
2	West	Quartz	95				Disturbed Sample – unable to establish	Immature sample Well sorted
	Тор	Feldspar	5	Sub- angular	Equant	Rough		
		Other						
3	West	Quartz	92				Disturbed Sample – unable to establish	Some decaying Feldspar
	Upper	Feldspar	8	Sub- angular	Equant	Rough		
	Centre	Other						
4	West	Quartz	90				Disturbed Sample – unable to establish	Some decaying Feldspar
	Centre	Feldspar	10	Sub- angular	Equant	Rough		
		Other						

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5	West	Quartz	92				Disturbed Sample – unable to establish	Some decaying Feldspar
	Lower	Feldspar	8	Sub- angular	Equant	Rough		
	Centre	Other				1		
6	West	Quartz	95				Disturbed Sample – unable to establish	Feldspar – Largely decaying
	Bottom	Feldspar	5	Sub- angular	Equant	Rough		
		Other						

So	urce: W	ENLOCH	ζ.			Magnificat	ion: 6.4	Date: 28 th June '99
No	Position in Sediment	Description	%	Angularity	Shape	Surface Texture	Orientation	Comment
1	West	Quartz	90				Disturbed Sample – unable to establish	Fairly well sorted
	Тор	Feldspar	10	Sub- angular	Equant	Rough to		
	· · · · · ·	Other				smooth		
2	West	Quartz	90				Disturbed Sample – unable to establish	Well sorted Indications of Fe
	Centre	Feldspar	10	Sub- angular	Equant	Rough		
		Other				1	· · · · · ·	
3	West	Quartz	90				Disturbed Sample – unable to establish	Immature sample Some decaying feldspar
	Bottom	Feldspar	10	Sub- angular	Equant	Rough		
		Other						
4	East	Quartz	95				Disturbed Sample – unable to establish	Poorly sorted Indications of Fe Some decaying feldspar
	Тор	Feldspar	5	Sub- angular	Equant	Rough		
		Other						

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5	East	Quartz	95				Disturbed Sample – unable to establish	Fairly well sorted Some decaying feldspar
	Centre	Feldspar	5	Sub- angular	Equant	Rough		
		Other						
6	East	Quartz	95				Disturbed Sample – unable to establish	Immature sample Some decaying feldspar Mica & Mafic
	Bottom	Feldspar	5	Sub- angular	Equant	Rough		
		Other						

SEDIMENT GRAIN ANALYSIS

27/06/2001

Dongamusi - Centre of River, Centre of Sediment

20 random grains, ommitting largest and smallest Quartz and Feldspar 0.02 grams

No.	Length	Width	Breadth	Sphericity
1	2.50	2.00	1.75	0.82
2	1.25	1.00	1.00	0.86
3	1.25	1.00	0.75	0.78
4	1.00	0.75	0.75	0.83
5	1.00	0.75	0.75	0.83
6	1.25	1.00	0.75	0.78
7	1.50	1.25	1.25	0.89
8	1.50	1.20	1.00	0.81
9	1.00	0.75	0.75	0.83
10	2.50	1.75	1.50	0.75
11	1.00	0.75	0.50	0.72
12	0.75	0.50	0.50	0.76
13	0.50	0.50	0.50	1.00
14	0.75	0.75	0.50	0.87
15	0.50	0.50	0.25	0.79
16	0.75	0.75	0.50	0.87
17	0.66	0.66	0.50	0.91
18	0.66	0.50	0.33	0.72
19	0.75	0.66	0.50	0.84
20	0.75	0.75	0.66	0.93
				0.83 Av.

SEDIMENT GRAIN ANALYSIS

27/06/2001

Huwana - Centre of River, Centre of Sediment

15 random grains, ommitting largest and smallest Quartz and Feldspar 0.62 grams

8	Material	Sphericity	Breadth	Width	Length	No.
-	quartz	0.91	1.50	2.00	2.00	1
	quartz	0.72	1.00	1.50	2.00	2
quart	feldspar &	0.72	2.00	2.00	3.25	3
	quartz	0.76	1.00	1.75	2.00	4
	feldspar	0.87	2.33	2.50	3.00	5
	quartz	0.83	1.75	2.33	2.66	6
	quartz	0.96	2.00	2.25	2.25	7
	feldspar	0.84	3.25	4.00	4.66	8
quart	feldspar &	0.90	2.00	2.00	2.33	9
	quartz	0.78	1.00	1.33	1.66	10
	quartz	0.90	1.50	1.50	1.75	11
	feldspar	0.69	1.00	1.75	2.33	12
quart	feldspar &	0.98	2.25	2.25	2.33	13
1.0000	quartz	0.73	1.33	1.50	2.25	14
	feldspar	0.85	1.75	2.66	2.75	15
	Av	0.83				

SEDIMENT GRAIN ANALYSIS

27/06/2001

Tshelanyemba - Centre of River, Centre of Sediment

60 random grains, ommitting largest and smallest Quartz and Feldspar 0.71 grams

No.	Length	Width	Breadth	Sphericity	and and and
1	2.50	2.25			feldspar & quartz
2	3.50	2.00	1.50	0.63	quartz
3	3.25	2.00	1.50	0.66	feldspar & quartz
4	3.25	3.00	2.50	0.89	feldspar
5	2.50	2.00	2.00	0.86	quartz
6	3.00	2.00	1.50	0.69	quartz
7	1.50	1.50	1.00	0.87	quartz
8	3.50	2.00	1.50	0.63	quartz
9	3.50	2.50	2.25	0.77	feldspar & quartz
10	3.50	2.00	1.50	0.63	quartz
11	2.00	1.25	1.00	0.68	feldspar
12	3.25	2.50	2.00	0.78	quartz
13	3.50	2.50	2.00	0.74	quartz
14	4.50	3.00	2.00	0.67	feldspar
15	3.00	2.00	1.50	0.69	quartz
16	4.00	2.75	2.00	0.70	quartz
17	2.00	1.50	1.00	0.72	quartz
18	3.50	2.50	2.50	0.80	feldspar & quartz
19	3.50	3.00	2.00	0.79	quartz
20	3.00	2.00	2.00	0.76	feldspar
21	2.25	1.75	1.50	0.80	quartz
22	3.25	2.75	1.75	0.77	quartz
23	3.50	3.00	1.25	0.67	quartz
24	5.00	3.75	3.25	0.79	feldspar
25	2.00	2.00	1.25	0.85	quartz
26	2.75	2.50	1.75	0.83	quartz
27	3.00	2.50	1.75	0.65	feldspar
28	2.25	1.75	1.00	0.70	feldspar & quartz
29	2.50	2.00	1.50	0.78	quartz
30	4.25	2.75	2.75	0.75	feldspar
31	1.50	1.25			quartz
32	4.50	2.50	2.50	0.68	quartz
33	2.00	2.00	2.00	1.00	quartz
34	2.00	1.50	1.25	0.78	quartz
35	3.75	3.25	1.00	0.61	quartz
36	2.50	1.25	1.00	0.58	feldspar & quartz
37	2.25	2.00	1.75	0.88	feldspar
38	2.50	2.25	2.00	0.90	quartz
39	3.50	3.00	1.25	0.67	quartz
40	3.25	2.50	1.50	0.71	feldspar

No.	Length	Width	Breadth	Sphericity	Contraction of the local division of the loc
41	2.00	1.50	1.00	0.72	feldspar
42	2.50	1.75	1.25	0.70	quartz
43	2.50	2.00	2.00	0.86	quartz
44	3.00	3.00	2.50	0.94	feldspar
45	3.75	2.75	2.50	0.79	feldspar & quartz
46	2.75	1.75	1.75	0.74	quartz
47	3.25	2.75	1.75	0.77	feldspar & quartz
48	2.25	1.75	1.25	0.76	feldspar
49	2.50	2.00	2.00	0.86	quartz
50	3.00	2.00	2.00	0.76	quartz
51	2.50	2.25	1.75	0.86	feldspar & quartz
52	2.25	2.50	1.75	0.86	quartz
53	3.50	2.00	1.50	0.63	feldspar
54	1.50	1.50	1.25	0.94	feldspar & quartz
55	2.25	2.00	1.75	0.88	quartz
56	2.25	2.00	1.00	0.73	quartz
57	2.00	1.25	1.00	0.68	feldspar
58	2.25	1.75	1.25	0.76	quartz
59	2.50	2.25	2.00	0.90	quartz
60	3.50	2.50	3.50	0.80	feldspar
				0.76	Av.

0.72 feldspar	0			
	0	1.50	2.00	41
0.70 quartz	5	1.75	2.50	42
0.86 quartz	0	2.00	2.50	43
0.94 feldspar	0	3.00	3.00	44
0.79 feldspar & quar	0	2.75	3.75	45
0.74 quartz	5	1.75	2.75	46
0.77 feldspar & quar	5	2.75	3.25	47
0.76 feldspar	5	1.75	2.25	48
0.86 quartz	0	2.00	2.50	49
0.76 quartz	0	2.00	3.00	50
0.86 feldspar & quar	5	2.25	2.50	51
0.86 quartz	5	2.50	2.25	52
0.63 feldspar	0	2.00	3.50	53
0.94 feldspar & quar	5	1.50	1.50	54
0.88 guartz	5	2.00	2.25	55
0.73 quartz	0	2.00	2.25	56
0.68 feldspar	0	1.25	2.00	57
0.76 quartz	5	1.75	2.25	58
0.90 quartz	0	2.25	2.50	59
0.80 feldspar	0	2.50	3.50	60
0.76 Av.				

SEDIMENT GRAIN ANALYSIS

27/06/2001

Wenlock - Centre of River, Centre of Sediment

15 random grains, ommitting largest and smallest Quartz and Feldspar 0.66 grams

	Sphericity	Breadth	Width	Length	No.
quartz	0.71	1.00	2.25	2.50	1
quartz	0.82	1.75	2.00	2.50	2
feldspar	0.76	0.66	1.50	1.50	3
feldspar & quart	0.75	1.50	1.75	2.50	4
feldspar	0.82	1.75	2.00	2.50	5
quartz	0.76	2.75	3.50	4.50	6
quartz	0.75	2.00	2.25	3.25	7
feldspar & quart	0.87	1.25	1.50	1.50	8
feldspar & quart	0.95	3.25	3.25	3.50	9
quartz	0.82	2.50	3.50	4.00	10
quartz	0.90	1.25	1.50	1.75	11
quartz	0.66	1.50	1.75	3.00	12
feldspar & quart	0.90	1.50	1.50	1.75	13
quartz	0.86	1.75	2.25	2.50	14
quartz	0.71	0.75	0.75	1.25	15
Av.	0.80				

Sub-surface Water Velocity from Water Surface Slope

	Dongamuzi		Huwana	Tshelanyemba	Wenlock
Percentage Surface					
slope	0.53		0.12	0.31	0.21
Permeability (m/hr)	0.55		7.27	4.01	5.12
	0.65		7.80	4.13	5.55
			7.29		6.05
					5.69
Porosity (%)	28.8		27.5	32.4	30.7
Darcy formula					
velocity (m/hr)	0.32		0.89	1.26	1.18
velocity (m/day)	7.63		21.47	30.28	28.24
Dilution formula					
velocity (m/hr)	0.32		0.14	0.57	1.11
Typical					
Permeabilities					
	m/sec		m/min	m/hr	m/day
gravel	1.00000		60.000	3,600.00	86,400
coarse sand	0.10000		6.000	360.00	8,640
fine sand	0.00100		0.060	3.60	86.4
silt	0.00010		0.006	0.36	8.6
clay	0.00001		0.001	0.04	0.9
Typical Porosity					
aravel	40.0	0/0			
coarse sand	40.0	10			
fine cand	25-40	%			
cilt	35-50	%			
clay	45-55	0/			
Cidy	40-00	70			

Sub-surface Water Velocity from Water Surface Slope





DONGAMUZI FIELD RESEARCH SITE

Dongamuzi River

			time	conc.	log	g(C-Cb)/(Ci-Cb)
Diameter	D	0.052 m	(min.)	(g/l.)		
Saturated Depth	Lsat	0.47 m		0	3.73	-2.234
Screened Depth	Lscr	0.24 m		1	3.39	-2.348
Porosity	n	0.285		2	3.34	-2.366
ratio	а	1		3	3.31	-2.377
				5	3.26	-2.396
Constant		0.28063057		7	3.24	-2.403
background conc.	Cb	0.58 g/l				
initial conc.	Ci	30 g/l				
slope		-0.019				
velocity		0.005 m/min				
		0.32 m/hr				
		7.59 m/day				



HUWANA FIELD RESEARCH SITE

Manzamnyama River

			time	conc.	log	g(C-Cb)/(Ci-Cb)
Diameter	D	0.052 m	(min.)	(g/l.)		
Saturated Depth	Lsat	1.00 m		0	3.64	-3.359
Screened Depth	Lscr	0.82 m		1	3.63	-3.369
Porosity	n	0.275		2	3.61	-3.391
ratio	а	1		3	3.59	-3.413
				5	3.57	-3.435
Constant		0.18111177		7	3.56	-3.447
background conc.	СЬ	2.69 g/l				
initial conc.	Ci	30 g/l				
slope		-0.013				
velocity		0.002 m/min				
		0.14 m/hr				
		3.46 m/day				



TSHELANYEMBA FIELD RESEARCH SITE

Shashane River,

			time	cond		log(C-Cb)/(Ci-Cb)
Diameter	D	0.052 m	(min.)	(g/l.)		
Saturated Depth	Lsat	0.56 m		0	2.93	-2.345
Screened Depth	Lscr	0.34 m		1	2.92	-2.348
Porosity	n	0.27		2	2.82	-2.384
ratio	а	1		3	2.75	-2.410
				5	2.42	-2.541
Constant		0.2491372		7	2.32	-2.584
background conc.	Cb	0.06 g/l				
initial conc.	Ci	30 g/l				
slope		-0.038				
velocity		0.010 m/min				
		0.57 m/hr				
		13.73 m/day				



WENLOCK FIELD RESEARCH SITE

Mtshelele River,

			time	con	IC.	log(C-Cb)/(Ci-Cb)
Diameter	D	0.052 m	(min.)	(g/l	.)	
Saturated Depth	Lsat	0.935 m		0	5.03	-1.803
Screened Depth	Lscr	0.653 m		1	4.88	-1.833
Porosity	n	0.307		2	4.26	-1.972
ratio	а	1		3	3.98	-2.042
				5	3.50	-2.174
Constant		0.19048171		7	2.56	-2.498
background conc.	Cb	0.10 g/l				
initial conc.	Ci	30 g/l				
slope		-0.097				
velocity		0.018 m/min				
		1.11 m/hr				
		26.56 m/day				



Model of Flow in Alluvium

channel width velocity plan area of channel depth of sediment initial water level average pan evaporation		30 30 300000 2.7 2.7 0.006	m m/day sq.m. m m m/day
abstraction sediment type		30 medium	cu.m./day sand
constants	C1	C2	C3
	0.9778	-1.9333	0.92
max depth for evaporation		0.798	m
dry moisture content		0.1	
saturated moisture content		0.4	
deep water level		2	m
shallow water depth		m	
moisture exponent (m)		2	
catchment ratio		18	



DAM DESIGNS

Mkaya Wokhoza Sand Dam

SIEVE ANALYSIS

Sieve	Sample		%
(mm)	(gms)	%age	passing
5	0.0	0.0	100.0
2	89.2	9.2	90.8
1	330.6	33.9	56.9
0.5	389.6	40.0	17.0
0.25	124.0	12.7	4.2
0.125	24.4	2.5	1.7
0.063	15.9	1.6	0.1
0	1.0	0.1	0.0
	974.7		



Anticipated Sediment Yield from Catchment

Mkaya Wokhoza Sand Dam

Catchment area (km2)	3.5
MAR (mm)	150
Mean Annual Inflow (m3)	525,000
Dam Capacity (m3)	18,958
Storage ratio	0.04
Trap Efficiency (%)	100
Sediment Concentration (mg/l)	10,000
Annual Deposit of Sediment (m3)	3,387
Annual Deposit of Sediment (%)	17.87
Years to fill with sediment	6
No. of times dam fills in a year	28

Tshibaba Sub-surface Dam

Catchment area (km2)	165
MAR (mm)	50
Mean Annual Inflow (m3)	8,250,000
Dam Capacity (m3)	68,250
Storage ratio	0.01
Trap Efficiency (%)	100
Sediment Concentration (mg/l)	5,000
Annual Deposit of Sediment (m3)	26,613
Annual Deposit of Sediment (%)	38.99
Years to fill with sediment	3
No. of times dam fills in a year	121





Appendix 08

SEDIMENT INCREMENT SURVEY

22/11/00

Mkaya Wokhosa Sub-surface dam - Tinago Stream

													Cumulativ
Station	Station	Total			Fall /	Total		Station	C	umulativ	Depth of	Width of	fVolume of
Number	Distance	Distance F	Reading	Reading	Rise	Fall		Slope		Slope	Sediment	River	sediment
1	0	0	1.49		0	0		0		0	0	8.50	-
2	50	50	1.89		0.40	0.40	1	125	1	125	0.90	6.30	167
3	50	100	2.19	0.65	0.30	0.70	1	167	1	143	0.50	6.20	245
4	50	150		0.95	0.30	1.00	1	167	1	150	0.40	6.00	306
5	50	200	0.61	1.75	1.10	2.10	1	45	1	95	0.20	5.00	333
6	50	250	1.47		0.86	2.96	1	58	1	84	0.20	6.00	361
7	50	300	1.76	0.69	0.29	3.25	1	172	1	92	0.75	7.40	486
8	50	350		1.00	0.31	3.56	1	161	1	98	1.00	8.00	679
9	50	400		1.28	0.28	3.84	1	179	1	104	0.40	7.00	754
10	50	450		1.56	0.28	4.12	1	179	1	109	0.30	6.10	803
11	50	500	1.30	1.86	0.30	4.42	1	167	1	113	0.91	6.80	950
12	50	550	1.60		0.30	4.72	1	167	1	117	0.92	7.30	1,112
13	50	600	1.77	0.96	0.17	4.89	1	294	1	123	0.87	9.80	1,298
14	50	650		1.44	0.48	5.37	1	104	1	121	0.69	13.50	1,499
15	50	700	1.12	1.72	0.28	5.65	1	179	1	124	0.48	8.70	1,632
16	50	750	1.51		0.39	6.04	1	128	1	124	1.47	6.20	1,906
			1.69	1.49	0.20	0.59							
17	50	800		1.60	0.11	0.70	1	161	1	1,143	1.72	10.70	2,136
18	50	850		1.92	0.32	1.02	1	156	1	833	0.93	6.00	2,330
			1.30	2.10	0.18	1.20							
19	50	900	1.44		0.14	1.34	1	156	1	672	1.12	7.80	2,439
20	50	950	1.77		0.33	1.67	1	152	1	569	0.57	17.20	2,617
			2.70	1.16	0.93	2.60							
21	50	1000		1.34	0.18	2.78	1	45	1	360	0.42	14.20	2,692
22	50	1050		1.74	0.40	3.18	1	125	1	330	0.95	9.40	2,972
23	50	1100	0.85	2.09	0.35	3.53	1	143	1	312	0.37	12.60	3,074
24	50	1150	1.22		0.37	3.90	1	135	1	295	0.51	8.40	3,208
25	50	1200	1.58	1.22	0.36	4.26	1	139	1	282	0.40	11.00	3,305
26	50	1250		1.56	0.34	4.60	1	147	1	272	0.38	14.60	3,426
27	50	1300	1.20	1.89	0.33	4.93	1	152	1	264	0.67	15.50	3,678
28	40	1340	1.32		0.12	5.05	1	333	1	265			
29	35	1375	3.47		2.15	7.20	1	16	1	191			

Water Storage Capacity a 25.00 % of total sediment volume Estimated average increase in depth of accumulated \$ 0.75 m 3,678

Volume of 1st level gabion: $3 \times 1,00 \times 0.33$ m Volume of 2nd level gabion: $2 \times 0.75 \times 0.33$ m Volume of 3rd level gabion: $1 \times 0.75 \times 0.33$ m In pyramid construction

NKWIDZE - ZABA STREAM - MKAYA WOKHOZI

			N	arrowes	t		Approx	Approx	Approx	
Width of	Cumulativ	Potential	Av of width	points o	Distance	No. of	volume	volume	volume	Total
River at	Volume of	Volume	of river +	river o	previou	Gabions	of gabion	of gabion	of gabion	volume
1,00m high	n sediment	of Water	width+1m	Station	point	Required	m3 yr 1	m3 yr 2	m3 yr 3	of gabions
13.50	-		15.25							
14.00	413	103	13.30	4	0	i.				
13.00	902	225	12.70	3	0	Alternat	e site bec	ause of st	eep slope	to next site
16.50	1,344	336	14.25	7	0	1	5.94	7.05	4.08	17.08
11.00	1,705	426	10.50	1	200	1	4.95	5.20	2.72	12.87
11.00	1,967	492	11.50	2	0	Further	alternativ	e is a sand	dam abov	ve this site
18.50	2,418	605	16.65	14	0	ĺ,				
11.50	3,028	757	13.75	5	0	1				
13.50	3,481	870	13.75	6	200	2	6.93	6.81	3.34	17.08
18.30	3,918	980	15.25	11	0	6				
16.00	4,499	1,125	14.80	8	0	6-				
15.20	5,148	1,287	14.90	9	150	3	7.23	7.38	3.76	18.36
17.00	5,810	1,453	18.30	17	0	Ē.				
29.50	6,700	1,675	28.25	24	0	i.				
22.50	7,568	1,892	19.95	18	0					
18.00	8,441	2,110	15.20	10	200	4	6.14	7.52	4.46	18.12
24.00	8,924	2,231	22.70	20	0	<u>(</u> .				
21.00	10,091	2,523	16.50	13	0	6				
		-								
15.00	10,337	2,584	15.30	12	150	5	7.72	7.57	3.71	19.01
32.00	11,274	2,818	33.20	27	0					
		-	-							
21.30	11,529	2,882	24.85	22	0	È.				
17.00	12,216	3,054	17.90	16	150	6	9.31	8.86	4.21	22.37
22.70	12,916	3,229	23.95	21	0	í.				
17.70	13,517	3,379	17.25	15	0	0				
21.80	14,112	3,528	21.90	19	150	7	10.89	10.84	5.40	27.13
25.50	14,786	3,696	27.35	23	0					
27.00	15,623	3,906	29.00	25	100	8	15.35	14.36	6.68	36.38
					4 000		00.54	00.50	24.00	474.00
m3	15,623	3,906	m3		1,300		68.51	68.53	34.28	171.32

METHODOLOGY OF DETERMING THE SIZE OF SCREEN APETURES FROM THE VELOCITY OF ABSTRACTED WATER

The flow through the well-point was modelled as a cylinder of water passing a point in a given period of time. The flow was considered laminar and frictional effects in the pipe were assumed to be negligible. This was considered a reasonable approximation of the flow conditions due to the low velocity intended and the short length of pipe work.

Thus: flow rate, $Q = \frac{\frac{\pi D^2}{4}h}{t} = \frac{\pi D^2 v}{4}$

A suitable diameter and class of pipe was chosen and the velocity through it calculated using a yield typical of that expected from a simple hand pump. An aperture diameter was selected small enough to restrict \pm 50% of graded sediment particle size in the region of the installation of the well-point.

The number of apertures on the circumference of the screen was determined by the minimum material allowance between apertures without weakening the pipe. The ideal total number of apertures in the screen was then set equating the velocity through the total area of apertures equal to the ideal abstraction velocity determined experimentally by others.

The screen length was then adjusted to keep the length of the screen 500 mm or less, but still ensuring that the velocity into the screen was approximately equal to the ideal velocity through the screen. This was necessary to ensure that the screen was permanently submerged within water saturated sediment. The velocity through the actual number of apertures was compared to the velocity through the pipe, ideally they should not differ considerably.

A theoretical blockage (as a percentage reduction in the number of apertures) was included in order to model the effect sand particles clogging the apertures would have on the performance of the screen over time. A situation where fifty percent of the apertures were blocked and the velocity through the apertures was still less than the ideal was considered best.

A similar procedure was used for slotted well- points, other well-points and caissons.

WELL POINT DESIGN - uPVC, Round Apertures

Pump Yield		
Pump yield	1.00	m ³ /hr
Ideal Velocity	0.030	m per sec
Perforated, Fabricated Wellpoint		
Outside Diameter of Screen	50.00	mm
Diameter of Apertures	2.50	mm
Wall Thickness of Screen	2.75	mm
Required Material Between Apertures	3.75	mm
Minimum Internal Diameter of Screen	44.50	mm
Circumference of Screen	157.10	mm
Apertures on Circumference of Screen	25	
Actual Distance Between Aperture Centres on		
Circumference of Screen	6.28	mm
Approximate Number of Apertures Required	1,886	
Rows of Apertures	76	
Adjustment to Screen Length - No. of Rows	-	
Actual Rows of Apertures	76	
Actual Number of Apertures	1,900	
Cross sectional area of pipe	1,555	mm ²
Actual Total Surface Area of Apertures	9,328	mm ²
Length of Screen	478	mm
Percentage Open Surface Area	12.4	%
Entrance Velocity into Screen	0.0298	m per sec
Velocity of Flow along the Screen	0.1786	m per sec
Assumed Blockage	25	%
Screen Entrance Velocity - After Blockage	0.040	m per sec

WELL POINT DESIGN - uPVC, Slot Apertures

Pump Yield	
Pump yield	1.00 m ³ /hr
Ideal Velocity	0.03 m per sec
Slotted, Fabricated Wellpoint	
Suggested Abstraction Velocity	0.045 m per sec
Slot depth	10.00 mm
Slot width	1.25 mm
Wall thickness of screen	2.75 mm
Required Material Between Apertures	20.00 mm
Slot rows on Circumference of Screen	2
Minimum Internal Diameter of Screen	44.50 mm
Circumference of Screen	157.10 mm
Pipe radius - OD	25.00 mm
Arc length - external wall	46.36 mm
Arc length - internal wall	41.55 mm
Slot surface Area - external wall	57.95 mm ²
Slot surface Area - internal wall	51.94 mm ²
No. of slots per row	38
Adjustment to Screen Length - No. of Rows	-16
Actual Rows of Apertures	22
Total external surface area of slots	2,500 mm ²
Length of screen	468 mm
Entrance Velocity into Screen	0.1547 m per sec
Velocity of Flow along the Screen	0.1786 m per sec
% open surface area	3.40 %

FORMULAE TO DETERMINE THE SIZE OF PARTICLES WHICH WILL BE RETAINED IN A WELL-CAISSON

Reynolds Number Calculations

Dimensionless quantity for comparative purposes

 $\operatorname{Re} = \frac{vd\rho}{\mu}$ Reynolds No:ReVelocity:v in m/secDiameter:d in mViscosity of water: $\mu = 0.001$ Pa.sec (Pascal seconds) also (Nsm⁻²)

Reynolds number needs to be calculated in order to establish that the calculation will be within Stokes Flow. Stokes formula is considered inaccurate between 0.2 - 500 However, for practical purposes applying it with a Reynolds number of up to 10 was found to be sufficiently accurate.

Velocity $\frac{Q}{Q}$

$$v = \overline{A}$$

where: Q = Pump Yield A = Cross sectional area of pipe ($A = \pi r^2$)

Density of Samples (Stone of particles)

Volume of water displaced

 $V = \frac{M}{\rho_w}$ Where: M = mass of displaced water ρ_w = density of water (1000)

 $\rho = \frac{M}{V}$ Where: M = mass of stone V = volume of water displaced Calculation using Stokes Formula to establish the diameter of sediment particles, above which particles cannot be raised by the fluid, at an input velocity.

$$d = \sqrt{\frac{18\nu\mu}{(\rho_p - \rho)g}}$$

Diameter of particledViscosity: $\mu = 0.001$ Pa.secDensity of transporting fluid $\rho = 1000$ Kg/m³ (water)Density of particle $\rho_p =$ (sediment particle)

Quartz = 2363.3 Granite = 2349.5 Sandstone = 2278.5

Acceleration due to gravity g = 9.81 m/sec

Derivation of formula

Weight of particle = Buoyancy + Drag force

 $M_p g = M_w g + 6rv\pi\mu$ where: $M_p =$ Mass of the particle g as above $M_w =$ Mass of the water displaced r = radius of particle v = velocity as above $\mu =$ viscosity as above

 $V_p \rho_p g = \rho_w V_w g + 6rv\pi\mu$ V_p = volume of the particle ρ_p = density of the particle ρ_w = density of water V_w = Volume of water displaced

$$\frac{4}{3}\pi r^{3}\rho_{p}g = \frac{4}{3}\pi r^{3}\rho_{w}g + 6rv\pi\mu$$

Appendix 10

Calculation of particle size using an extension of Stokes formula to increase the accuracy for Reynolds numbers of up to 100

Drag coefficient

$$C_D = \left(\frac{24}{\text{Re}}\right)\sqrt{1 + \frac{3}{16}\text{Re}}$$

Velocity

$$v = \sqrt{\frac{\frac{4}{3}d(\rho_p - \rho)g}{C_D\rho}}$$

Note:

The answers obtained using the above formulas were consistent with those obtained using Stokes formula, within the range of Reynolds numbers calculated.
APPENDIX 10

CALCULATIONS TO DETERMINE THE SIZE OF PARTICLES WHICH WILL BE RETAINED IN A uPVC WELL CAISSON

Reynolds Number	833.8	
Note:		
Stokes formula is considered inaccura	te between 0.2 - 500	
However, applying it with a Reynolds r	number of uo to 10 was found to be s	sufficiently accurate
Velocity	0.7997 m/sec	
Internal Diameter of caisson	0.133 m	
Percentage of Well-point Block	age 75 %	
Area of cross section of caisso	n 0.0139 m^2	
Effective cross section after blo	ockage 0.0009 m*2	
Pump yield 1,250 l/hr	0.6944 l/sec	Note: Single action pump
		= 1,00m^3 / 30 mins
Mass of stone (Granite)	0.359 кд	Experimentally determined
Mass of displaced water (Grani	ite) 0.153 κg	Experimentally determined
Volume of water displaced (Gra	anite) 0.0002 m^3	
Density of stone		
Granite	2349.5	
Quartz	2363.3	
Sandstone	2278.5	

Calculation using Stokes formula to establish the diameter of sediment particles above which particles cannot be raised by the fluid at an input velocity

Granite Particle size	1.0 mm
Quartz Particle size	1.0 mm
Sandstone Particle size	1.1 mm

Calculation of particle size using an extension of Stokes formula to increase the accuracy for Reynolds numbers of up to 100

			Reynolds
acceleration due to gravity (g)	9.81 Re	207.5	Number
density of particle	2349.4764 CD	0.7	
density of water	1000 v	0.079 r	n/sec
viscosity	0.001		
velocity	0.800 m/sec		
Diameter of particle (d)	0.00026 m	0.26 r	nm

Accuracy is proved by near identical values of required velocity (velocity) and calculated velocity Inaccuracy 0.783 mm

APPENDIX 11

ABSTRACTION EQUIPMENT DESIGN











APPENDIX 12

Rower Pump Manual - Sample Pages

1.0-Introduction.

The Rower pump is basically made up of three important parts; a length of pipe (the pump cylinder), a piston and a non-return valve. The Rower pump is used for pumping water from a well point to a tank directly beneath the pump itself. The well point is situated beneath a dry river bed, the well point is also a filter which allows water to pass through it but prevents sand entering the pipe line and pump. The Rower pump has been found to work exceptionally well for this application.

The Rower pump can only pump water to a small height (head) approximately 3 metres, it is ideal for the first stage of water transfer from river to a garden, as it requires only a small amount of energy to operate it. If the components of the pump are in good repair then it is capable of pumping approximately 38 litres per minute, this also depends upon the person using it.

Not only is the rower pump easy to use and maintain but it is also reliable if correctly cared for, therefore this manual should prove a valuable asset for conscientious users of the Rower pump who wish to keep it in good working order.

2.0- 63mm Rower pump parts.



- 1) Handle.
- 2) Steel Collar.
- 3) Pump rod.
- 4) Pump cylinder.
- 5a) Piston Rubber washer.
- 5b) Foot-valve Rubber washer.
- 6) 3 Cup seals.

- 7) Piston valve body.
- 8) 10mm Nylock nut.
- 9) 6mm foot-valve hook.
- 10) Foot-valve body.
- 11) Retaining Sleeve.
- 12) 6mm Nylock nut.
- 13) 10mm Galvanised nut.

3.0-How It Works.

3.1-Pulling the pump rod (3) outwards closes the piston rubber washer (5a), which in turn opens the rubber washer on the foot-valve (5b) and pulls water from point A through the foot-valve(10) into the cylinder (4) to point B. Any water in C is pulled out of the top of the pump cylinder.

A ®

3.2-Pushing the pump rod (3) inwards opens piston rubber washer (5a) and closes the foot-valve rubber washer (5b), this forces the water in B to pass to point C.



3.3-Repeating the above two actions will enable water to pass from A to C.

4.0-How To Use The Pump.

4.1-The cup seals (6) on the piston valve body (7) must be lubricated before use to reduce wear and to prevent them from drying and cracking. Lubrication also makes the pumping smoother and easier. A small amount of Vaseline must be smeared onto the cup seals, ensuring that they have a thin layer of Vaseline all over. Too much Vaseline will make the cup seals soft, they will then loose their shape and will not seal.



4.2-The pump must now be primed, this is done by pouring water into the pump cylinder (4) until it is full.

4.3-The piston valve body (7) can now be inserted into the cylinder.

4.4-Work the pump rod (3) in and out using short strokes whilst the cylinder is being primed again by a second person.





This is done until the water from the river reaches the cylinder (point C page 2). This will be noticed as the pump will become slightly harder to pull on the outward stroke.

4.5-During pumping do not allow the pump rod to drag along the cylinder steel collar (2), as it will cause the pump rod (3) to wear and eventually bend and break, it will also cut the cylinder steel collar. Rubbing the pump rod against the cylinder steel collar also requires more effort and consequently makes pumping more difficult.



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as it will cause the pump rod (3) to wear and eventually bend and break, it will also cut the cylinder steel collar. Rubbing the pump rod against the cylinder steel collar also requires more effort and consequently makes pumping more difficult.

5.0-Caring for the Pump Rod Assembly.

5.1-Always:-

- Lubricate cup seals (6) with Vaseline before use.
- Cover piston with polythene/plastic l
- to prevent it from attracting sand and du
- Store in a cool safe place.
- Store with piston (7) up most leaning a wall to prevent damage from rats.
- Check that the cup seals (6) are fitted correctly.
- Check for loose handle nuts (8) & (13).
- Inspect piston valve body (7) and cup seals (6) before and after use for damage or dirt.
- Clean excessive and old Vaseline from cup seals (6) regularly.
- Follow instructions for pump use.

5.2-Never:-

- Use pump without Vaseline on the cup-seals (6).
- Use the pump with one cup seal (6).
- Use the pump when the piston valve body (7) or it's parts are damaged.
- Use the pump with incorrect rubber washers (5a) & (5b).
- Put too much Vaseline on the cup seals (6).
- Allow children to play with the pump rod.
- Store uncovered.









- Drag the piston valve body (7) along the ground.
- Store in a hot place as the cup seals (6) will dry and crack.
- Use an alternative to Vaseline for lubricating the cup seals (6).

6.0-Care of the Pump Cylinder.

6.1-Making a cover for the pump cylinder.

To prevent damage to the pump cylinder (4) and cup seals (6), dust and dirt must be prevented from entering the inside of the pump. This is done by making a simple cover. Find an old plastic bottle, the diameter of which must be greater than the outside diameter of the pump cylinder (4). Using a sharp knife cut the bottle 15cm from the closed end across the diameter. Wash the bottom part of the bottle and place over pu





- Keep fence around the pump in good repair.
- Follow instructions on pump use.

6.3-NEVER:-

- Leave the sump tank or pump cylinder (4) uncovered when not in use.
- Allow livestock into pump area.
- Allow people to throw sticks, stones or rubbish into the pump cylinder.



Symptom	Cause	Remedy.
Difficult to prime.	Incorrect rubber washers (5a) (5b).	Make new ones and replace.
	Damaged or dirt under foot-valve rubber (5b) washer.	Make new ones or clean and refit.
	Damaged foot-valve cup seal (6).	Replace.
	Damaged foot-valve (10).	Replace.
Difficult to pump.	Head is to great because water level in river has dropped.	Nothing can be done, wait for rain.
Pumps little water.	One cup seal missing (6).	Replace.
	Incorrect or dirty rubber washers (5a), (5b).	Make new ones or clean.
	Damaged cup seals (6).	Replace.
	Leaves or paper blocking foot-valve (10).	Remove & un-block.
	Sand build-up in foot-	Remove and clean.

7.0-Problem Solving.

	valve (10).	
	Damaged foot-valve (10).	Replace.
	Damaged piston valve body (7).	Remove and replace.
	Damaged pump cylinder (4).	Remove and replace.
	Well point out of water.	Dig and lower well point.
Symptom	Cause	Remedy.
Pumps little water with air bubbles.	Well point out of water.	Lower well point.
Will not pump water.	Not primed.	Prime.
	Leaves or paper blocking foot-valve (10).	Remove and un-block.
	Dirt in valves or under rubber washers (5a), (5b).	Remove and clean.
	Damaged cup seals (6).	Replace.
	Incorrect or damaged rubber washers (5a), (5b).	Make new rubber washer and replace.
	Damaged foot-valve (10).	Replace.
	Damaged pump cylinder (4).	Replace.
	Damaged pipe between well point and pump.	Locate damage and Repair.
	Well point out of water.	Dig and lower well