WATER RESOURCES AND WATER DEMAND MANAGEMENT FOR ARID AND SEMI-ARID AREAS: WEST BANK AS A CASE STUDY

BY

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A Doctoral Thesis Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of Loughborough University

July, 1999

DEDICATION

This Thesis is dedicated to Ruba, my wife for her patience and support during the research work; and to my parents.

ACKNOWLEDGEMENT

The research work has been made possible by the help, assistance and advice of a number of people. First, of all, I am deeply indebted to my friend and supervisor Eng. Mike Smith and his wife Isabel for their hospitality and help during my visits to England. I am also grateful to the director of the research Prof. A.D. Wheatley and my supervisor Mr Ian K. Smout and to my local supervisor Dr Annan Jayyossi for their helpful remarks during the research.

I am also grateful to my colleagues at Birzeit University, Civil Engineering Department. My particular thanks go to Dr Khaled Abatha, and Dr Amjad Aliwi, for reading and commenting on my initial drafts and for continuous encouragement and interest in my work.

ABSTRACT

Keywords: arid and semi-arid areas, water resources, water disputes, water policy, water deficits, demand management, water resources management.

A water resources and water demand management model has been developed applicable to locations which experience specific constraints such as rapid population growth, limited water resources and political disputes over water resources. The West Bank was chosen as a case study.

The Research has suggested a paradigm for a comprehensive management framework for large-scale water management problems in arid and semi-arid areas. This management framework can help to achieve sustainable water resources for meeting water demand and preventing the gridlock and excessive legal expense of uncoordinated and conflict-filled decision processes.

The attributes of management frameworks (some well known and others not so familiar) begin with inclusion; that is, the framework should be comprehensive, with extensive stakeholder involvement and collaboration. The decision processes should be clear, action oriented, and adaptive. Other desirable qualities of the framework include a focus on environmental integrity, technical aspects, financial aspects, social implications, institutional aspects, political implications and use of proven management practices.

Today's international legislative structure is incapable of solving complex water disputes. The Research has introduced one such multi-criteria decision tool for quantification of water resources rights. For illustrative purposes, it was presented in terms of the water-sharing problem facing Israel and the Palestinians. The methodology is based upon the several factors identified by the International Law Commission in its draft articles on the non-navigational uses of water.

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LIST OF ACRONYMS AND ABBREVIATIONS*

ARIJ	Applied Research Institute - Jerusalem
AWRA	American Water Resources Association
AWWA	American Water Works Association
CDM	Camp Dresser and McKee International Inc.
CROPWAT	Computer Program for Irrigation Planning and Management
EC	Electrical Conductivity
EPD	Environmental Planning Directorate - Ministry of Planning, Palestine
ESCWA	Economic and Social Commission for Western Asia
FAO	Food and Agriculture Organisation of the United Nations
GDP	Gross Domestic Product
GNP	Gross National Product
GTZ	Deutsche Gesellschaft fur Technische Zusanimenarbeit International
Habitat	United Nations Centre for Human Settlements
ILA	International Law Association
ILC	International Law Commission
ISPAN	Irrigation Support Project for Asia and the Near East
IWRM	Integrated Water Resources Management
JWU	Jerusalem Water Undertaking
LR	Leaching Requirements
LWE	Land and Water Establishment
Max. Tem.	Maximum Temperature
MCDM	Multicriterion Decision Making
Mekorot	The National Water Company of Israel
Min. Tem.	Minimum Temperature
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Co-operation and Development- Paris
PCBS	Palestinian Central Bureau of Statistics
PHG	Palestinian Hydrology Group
P.L.O	Palestine Liberation Organisation
PNA	Palestinian National Authority
PWA	Palestinian Water Authority

Rad.	Solar Radiation
R.H.	Relative Humidity
RO	Reverse Osmosis
UFW	Un-accounted-for water
UN	United Nations
UNDDSMS	United Nations Department for Development Support and Management Services
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNRWA	United Nations Relief and Works Agency
WBWD	West Bank Water Department
WESC	Water and Environmental Studies Centre, Nablus
WHO	World Health Organisation
WRAP	Water Resources Action Program, Palestine
WSM	Water Systems Management - Pietersburg
WSSA	Water Supply and Sewerage Authority of Bethlehem-BeitSahur

* Other abbreviations are explained in the text

UNITS OF MEASUREMENTS*

cm	centimetre
C^{O}	degrees centigrade
ET_P	mean annual potential evapotranspiration (mm)
hr	hour
kg	kilogram
km/day	kilometre per day
l/c/d	litres per capita per day
m	metre
Mcm	million cubic metre
Mcm/yr	million cubic metre per year
mm/day	millimetre per day
mmhos/cm	millimmhos per centimetre
m/s	metre per second
m^3/c/yr	cubic metre per capita per day
ppm	part per million
Tonne	1000 kilogram
P	mean annual precipitation (mm)
P_e	mean annual potential evapotranspiration (mm)
$	U.S.A Dollar

* Other units of measurements are explained in the text

CHAPTER 1
INTRODUCTION

1.1 Management of Water- a prerequisite for life

From the dawn of history, water has had an immense impact on the political and socio-economic life of man. The most remarkable civilisations of the ancient world emerged and flourished in areas blessed with abundant water resources; i.e., the Nile Valley in Egypt and the Indus Valley in India.

With the fast growing population and the expansion of development activities exerting pressure on available water resources, management of water resources is becoming an increasingly serious concern throughout the world. Until early in the twentieth century, much attention was given to the supply side of water resources. Demand considerations and efficiency in use generally played a secondary role. The galloping rise in demand associated with the rapidly changing patterns of water use indicate that the availability of water can no longer be taken for granted, and water use in the immediate future will be governed by increasing scarcity in various parts of the world.

Every country in arid and semi-arid areas has faced, or shortly will have to face, a 'Problem of optimisation'. This will require them to discover the most effective methods for using and distributing water resources. Water management is multidimensional. It embraces planning, design, construction, operation, and maintenance. Its ingredients include technological capabilities, social attitudes, economic realities, political viewpoints, and environmental goals.

1.2 Statement of the Problem

Water resources in arid and semi-arid countries, like most Mediterranean countries, are limited, scarce and difficult to predict from one year to another, while water demand by various users is known.

Even with today's population the demand for water is exceeding supply in several regions of the world. In recent years the world's population has been growing by approximately 90 million people a year. This rapid rate of increase is concentrated in areas where resources are already over-exploited. We can expect an extremely rapid increase in population in the dry climate areas. By the year 2025, around 3 billion people will be living in areas of water shortage (Frederiksen 1996).

Population growth, in addition to recurrent dry years, urbanisation, industrialisation, and irrigation needed to satisfy the additional demand for food, drive arid and semi-arid countries towards resource crises, which are difficult to surmount unless it is made clear that water is a finite and scarce resource (El-Ashry 1991a).

This situation compels us to adapt an entirely new approach to the water issue. As a rule the first step has been to assess the quantity of water required. Efforts have then been made to find the technical means to meet this need. This approach does not work when water is scarce. This situation must instead be looked at from the opposite end: How can that limited amount best be used to serve the interests of social and economical development? (Falkenmark and Lundqvist 1994; ESCWA 1995).

Most natural resources have been the source of international controversy and conflicts. The fact that nature does not always draw carve its boundaries to coincide with the designs of man makes it imperative for people, who otherwise would have been outside the political influences of events, to be dragged in.

In the case of the Israeli-Palestinian water question, the sources of surface (Rivers Jordan and Yarmouk) and ground water supplies cross the limits of their political boundaries so that other political entities like Jordan, Syria, and Lebanon are indirectly associated. It is no exaggeration to say that, unless water issues are resolved the next war in the region may be about water, most likely over the water of the Jordan River basin (Brooks, 1993).

For the West Bank, (the case study of this research), the present range of problems that are related to water are very wide and the disparity between water supply and demand is growing with time. The problems basically stem from the following three difficulties:

•Due to rapid growth of population, there does not appear to be enough water to meet existing demand levels. This situation applies throughout the region, which is generally characterised by aridity and water scarcity (Agnew and Anderson 1992; Lonergan and Brooks 1994; Vajpeyi 1998).

•The conflict over water resources between Palestinians and Israel has always occupied a significant position on their agendas. Since the majority of the region's water resources are shared by more than one country, allocation and management of transboundary water resources assumes great importance. Israel, the West Bank and Gaza Strip share aquifers and thus need to agree on their management. In addition, Israelis and Palestinians (together with other riparian parties) need to reach accommodation regarding the Jordan River basin. The aquifers serve as the major long-term storage for the area as a whole, and are susceptible to overpumping and pollution. Such long-term storage is the central element in any water management system in a semi arid region, and thus its availability is vital to both Israelis and Palestinians alike (Brooks 1992; Naff 1993; Medzini 1996).

•The prolonged subjugation of Palestine to foreign rule from the Ottoman period to the present day has not only prevented the Palestinians from developing themselves and their natural resources, but also adversely affected their national coherence and well being. Nowadays, Palestinians are experiencing a severe water crisis caused mainly by Israel's control over Palestinian water resources. Since the occupation in 1967, the Israeli authorities subjected all works related to water to its direct supervision and control through a military order. This order prevented any Palestinian organisation or undertaking from the execution of any work connected with the running, management, maintenance or development of water services or resources without the prior approval and licensing from the Israeli military authorities (Lonergan and Brooks 1994).

The Palestinian community and National Authority are seriously concerned with their water resources and other related environmental problems in Palestine. They are committed to make structural efforts for the development of this sector. Rehabilitation of existing systems and developments of new systems are urgently required to cater for existing requirements. In addition, in view of the expected population growth, future expansion will be required (WRAP 1994).

As an emergency measure, with the support of International Aid Donor Agencies, several programmes and projects have been initiated and are currently under implementation. Different actors are involved in rebuilding and reshaping the Palestinians' water sector.

1.3 Objectives and hypothesis

1.3.1 The hypothesis

As a basis of the research, the foregoing discussion on the nature and scope of the problem under investigation led to the proposal, formulation and testing of the following hypothesis:

"A water resources and water demand management model can be developed applicable to locations which experience specific constraints such as rapid population growth, limited water resources and political disputes over water resources"

1.3.2 Objectives

This research will attempt to establish a comprehensive scientific water management model through which the optimal development and management of water resources and demand for arid and semi-arid areas will be determined on the basis of comprehensive demand forecast.

To test the above hypothesis, the West Bank was chosen as a case study. It is hoped that the results of this research will assist water managers and engineers to formulate a water resources management framework and initiate actions (that are environmentally, socially, politically, economically sustainable) to improve and manage the water sector.

Although past literature about comprehensive management models is comparatively rich, as will be shown in chapter two of this research, only a few models for management frameworks for large-scale problems are available, which mostly deal with a specific problem in a case study (Grigg 1996b).

The Researcher believes that the case study of this research suggests a paradigm for a comprehensive management framework for large-scale water management problems in arid and semi-arid areas. This management framework can help to achieve sustainable water resources for meeting water demand and preventing the gridlock and excessive legal expense of uncoordinated and conflict-filled decision processes. This research is presented to identify attributes of the paradigm and explain how it can be applied. Physical interactions of the ground and surface water systems, environment, politics, economics, and sociological requirements will be integrated and quantified into the management model. Consequently the specific objectives of this research are:

1. Collecting and assessing basic data including water consumption rates to rationalise water demand analysis as an element of integrated water demand management.

2. Optimising water use in agriculture to increase economic revenues.

3. Examining the availability of water resources covering surface water, ground water and non-conventional water resources.

4. Innovating and identifying new structures to resolve water disputes and achieving equitable allocation of the shared water resources.

5. Identifying and screening potentially applicable water resources management options, and demand side management measures to close the supply-demand gap.

6. Investigating any necessary reforms in the institutional framework, legislation, water tariff structure, or other relevant aspects in order to allow water saving measures to be introduced.

1.4 Approach and scope of the Thesis

Chapter one introduces the subject matter, provides the background information into the aim of the study, and explores the scope of the problem through a series of objectives and a hypothesis. The chapter concludes with a brief summary of the Thesis in Figure 1.1

Chapter two reviews literature on the subject matter and investigates previous water resources management models.

Chapter three documents the general approach for water resources and water demand management models, concepts of integrated water resources management, and models' parameters.

Chapters four to six describe the elements of the main water management model that consists of the three inter-linked models. These models are the water demands model, the allocations and entitlements of shared waters model, and the water balance model.

Chapters seven to ten introduce the application of water resources and water demand management models to the case study area. These chapters cover existing water resources, present and future demands, anticipated deficits in water resources, and a discussion of management options for meeting future demands in the West Bank.

Chapter eleven addresses institutional requirements that are necessary for implementing strategies and engineering works conceptualised in the comprehensive planning management model.

Chapter twelve highlights the main findings of the various aspects of this Research and outlines the policy recommendations and implications for future research.

Fig 1.1 The approach and scope of the Thesis

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Water resources management could be defined as 'skilful use of potential wealth and powers of water'. Water resources management is therefore, a task or function that requires appropriate skills, if it is to be effective (Musa 1984).

Effective management of water resources has been known to play, and will continue to play, a decisive role in the success of many activities to promote human welfare and economic prosperity. On the other hand, unsolved water problems in water resources place restraints on economic growth at a particular place and time (Oyebande and Oluodo 1984).

Rational water management is even more important for arid and semi-arid areas due to lack of water. In order to improve management and use patterns of water resources, water managers must learn from past experience, utilise available information effectively, and avoid making the same old mistakes.

One lesson from the past is very clear: without appropriate policy and institutional adjustments, no technical or engineering solution will succeed. In many regions around the world, resolving these critical water resources management issues, however, will require basin-wide, comprehensive solutions encompassing actions on the political, economic, social, and environmental fronts.

2.2 Definition and hydrological characteristics of arid and semi-arid areas

Arid zones occupy about one-third of the land area of the earth, and include both some advanced countries and many developing countries in North and South America, North and Southwest Africa, Middle East, Central Asia, West Asia, and Australia. One of the simplest classifications of dry climates delineates 250 mm of precipitation as the dividing line between arid and semi-arid, and 500 mm between semi-arid and humid. Most classifications today use combinations of temperature and precipitation, in order to make some allowance for the increasing evaporation with higher temperatures (Murakami 1995).

Oyebande (1985) has summarised the major hydrological characteristics of semi-arid and arid lands in contrast to another environments in Table 2.1.

Table 2.1

Regional Typicalities in Different Zones

Phenomenon	Humid tropics	Arid & semi-arid
Rainfall Annually	High 1000-2000 mm	Low 0-1800 mm
Soil wetting	1400 mm	300-900 mm
Evapotranspiration Actual Potential	 800 mm 800 mm	 300-900 mm 1000-1300 mm
Groundwater recharge	600 mm	2-240 mm
Runoff annually	1200 mm	20-600 mm

Source: Oyebande (1985)

The basic Koppan's (1931), Thornthwait's (1948), and UNESCO's (1977) formulas as quoted by Agnew and Anderson (1992) for classification of arid and semi-arid areas are:

Koppan (1931)

Arid boundary $=P/T < 1$

Semi-arid boundary $=1 < P/T < 2$

Where:

P= Mean annual precipitation (cm)

T= Mean annual temperature (C^o)

Thornthwait (1948)

Arid boundary $I_m \leq -66.7$

Semi-arid boundary $-33.3 > I_m > -66.7$

Where:

$I_m = 100 [(P/P_e) -1]$

P = Mean annual precipitation (mm)

P_e = Mean annual potential evapotranspiration (mm)

UNESCO (1977)

Arid and hyper-arid boundary P/ET_P = less than 0.20

Semi-arid boundary P/ET_P = 0.20 to 0.50

Where:

P = Mean annual precipitation (mm)

ET_P = Mean annual potential evapotranspiration (mm)

Table 2.2 reveals that estimates of the world's arid and semi-arid areas according to different climatic classification vary from 26 to 33 percent.

Table 2.2

Climate classification of arid and semi-arid areas (% of world land area)

	Koppan	Thornthwait	UNESCO
Arid	12.0	15.33	19.5
Semi-arid	14.3	15.24	13.3
Total	26.3	30.57	32.8

Source: Agnew and Anderson (1992)

Table 2.2 presents three different definitions of arid and semi-arid areas and illustrates that the question of defining arid and semi-arid areas is complicated by spatial and temporal variations in factors such as rainfall, temperature, and evapotranspiration. There is no universal agreement over the definition of arid and semi-arid areas. For this Thesis a precise definition is not necessary, it is more important to consider the general principle that evapotranspiration is much more than precipitation.

2.3 Complexity of water resources management

At the beginning, the magnitude and the complexity of resources management and environmental problems were not complex. During the late Stone Age, man started to grow his food by raising livestock and farming near river valleys. Circumstances changed very quickly with the passage of time and the advent of the Industrial

Revolution when a great migration from the rural areas to the cities began, and industries were established close to rivers (Biswas 1976).

Planning and management of water resources are complex because of the many considerations (physical interactions of the ground and surface water systems, environment, politics, economics, sociological requirements) that must be integrated into the total plan. Thus one should search for efficient, simple planning and operation models. The dimensions of complexities can be realised by the facts that relatively few methodologies exist for quantification of social and community goals (Nyumbu 1984).

Even the terminology of water resources management presents difficulties. Words like "comprehensive," "framework," "planning," "integrated," and "co-ordinated" do not mean much to water managers who have their own problems. Recently, a task group of the American Water Works Association (AWWA) introduced a new term, "total water management," apparently rejecting terms used previously. Based on frequency of use, interest in the term "integrated water management" seems on the rise. However, use of the term is not consistent (AWWA 1994).

2.4 Progress in the organisation of water resources management in arid and semi-arid areas

Many arid and semi-arid countries have recognised the need to conserve and manage their water resources through the formulation of medium and long-term policies for their utilisation. At the same time they have made serious efforts to establish or improve meteorological and hydrological networks as well as to improve water administration. Some countries have taken measures to establish unified and centralised institutional arrangements capable of applying modern techniques and methodologies to water management. For example, Jordan and Lebanon have established national water authorities responsible for central management, planning, and administration of water resources (UN 1991).

The Arabian countries of the Gulf co-operation (Kuwait, Saudi Arabia, Oman, Qatar, Bahrain, and the United Arab Emirates) have made remarkable accomplishments in water resources management in the past three decades by developing water supply sources to meet their national demands, which grow at increasingly high rates. Despite these accomplishments, however, the scarcity of natural sources of useable water in the arid area of the Arabian Gulf have continued to impose important limitations on the national development of these countries.

When it comes to the role and fate of water resources in semi-arid and arid areas, despite the many differences socially, politically, culturally, and economically among regions around the globe, many similarities actually exist. High among them: (1) Many have poor management practices, inefficient water use, and failure to place a high economic value on water, (2) The outlook for developing significant new water supplies to meet increasing demands is questionable, given limited financial resources, escalating construction costs, and rising environmental opposition (El-ashry 1991a).

Water resources management strategies in most parts of the world have long been directed towards supplying the demands of different sectors without taking into account the scarcity of the resource. The World Bank has evaluated strategies in various countries and has identified the following principal constraints that lead to water management failures (Frederick 1993):

- Inadequate institutional arrangements and malfunctioning of institutions
- Negligence of the need for economic pricing, financial accountability and user participation
- Insufficient attention to water quality, health and environmental concerns.

2.5 Extracts of international water conferences recommendations

In the last thirty years many international water conferences have forewarned the international community, governments, and politicians of the long-term consequences of poor management of water resources. The recommendations of these meetings have stimulated the international debate and a broad consensus has emerged over the years on the basic principles of sustainable water resources management. However, as implementation of the many recommendations is severely lagging, new initiatives should start from an evaluation of past failures and build on proven solutions and on the success of pilot activities.

The United Nations Conference on Water, held in Mara del Plata, Argentina, in 1977, announced that *"All people, whatever their stage of development and their social economic conditions, have the right to have access to drinking water in quantities and of quality equal to their basic needs."* (UN 1991).

The guiding principles from the Dublin Statement in 1993 on water and sustainable development proposed concerted action to reverse the present trends of overconsumption, pollution, and rising threats from drought and floods. The Conference Report sets recommendations for action at local, national, and international levels based on four guiding principles (UNDDSMS 1996):

- Fresh water is a finite and vulnerable resource, essential to sustain life, development, and the environment.
- Water development and management should be based on a participatory approach, involving users, planners, and policy makers at all levels.
- Women play a central part in the provision, management, and safeguarding of water.
- Water has an economic value in all its competing uses and should be recognised as an economic good.

There are many other numerous international conferences that have called for medium to long term policy measures to protect and conserve water like the Earth Summit-Agenda 21, held in Brazil in 1992, and the UNDP symposium entitled "A Strategy for Water Sector Capacity Building" in Delft in 1992.

2.6 Previous water resources and water demand management models

Historically, the main objective of water resources management models has been economic efficiency. Gradually other objectives have been added. These, in order of their emergence, are regional income redistribution, environmental quality, and social well being (Biswas 1976; Loucks et al. 1981).

To deal with the complexities of multiobjectives of planning, planners are usually forced to construct simplified representations (models) of their problems to enable them to process more efficiently information they have, in order to predict and evaluate the possible outcomes. Even though the application of sophisticated systems analysis techniques to the planning, management, and operation of water resources systems is of comparatively recent origin, the study and use of models probably antedate recorded history. Man has always used models to make decisions. Thus, the question is not whether models should be used, but what type of models should be used to obtain the best possible results.

Water resources management models can be divided into two categories: programming (optimisation) models and descriptive (simulation) models, depending on the relationship of the model to problem solving. Programming models, for a given objective function, attempt to drive the optimal policy. Descriptive models, on the other hand, attempt to predict possible future consequences due to a set of assumed exogenous variable and policy alternatives. Theoretically, water resources managers should find programming models more relevant as an aid to decision making, since they are geared to obtain optimal policies (Major and Lenton 1979; Loucks et al. 1981).

During the last 15 years, tremendous progress has been made on the development of physical models for water recourses planning and management. Several models currently exist that consider some economical and demographic parameters, but very few, if any, include sociological and institutional factors.

The multi-objective optimisation technique, both for quantitative as well as non-quantitative dimensions, is the present tool for long-term management. Technical aspects of optimisation are not the only criteria, since socio-economic and environmental considerations are now of equal or higher priority. Environmental optimisation is primarily a function of the ecosystems, including the consideration of land, air and water resources as well as the interactions between them.

Several optimisation models have been developed in the past for water management purposes, considering one or more objectives discussed above. Louie et al (1984) has developed a multiobjective optimisation management model using linear programming techniques in which they considered water supply allocation. That model gave no attention to social and political impacts.

Miloradov (1992) developed a multiphase optimisation model leading to the development of complex, multipurpose water-resources management in developing countries. He determined the most rational solution (from the point of the view of economy, society, and environmental protection) that would make it possible to transform the available water resources to satisfy demands. One of the limitations of this model that Miloradov assumed that there will be no shortage of water after development and the model only optimises the transformation of available water to demand.

Rubinstein and Ortolano (1984) presented a framework that allows planners of water supply systems to make efficient use of water resources by explicitly considering the management of the demand for water as a supplement to traditional supply augmentation projects. The framework includes a dynamic programming algorithm to determine the optimal combination of supply augmentation and demand management projects. That approach had a single objective, economical efficiency, and ignored other impacts.

Economic valuation and approaching the issue of water rights, is at the heart of the water model for the Middle East and was developed at the Institute for Social and Economic Policy in the Middle East at Harvard University (Fisher, 1994). The Institute created the Harvard Middle East Water Project to investigate and propose a rational economic method for analysing water issues that may help the parties to perceive the conflict and approaches to its resolution in a new way. The work's goal is to promote the adoption of an economic approach to regional water management- an approach that will lead to optimal social use of the limited water resources in the region, through water sales and transfers between areas and economic sectors within nations. It appears that the value involved in different suggested solutions to the property rights dispute between Israel and the Palestinian is less than roughly $200 million per year. This means as the model suggested that the property rights dispute is one over a sum sufficiently small that nations can negotiate about it. The Palestinians' leadership and experts refused to accept this model because they consider that both water and land are valuable things and not for sale even with a high price.

2.7 Summary and conclusions

This research is based on the literature that exists at present. The literature is very disperse, it is very varied, and it deals with a lot of different topics (disputes over water resources, decision-making techniques, demand modelling ...etc.). Individual studies have been carried out in a variety of different scales in different countries with different aims and results. Only a few models for management frameworks for large-scale problems are available. This Thesis brings together the various studies, reviews and evaluates them. An effort has been made to draw out the critical points from the literature as shown in the subsequent chapters.

None of the models reviewed in the literature, however, provides a means of managing water resources considering the various limiting factors and that can readily be applied to locations which experience specific constraints (rapid population growth, limited water resources, and dispute over water resources). Moreover, no single theory or model has been developed that can resolve the layered requirements of water resources management. Most of the reviewed water resources management models are based on narrowly conceived, fairly simple assumptions, and are too restricted to contain all the intricacies of water.

CHAPTER 3

METHODOLOGY

3.1 General approach for water resources management models

The water resources planning and management models include two basic components: a conceptual framework (which include problem identification, choice of objectives, screening of options, formulation of promising strategies, simulation, and evaluation of strategies), and a computational framework (consisting of a detailed calculation procedure).

In general, a number of essential steps towards water resources management should be taken into consideration (Biswas 1976; Sonuga 1984; Musa 1984; Viessman 1990; Miloradov 1992):

1. Definition of objectives
2. Analysis of available water resources
3. Analysis of water demands
4. Development and definition of options for solution considering:
   a- environmental, economical, social, and legal aspects
   b- institutional consideration and public participation
5. Generation of options
6. Choice of optimal option.

3.2 Integrated Water Resources Management: A new concept

In recent years policy makers world-wide have become increasingly aware that water is a limited resource and that its scarcity is becoming a limiting factor for social and economic development. This is especially true in arid regions where scarcity and water quality deterioration have created tensions between user groups. Thus, a change should be observed in the scope of water resources management. Water resources management should start to address resource issues and the often-conflicting interests of the different beneficiaries. This means that new approaches and new concepts must be introduced (EPD 1996).

Demand and supply can be matched according to different scenarios and under different assumptions. A range of scenarios should be evaluated; not only on economic and financial criteria, but also against environmental, ecological, institutional, political and other criteria. Such an exercise requires the involvement of all major stakeholders and is essential in order to formulate a water management strategy that is accepted and supported by the relevant actors.

Integrated Water Resources Management (IWRM) is a process with many dimensions and with the involvement of not only the different administrative levels but also of other sectors of the society, including the private water users. It is strongly interdisciplinary and multi-sectoral and should include many conflicting issues. The essence of the approach is to match demand and supply in an adequate manner. IWRM has many dimensions and pays attention to a large number of often-related issues and principles that has been assembled and used under this research to guide the preparation of the various management options. Some of these principles are efficient and equitable water allocation, public health and environmental sustainability, institutional arrangements, and international water rights (FAO 1995).

Carter (1998) has summarised water policy principles set out in the World Bank, FAO, and UNDP publications, together with those put forward in other places (e.g., Howsam and Carter 1996). He also has exposed the magnitude of the obstacles facing developing countries (some of which are considered as arid and semi-arid areas) as they attempt to introduce the water policy principles. These principles and obstacles are presented in Table 3.1.

Carter (1998) has also pointed out: "*Sustainable water policy needs to be examined carefully within the context of the natural and human environment involved, and against the background of the externalities which affect developing countries. Very real natural, social, cultural, economic, and political obstacles exist to the wholesale adoption of internationally accepted water policy principles*". The management model introduced in this research will be based on the above water policy principles to guide the preparation of the various management options.

Table 3.1

Water Policy Principles and Cultural Obstacles

Principle	Obstacle
Water as an economic good	Water is perceived as a gift of God payments inappropriate; even more so when payment is to a government perceived in paternalistic terms
Integrated, holistic approach	Short planning horizon; uncertainty of political-economic climate; difficulties of coordination between line ministries with rigid procedures in which power is not lightly given up.
Desirability of decentralisation	Large power distance: centralisation of power is accepted as the norm, and has significant personal advantages for those exercising it.
Stakeholder participation (especially women)	Large power distance: those traditionally lacking power do not demand it, nor do they have the time to exercise it.
Private sector participation	Collectivism, not individualism, is the norm; entrepreneurship is not highly developed.
Demand-management rather than supply-augmentation	Paternalistic attitudes encourage attempts to supply perceived demands rather than manage or control them.
Polluter pays	Natural environment perceived as effective repository of waste; no culture of communal waste collection or disposal.

Source: Carter (1998)

Because future conditions are uncertain, management must be sufficiently flexible to allow for possible changes in the political and economic situation in the region. The water resources management framework must:

- Be a "living" entity, with opportunities for periodic corrections to the direction of the water resources development.
- Maximise the use of the available natural resources for purposes that address the water resources needs of society.
- Not preclude the future utilisation of any resources within the region.

3.3 Models' parameters and structure

Models can amplify our available knowledge of the behaviour of complex systems, provide effective frameworks for organising data, incorporate measures of performance of the systems under study, and produce comparative evaluations of performance (Major and Lenton 1979).

For any area, the first step in planning and managing water resources is the definition of a study area and identifying its demand centres and people to be served. The time of the analysis should reach as far into the future as population growth and development within the area can be forecasted with reasonable confidence. This will extend as far as statistical projections are available, particularly demographic data on population, land use, employment, industrial development, housing, etc., and data on municipal, industrial, and agricultural water use within the study area. Typically, this may extend 25 years into the future.

Figure 3.1 shows a general flow chart of the comprehensive model through which the optimal development and management of water resources and demand management for arid and semi-arid areas are determined. It consists of three inter-linked models, which are:

1. Water Demand Model which, as its name implies, calculates the projected water demands based on economical, demographic and technological assumptions. It consists of two sub-models: Domestic Water Demand Model and Agricultural Water Demand Model.

2. Allocations and Entitlements of Shared Water Resources Model which is an inventory of the resources available from existing and potential sources and will

identify new and innovative structures to resolve water disputes. Much data is needed to evaluate water resources quantity and behaviour. All of this information is part of the hydrologic cycle: solar radiation, precipitation, soils, geology, and evaporation. There are many methods and approaches to water resources yield evaluation (or assessment). No attempt is made here to exhaust this research, as it is fully covered by a rich literature.

3. Water Balance Model for Matching Supply and Demand to develop optimal option based on a given set of demands and specific constraints.

Stage one and part of stage two of the flow chart shown in Fig. 3.1 present the Demand and the Allocations and Entitlements of Shared Water Resources Models, while stages three to six show the Water Balance Model. The following three chapters describe the three models in detail.

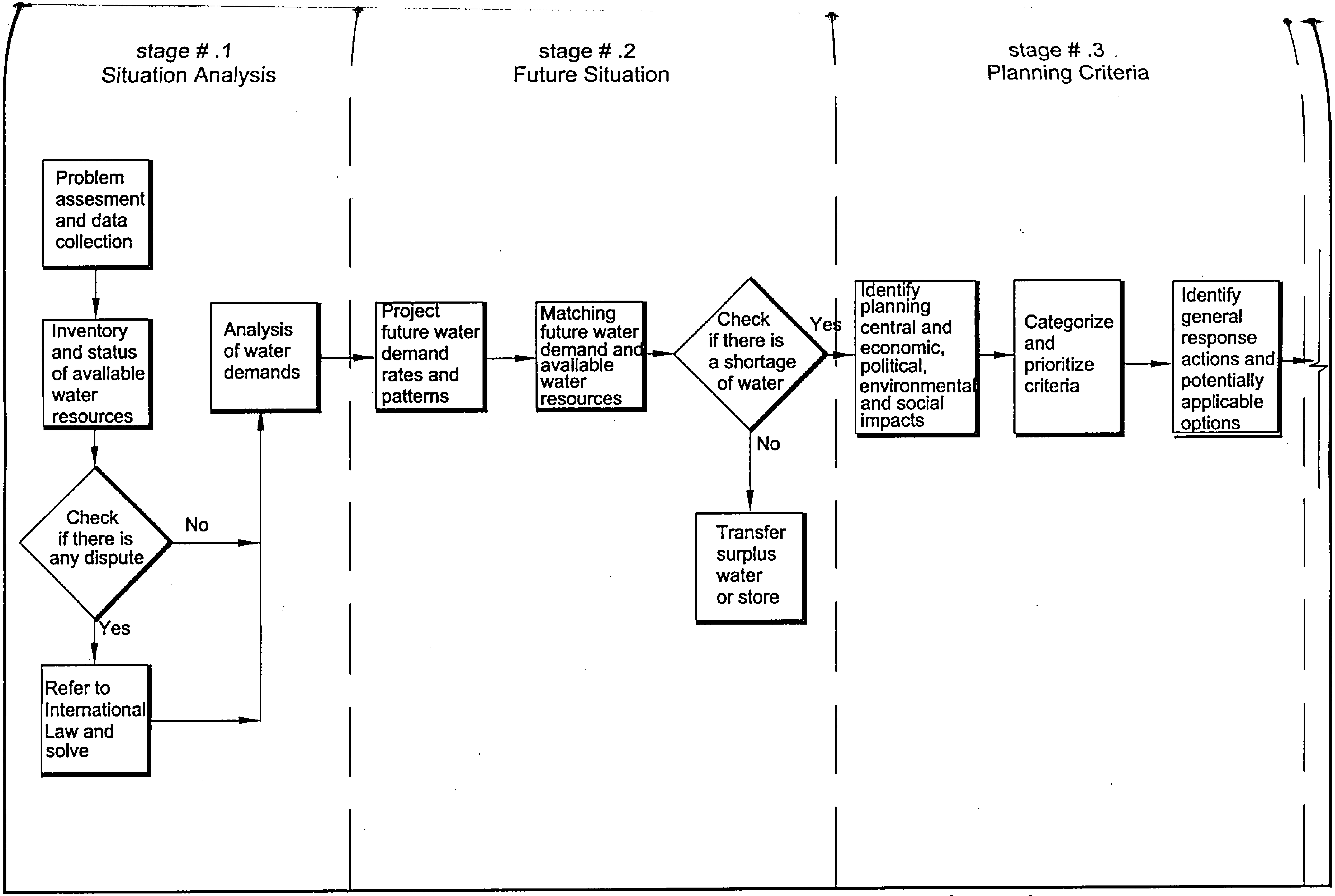


Fig 3.1 General procedure for the development of water resources and water demand management models for arid and semi-arid areas (Source: Author)


Stage #.4
General response actions and water management options
Stage #.5
Alternatives and water management measures/sources
Stage #.6
Selection of water management strategy
Demand management
Supply management
Agricultural
Municipal
Industrial
Domestic
-Pricing and reallocation
-improve irrgation efficiency
-improve crop water use
-water tariffs/metering
-reduce irrgated area and livestock numbers
-promote low water use industry
-water taniffs/metering
-promote wastewater re-use
-promot low water use equipment
-reduce system losses
-water tariffs/metering
-public awareness campaign
Existing sources
Import distant sources
Desalination
Other non-conventional sources
-regulate groundwater abstraction
-encourage rainwater harvesting
-use of poor quality water
-small dams
-freshwater skimming
-artificial recharge
-transfer water rights
-pipeline
-tanker
-brackish grounwater
-saline water
-wastewater
-rainfall harvesting
Check if options meet criteria
No
Discard options
Yes
Formulate scenarios using retained options
Comparatively evaluate feasible scenarios
Check if scenarios meet comparison criteria
Yes
Recommend scenarios
No
Discard scenarios

FIG. 3.1 (Cont.)

CHAPTER 4

MODELLING WATER DEMANDS

4.1 Introduction

Water management, especially in arid and semi-arid countries, calls for planning with consideration being given to the use of non-conventional sources of supply. As a result, there will be a substantial increase in water costs, and the problem of water supply can no longer be seen simply as development of new sources. Accordingly, levels of demand should be affected, and anticipation of water problems and identification of control factors will depend on the forecasts of future water demand.

The procedures that are used for forecasting water demands may vary from relatively simple historical extrapolation to analytical models at various levels of sophistication. The chosen procedures will depend upon the quality and quantity of data and the purpose of the forecast (Khater 1994).

This chapter presents part of stage one of Fig 3.1 (analysis of water demand) and addresses the growing interest in the examination of water demands and the need to pay careful attention to modelling and forecasting water demand in the future. This chapter also discusses the framework of the alternative approaches to water demand modelling and presents a review on how these approaches can be applied to the various water use activities, aiming at guiding the choice between modelling approaches.

4.2 Definitions of water use categories

From the hydrologic perspective, water use data can be defined as all water flows that are a result of human intervention within the hydrologic cycle. A more restrictive definition of water use refers to water that is actually used for a specific purpose. The United States Geological Survey distinguishes nine categories of water use which are domestic, commercial, irrigation, industrial, livestock, mining, public, rural, and thermoelectric power (Dziegielewski et al. 1996).

For the West Bank, the total demand for water comprises demands for domestic, industrial and irrigation uses. Each of these demands will be dealt with separately in chapters eight and nine.

4.3 Measurements and estimation of water use

Quantities of water use can be in the form of direct measurements obtained from water meters, which register the volume of flow, or they may be estimates. Estimates of water use that are derived from the measurements of water levels in storages or from pumping logs are generally more accurate than those derived from estimates of water volumes used for various activities.

Water use data from water supply agency (i.e., water utility company) records can be used for examining historical trends in water use and disaggregating total use into seasons, sectors, and specific end uses within each sector.

Water production records are a good source of data on total water demands in the area served by a public system. Water utilities usually have one or more production meters that are generally read at least daily. The usefulness of the production data for water demand analysis may include, but not be limited to: (1) the analysis of unaccounted water use (comparing production with water sales data), (2) the measurement of the aggregate effect of emergency conservation campaigns on water use.

Customer billing data can be used both for disaggregating water use into customer sectors and for water use modelling. Typically, retail water agencies maintain individual computer records of monthly, bimonthly, or quarterly water consumption records for all metered customers.

4.4 Modelling approaches

Demand models provide simplification, or abstraction, of complex physical reality and the processes involved in it, and serve as tools in the solution of demand forecasting problems.

The choices of an appropriate approach to water demand modelling play a vital role in making planning and management decisions. The discussion here comprises the methodological framework for three broad approaches, namely: historical extrapolation, statistical techniques and mathematical programming.

4.4.1 Historical Extrapolation

The first step in the analysis of water demands in an area served by a public water-supply system is to determine average annual rates of water use. The simplest rate is the gross per capita water use that is determined by dividing the total annual amount of water delivered to the distribution system by the estimated population served.

Although there are many types of forecasting approaches, they can be reduced to several prototypical methods that differ with respect to the level of disaggregation and the structural complexity of water-use equations. The simplest technique, known as time extrapolation, extrapolates the average change in past water use records into the future. The forecasting equation can be written as (Dziegielewski et al. 1996):

$$Q_t = f(Q_{h1} \ldots Q_{hm}, t)$$

Where: Q_t : water use in forecast year t

$Q_{h1} \ldots Q_{hm}$: historical time series of water use

The change in water use over time may be assumed to be linear, exponential, logarithmic, or other. The linear extrapolation uses the following relationship:

$$Q_t = Q_0 + g\,T$$

Where: Q_0 : intercept of the historical time series of water use $Q_{h1} \ldots Q_{hm}$

g : average change in water use per time period (i.e. the slope of the trend line fitted to historical data)

T : the number of time periods between the beginning of the historical record and the forecast year t

A distinctive class of forecasting approaches introduce a simple water use relationship in which total water use is represented as the product of the number of users and an average rate of water use:

$$Q_t = N_t q_t$$

Where: Q_t : total water use in forecast year t

N_t : number of water users in year t

q_t : average rate of water use per customer (or unit use coefficient) in year t

4.4.2 Statistical Techniques

In the statistical modelling of water demand relations, a water activity is conceptualized as a black box with input and output variables, and their associated costs or prices are defined. In the black box representation, inputs and outputs are known as explanatory variables and dependent variables, respectively. Among the explanatory variables one should distinguish the so called exogenous variables that have an effect on the dependent variables but are not explained by the model. These include variables such as administered prices, and environmental standards (Kindler and Russell 1984).

A statistical model of a water demand relation can generally be expressed as

$$D = f\,(X_1, X_2, \dots X_n) + E$$

Where D denotes demand, $f(\quad)$ the function of explanatory variables $X_1, X_2, \dots\dots,$ X_n and E is a random error variable describing the effect on D of all factors other than those explicitly considered in the form of explanatory variables.

In practical applications, the analytical form of function f is commonly assumed to be either additive, multiplicative, or a combination of the two. These possibilities translate into linear, full logarithmic, or semilogarithmic forms:

$$D = a_0 + a_1 X_1 + \dots + a_n X_n + E$$

or

$$\ln D = b_o + b_1 \ln X_1 + \ldots + b_n \ln X_n + E$$

or

$$D = c_o + c_1 \ln X_1 + \ldots c_n \ln X_n + E$$

Where D is the total unit amount of water demand; a_o ....., a_n , b_o,....., b_n and c_o ,..... , c_n are the structural parameters of the alternative models, X_1 , ... , X_n are explanatory variables, and E is the random error term. These forms are convenient because they allow for easy estimation of model parameters by use of multiple regression analysis (Taylor et al. 1987).

The identification and selection of appropriate explanatory variables is closely connected with determination of a suitable model structure for each dependent variable. Statistically, there are several properties of explanatory variables to be considered in the identification and selection process:

i. High correlation with the dependent variables.

ii. Low correlation with other explanatory variables.

iii. High relative variation (ratio between standard deviation and mean) in the observed values of the variables.

iv. Ease of reliable forecasting of the variables.

The random error term E is almost always assumed to have the following properties:

i. The expected value of E is zero.

ii. The variance of E is a constant.

The ordinary least squares method is the most commonly used technique for estimation of model parameters under the assumptions mentioned about the random error term (Norusis 1991). In the modelling process, after estimating the model parameters, the next step that should proceed using the model is verification and validation of the model. Verification of a statistical model estimated by application of multiple regression analysis involves (Sirkin 1995):

- computation of various measures of fit goodness (e.g., multiple correlation coefficient.)
- application of several tests of significance (e.g., F-test for the overall significance of the regression equation, t-test for the significance of the individual regression coefficients)
- checking of the extent to which some basic assumptions of multiple regression are met, like linearity.

In addition, the model should be verified from the qualitative point of view by ascertaining whether the regression coefficients have correct signs in the sense of being in agreement with theory and common sense.

4.4.3 Mathematical Programming

Mathematical programming techniques are concerned with establishing the best or optimal solutions to decision-making problems. Thus, they involve the use of optimisation methods such as linear, integer, dynamic, and multi-objective programming.

A mathematical programming model of water use activity is a combination of unit processes written in the form of a set of inequality and equality constraints of the system, where the decision variables are the levels of operation of the process. The objective function for the model represents the criterion for choosing the optimum combination of unit processes, the measure that must be minimised or maximised. In water demand analysis, it is most common that the objective function represents cost. In such cases the problem is stated as follows (Hall and Dracup, 1970; Loucks et al. 1981; Gupta and Hira 1997).

Find X that minimises $f(X)$

$$D = f(X) + E$$

Subject to the constraints

$g_i(X) < 0, i = 1,2, \ldots, m$

and

$l_i(X) = 0, i = 1,2, \ldots, p$

Where X is an n- dimensional vector called the design vector which denotes the levels of unit processes, $f(X)$ is the objective function to be minimised and $g_i(X)$ and $l_i(X)$ are respectively, the inequality ($g_i(X) < 0$) and equality constraints ($l_i(X) = 0$). The number of variables n and the number of constraints m and / or p are not to be related in any way (Gupta and Hira 1997).

A linear programming model is applicable for the solution of problems in which the objective function and the constraints appear as linear functions of the decision variables. Integer programming is used when the variables are restricted to non-negative integer values. Dynamic programming technique is well suited for the optimisation of multi-stage decision problems when decisions have to be made sequentially at different points in time and space, and at different stages in the decision making process (Ossenbruggen 1984).

The choice of objective function expressed in terms of decision variables is governed by the nature of the problem, being the criterion with respect to which the solution to the problem is optimised. In some situations, there may be more than one criterion to be satisfied simultaneously. An optimisation problem involving multiple objective functions is known as a multi-objective programming problem.

4.5 Choice of modelling approach

The choice between modelling approaches depends on such factors as data availability, data reliability, skills, and access to computational facilities. But this choice is also linked to the intended application of the model to be constructed. One way of summarising the links between application and model type is to look at combinations of two principal characteristics of a specific application: the level of analysis, and the problem to be addressed. However, the variety of situations under which demand analysis is required is so large that there is simply no way to provide a general recommendation of the best way to proceed (Kindler and Russell 1984).

The following discussion on the application of demand models for the various water use activities provides guidelines for the choice of modelling approach.

4.5.1 Domestic water demands

A criticism of the historical forecasting procedures is that they are trying to solve a complex problem with a simple solution procedure that ignores many factors that could affect the future demand. Statistical techniques are very helpful in identifying factors to account for variations in domestic water use. The most commonly used statistical technique has been regression analysis.

Domestic water demands have been the subject of considerable statistical modelling. In these model studies, per capita water use has been correlated with income, household size, price, number of occupants...etc. (e.g., Bhattacharya 1982; Khadam 1984; Clarke et al., 1997).

Mathematical programming techniques are not often used in modelling domestic water demand.

4.5.2 Agricultural water demands

Statistical methods have not been widely used for modelling water demand relationships in agriculture while mathematical programming is a planning tool that is well suited for the analysis of water demand in the agricultural activities. Mathematical programming techniques are able to answer questions concerning economic demand for water, and to find the best solution in a set of feasible solutions. Linear programming is the most widely used technique for modelling agricultural activities (UN 1976).

Although Linear Programming is the most widely used technique for modelling agricultural water demands by individual and regional activities, a number of other mathematical programming and simulation methods have also been applied. To mention just a few, the studies of Palmer-Jones (1977), Windsor and Chow (1971), and Ahmed and Van Bavel (1976) are representative in this respect.

Models used in agricultural water demand analysis vary in complexity and methodology. To estimate crop water requirement in the conventional approach, the area to be developed for irrigation is specified and multiplied by a coefficient reflecting the volume of water required per unit area, thus giving an estimate of the water requirements.

The Food and Agriculture Organisation of the United Nations (FAO) has developed a computer program for irrigation planning and management (CROPWAT) in 1984. The Modified Penman-Monteith method can be used with CROPWAT software to calculate reference and crop evapotanspiration as well as irrigation requirements for any irrigated area (FAO 1984; FAO 1992; ARIJ 1998).

Chapter nine of this research presents a summary of the definitions and calculation procedure of the Modified Penman-Monteith method and CROPWAT software with an application of the method to the West Bank, the case study of this research.

The next important subsystem in the agricultural sector is livestock production and processing. Livestock processing uses considerable amounts of water. The unit process water use in livestock production refers to the amount of water needed to sustain a given animal provided all other inputs are kept constant. Such water use can be divided into two categories: drinking water consumption and other water needs. Drinking water use varies with the type, age, and environment of the animal. The amounts of water needed depend on various factors such as animal species, size, age, amount and content of feed, accessibility of water, and air temperature (Gouevsky and Maidment 1984).

4.5.3 Industrial water demands

Water is not a major input factor for industrial development, and the cost of water supply represents only a very small part (usually below 1%) of the total production cost or of the value of output. Two important conclusions may be derived from this fact (UN 1976; UN 1988):

(a) Industrial planners and managers are inclined to select alternatives which tend to optimise aggregate production objectives and, hence, may deviate considerably from alternative criteria for optimisation of water component or the criteria of the over-all regional management and development of water resources.

(b) In the case of industry, there are much greater opportunities for achieving the required level of efficiency in water use and pollution control through price structures and other economical incentives than in the cases of agricultural and domestic water uses.

Because the purposes to which the water is used in industrial processes vary widely, and there are different uses of water within an industrial plant, the development of specific and accurate relationships explaining water use patterns is difficult. When the analysis is concerned with individual industrial plants, mathematical programming seems better suited. This is partly because the data problems of the statistical approach result in a rather crude average representation of the activity in question. When the problem at hand is of analysis beyond that of the individual activity, the model of choice is usually the statistical one.

The development of a sufficiently "realistic" industrial mathematical programming model requires specialised expertise and a great deal of cost and technological data. These necessary data are, of course, only a subset of the data required to construct and operate the modelled facility anyway, but this does not mean that such data are easily collected. In addition, the development and operation of a model typically require considerable outlays in terms of both human and computer time (Stone and Whittington 1984).

Given an economical base study, forecasting industrial water demand involves classifying existing plants by process, product mix and size, forecasting technology, and analysing the alternative internal water utilisation patterns and costs (UN 1976).

The future water demand will be projected considering the future plans for the industrial and development in the country, such as extension works and establishment of new ones. There are a great variety of factors affecting future industrial water demands on regional or national scales. Several of these factors depend on future policies and decisions hardly predictable in advance. One reasonable way of overcoming this difficulty consists in identifying a number of possible sets of future conditions and assessing the levels and ranges of water demands corresponding to these assumed alternative future scenarios.

4.6 Concluding remarks

The process of projecting water demands should be directed towards analytical modelling approaches such as statistical techniques and mathematical programming if reliable and valid data are available. The superiority of analytical models over extrapolation methods lies not only in their greater accuracy but also in their capability of including economic factors and assessing the consequences of various policy options. One advantage of the mathematical programming approach over the statistical one is that the costs and prices may be allowed to vary beyond their values recorded in the past and the resulting predictions of the demand may be accepted with reasonable confidence.

Because of the diversity of local conditions under which demand analysis is required, general rules of standard solutions can only be of limited value in working out details of modelling procedures. However, based on the nature use of activities, mathematical programming as a planning tool seems well suited for the analysis of a wide range of demand forecasting problems in the agricultural and industrial activities. On the other hand, the statistical approach appears to be most promising for modelling domestic water demands.

For this thesis historical extrapolation was used to project domestic and industrial demands for the West Bank due to the absence of data, while statistical approach was used to develop the domestic demand model for the West Bank to monitor the different factors affecting the domestic water demand as shown in chapter eight. Mathematical programming was used in modelling agricultural activities of the West Bank, as shown in chapter nine.

CHAPTER 5

ALLOCATIONS AND ENTITLEMENTS TO SHARED WATER RESOURCES MODEL

5.1 Introduction

Shared fresh water resources have been the source of international friction and tensions for many years, in many places. World wide, approximately fifty percent of all land area is an international drainage basin, and more than 200 rivers are shared by two or more nations. This geographical fact has led to the geopolitical reality of disputes over shared international rivers, including the Nile, Jordan, Litani, and Euphrates (Gleick 1992).

Some states with joint aquifers have solved their problems peacefully, others reached agreement on the joint agreement of the aquifers only after several wars as in the case of India and Pakistan during the years 1948, 1965, and 1971. Another example is the continuing dispute between France and Belgium regarding the management of a joint carbonate aquifer, where France has been exercising abstraction controls for many years and the Belgians have not. Recent progress has been made as both countries have worked together to produce a mathematical model of the aquifer. In resolution of this dispute there is a chance that the language of mathematics will work where the language of diplomacy has not (Feitelson and Haddad 1994).

This chapter presents part of stage one of Fig 3.1 (disputes over water resources), provides an overview of current resolution principles and procedures, describes the characteristics and dynamics of water resources conflicts, and presents the conflict resolution process in theory. Chapter seven presents the application of those procedures and principles to the case study area.

5.2 Approaches to resolving water conflicts

Successful solutions will require a renewed emphasis on both regional co-operation and the participation of a broader range of affected interests, which in turn will require more effective processes for dealing with differences. Comprehensive water management will only work if all significant interests and their concerns are recognised and a greater diversity of management options are considered to meet their varying needs (ISPAN 1994).

The satisfactory resolution of water disputes requires both improved conflict resolution methods and innovative measures such as water marketing and conservation. This combination of decision-making processes and technical or policy solutions is critically important to creating workable solutions to controversial water resource problems.

How can we reduce the risks of water related conflict? International law and international institutions must play a leading role. There have already been some attempts to develop agreeable international law protecting environment resources, but almost all of these focus on attempting to limit environmental damages from conflict and war. No satisfactory water law has been developed that is acceptable to all nations, despite years of effort by various organisations. Developing such agreements is difficult because of the many intricacies of interstate politics, national practices, and other complicating political and social factors (Gleick 1992).

5.2.1 The principles of a water sharing regime

Fresh water has been a central focus of almost every international meeting on the environment and economics as back, and even before, World War II. Modern approaches to management of international waters began in 1956 when the International Law Association (ILA) issued the Dubrovnik rules that, among many other things, stated that river basins should be treated as an integrated whole, regardless of national borders. A decade latter in 1966, the association adopted what have come to be called "the Helsinki Rules" for rivers and lakes that cross or form borders but for which there is no formal agreement.

The Helsinki Rules were further developed by the International Law Commission (ILC), an organisation created by the United Nations to focus on specific international legal issues. In 1991, the ILC completed the drafting and provisional adoption of 32 articles on the law of the Non-Navigational Uses of International Watercourses. Moreover, the United Nations General Assembly adopted a Convention on the Law of the Non-Navigational Uses of International Watercourses in May 1997. Among the general principles that help to reduce tensions and encourage effective and productive negotiations by the parties involved are (FAO 1986 b; Benvenisti 1992; Moore 1992; Gleick 1992; UN 1997):

- equitable allocation
- obligation to resolve water related disputes peacefully
- obligation not to cause harm to other riparian states
- obligation to exchange hydrologic and other relevant data and information on a regular basis.

Questions remain about their relative importance and means of enforcement. It has been often pointed out that the international water law is nonbinding and lacks enforcement mechanisms. This is true, but it may also be the " What we have got" as a guide for negotiations (Caponera 1992; Elmusa 1992).

In some ways the more challenging task for negotiators is to translate those principles into operating rules and procedures to determine the equitable apportionment of waters from shared water resources.

5.2.2 Equitable allocation of trans-boundary waters under international law

Equitable allocation of trans-boundary waters principle under international law is one of the most important developed by ILC and the Helsinki statements. At the same time it is one of the most difficult to define, given the multitude of variables that should be taken into account (Gleick 1992).

The principle of equitable utilisation means that each basin state is entitled to a reasonable and equitable share in the beneficial use of shared water. "Equitable" does not mean equal use. Rather, it means that a large variety of factors, including population, hydrology, climate, existing uses, economic and social needs, geography, availability of alternative resources, and so on, must be considered in the allocation of water rights (PHG and LWE 1991).

It is to be noted that each factor is not to be considered in isolation, but looked upon together with all the other factors, without any of them being given priority. This theory neither purports to identify fixed criteria in the sharing of international water, nor to protect existing water rights. Rather it aims at establishing a mechanism for cooperation and negotiation with a view to reaching an agreement (Caponera 1992).

It would be convenient if some rules could be used to allocate water fairly between the parties, but no single clear-cut international standard of water allocation fairness exists. The following lists the diverse factors that the International Law Association associates with equitable water use (Eaton and Eaton 1992):

- Factor A: *The geography of the basin, including in particular the extent of the drainage area in the territory of each basin state, the hydrology of the basin, including in particular the contribution of water by each basin, the climate affecting the basin, ecological and other factors of a natural character.*

- Factor B: *The past utilisation of the waters of the basin, including in particular existing utilisation.*

- Factor C: *The economic and social needs of each basin state.*

- Factor D: *The comparative costs of alternative means of satisfying the economic and social needs of each basin states.*

- Factor E: *The degree to which the needs of a basin state may be satisfied, without causing appreciable harm and substantial injury to a co-basin state.*

5.3 Quantification of water resources rights

This research introduces one such multi-criteria decision tool for quantification of water resources rights. For illustrative purposes, it is presented in terms of the water-sharing problem facing Israel and the Palestinians. The approach presented in this Thesis should be seen as a first step in grappling with the problem of trans-boundary water resources rather than as the final word.

The methodology which is introduced in chapter seven translates the principle of equity in the use of a common property resource into a set of procedures to determine Israeli and Palestinian entitlements to the shared waters. The methodology is based upon the several factors listed above identified by the International Law Commission (ILC) in its draft articles on the non-navigational uses of international watercourses.

CHAPTER 6

WATER BALANCE MODEL

6.1 Options for closing the supply demand gap in arid and semi-arid areas

This chapter presents stages three to six of Fig 3.1 that deal with the growing disparity between water supply and demand in arid and semi-arid areas; this disparity is calling for shifting emphasis in water management from supply to demand management. It has been demonstrated in many countries, and under varying conditions, that the "next" best source of water is often that which can be saved in almost any system. Saving water, rather than development of new water resources and supply projects may prove in many cases to be the optimal policy for several reasons. It is advisable also for environmental reasons, for instance, to minimise leakage, to prevent pollution, and to reduce sensitivity to emergencies such as drought (Brooks 1992; Biswas 1993; Habitat 1996).

It is hardly surprising that Mohammed El-Ashry (1991b), head of the World Bank's Environment Department, concludes that: *"The traditional strategy of responding to water shortages by increasing supplies through capital intensive water transfer or diversion projects has already clearly reached its financial, legal and environmental limits. Attention must now shift from development to management."*

El-Ashry's view reflects a major shift in the World Bank's approach to water resources management, one that is bound to reverberate throughout the entire international aid community. Where the World Bank goes, others are sure to follow.

Demand management consists of actions that influence water use behaviour while providing an acceptable level of service with a reduced volume of water in most cases.

The options for closing the gap between supply and demand in arid and semi-arid areas should consider various means of matching supply and demand, and of satisfying environmental concerns. Besides demand management possibilities the strategic options should include (Le Moigne et.al. 1994):

- Broad technical arrangements needed to meet physical developments of water resources.
- Options for institutional and human resource arrangements, highlighting the potential of involving water users, non-government organisations, professionals, and local government in water resources management.
- Requirements and alternative means for capacity building in institutions and skills for water sector management.
- Environmental and health protection measures.

6.2 Description of planning criteria

The multi-objectives of water resources planning and management have made the planning process much more complex than ever before. The dimensions of the complexities can be realised by the fact that, currently, relatively few methodologies exist for quantification of social and community goals, and no adequate method has been found for measuring them or determining what they should be (Helweg 1992).

In developing and analysing options in making recommendations, the water resources manager must strike a balance between the ideal and the practical forms of water resources management for a country. The manager should in any event avoid producing a list of options and recommendations that is a "wish-list", divorced from practical considerations of the resources available to implement a water resources strategy.

Options for reducing the gap between supply and demand differ in the amount and timing of the capital investment required, in the amount of operating and maintenance cost, in useful life of the capital investment, in effectiveness, and in their economical and environmental impact on the area. The assessment criteria used to rank the different potential options to meet the future national and regional water demand in terms of quantity and quality includes different aspects. These are technical aspects, financial aspects, environmental impacts, social implications, institutional aspects, and political implications.

Planning criteria will serve as a tool and set the framework for decision making regarding the development and selection of different options. The criteria can be classified into the following categories:

A. Financial viability

Financial analysis plays a major role in assessing the different development options. This category includes the following sub-criteria:

1. Fundability

As less expensive local sources of water become fully developed, additional supplies can generally be made available only through development of more expensive, and often more distant, sources. Since available funding for water resources development is always scarce, it is important that the total cost of water supply options be within the capabilities of the government.

2. Unit cost of water, dollars per cubic meter

Competing options may be evaluated based on the overall cost (i.e., capital investment and recurrent costs). However, since water demand may not be inelastic to the price of water, and since costs are not fixed over time, it may be more appropriate to use the cost of a unit of water for evaluating competing water resource options. This criterion, which is a measure of efficiency of options, can be obtained from a cost/benefit analysis.

3. Affordability

Water supplies for all uses must be reasonably priced. Water that has too high a price for a given use will be unavailable to some potential users, and water that is under priced will attract a demand that may exceed the quantity that can be supplied. A subsidy of water supply risks over-use of the resource and invites a degradation of the supply system if the full costs of operation and maintenance are not recovered from the users. It is, therefore, important that water supplies be obtained at a cost to the user that is consistent with the value of the water to the user, and at a price that generates sufficient revenue to provide for operation and maintenance costs.

B. Technical viability

Criteria included in this category are:

1. Availability of technology

Some proposed large-scale water import schemes are characterised by technologies that are complex or at a scale never attempted for water supply. Others require technologies that are as yet unproved and which require research and development. Long-range water supply plans that are based on such schemes have inherently greater risks, and imply relatively greater uncertainty in terms of cost than those that use only proven technologies.

2. Implementability

This criterion addresses considerations (such as data, infrastructure, manpower, expertise, reasonable time schedule for implementation, equipment, level of effort, energy form needed for operation and its source, and land requirements) which are necessary to implement the various water supply technologies. Invariably, some technologies require a level of effort or equipment that may be available locally, whereas others may necessitate the import of specialised contractors or manpower.

3. Flexibility and reliability of technology

This criterion is a measure of the ability of technologies to meet the design objectives, the ability for expansion and modifications to meet future demands, and susceptibility to failures and breakdowns.

3. Feasibility

This criterion is a measure of the relative complexity of constructing, operating, and maintaining the various technologies and components of water resources options.

C. Source viability

Criteria included in this category are:

1. Availability and hydrologic certainty of the source

Water sources that have a relatively high degree of uncertainty in their supply, due to hydrologic randomness, are less desirable than those which are predictable. Since it is critical that investments in the development of new water supply sources have a high probability of success, it is important for those sources to be hydrological dependable.

2. Sustainability of quantity and quality

It is important that options be capable of providing significant quantities of water in relation to the total unsatisfied demand, and sustaining these quantities during the planning period. Water from various sources may have different qualities. It is essential, thus, that the quality of supplied water meet the established standards for the intended use, and that this quality be sustainable.

3. Flexibility of Supply development

This criterion is a measure of the potential expandability for further developing the source to accommodate growing future demands. Options that offer easy or modular expandability of water supply and which are not restricted to operation in particular or limited locations are relatively more attractive.

D. Political viability

Political viability includes political constraints and risks, and political acceptance. On the question of the final plan, it is often very much a political process and the real decision-making lies with politicians. Political implications encompass the following criteria:

1. Willingness of participants

Most of the large-scale water import schemes require the participation of several countries in the acquisition and transportation of water. The ultimate success of any such plan necessitates long term political and economic commitments on the part of all countries involved, as well as the development of institutions for recognition of international water rights and management of conveyance systems. Accordingly, any large-scale import plan must be evaluated from the point of the long term willingness and institutional reliability of the participating countries.

2. Political certainty of the source country

This criterion pertains to the long-term political reliability of the commitment and stability of the source country. Thus, this criterion is a measure of the long-term accessibility to the source independently of the internal political situation of the source country.

3. Compatibility with the international laws and the existing agreements.

This criterion pertains to the ability of options to accommodate riparian rights and other international laws and existing agreements regarding exploitation of water resources.

E. Institutional viability

This aspect includes:

1. Availability and capacity

The short and long term success and sustainability of any water resources option is closely related to the availability of various institutions, and the ability to develop adequate capabilities that can accommodate the increasing future demand requirements. Managerial, regulatory, legal, and political institutions within the planning area and participant countries must all be considered in the evaluation.

2. Reliability of institutions

It is incumbent upon these institutions to be effective, reliable, and efficient in administering and managing the required water delivery and treatment system. Accordingly, management and service-providing institutions should be financially viable, and able to provide services equitably in a timely and cost effective manner.

F. Environmental viability

Large-scale manipulations of the hydrologic cycle are likely to have beneficial and adverse impacts on the environment, and this is the case with projects involving major improvements in water supply. The range of potential environmental impacts is very large and the environmental impact of each option needs to be classified. This classification includes (OECD 1985):

1. Impacts on the built environment

Positive impacts include improvement of public health and hygiene as a result of increasing supplies to meet domestic water demands. Negative impacts include: (1) the increase of wastewater flows as a result of increasing water consumption; (2) generation of various waste steams such as disposal of brine water produced by desalination; (3) greater use of fuels for energy generation; (4) disturbing existing land use patterns and ownership. Additional short-term adverse impacts could include noise pollution and traffic disruption during construction. Noise pollution can be a long-term effect for some options.

2. Impacts on the physical and natural environment

Potential impacts on the physical and natural environment may include: (1) reduction of groundwater and surface water flows and resources; (2) impacts on flora and fauna; (3) possible pollution from the output of chemicals and solid to soil, and land.

G. Social viability

The social impacts of each option need to be classified. This classification includes (OECD 1985):

1. Public acceptance

This criterion addresses public attitudes towards, and willingness to sustain additional cost burdens associated with, various technologies or alternative water resources options due to cultural or political views.

2. Fulfilment of development needs

Positive impacts of large-scale water supply and resources development encompass economic growth and social development due to: (1) job creation; (2) expected growth of water-reliant economic sectors such as agriculture and industry; (3) improvement of property values and quality of life.

6.3 Screening and comparative evaluation procedures

The major objective of this section is to discuss Multicriterion Decision Making (MCDM) techniques that can be applied to evaluate and choose optimal and applicable water resources management options in which discrete options are evaluated against criteria or factors ranging from cost (a quantitative criterion) to aesthetics (a qualitative criterion).

A wide variety of tools are currently being employed for addressing challenging decision. problems in water resources management. Many of these techniques originated from the field of operational research for addressing systems management problems such as those often arise in water resources. By being cognizant of the main characteristics of the problems being studied, one can select one or more decision-making methods that match the characteristics of the actual problem (Duckstein et.al. 1982; Gershon and Duckstein 1984).

More than 70 MCDM techniques and 49 different criteria upon which the choice of an appropriate MCDM technique can be based are identified in Tecle (1988). However, it would be very difficult, if not possible, for any one individual to possess the skills necessary to apply all the available techniques and evaluate them with respect to all criteria. Furthermore, experience in the use of a particular technique appears to be a pre-requisite for evaluating the technique with respect to a set of criteria.

Table 6.1 depicts the basic layout of the discrete version of an MCDM technique. In a sense, a multi-criterion tableau is like a spreadsheet on a computer for systematically organising and presenting information about a problem. The evaluations of the criteria for each option reflect the objectives or preferences of the decision-maker. For each option, one has a row or column of *n* entries for comparing this option to the others in order to determine the set of preferred solutions. Most MCDM techniques differ in the types of information required for evaluating the options, as well as the definitions of the search procedures for finding the better solutions (Hiple 1992).

Table 6.1

Tableau Used in Multicriterion Decision Making

A: Alternatives and C: Criteria

	A_1	A_2	....	A_n
C_1				
C_2				
C_n				

Source: Hiple (1992)

Belief networks (also known as Bayesian networks) provide a method of presenting relationships between variables even if the relationships involve uncertainty, unpredictability, or imprecision. Links between variables can be established deterministically or probabilistically using field data or, if more appropriate, expert opinion. By adding decision variables (variables that can be controlled), and utility variables (variables to be optimised) to the relationships of a belief network, it is possible to form a decision network. This can be used to identify optimal decisions. The theory and methods of construction of belief and decision networks have been described by a number of authors (e.g. Spiegelhalter et al., 1993).

MCDM techniques for quantification of social and community goals rang from simple visual procedures, rating and ranking methods, matrix and linear scoring methods, to multipleobjective programming techniques. The choice of a suitable MCDM to be applied in this research is based on the author's familiarity with some of these techniques.

The most appropriate technique for application to the type of problem typified by watershed resources management, is the rating technique which is based on the "direct weighting" approach. Each general category will be assigned a weight (1 to 100) by each member of a Water Focus Group, based on expert opinions (i.e., past experience and data from the literature) which can be obtained by distributing a questionnaire to each member of the Focus Group. Then the simple average weight can be obtained for each category. (The Water Focus Group is comprised of individuals who are involved and interested in the various aspects of water resources development, planning, management, research, and utilisation.)

The procedure for screening the options involved the specification of a rating of each option with respect to its consistency or compatibility with each general category of criteria on an ascending scale of 1 to 10. After this qualitative rating, an overall score will be determined for proposed options, by calculating the product of the option rating for a given general criterion, times the criterion weight, and then summing these products across all general planning criteria. Symbolically, if w_i is the weight assigned to the i^{th} planning criterion by members of the Focus Group, and if r_{ij} is the rating of the j^{th} option with respect to the i^{th} criterion, the overall score, S_j, for the j^{th} option is calculated as:

$$S_j = \sum^{n}_{i=1} r_{ij} W_i$$

The scores, which will be obtained by various members of the Focus Group, will be summed to obtain an overall score for each option. Options with higher scores are ranked higher, and considered more compatible with the planning criteria than those with lower scores. Chapter ten of this Thesis presents an application of the above technique to the West Bank.

Chapter 7

ALLOCATIONS AND ENTITLEMENTS MODEL TO ISRAEL'S & THE PALESTINIANS' SHARED WATER RESOURCES

7.1 Introduction

The issue raised in this Research, dispute over both groundwater and surface water, seeks a solution. Israel, the West Bank and Gaza Strip share aquifers and thus need to agree on their entitlements. In addition, Israelis and Palestinians need to reach agreement regarding the Jordan River basin (together with other riparian parties).

Unless both sides cooperate and jointly manage their shared water they both stand to lose, in terms of the long-term viability of their water systems. In other words, the only real choice both sides face is between a lose-lose situation if they do not cooperate, and a potential win-win situation if they do. This chapter outlines one possible approach to the problem of allocating the waters of the aquifers and Jordan River Basin between all riparian parties. It depends on the discussion of the principles of a comprehensive water-sharing regime drawn from the international law of trans-boundary waters presented in chapter five.

7.2 General features of the West Bank

7.2.1 Geography

Palestine is composed of two separated areas, Gaza Strip and the West Bank that have been under the Israeli military occupation since 1967. The West Bank is situated on the central highlands of Palestine. The eastern boundaries are the Jordan River and the Dead Sea, the western, northern and southern are the 1948 cease-fire line. The total area of the West Bank is 5788 km^2. Under occupation, the West Bank has been administratively divided into eight districts, namely: Bethlehem, Hebron, Jericho, Nablus, Jenin, Tulkarem, Ramallah, and Jerusalem, the towns from which these districts take their names are shown in Fig. 7.1 (WESC 1996; CDM 1997; ARIJ 1998).

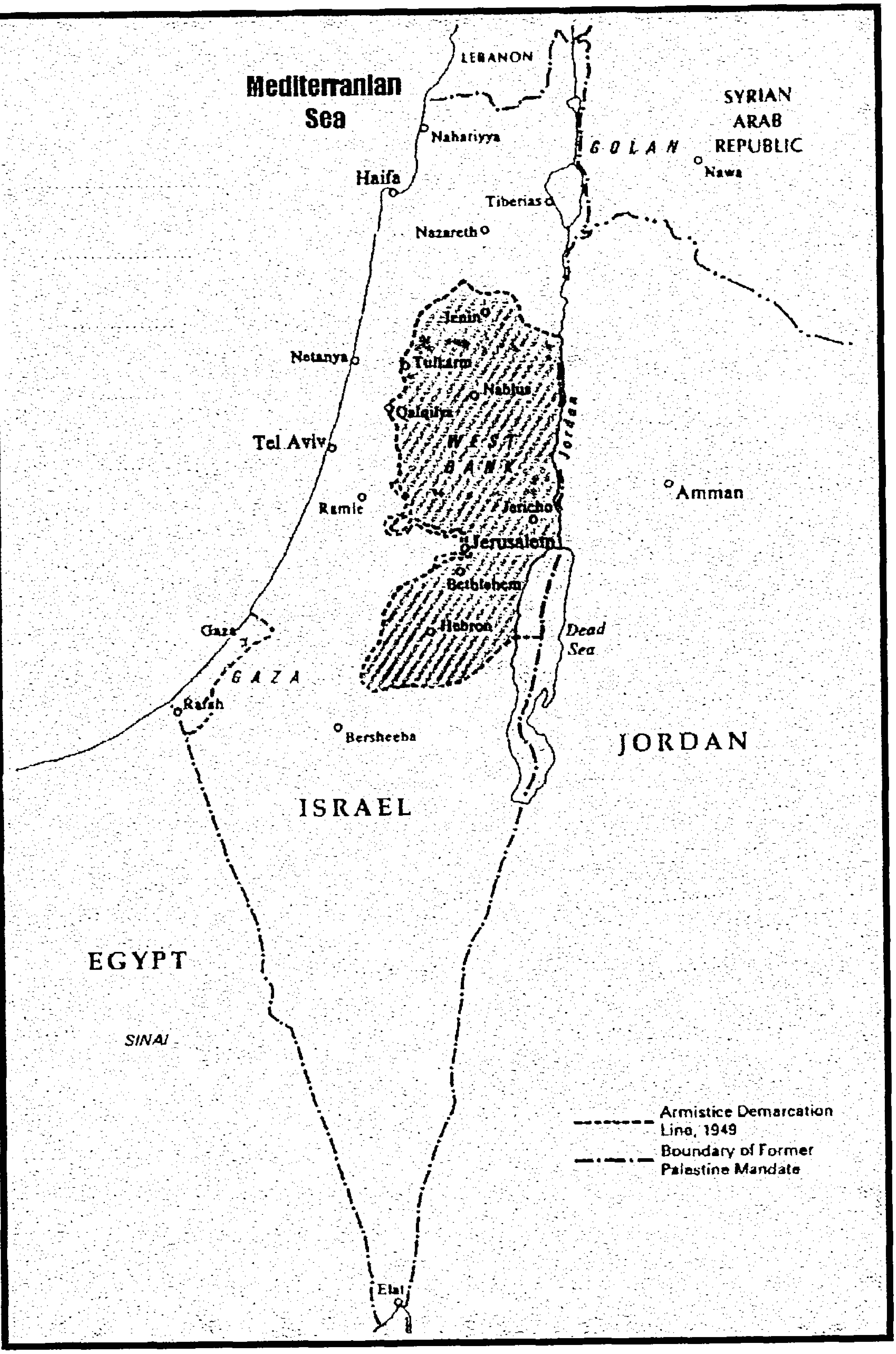


Fig. 7.1 West Bank Location Map (Source: WESC 1996)

7.2.2 Climate

Rainfall is limited to winter and spring months (October to May) and the summer is completely dry. The western slopes of the West Bank receive an annual rainfall of 500-700 mm, and the eastern slopes 100-250 mm. Annual average rainfall in the West Bank is around 450 mm. Temperatures are relatively high and vary from one place to other. January is the coldest month with temperature averaging between 8-10^{0}C in the highlands and 12-13^{0}C in the Jordan Valley. On the other hand, August is the warmest month, with temperatures ranging between 22-26^0 C in the highlands, and 28-34 ^{0}C in the Jordan Valley. The measured relative humidity in the West Bank ranges from 50%-70% and it is considered as a semi-arid area (WESC 1996).

7.2.3 Shared water resources

7.2.3.1 Surface water resources

The Jordan River system is the only surface water resource in the West Bank. The Jordan River flows from Lebanese and Syrian territory to the Lake Tabarias (Kinneret) to its mouth in the Dead Sea. Northern tributaries to the Jordan River, which deliver approximately 540 Mcm/yr to Lake Tabarias come from Lebanon (Hasbani River), Israel (Dan Spring), and the Golan Heights (Banias River and Hermon Spring). These flows combine with local runoff and precipitation to represent the total inflows to the Lake, which has a total storage capacity of approximately 4000 Mcm.

The National Water Carrier, which is the main distribution system for water from Lake Tabarias south to the Negev, draws annually 500 Mcm/yr from the Lake. Roughly 72 Mcm/yr of water passes out of the Lake to the Jordan River, which then combines with the Yarmuok River, the Zarqa River, various salt springs and precipitation and runoff. In conclusion, the total quantity of water which runs in the Jordan River starting at its sources and ending at the Dead Sea where it last empties amounts to approximately 1151 Mcm/yr of water. Fig. 7.2 provides a schematic diagram of the Jordan River's water flow (Abu Faris 1988; Soffer 1992; Lonergan and Brooks 1994).

7.2.3.2 Ground water resources

The two-shared aquifers between Palestine and Israel are:

1. The Mountain Aquifer: The hydrogeological map of the Mountain Aquifer is shown in Fig. 7.3, that aquifer can be divided into:

a. Western Aquifer (Yarkon-Tanninim): This aquifer flows towards the Mediterranean Sea and recharges the Coastal aquifers. The feeding area spreads over 1800 km^2 of which 1400 km^2 lie in West Bank, and 400 km^2 in Israel. The storage area of the aquifer spreads over 2500 km^2, almost all in Israel. This aquifer has an estimated safe yield of about 362 Mcm/yr (Gutman 1988; UN 1992).

b. North-eastern Aquifer (Nablus-Gilboa or Eocene Aquifer): This aquifer discharges into the Zirien Valley Basin. Groundwater flows mainly northward. The feeding area and the storage area, spread over 700 km^2 of which 650 km^2 are located in the West Bank, only 50 km^2 are located in the area of Israel. The average safe yield of this aquifer is about 145 Mcm/yr (Shaliv 1980).

c. Eastern Aquifer: The feeding area and the storage area, spread over 2200 km^2 of which 2000 km^2 of the feeding area are located in the West Bank, and all of the storage area is located in Israel. The average safe yield of this aquifer is about 94 Mcm/yr of fresh water and 78 Mcm/yr of brackish water for further development (Gvirtzman 1992).

2. The (Gaza) Coastal Aquifer (Pliocene-Pleistocene Aquifer): The estimated safe yield of this aquifer is about 65 Mcm/yr (Shuval 1992).

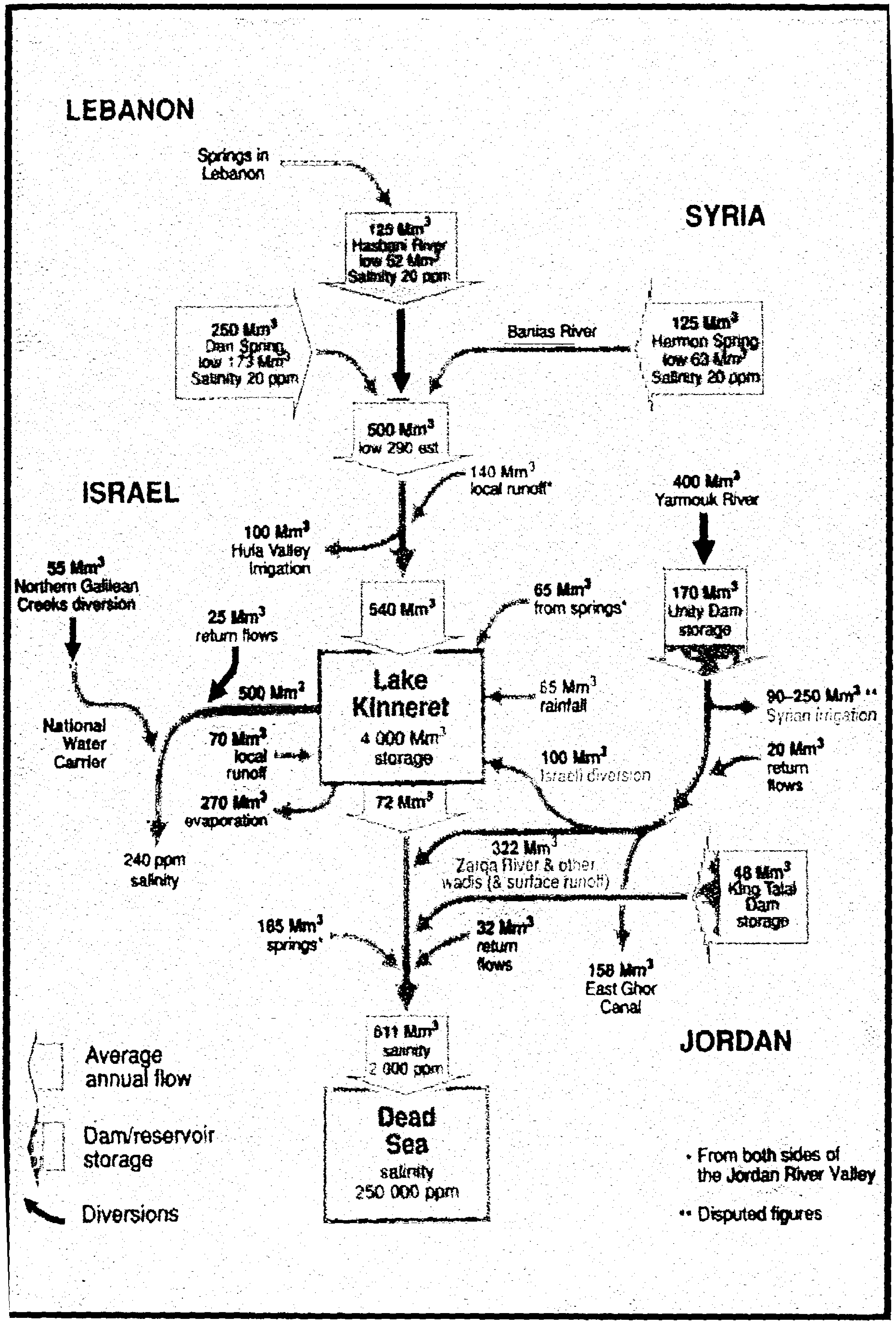


Fig. 7.2 Water flow in the Jordan River Vally (Source: Lonegan and Brooks, 1994)

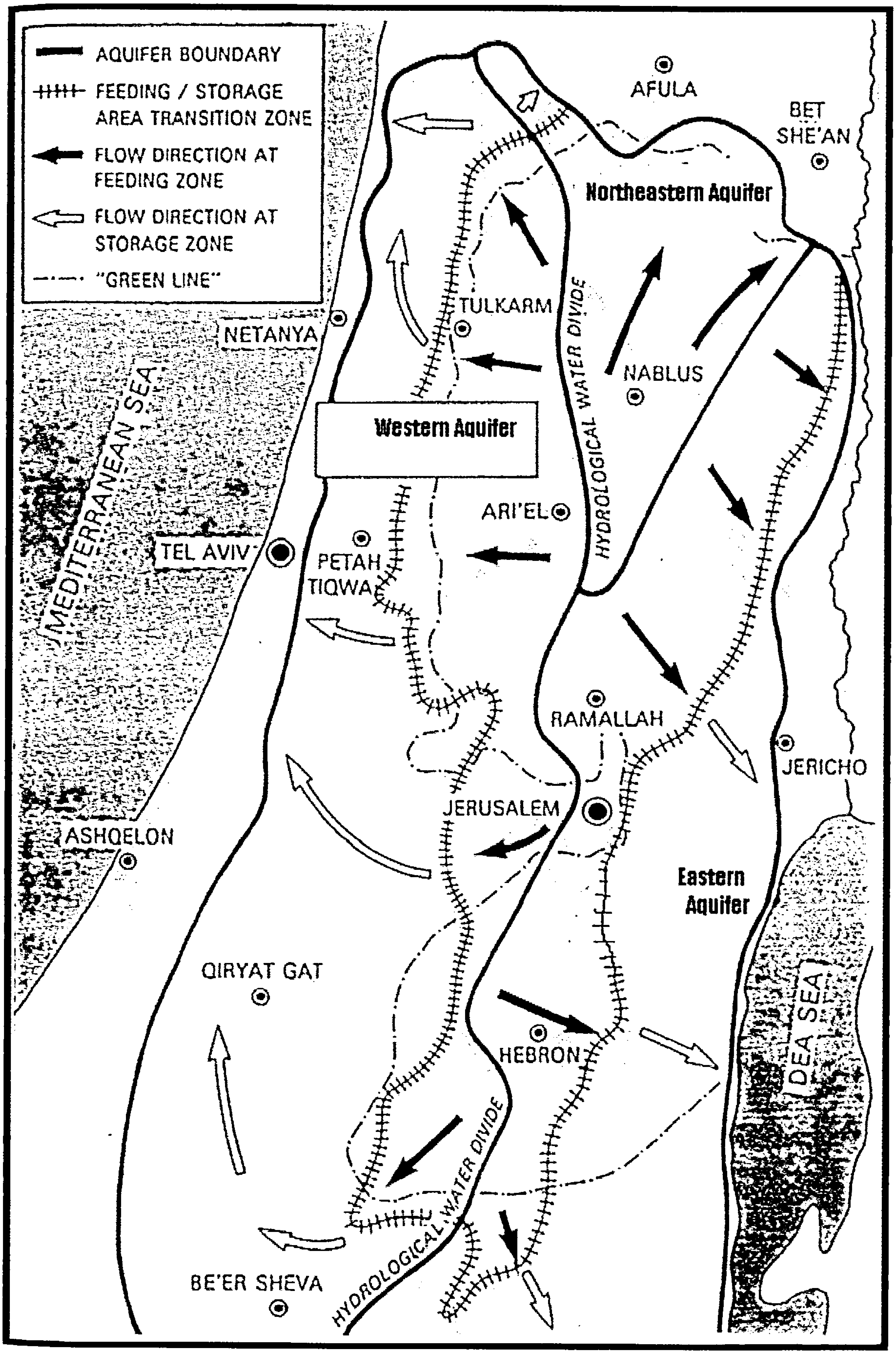


Fig. 7.3 Hydrological map of the Mountain Aquifer (Source: Givrtzman, 1992)

7.3 Parting the waters

7.3.1 Calculating Israeli's and Palestinian's entitlements to the shared Aquifers

7.3.1.1 Quantification of equitable allocation factors

While much can be learned from international experience, no single methodology is directly applicable to the Israeli-Palestinian situation. In other words, there is no methodology we should try to emulate. As stated in Chapter Five a methodology is introduced here to translate the principle of equity in the use of a common property resource into a set of procedures to determine Israeli's and Palestinian's entitlements to the shared aquifers. These procedures are based upon the several factors identified by the International Law Commission (ILC) in its draft articles on the non-navigational uses of international watercourses presented in Section 5.2.2.

Five of these factors were operationalized yielding seven alternative equity standards. These equity standards served as benchmarks against which various possible allocation outcomes are measured. They are produced along with the operational definitions from which they were derived.

An allocation outcome $A(a,b)$ specifies the entitlement in Mcm assigned to Israel and the West Bank respectively, where a represents the Israeli share, b the Palestinian share, and the sum of the two shares equals the combined water potential of the transboundary aquifers (601 Mcm).

The five factors from which the equity standards are derived were operationalized as follows:

Factor A: *"The geography of the basin, including in particular the extent of the drainage area in the territory of each basin State, the hydrology of the basin, including in particular the contribution of water by each basin, the climate affecting the basin, ecological and other factors of a natural character."*

Allocation could be calculated according to the ratio between the area of the aquifer (feeding area as well as storage area) which would be under Israeli control and that which would be put under Palestinian control.

1. Recharge area

Recharge area is "the surface area composed of permeable rock outcrops through which rainwater is able to penetrate underground reservoir" and represents a measure of the inflow to the aquifers (Todd 1976). In such a scenario, 14 percent of the combined recharge area of all aquifers lies within Israel's borders. Accordingly, the Israeli entitlement is 84 Mcm/yr or 14 percent of the combined water potential of the aquifers. On this basis the Palestinian entitlement is 517 Mcm/yr or 86 percent, as shown in Table 7.1

2. Storage area

The combined storage area of the aquifers as 5400 km^2, of which 4750 km^2 and 650 km^2 (88 and 12 percent of the total respectively) lie within Israel and the West Bank. Thus Israel is assigned 529 Mcm/yr (88 percent) and the West Bank 72 Mcm/yr (12 percent), as shown in Table 7.2 (Shalive 1980; Gutman 1988; Gvirtzman 1992).

Table 7.1

Summary of the recharge areas laying within Israel and West Bank (km^2)

Aquifer	Safe yield Mcm/yr	Total recharge area	Recharge area Within West Bank	Recharge area Within Israel
Western	362	1800	1400	400
North-eastern	145	700	650	50
Eastern	94	2200	2000	200
Total	601	4700	4050	650
Percent		100	86	14

Table 7.2

Summary of storage areas laying within Israel and West Bank (km^2)

Aquifer	Safe yield Mcm/yr	Total storage area	Storage area Within West Bank	Storage area Within Israel
Western	362	2500	0.0	2500
North-eastern	145	700	650	50
Eastern	94	2200	0.0	2200
Total	601	5400	650	4750
Percent		100	12	88

Factor B: *"The past utilisation of the waters of the basin, including in particular existing utilisation."* This factor can be operationalized as follows:

Western Aquifer

This aquifer was naturally drained through the Rosh-Ha'ayin springs (220 Mcm/yr) and the Taninnim springs (100 Mcm/yr) which are located in Israel. Since the 1950s, the whole potential of this groundwater resource has been utilised (Mandel and Shiftan 1981). Before 1967, Israel used 340 of the 362 Mcm/yr available in the basin. The other 22 Mcm/yr were used by Palestinians in the towns of Qalqilya and Tulkarem, who diverted some springs and wells. These figures have remained basically unchanged to the present time (Gvirtzman 1992).

North-eastern Aquifer

This aquifer was naturally drained through the Giboa and Bet-Shean Valley springs in Israel (103 Mcm/yr), and the Wadi Farih springs in West Bank (17 Mcm/yr). Both before and after 1967 Israel utilised about 103 Mcm/yr from this basin. In the same period, the Wadi Farih springs, the Bardela springs, and some other springs, yielding all together 42 Mcm/yr, were utilised by Palestinians (Boneh and Baida 1977).

Eastern Aquifer

This aquifer was naturally drained through springs located in the West Bank including the Auja, Samiya, and Ein Gedi springs. Today, 40 Mcm/yr is allocated for irrigation by Jewish settlements, and Palestinians use 54 Mcm/yr (Nusseibah and Nasser Eddin 1995). Table 7.3 summarises the past utilisation of water of each aquifer. According to this table Israel is entitled to 80% of the water of the Mountain Aquifer, while 20% for the Palestinians.

Table 7.3

Summary for past utilisation of water of each aquifer

Aquifer	Safe Yield (Mcm/yr)	Used by Palestinians (Mcm/yr)	Used by Israeli (Mcm/yr)
Western Aquifer	362	22	340
North-eastern Aquifer	145	42	103
Eastern Aquifer	94	54	40
Total	601 (100%)	118 (20%)	483 (80%)

Factor C: *"The economic and social needs of each basin state."* This factor can be operationalized as follows:

1. Domestic Needs

Total water consumption for domestic purposes is projected to be 1046 Mcm in the year 2000: 692.9 Mcm for Israel and 353.1 Mcm for Palestinians, or 66.2 percent and 33.8 percent of the total respectively (Gvirtzman 1992; Schwarz 1992). Therefore, Israel is entitled to 398 Mcm and the Palestinians 203 Mcm.

2. Industrial Needs

Industrial consumption of water in the year 2000 is projected to be 135 Mcm for Israel and 18.2 Mcm for the Palestinians (Gvirtzman 1992; Schwarz 1992). Thus, Israeli and

Palestinian entitlements to the waters of the aquifers are 529 Mcm (88.1 percent) and 72 Mcm (11.9 percent) respectively.

3. Agricultural Needs

Total water consumption for irrigation purposes in the year 2000 is estimated to be 1379 Mcm: 1180 Mcm for Israel or 85.6 percent of the total, and 199 Mcm for the Palestinians or 14.4 percent of the total (Gvirtzman 1992). Thus, Israeli and Palestinians entitlements to the waters of the aquifers are 514 Mcm (85.6 percent) and 87 Mcm (14.4 percent) respectively.

Factor D: *"The comparative costs of alternative means of satisfying the economic and social needs of each basin states."* This factor can be operationalized as follows:

Water resources options refer specially to potential sources such as desalination of seawater and imported water. Desalination technology can be used to extract fresh water from either brackish or saline water. The West Bank is a landlocked territory and does not have a sea front, while Gaza has a modest front that may be able to support a major desalination plant. Israel, on the other hand, enjoys a broad sea front extending from the Lebanese border to Gaza's, that gives flexibility in plant location.

Desalination technology is available and represents a viable option, particularly for Israel. As for costs, it is reasonable to suppose that the comparative costs both for national economy and to consumers are far more favourable to Israel. All of this makes Israel more capable of tapping the desalination option than the Palestinians. Furthermore, Israel already possesses the industry and technology of desalination, while Palestinians would have to import it (Kally 1992).

Table 7.4 shows that about 22% of the Palestinian population make their living from agriculture compared to less than 5% in Israel. Any reductions in water use by the agricultural sector could alleviate water problems in Israel at little or no economic cost. Any further decline as a result of lower water allocations would be almost negligible (Lonergan and Brooks 1994).

Table 7.4

Economic characteristics of Israel and the West Bank, 1994

	Israel	West Bank
GDP per capita (U.S $)	11687	1643
GNP per capita (U.S$)	11487	2127
Sector contribution(%)		
Agricultural	2.3	22.2
Industry	21.8	5.7

Source: Lonergan and Brooks (1994)

Measured in Gross Domestic Product (GDP), Israel's economy in 1994 was more than 7 times that of the West Bank and its Gross National Product (GNP) per capita about 5 times higher. This makes Israel more capable to pay for water and tapping the desalination option than the Palestinians. Thus, the Palestinians would be entitled to a larger portion of the common waters than Israel, proportional to GNP (GNP per capita for Israel is about 5 times higher than for the West Bank) i.e., 83.3% (501Mcm) to Palestinians and 16.7% (100 Mcm) to Israel from the common aquifers.

Factor E: *"The degree to which the needs of a basin state may be satisfied, without causing appreciable harm and substantial injury to a co-basin state."*

Appreciable harm refers to costs that can be objectively measured as result of denial of water rights. The implication of this factor is obvious: no riparian can deny water to a co-riparian if that denial causes appreciable harm and water must be reallocated in order to stop the infringement (Goldberg 1992).

Palestinians have undoubtedly sustained appreciable harm due to Israel's unilateral, lopsided appropriation of the common water that has left Palestinians with a substandard level of consumption, and created a wide water gap between them and Israelis. Israel not only does not have to sustain appreciable harm as a consequence of redistribution; it also stands to gain in the context of a peaceful settlement through selling desalination technology as well as generating hydroelectric power from projects that require approval of the Arab side like Red-Dead Canal (World Bank 1993).

The words "appreciable harm" have created definitional problems to both Palestinians and Israelis, therefore and to be non-allied, factor E was not included in the alternative equity standards shown in Table 7.5.

7.3.1.2 Optimal allocation and entitlements to shared groundwater resources

The following methodological approach may be one way of approaching the problem of water allocations to water short partners. Returning to the seven equity standards in Table 7.5 and Fig. 7.4, there is no manifestly "best" definition of entitlements; the standards do not converge on any one particular allocation outcome. The task, then, is to identify that outcome which did the "least violence" to the seven equity standards taken together. (i.e. to distinguish an optimal allocation outcome which not necessarily the best measured against each equity standard in isolation, is the least worst of all outcomes when all seven taken equally into account).

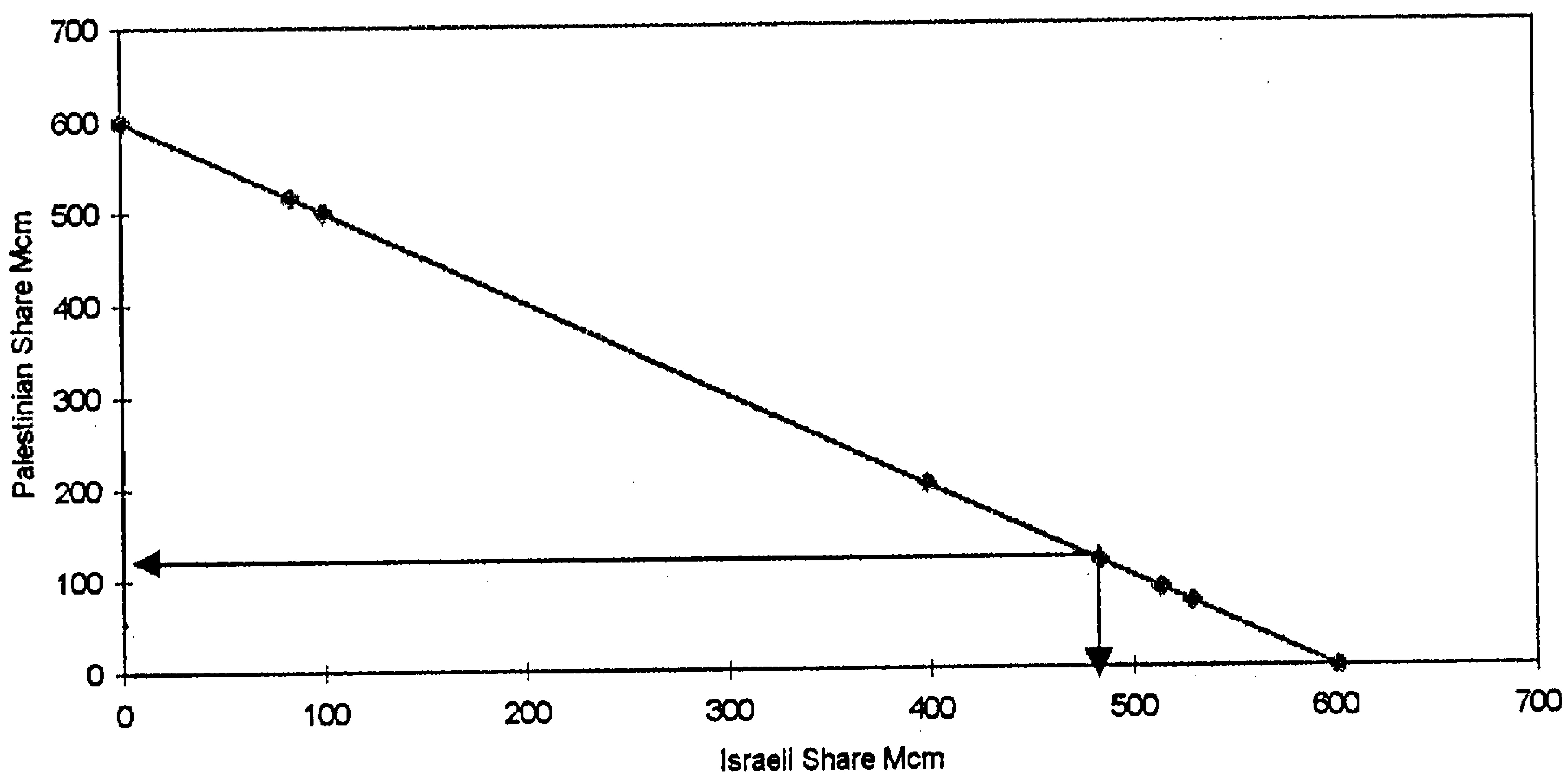
Table 7.5

Alternative Equity Standards (Mcm)

Factor		Share (Mcm)	
		Israeli	Palestinians
Factor A	Recharge Area	84	517
	Storage Area	529	72
Factor B	Past Utilisation	483	118
Factor C	Domestic Needs	398	203
	Industrial Needs	529	72
	Agricultural Needs	514	87
Factor D	Comparative costs of other options	100	501

A multi-criterion decision rule, based on the concept of *error distance* is used to determine the optimal allocation outcome. This concept was used by Moore (1992), in which he defined the *error distance* as the absolute linear distance from a given allocation outcome to a particular equity standard. The optimum allocation outcome is the one that minimises the summation of the *error distance* measured outward from itself to each equity point along the diagonal line in Fig. 7.4.

Figure 7.4 Allocation Outcomes



In general, the formula for calculating the sum of the *error distances* from a given point on the line to each of the seven equity points is (Moore 1992):

Total *error distance* = $\sum_{i=1}^{7} [(X_t - X_i)^2 + (Y_t - Y_i)^2]^{1/2}$

Where X_t : Israeli share in the given allocation outcome

Y_t : Palestinian share in the given allocation outcome

X_i : Israeli share in the ith equity standard, i=1,....7

Y_i : Palestinian share in the ith equity standard, i =1,...7

A search program was written to determine which outcome from the set of possible allocation outcomes satisfied the above stated criterion. The search revealed that the optimal solution is (483, 118) i.e., to entitle Israel 483 Mcm and the Palestinians 118 Mcm from the common aquifers in which the summation of the error distances to the seven equity points is minimised.

7.3.1.3 Previous allocation and entitlements to shared groundwater resources

There has been much written in recent years about the application of surface water and groundwater law in international river basins in the region, as well as the development of different allocation schemes based on the interpretation of these "laws" or using other criteria. To benefit from experience gained elsewhere, a brief literature review was conducted that included an overview of reports of relevant experience. Some of these schemes involve the use of mathematical formulae.

Zarour and Isaac (1992), for example, have proposed a "pragmatic, applicable and dispassionate formula" for the allocation of water rights based on the Helsinki Rules of 1966. Their allocation scheme is presented in the following equation:

$$S_i = 50 \times [B_i / B_T + (I_i - L_i)/(I_T - L_T)]$$

Where: S_i : size of rights /obligation of state i (percent)

B_i : area of the basin / storage volume within or under the territory of state i

B_T : total area/storage volume of the basin

I_i : natural input to the basin originating within the territories of state i

I_T : total input to basin T

L_i :natural loss from the basin's waters occurring within territories of state i

L_T :total natural loss of water occurring throughout the basin.

In a different approach to setting allocations by formula, Moore (1992) started from the perspective that both the surface water and the aquifers shared by Israelis and Palestinians are common property resources, and that, therefore, it is futile to search for an ideal allocation that is inherently "equitable and reasonable". Instead, he offered four possible perspectives on equity, adopted from the Helsinki Rules: existing water utilisation, recharge area, natural flow, and population. He then suggested that the "optimal allocation regime" could be determined mathematically by minimising the summation of the "error distances" from a national line connecting points of 100% allocation to Israelis and 100% allocation to Palestinians.

It is obvious that the above two models focus mainly on the natural boundaries of surface and subsurface basins and ignore the social and economical aspects included in the Helsinki Rules.

7.3.2 Quantification of the Jordan River Basin

7.3.2.1 Quantification of equitable allocation factors

Israeli and Palestinian entitlements to these waters must also be calculated. However, the process is complicated by the fact that there are three other riparian states (Jordan, Lebanon and Syria) whose claims must also be taken into account. As before, the first step is to operationalize some of the ILC factors and derive equity standards against which to measure the allocation outcomes. An allocation outcome A *(a,b,c,d,e)* specifies the proportional shares of the Jordan River riparian, where *a* represents the Israeli, *b* the Jordanian, *c* the Lebanese, *d* the Palestinian, and *e* the Syrian shares, and the sum of the five shares equal one. The six equity standards used are presented in Table 7.6. These standards are derived from the following operational definitions corresponding to the ILC factors.

Table 7.6

Alternative equity standards (share)

	Factor A		Factor B	Factor C		
Share	Catchment area	Avg. Annual discharge	Existing utilisation	Domestic needs	Industrial needs	Agricultural needs
Israeli	0.11	0.30	0.68	0.23	0.22	0.47
Jordanian	0.38	0.20	0.13	0.12	0.14	0.29
Lebanese	0.04	0.10	0.00	0.09	0.19	0.00
Palestinian	0.06	0.03	0.01	0.11	0.03	0.08
Syrian	0.41	0.37	0.18	0.45	0.42	0.16
Total	1.000	1.00	1.000	1.000	1.000	1.000

Factor A

1. Catchment Area

The area of the catchment determines the amount of rainfall caught and, consequently, the total volume of surface and groundwater run-off into the main -stream courses. Thus, the proportion of the catchment area laying within each watercourse state represents a measure of the inflow to the basin coming from these states. Table 7.7 presents an estimate of each riparian state's share of the Jordan -Yarmouk catchment area (Kliot 1994).

Table 7.7

Share per country in catchment area of the Jordan and Yarmouk Rivers (km^2)

Total area	Israel	Jordan	Lebanon	Syria	West Bank
17665	1955	6795	635	7180	1100

2. Average Annual Discharge

Average annual dicharge is used as a measure of the riparian state's shares in the outflow of the basin's main stream courses. Table 7.8 offers an estimate of the average annual discharge of the Jordan -Yarmouk river system (Kliot 1994).

Table 7.8

Average Annual Disharge of the Jordan Yarmouk System (Mcm)

Total Discharge Mcm	Israel	Jordan	Lebanon	Syria	West Bank
1151	344	250	115	416	26

Factor B

Israel is currently the dominant user of the waters of the Jordan basin. With the capture of the Golan Heights during the Six-Day War and the extension of the security zone into southern Lebanon, Israel became the virtually exclusive user of the Jordan River. Table 7.9 presents the existing utilisation of the Jordan and Yarmouk Rivers (Lonergan and Brooks 1994).

Table 7.9

Existing utilisation of the Jordan and Yarmouk Rivers (Mcm/yr).

Country	Israel	Jordan	Lebanon	Syria	West Bank	Total
Quantity (Mcm/yr)	640	120	0.0	170	10	940

Factor C

The projected water consumption in the domestic, industrial and agricultural sectors for the five riparian states in the year 2000 is summarised in Table 7.10 (Amery and Kubursi 1992; Gvirtzman 1992; Schwarz 1992; Al-Udwan 1992; Mikhail 1993).

Table 7.10

Projected consumption for the year 2000 (Mcm)

Country	Domestic Needs	Industrial Needs	Agricultural Needs
Israel	692.9	135	1180
Jordan	360	82	720
Lebanon	272	119	0
Palestine	353.1	18.2	199
Syria	1385.6	258	409
Total	3063.6	612.2	2508

7.3.2.2 Optimal allocation and entitlements to shared surface water resources

The optimal allocation outcome was calculated using a computer search program to derive the solution. The allocation outcome A (0.3, 0.2, 0.10, 0.03, 0.37) represents the global minimum of the annual average flow of millions of possible allocation outcomes searched.

7.3.2.3 Previous management plans in the Jordan River Basin

The purpose of this section is provide a historical perspective on the development of management plans and attempts to reach agreements over water resources in the Jordan Basin.

Many plans have been proposed in the past for sharing the waters of the Jordan River basin, the most famous of these being Johnston Plan. In October 1953, U.S. President Eisenhower assigned special ambassador Eric Johnston the task of brokering a comprehensive development and distribution agreement for the Jordan River basin among Israel, Jordan, Lebanon and Syria. Not surprisingly, the Johnston Plan was unacceptable to either Israel or to the Arab states. Israel argued that the regional plan should include all water sources of the region, including the Litani, and considered the allocations it was to receive under the plan insufficient. The Arab states remained concerned about the storage of Yarmouk River water in Lake Kinneret as well as the high allocation given to Israel (Soffer 1992).

Since 1955, there has been little discussion about shared water agreements. Countries in the region have continued to develop their water resources, often at the expense of other countries. Subsequent to the dissolution of the Johnston Plan, Israel constructed the National Water Carrier, and Jordan further developed the East Ghor Canal off the Yarmouk River for irrigation.

Assaf et al (1993) presented a methodology to analyse the water needs of the five riparian sharing the international water resources in the area. They concentrated on evaluating the human needs of each partner in an equitable manner. The basic principle is drawn from Article IV of the Helsinki Rules: - each party is entitled to a "reasonable and equitable share in the beneficial use" of shared international water resources. A "Minimum Water Requirement" allocation of 125 m^3/c/yr needed to meet minimum human needs for domestic and fresh food (from irrigated agriculture) of each party was proposed.

CHAPTER 8

DOMESTIC WATER DEMAND MODELLING FOR THE WEST BANK

8.1 Introduction

This chapter outlines one possible approach of modelling domestic water demand for the West Bank. It depends on the discussion of the principles of modelling techniques drawn from chapter four. Historical extrapolation was used to project domestic and industrial demands for the West Bank due to the absence of data, while a statistical approach was used to develop the domestic demand model as shown in section 8.5. Mathematical programming was used in modelling agricultural activities of the West Bank as shown in chapter nine.

8.2 Present domestic water consumption rates in the West Bank

Estimates of water consumption rates for West Bank are based on a questionnaire survey sent out during summer of 1997, to all responsible authorities and utilities in the West Bank. These entities include the Palestinian Water Authority (PWA), Ministry of Agriculture, West Bank Water Department (WBWD), Jerusalem Water Undertaking (JWU), Water Supply and Sewerage Authority of Bethlehem-Beit Jala - Beit Sahur (WSSA), and several municipalities.

The questionnaire, which was sent out to the utilities and presented, in Annex A contains questions about many variables and categories that are:

- General information
- Infrastructures
- Water sources
- Inventory of equipment and staff
- Water consumption
- Water Tariff
- Unserved Localities
- Current Water Supply Projects

- Waste water infrastructure
- Issues related to future activities

The following summary details the main findings of the questionnaire:

- The major sources for supplying water for use in the West Bank are groundwater wells and springs.

- Due to the lack of a detailed database about water consumption rates, water uses have been classified into two different categories: Municipal as one category and Irrigated agriculture as the second category. Municipal water uses encompass household, public, industrial, and commercial purposes, as the current water supply data do not segregate these categories.

- The present industry in Palestine can be classified as a narrow base industry with the absence of medium and large industries. Industrial firms in the West Bank are characterised by their small size and household nature. The vast majority of firms are merely small workshops that are located mostly within municipal boundaries taking water from municipal sources. As has been already noted, the demand for this kind of activity is accounted for within domestic consumption estimates.

- Based on the questionnaire response, a summary of water supply data for municipal uses in each district is presented in Table 8.1. This Table indicates that during the year 1996, the total water supply for the West Bank for domestic purposes was estimated to be approximately 58 Mcm.

- The overall loss or unaccounted for water rate was estimated to vary between 16% (in Jerusalem) and 44% (in Jericho). This unaccounted for water comprises: Physical losses at the source, main transmission system, and distribution network, unregistered connections, and meter losses.

Table 8.1

Present urban/domestic water supply and consumption (1996) [1]

District	Population [2] 1996	Network supply $10^3 m^3/y$ (1996)	per capita l/c/d	Sources [3]	Billing records $10^3 m^3/y$	Overall losses % [4]	Apparent consumption l/c/d [5]	Physical losses % [6]	Adjusted consumption l/c/d [7]
Hebron	294116	7167	67	WBWD, MW	5089	29	47	24	51
Bethlehem	113013	4316	104	WSSA, WBWD	2633	39	64	34	69
Jenin	178170	3898	60	WBWD, M, PW	2729	30	42	25	45
Tulkarem	175698	7270	113	MW, PW, WBWD,M	4653	36	72	31	78
Nablus	293718	8825	82	WBWD, M, PW, MW, PS	5913	33	55	28	59
Rammallah	234390	15980	186	JWU, M, WBWD	12944	19	151	14	160
Jericho	28083	1370	133	PS, MS, M, PW	767	44	75	39	81
Jerusalem	254387	9285	100	JWU, WBWD	7799	16	84	11	89
Total	1571575	58111							

(1) Quantities (which are rounded account for domestic, public, commercial, and industrial) are for end of year 1996, and are based on the Questionnaire.
(2) Population estimates for end of year 1996 are based on Palestinian Central Bureau of Statistics (1996)
(3) WBWD= West Bank Water Department; M= Mekorot; JWU= Jerusalem Water Undertaking; PW= Private Well, PS= Private Spring; MW= Municipality Well WSSA=Water Supply and Sewerage Authority of Bethlehem-Beit Jala-Beit Sahur; MS= Municipality Spring;
(4) Overall losses are based on data obtained from the Questionnaire based on network supply quantities and billing records quantities
(5) Apparent consumption rates are weighted averages that were estimated by applying the overall loss rate to the supply
(6) Physical losses were estimated by subtracting 5% from overall losses for unregistered connections and meter losses
(7) Adjusted consumption rates are weighted averages that were estimated based on physical losses

Evidently, the use of the overall loss rate for estimating the consumption rate is not realistic. Water consumption rates should be estimated based on actual physical losses. Losses related to unregistered connections and meterings do not constitute an actual loss of water from the system. The combined losses from unregistered connections and meter losses were assumed to be about 5 percent of the total supply.

8.3 Projection of water demands

8.3.1 Rationale and strategy

The historic water demands in the West Bank have been artificially constrained by non-market forces. As a result, they cannot be used to forecast future demands without any modifications to reach target consumption rates, particularly for domestic consumption rates. In fact, on the basis of various world and regional water consumption levels, the present magnitude of unsatisfied demand in the West Bank nearly surpasses current supplied quantities. Thus, it is necessary to plan for and develop more equitable, yet feasible, future water consumption rates and supply capabilities for needed social and economical development.

Water demands projected herein represent forecast "potential" demands. That is, the forecasts for the various sectors represent unconstrained demands that would result during the planning period if present physical and non-market constraints on supply were relaxed and economic growth will have occurred within the time frame associated with a demand forecast.

Water demand projections are based on the following strategy:

- The economic future of the West Bank will be largely based upon the development of light industry and regional commerce, and that the assumed future demands for, and value of, water will reflect these characteristics of the Palestinian economy.
- Land and water will have a much higher economic value if used by industry.
- The amount of irrigable land in the West Bank is limited and declining.
- The use of land and water for agricultural production will provide only very limited employment and economic growth potential.

- Demand forecasts are based on present water demand with modifications to reach target consumption rates, particularly for domestic consumption rates.
- Water demands and supplies are prioritized, with the highest priority assigned to domestic uses.
- Water conservation is inherent in these rates, as it is assumed that losses will be gradually reduced from current levels. This reduction is predicted on the assumption that the water supply system will be upgraded and adequately managed by well-staffed and equipped utilities along with the necessary maintenance programmes.

8.3.2 Projection of domestic water demand

For the purpose of projecting future domestic demands, three variables will be considered: Unaccounted for water and water losses in distribution systems, changes in per capita consumption of domestic water, and changes in population.

(1) Unaccounted for water and water losses in distribution systems

These quantities consist of technical losses in the system, such as leakage and losses from flushing out of the mains, as well as water that is supplied but not paid for because of faulty meters, and illegal connections. Based on Table 8.1, the present losses are high. The target for the year 2020 is to reduce the percentage to 25% for the West Bank due to the new water infrastructure and distribution system that will be constructed by year 2000 in some cities, and rehabilitation of some old water supply systems (JWU 1995).

(2) Per Capita water consumption

On average, developing areas usually have a rate of increase of 2.5% per year for water demand. The present water per capita consumption for the West Bank (Table 8.1) for all districts will be projected based on a rate of increase 2.5% per year for water demand with modifications to reach target consumption (CDM 1997).

Two target rates have been set for domestic water consumption based on "Guidelines on Technologies for water supply systems in small communities," published by the WHO (1993). These rates are 100 l/c/d (a minimum WHO rate for house connections in small communities), and 150 l/c/d (a typical WHO average rate for house connections in small communities), which are to be met in the year 2020. The estimated per capita consumption for all districts are listed in Table 8.2 for year 2020.

(3) Population

Most population forecasting methods require the knowledge of past and present population concerned. These methods use the initial population (from Central Bureau of Statistics of the country) as a base for projecting into the future. Broadly speaking methods of population forecasting are graphical methods, ratio methods, and mathematical methods (Oyegoke and Oyesina 1984).

Mathematical methods such as the geometric growth model are commonly used. The geometric model can be expressed as:

$P_{t+n} = P_t (1+r)^n$ geometric growth model

Where:

P_{t+n} : population at time (t+n)

P : population at present time

r : rate of growth per unit time

n : length of time for which the projection is made.

According to the Palestinian Central Bureau of Statistics the population of the West Bank was 1,571,574 in the year 1996 (PCBS 1996), and according to the agreement between the Palestinian National Authority and Israel 0.5 million returnees will return gradually to Palestine by the year 2000. Due to the limited land and resources in Gaza, it is assumed that only 100,000 of the returnees will return to Gaza and the rest will be allotted to the West Bank districts based on current proportions of population distributions.

The following declining annual growth rates have been adopted from the Palestinian Bureau of Statistics (PCBS 1996):

- 3 percent for the period 1996 to 2000
- 2.5 percent for the period 2000 to 2020

Population projections were used to calculate total domestic water demands for the year 2020. Table 8.2 shows the forecast future domestic demands. The total domestic water demand was estimated to be approximately 210 Mcm for the year 2020.

8.3.3 Projection of industrial water demands

Due to a lack of detailed economic and industrial development plans for the West Bank, it is not possible to base estimates of future industrial demands on economic projections. As a result, projected industrial water demands have been calculated as an assumed percentage of the total domestic water demands. Future industrial water demands quantities have been estimated to be 15 percent of the total domestic demand for year 2020 based on data provided by WESC (1996) and World Bank (1993). This scheme is designed to sustain and facilitate the growth of existing industries, phased development and implementation of possible industrial zones. A summary of projections of future industrial water demands is presented in Table 8.2.

8.4 Development of the domestic water demands model for the West Bank

8.4.1 Introduction

The conventional practices of designing and managing water supply should be revised and adjusted and should give way to approaches and strategies depending on local comprehensive analysis. Water use data can be used for statistical analysis of water use trends as well as for the development of water use models. Water use models would also require data and variables that influence water use. Household water demand cannot be directly linked to a single determining factor. Rather, it results from interplay between many household characteristics, ranging from size to socio-economic characteristics of individual household members (Bhattacharya 1982; Khadam 1984; WSM 1996; Clarke et al. 1997).

Table 8.2
Projected Domestic and Industrial Water Demand for year 2020

District	No. of inhabitants in 1996	No. of inhabitants for 2000			No. of inhabitant for 2020	Present per capita consumption (1996)	Projected per capita consumption (2020)	Adjusted projected per capita consumption (2020)*	Projected domestic demand (2020)	Adding Industrial demand (15%)	**Total** including losses (25%)
		Growth Rate 3%	Returnees	Total	Growth Rate 2.5%	l/c/d	l/c/d	l/c/d	Mcm/yr	Mcm/yr	Mcm/yr
Hebron	294116	331030	74859	405889	665096	51	92	150	36.41	5.46	52.35
Bethlehem	113013	127197	28764	155961	255561	69	125	150	13.99	2.10	20.11
Jenin	178170	200532	45348	245880	402903	45	81	150	22.06	3.31	31.71
Tulkarem	175698	197750	44719	242469	397313	78	141	150	21.75	3.26	31.27
Nablus	293718	330582	74758	405340	664196	59	107	150	36.36	5.45	52.27
Rammallah	234390	263808	59657	323465	530036	160	289	289	55.91	8.39	80.37
Jericho	28083	31608	7148	38755	63505	81	147	150	3.48	0.52	5.00
Jerusalem	254387	286315	64747	351062	575256	89	161	161	33.80	5.07	48.59
Total	1571575	1768821	400000	2168821	3553866				223.78	33.57	321.68

*150 l/c/d is the typical WHO average rate for house connections in small communities which are to be met in the year 2020 (WHO 1993).

The absence of collected information on household water demand and variables which influence water use of household the West Bank has made it difficult to study the whole West Bank; such a task would be beyond the scope of any individual and would be more appropriate to census collection agency. It was, therefore, decided to confine the study to Rammallah District to monitor the different factors affecting the domestic water supply.

Despite problems and limitations always present in developing countries, the model is an attempt to present evidence that highlights the importance of exerting extra effort in this area with the ultimate goals of conserving water resources.

8.4.2 Data collection and sampling

Knowledge of water use is almost invariably based on samples or fragments of total populations. Sampling has many advantages over a complete enumeration of the population under study. These advantages include reduced cost, greater speed of obtaining information, and a greater scope of information that can be obtained. Probability sampling refers to any sampling procedure that relies on random selection and amendable to the application of sampling theory to validate the measurements obtained through sampling. There are many ways of constructing a probability sample of water users. Simple random refers to a method of selection n sampling units of a population of size N, such that every one of the distinct samples has an equal chance of being drawn.

The size of the sample depends on the precision of measurement that is required and the variance in the parameters to be estimated. The first approximation of the desired sample size can be calculated from the following formula (Dziegielewski et al. 1996):

$$n_o = \left(\frac{tS}{rY}\right)^2$$

Where:

n_o : first approximation sample size

t : confidence probability (t-statistics). This value is 1.64, 1.96, and 2.58 for Confidence probabilities 90, 95 and 99 percent, respectively.

S : population standard deviation

r : relative error

Y : population mean

The sample size n can be calculated using the finite population correction to sample size from the following formula:

$$n = n_0 / (1 + n_o / N)$$

Where:

n : sample size

N : population size

n_o : first approximation sample size (see previous equation)

Rammallah, which will be used as a case study to illustrate the proposed framework of the analysis, has no detailed database on household water consumption. Jerusalem Water Undertaking served 234390 customers in Ramallah in year 1996. The analysis of billing frequencies for the entire year indicates the average daily use per customer is 151 l/c/d and the standard deviation is 33.55 l/c/d (JWU 1995). Using the simple random sampling, the number of customers who must be surveyed to be 95 percent confident of estimating average daily use within 2 percent of the true value using the above equations is:

$$n_0 = \left(\frac{tS}{rY}\right)^2 = [(1.96)(33.55)/(0.02)(151)]^2 = 474 \text{ and}$$

$$n = n_o / (1 + n_o / N) = 474 / (1 + 474 / 234390) = 473$$

The results indicate that if the average water use is unknown, to be 95 percent confident of estimating it by sampling billing records with an error of 2 percent, a sample of 473 family homes would be required.

The primary data source was a questionnaire survey sent out during summer of 1997, to 473 a random sample of consumers. The selected sample consumers were requested to answer the questions presented in Annex B. The questionnaire was prepared to gather information on the following characteristics: -

1. Personal characteristics.
2. Water Use and Consumption.

3. Economic Activities
4. General Housing Conditions.

The questionnaire was designed with adequate parameters to provide comprehensive information on the above mentioned characteristics. Information gleaned from the literature reviewed, personal communication, experience from field visits and other sources of data and information, were used to draft a list of all possible factors which may influence water demand. It is recognised that many of the factors are interrelated and certain of the factors have a lesser to negligible impact on water demand. This research is aimed at identifying those factors which have a major impact on water demand and which therefore need to be included in the water demand model.

The household variables and factors initially assumed to have a reliable impact on domestic water consumption for Rammallah District household include: number of occupants, price of water, number of children, income level, irrigated area, lot size, number of cars, number of taps, and the number of rooms.

Actual water consumption which represents the total water use of each user during a billing period was taken from Jerusalem Water Undertaking for the year 1996. To charge for water consumption, the water utility adopted the following tariff schedule that is divided into four categories as shown in Table 8.3 (Consumers are billed every two months).

Table 8.3

Tariff Schedule

Water Consumption	Fixed charge and price
Up to 10 m^3	\$12.66 per bill
10 to 20 m^3	\$1.00/ m^3
21 to 40 m^3	\$1.05/ m^3
Over 40 m^3	\$1.50/ m^3

Source: Jerusalem Water Undertaking (1995)

8.4.3 Statistical Analysis and Results

Water use models are usually obtained by fitting theoretical functions to the data sets.

The most commonly used technique for developing water use models is regression analysis. Multiple regression procedure will be used for generating mathematical models for household water consumption. The theoretical model of multiple regression for three independent variables as an example can be written as (Norusis 1991):

$$y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \in$$

Where:

α : constant (intercept)

X_1 ,X_2, X_3 : idepedent variables assumed to affect the dependent variable y

$\in$: random error term

β_1 , β_2, β_3 = estimated coefficients

The analysis of the data was performed by using computer software package (SPSS-X) and models were generated by multiple regression analysis. The variable symbols and somewhat abbreviated definitions for factors hypothesised as influencing domestic water consumption were:

Q = average annual quantity consumed in cubic metre per dwelling per day

q = average annual quantity consumed in litres per capita per day (1/c/d).

X_1 = number of cars per household

X_2 = number of children

X_3 = monthly income in U.S $

X_4 = lot size in square meters

X_5 = number of occupants per dwelling

X_6 = the price of water that varies with individual household consumption evaluated at the rate applicable to average domestic use in each group of classification (U.S $ per cubic meter) as shown in Table 8.3

X_7 = number of rooms

X_8 = irrigated area in square meters

X_9 = number of taps inside the house or in the courtyard

Table 8.4 gives the means, medians, standard error of means, standard deviations, and variances for all the variables used in generating the models. This table displays statistics of some of the essential factors or variables necessary as records for planning or managing purposes. These factors may change from country to country or from one region to another.

Table 8.4

Statistics for households in Rammallah District

Variable	Mean	Median	Standard error of mean	Standard deviation	Variance
Cars	0.34	0	0.02	0.49	0.24
Children	2.99	3	0.05	1.18	1.39
Income U.S $	800.9	900	19.49	423.95	179736.3
Lot-size (m^2)	172.8	150	3.84	81.56	6652.5
Occupants	6.66	7	0.10	2.07	4.28
Price U.S $\$/m^3$	1.36	1.5	0.01	0.21	0.04
Consumption (l/c/d)	154	145	3.0	34.0	1142
Rooms	3.26	3	0.06	1.24	1.53
Irrigated area (m^2)	249.25	200	13.2	272.09	74031.1
Taps	9	8	0.08	4.0	19.0

The relationship between domestic water consumption and the explanatory variables was tested using regression model and correlation matrix.

Regression Model

The linear equation of best fit generated by multiple regression models that is shown in Figure 8.1 is:

$$q = 228.4634 + 1.0912 X_1 - 6.9392 X_2 + 0.00276 X_3 + 0.0212 X_4 - 8.3744 X_5 -$$

$$52.9612 X_6 - 1.5924 X_7 + 0.0041 X_8 + 3.6830 X_9$$

The regression coefficients and associated statistics are shown in Figure 8.1. The values of the regression coefficients are in the column labelled "B". The next column labelled "SE B", contains the standard errors of the regression coefficients. The observed significance level is based on the t statistics in the column labelled "T". These t statistics are calculated by dividing a sample value by its standard error (Column B/ column SE B) (Norusis 1991).

In the column labelled "Sig T" are two-tailed significance levels for the tests of the hypotheses that the slope and intercept are zero in the population. In Figure 8.1, the values 0.0000 are printed for some variables (children, occupants, and price). This indicates that the probability is less than 0.00005 that a sample slope at least as large (in absolute value) as the one we have observed would occur if the true slope is zero.

If there is no linear relationship between two variables in the population, the true slope is zero. A 95% confidence will be achieved only if one can reject the hypothesis that the slope is zero at an observed significance level of 0.05 or less (Norusis 1991). Number of occupants, children, and taps, besides the price are the only variables appeared to be of significance in predicting the per capita consumption. Negative signs indicate that these variables are of decreasing rate of increase i.e. the per capita decreases with the increase in values of these variables.

The entry labelled "Multiple R" is just the absolute value of the correlation coefficient between the dependent variable and the independent variable. It is also the correlation coefficient between the values predicted by the regression model and the actual observed values. If the value is close to 1, the regression model fits the data well. If the value is close to zero, the regression model does not fit well.

Label "F" which is the ratio of the mean square for regression to the mean square for the residual, and the mean squares are the sums of squares divided by their respective degrees of freedom. Large F values suggest that there is a linear relationship between the two variables. In Fig. 8.1 the F value is 90.360 and the observed significance level associated with it is less than 0.00005, so the regression model does fit well. Considering R Square, 71.699% of consumption is explained by the independent variables in the equation.

Figure: 8.1 Output from the Regression commands (Enter Method)

* * * * M U L T I P L E R E G R E S I O N * * * *

Listwise Deletion of Missing Data

Equation Number 1 Dependent Variable.. q (l/c/d)

Block Number 1. Method: Enter
CARS CHILDREN INCOME LOT-SIZE OCCUPANT PRICE ROOMS SPRINKLING TAP
Variable(s) Entered on Step Number
1.. TAP
2.. CARS
3.. OCCUPANTS
4.. CHILDREN
5.. IRRIGATED AREA
6.. PRICE
7.. INCOME
8.. ROOMS
9.. LOT-SIZE

Multiple R	0.84675
R Square	0.71699
Adjusted R Square	0.70906
Standard Error	18.05140

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	9	264998.45137	29444.27237
Residual	321	104598.85112	325.85312

F = 90.36057 Signif F = .0000

------------------------------ Variables in the Equation --------------------------

Variable	B	SE B	Beta	T	Sig T
CARS	1.091611	2.180300	0.015545	0.501	0.6169
CHILDREN	-6.939151	1.141204	-0.246526	-6.081	0.0000
INCOME	0.002666	0.003446	0.032839	0.774	0.4396
LOT-SIZE	0.021204	0.046226	0.048032	0.459	0.6468
OCCUPANT	-8.374381	0.535844	-0.530667	-15.628	0.0000
PRICE	-52.961199	6.300726	-0.336136	-8.406	0.0000
ROOMS	-1.592465	1.371103	-0.058909	-1.161	0.2463
IRRIGATED	0 .004111	0.004403	0.033111	0.934	0.3511
TAP	3.683062	0.901459	0.434625	4.086	0.0001
(Constant)	228.463443	6.821417		33.492	0.0000

End Block Number 1 All requested variables entered.

<u>**Correlation matrix**</u>

The most commonly used measure for correlation is the Pearson correlation coefficient, which is abbreviated as *r*. Some of its characteristics (Taylor et al. 1987):

- If there is no linear relationship between two variables, the value of *r* is 0
- If there is a perfect positive linear relationship, the value is +1
- If there is a perfect negative linear relationship, the value is -1

The matrix presented in Table 8.5, which is the output of the SPSS-X computer software package shows the interdependency among the independent variable relationships varied from low to high. Each row and column of the table represent one of the variables. In each cell there are three numbers. The first is the value of the coefficient. The second is the number of cases used to calculate it. The third number is the observed significance level (P). As an example if one looks at Table 8.5, the value of the correlation coefficient (r) for q (consumption in liters per capita per day) and price is -0.3743. It is based on 473 cases. The relationship between q (dependent) and price (independent) is negative, so the sign of the correlation coefficient is negative.

8.4.4 Reliability analysis

Internal consistency reliability is commonly used as a measure in assessing survey instruments and scales and it is an indicator of how well the different items measure the same issue. It is measured by calculating coefficient alpha values (Litwin 1995). Alpha ranges from 0 when the measure is completely unreliable, to 1, when it is perfectly reliable. Figure 8.2 shows a good internal consistency coefficient (alpha = 0.4501) estimated using the SPSS-X computer program, accordingly the sample size was suitable.

Figure 8.2 Reliability analysis

R E L I A B I L I T Y   A N A L Y S I S - C A L E (A L P H A)

Reliability Coefficients

N of Cases = 331.0   Alpha = 0.4501

Table 8.5 Corrlation Matrix

	Cars	Children	Income	Lot-size	Occupants	Price	q (l/c/d)	Rooms	Sprinkling	Tap
Cars	1.0000	0.1730	0.1901	0.0942	0.2087	0.0655	-0.0809	0.0596	0.0343	0.1198
	450	450	450	430	450	450	450	399	404	439
	P = .	P=0.000	P=.	P=0.051	P=.	P=.	P=0.086	P=0.235	P=0.492	P=0.012
Children	0.1730	1.0000	0.5351	0.2390	0.3564	0.5153	-0.4507	0.3748	0.2881	0.2258
	450	473	473	452	473	473	473	417	425	462
	P=.	P=.	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000
Income	0.1901	0.5351	1.0000	0.5472	0.3665	0.5362	-0.1801	0.5519	0.3905	0.5295
	450	473	473	452	473	473	473	417	425	462
	P=0.000	P=0.000	P=.	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000
Lot-size	0.0942	0.2390	0.5472	1.0000	0.1497	0.4237	0.2747	0.7514	0.5593	0.9624
	430	452	452	452	452	452	452	400	406	442
	0	P=0.000	P=0.000	P=.	P=0.001	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000
Occupants	0.2087	0.3564	0.3665	0.1497	1.0000	0.3252	-0.6092	0.1245	0.0862	0.1572
	450	473	473	452	473	473	473	417	425	462
	P=0.000	P=0.000	P=0.000	0.0010	P=.	P=0.000	P=0.000	P=0.011	P=0.076	P=0.001
Price	0.0655	0.5153	0.5362	0.4237	0.3252	1.0000	-0.3743	0.4980	0.2492	0.4139
	450	473	473	452	473	473	473	417	425	462
	P=0.166	P=0.000	P=0.000	P=0.000	P=0.000	P=.	P=0.000	P=0.000	P=0.000	P=0.000
q (l/c/d)	-0.0809	-0.4507	-0.1801	0.2747	-0.6092	-0.3743	1.0000	0.0593	0.1467	0.3058
	450	473	473	452	473	473	473	417	425	462
	P=0.086	P=0.000	P=0.000	0.0000	0.0000	P=0.000	P=.	0.2270	0.0020	P=0.000
Rooms	0.0596	0.3748	0.5519	0.7514	0.1245	0.4980	0.0593	1.0000	0.3547	0.7483
	399	417	417	400	417	417	417	417	372	408
	0.2350	P=0.000	P=0.000	P=0.000	0.0110	P=0.000	0.2270	P=.	P=0.000	P=0.000
Sprikling	0.0343	0.2881	0.3905	0.5593	0.0862	0.2492	0.1467	0.3547	1.0000	0.5867
	404	425	425	406	425	425	425	372	425	414
	P=0.492	P=0.000	P=0.000	P=0.000	P=0.076	P=0.000	P=0.002	P=0.000	P=.	P=0.000
Tap	0.1198	0.2258	0.5295	0.9624	0.1572	0.4139	0.3058	0.7483	0.5867	1.0000
	439	462	462	442	462	462	462	408	414	462
	P=0.012	P=0.000	P=0.000	P=0.00	P=0.001	P=0.000	P=0.000	P=0.000	P=0.000	P=.
Note:	." is printed if a coefficient cannot be computed.									

8.4.5 Discussion of the Results

The most significant factors affecting domestic water demand in arid and semi-arid countries are presented in the above model. Of the variables, which appear in predicting the consumption, the number of occupants is of significant importance but in a decreasing rate. This is quite logical as the household members share many uses of water such as cooking, cleaning, sprinkling and other similar activities.

The price factor as mentioned many times in the literature is very important as a managing tool. Quantitative results can be produced from the above equation by estimating the price elasticity of demand which can be defined as the percentage by which the quantity taken changes in response to a one-percent change in the price.

The price elasticity of demand for water measures the willingness of consumers to give up water use in the face of rising prices, or conversely, the tendency to use more as price falls. In one sense, price elasticity reflects the availability of opportunities for water conservation, or for substituting other goods or services for water. For example, water-saving toilets and showerheads reduce the amount of water needed by a typical family (Young 1996).

The price elasticity for households in Rammallah derived from the model was -0.6, meaning that other factors held constant, a 10 percent increase in price would lead to about 6 percent change (decrease) in the amount purchased.

Despite the differences in regions, collection of data, and methods of analysis the results of the above model are comparable to some extent with findings of other studies held in other cities. Schneider and Whitlach (1991) presented one of the most comprehensive water demand studies available, they analysed a very large data set for the City of Columbus and derived price elasticity estimates of -0.26. Griffin and Chang (1991) found from a sample of Texas counties that demand is somewhat more inelastic in winter (about -0.3) than in summer (about -0.4). Abu Rizaiza (1991) found that the price elasticity for major cities of the Western Region of Saudi Arabia is -0.78

It is also important to distinguish between long- and short-term elasticities of water demand. As noted by Carson (1979), *"A change in the price of water may have a very small instantaneous effect on demand, but as time passes and the home-owner fixes his leaks, the industrial plant installs a recirculating system. Water demand tends to respond to price changes."* Hence, in the long term, demand is more elastic than in the short term, because greater time allows for more opportunities to adjust, and thus presents more options for substitution.

8.4.6 Conclusions

Household water demand cannot be directly linked to a single determining factor. Rather, it results from interplay between many household factors like economic, physical, social, technological, geographical, and factors relating cultural tradition and religion. More research and models taking into account the above factors for different areas should be generated from available data to provide a clear insight of the different factors that can be used as effective managing tools.

The statistical analysis is of vital importance to have sound management as well as community welfare and should be clearly recognised by water utilities managers in arid and semi-arid countries to facilitate the financial constraints and to achieve optimal conservation of water.

The results of this study indicate that water utility authorities can use price as a tool to ration or discourage water consumption in the households. Obviously, this is an acceptable practice and water resources will be conserved if it is applied taking the following points into account (Mehrotral and Kumar 1996):

- The poorest of the society will be provided with basic minimum requirements of water at the minimum price.
- For any supply scheme, the pricing structure should be such that 100 per cent recovery should be ensured with minimum financial burden on the poorest.
- Factors such as "capacity to pay", "benefits derived" and "proportionate cost of service" have to be considered.

- The rate must be high enough to fetch the necessary revenue and at the same time not excessive as to discourage consumers from making use of water.
- The typical WHO rate for house connections in small communities is 150 l/c/d. However, at the present time, in all West Bank's districts (except Rammallah) the consumption is below the typical rate, therefore, increasing price of water may affect health water requirements.

To summarise, price is one of the leading factors for conservation of water in areas with high consumption rates as appeared in the following example. Tucson (in Arizona) has not chosen to use price, except the increasing block-rate schedule, as a conservation management tool, even though they have a stated conservation objective. The apparent objective for Tucson was to lower per capita use through education and information while keeping prices as low as possible (Burchell 1988). The analysis conducted by Martin and Kulakowski (1991) showed that the city is unlikely to achieve its goal without a significant real price increase.

CHAPTER 9

AGRICULTURAL WATER DEMAND MODELLING FOR WEST BANK

9.1 Introduction

Water is one of the basic input factors of agricultural production. In arid regions, virtually all the water required for agricultural production is to be provided from "outside," e.g. from neighbouring rivers or ground waters through water supply and irrigation systems. Within semi-arid regions agricultural water demands are frequently satisfied by a combination of on-site and external supplies.

Irrigated farming occupies a dominant role in the agricultural sector and economy of Palestine. Irrigated agricultural can also help generate additional employment opportunities and satisfy rapidly growing demand for food. This chapter depends on the discussion of the principles of modelling techniques drawn from Chapter Four. It outlines one possible approach of modelling agricultural water demand for the West Bank. Mathematical programming was used in the modelling as shown in Section 9.7

9.2 Crop water requirements in the West Bank

In the northern West Bank, irrigation is needed to supplement a shortage of rainfall for winter crops and to extend cropping into the summer months. In the Jordan Valley, where the rainfall is inadequate for optimum crop production, irrigation is the only way to supply crops with their requirements.

CROPWAT software was used in this research to calculate crop water requirements as well as irrigation requirements for various districts of the West Bank. All the data needed are considered with aspects of the hydrologic cycle: solar radiation, precipitation, humidity, soils, geology, sunshine, evaporation, cropping patterns...etc. There are many formulas and approaches to agricultural water demand evaluation. No attempt is made here to exhaust this research, as it is fully covered by the following references: FAO (1984), FAO (1992), FAO (1993), and ARIJ (1998). These references explain how to use the computer program, identify approaches to agricultural water demand evaluation and present the underlying calculation procedures.

Calculation Procedures

1. Reference crop evapotranspiration (ET_o)

To calculate ET_o it is necessary to collect and evaluate available climatic and crop data based on meteorological data available. The Modified Penman-Monteith method will be used for calculating reference evapotranspiration. The equation is:

$$ET_o = [0.408\,\Delta\,(R_n - G) + \gamma\,(900/(T + 273))\,U_2\,(e_a - e_d)]\,/\Delta\; + \gamma\,(1 + 0.34\,U_2)$$

Where: ET_o : reference crop evapotranspiration (mm/day)

Δ : slope vapour pressure curve (kpa/C°)

R_n : net radiation at crop surface ($MJ/m^2/day$)

G : soil heat flux ($MJ/m^2/day$)

γ : psychometric constant (kpa/C°)

T : average temperature (C°)

U_2 : wind speed measured at 2m height (m/s)

$e_a - e_d$: vapour pressure deficit (kpa)

The equation listed above can be used for calculation of ET_o for open field planting. However, weather conditions inside plastic houses differ from those found in the open field due to differences in wind speed, humidity, sunshine and temperature. The following equation can be used to calculate ET_o inside plastic houses (ARIJ 1998):

$$ET_o \text{ for plastic house} = (0.67 \times R_g \times K_t)/L$$

Where: R_g : sunshine radiation ($MJ/m^2/day$)

K_t : transfer factor of sunshine to the plastic house (equals 0.7 for plastic houses and 0.9 for glass houses)

L : potential heat for evaporation (constant value) = 2.51 MJ/kg

The procedures to calculate ET_o may seem rather complicated. This is due to the fact that the formula contains components that need to be derived from measured climatic data when no direct measurements of needed variables are available. For instance, for places where no direct measurements of net radiation are available, as in the case of the West Bank, these can be obtained from measured solar radiation, sunshine duration or cloudiness observations, together with measured humidity and temperature. FAO (1993) presents useful formulas that can be used in the absence of collected information on needed climatic data.

2. Crop coefficient (k_c)

To calculate k_c it is necessary to select cropping pattern, determine time of planting or sowing, rate of crop development, length of crop development stages and growing period.

Crop evapotranspiration (ET crop) can be determined using the following equation:

$$ET\ crop = k_c \times ET_o$$

Climatic data for the West Bank used in this Research have been collected from either the Israeli Meteorological Service or Palestinian Weather Stations. Values for different crop characteristics like rooting depth, yield response, allowable depletion, crop coefficients and length of individual growing stages are referenced in *"Yield Response to Water"* by FAO (1986a) and *"Water Resources and Irrigated Agriculture in the West Bank"* by ARIJ (1998).

Annex C presents summary output tables of the CROPWAT software using climatic and agricultural data concerning the West Bank. Tables C1 and C2 of Annex C show the average climatic parameters, and reference crop evapotranspiration (ET_o) for Bethlehem and Jericho Districts, as examples. Table C3 shows a summary output of ET_o for the other districts of the West Bank in open field planting. Table C4 shows the output for reference evapotranspiration under plastic houses.

Based on the results of ET_o and k_c values, crop evapotranspiration was calculated. Tables C5 and C6 show the monthly crop water requirements (ET crop) for crops planted in open fields in Bethlehem and Jericho Districts. Table C7 presents a summary output table for other districts in the West Bank. Table C8 presents the monthly crop water requirements for crops planted under plastic houses in the various districts of the West Bank.

9.3 Irrigation requirements and optimisation of water use

The irrigation requirement of a crop is the total amount of water that must be supplied by irrigation to a disease free crop, growing in a large field with adequate soil water and fertility, and achieving full production potential under the given growing environment. Irrigation requirement includes water consumed by crops (ET crop) plus losses during the application of irrigation water and the quantity of water required for leaching. It does not include water from natural sources such as precipitation that crops can effectively use (Hansen et al. 1980). In order to determine irrigation requirements, the following variables are taken into consideration:

Effective Precipitation

Effective rainfall is that portion of the rainfall that is effectively used by the crop after rain. The amount of effective rainfall depends on the precipitation rate, and soil moisture conditions. A simplified method developed by FAO (1992) has been useful for determining effective rainfall:

$P_{eff} = 0.6\ P_{tot} - 10$ for $P_{tot} < 70$ mm

$P_{eff} = 0.8\ P_{tot} - 24$ for $P_{tot} > 70$ mm

Where: P_{eff} : effective rainfall (mm)

P_{tot} : total rainfall (mm)

Table C9 shows the effective rainfall based on average rainfall conditions calculated for all districts of the West Bank.

Rooting characteristics

The moisture characteristics of the soil, the depth to which the plant roots extends and the densities of the roots determine the amount of soil moisture that is available to a plant.

Soil Textures

Soil properties vary from region to region in the West Bank. Clay loam is considered to be a dominant soil texture in Jerusalem, Hebron, Bethlehem, and Nablus, while in Jericho the dominant soil texture is sandy loam. In the Tulkarm district the soil texture is silty clay loam (ARIJ 1995; ARIJ 1996).

Leaching requirements

Leaching is the process of dissolving and transporting soluble salts by downward movement of water through the soil. The fraction of irrigation water that must be leached from the root zones to keep salinity of the soil below a specific limit is termed the leaching requirement (LR). Mathematically it can be expressed as (ARIJ 1998):

$$LR = EC_I / (5\,EC_E - EC_I)$$

Where: LR : leaching requirement (ratio)

EC_I : electrical conductivity of irrigation water (mmhos/cm)

EC_E :electrical conductivity of the soil saturation extract for a given crop appropriate to the tolerable degree of yield reduction (mmhos/cm)

Irrigation Efficiency

This is the ratio between water made directly available to the crop and that released at head-works and includes field canal efficiency, water application efficiency, and water conveyance efficiency (Birdie and Dass 1996). In this study irrigation requirements were calculated based on 75% percent irrigation efficiency according to ARIJ (1998).

Gross Depth per Irrigation

The gross depth per irrigation should include sufficient water to compensate for system uniformity and allow for unavoidable losses or for the required leaching water. To keep the gross depth per irrigation at a minimum, systems should be well designed, accurately scheduled and carefully maintained. Gross irrigation requirements can be calculated with this formula:

$d_g = d_n / E_I (1\text{-}LR)$

where: d_g : gross irrigation requirements (mm)
d_n : net irrigation requirements (mm)
E_I : irrigation efficiency (%)
LR : leaching requirements (fraction)
If $LR \leq 0.1$ use $d_g = d_n / E_I$

Tables C10 to C13 present an example of some of the output of CROPWAT and show the irrigation scheduling for cucumbers and tomatoes planted in open fields and under plastic conditions in Jericho.

9.4 Efficient use of water in agriculture

Water use efficiency, which indicates how much food a cubic metre of water can produce, is an acceptable criterion to evaluate wise use of water. To estimate the efficiency of use of water in irrigation in the West Bank, the following points have been taken into consideration: agricultural water requirements for the West Bank, areas and production of irrigated crops for the year 1996, and actual water quantity consumed by the agricultural sector in 1996.

Tables C14 and C15 show the optimal water requirements for irrigated crops under various agricultural patterns for Bethlehem and Jericho Districts. Table 9.1 is a summary table of irrigated areas, actual water use, and optimal water requirements for agriculture in various districts of the West Bank. It is shown in this table that the total agricultural water demand is about 85.14 Mcm without leaching requirements and

98.14 Mcm with leaching requirements. There is a water deficit in Jenin, Tulkarem, Jericho, Bethlehem and Hebron, where more quantities of water are needed to achieve the optimal crop yield. In Nablus, Ramallah and the Jordan Valley, quantities of water can be saved, since the optimal water requirements are much lower than the water applied for irrigation.

Table 9.1

Optimal agricultural water requirements relation to actual water use for agriculture in all districts of the West Bank (1996)

District	Total Area 1000m^2	Actual water use[1] (Mcm)	Optimal water use (Mcm)		Water Deficit/Surplus (Mcm)	
			Without LR	With LR	Without LR	With LR
Jenin	11779	4.04	9.82	10.55	-5.78	-6.51
Tulkarem	29345	16.62	22.33	22.53	-5.71	-5.91
Nablus	4639	14.65	3.28	3.33	11.37	11.32
Jerusalem	0.0	0.0	0.0	0.0	0.0	0.0
Jericho	24194	34.84	35.87	44.68	-1.03	-9.84
Rammallah	890	1.17	0.7	0.72	0.47	0.45
Bethlehem	814	0.37	0.45	0.45	-0.08	-0.08
Hebron	993	0.17	0.32	0.32	-0.15	-0.15
Jordan valley	28962	17.28	13.12	15.56	4.16	1.72
Total	101616	89.14	85.89	98.14	3.25	-9.0

(1) (ARIJ 1998)

Excess water can reduce yields and harm the plants themselves as much as the same degree of water depletion; this can be seen from the low productivity per cubic metre in these areas. For instance, in Nablus the productivity per cubic metre of crops planted in open field is 0.9 kg, while under plastic houses the productivity is only 1.3 kg per cubic metre. In contrast, in areas like Tulkarem, and Jericho the productivity is 6.0 and 5.9 kg per cubic metre for crops in open field and 7.5 and 10.6 kg per cubic metre for crops planted under plastic houses. The productivity can be increased if more water is available, as there is a water deficit in that area and more quantities of water are needed to achieve the optimal crop yield (ARIJ 1998).

9.5 Reallocation of agricultural water and future irrigation water demand

When discussing potential uses, one should distinguish between domestic uses on the one hand, and agricultural and industrial uses on the other. Domestic needs are of course the primary concern in water allocation. Elias Salameh, a noted Jordanian hydrologist, who is quoted in Vesilind (1993) has pointed out: *"We should take what we need for domestic purpose first, and then use the rest for irrigation, not the reverse. We have a crisis because we are not able to put enough investment into industrialization, so we rely on agriculture, which needs less investment and more water."* Salameh is taking about Jordan, but his words apply equally well to West Bank.

Reallocation of water from irrigation holds little promise for the West Bank and would run counter to a national policy to increase food production and promote a greater self-sufficiency. Furthermore, present agricultural water use is not as large in volume compared to municipal uses, and its reallocation would in many districts cause an overcome loss of fruit and vegetables production, as well as a potential disruption of the livelihood of farmers and the economy of Palestine. Accordingly, the future water demand for irrigation in the West Bank is ascertained in view of the assumption that it will be as the present time (98 Mcm).

Allan (1996) has used the term "virtual water" to refer to the water used to grow exported crops. The water content of grain is, then, tiny in comparison with the total water necessary to grow it. This total, virtual water, has been conceptually invisible in the analysis of the global trade in agricultural produce. However, in respect of the Middle East, understanding the import of virtual water is critical in understanding the region's ability to grow in terms of GDP and population, despite the aridity of its climate. It is the import of virtual water that has made wars over water unnecessary, which has permitted the long dominance of supply-fix measures, and which has constrained the space available for a demand management philosophy. Allan concludes that the region's governments have been able to take a less than urgent approach to managing their water according to sound economic and environmental principles because there has been a ready supply of extremely cheap water available in a very effective and operational system world trade in foods staples. Trade in virtual water is possible if importing countries possess resources which can be traded for commodities containing virtual water.

9.6 Livestock water use

A summary of livestock water consumption has been furnished by the Ministry of Agriculture, and is presented in Table C16 of Annex C. The livestock water consumption was about 6.6 Mcm during 1996. This quantity was estimated for various types of animals and livestock. Water for livestock consumption is supplied from different sources that include the municipal system, irrigation wells and springs. CDM (1997) projected future livestock water demand for the West Bank for the year 2020 to be 20 Mcm, which seems too high in comparison with the present demand.

9.7 Modeling agricultural activities in West Bank on a district by district basis

The agriculture sector in the West Bank is faced with a situation where more food will have to be produced with less water in order to ensure global food production and food security. The Author, however, designed the following model to serve as an integrated model for optimisation of use of land and water resources in agriculture. This necessitates that the model be based on a wide spectrum of relevant factors and data such as crop types, climate crop production and distribution, consumption, cultivation method, irrigation technology, agricultural markets, prices pf produce, cost of production, net export/import, water availability, availability of land, soil type, and others.

The objective function of the model is to maximize profits. Profits are defined as the differences between revenues and production and water costs, according to the function below. There are three major constraints, the first constraint relates to the availability of land for agriculture use. The second constraint defines the total amount of water allocated for a district. The third one relates to the crop production, different marketing potentials and food security requirements. Combining these three constraints, the following equation has been developed to maximize profits for district j, from crops i, and using irrigation system s:

Maximize profits of district j

$$\sum i\sum s[P_{ij}*X_{ijs}]-\sum i\sum s[C_{ijs}*L_{ijs}*X_{ijs}]-\sum i\sum s[W_{ijs}*L_{ijs}*X_{ijs}]*P_{*wj}$$

Land Constraint

$$\sum i\sum s[L_{ijs}*X_{ijs}] \le \sum s L_{*js} \qquad \forall j$$

Water Constraint

$$\sum i[W_{ijs}*L_{ijs}*X_{ijs}] \le W_{*js} \qquad \forall j, s$$

Commodity Balance

$$\sum s X_{ijs} \ge [C_{*ij} + E_{ij} - M_{ij}] \qquad \forall i \quad \text{in a given district j}$$

Definitions

P_{ij} Price for crop i in district j (\$/tonne)

X_{ijs} Output of commodity crop i in district j using irrigation system s (ton)

C_{ijs} Total cost to produce crop i in district j using irrigation systems s (\$/1000 m^2)

L_{ijs} Amount of land required to grow one tonne of crop i in district j using irrigation system s (1000 m^2/ tonne)

W_{ijs} Water required to produce crop i in district j (m^3/1000 m^2)

P_{*wj} Price of water for agricultural use in district j (\$ /m^3)

L_{*js} Total amount of agricultural land in district j available (1000 m^2)

W_{*js} Total amount of water allocated for agricultural use in district j and irrigation system s (m^3)

C_{*ij} Total consumption of crop i in district j (tonne)

E_{ij} Total exports of crop i from district j (tonne)

M_{ij} Total imports of crop i for district j (tonne)

Several additional constraints may be introduced to enrich the model and to account for realistic restrictions in the system such as type of soil and proper season. These constraints were not introduced in modeling agricultural activities in West Bank due to the shortage of data. The above linear optimisation model was solved using the GAMS Software to find X_{ijs} .The output for Bethlehem District- as an example- is shown in Table C 17 of Annex C.

CHAPTER 10

WATER BALANCE MODEL FOR THE WEST BANK

10.1 Introduction

The objective of the water balance model is to develop a comprehensive planning framework to achieve a sustainable water supply for the Palestinian communities in the West Bank for meeting water demands for the year 2020.

Numerous water resources management and supply options have been proposed for the study area over the past few decades. Some of them rely on technologies or concepts that are not presently known to be feasible. Attempts are made in this Research to consider a wide host of views and options, but greater emphasis is placed on those technologies and principles that have been proven to be implementable and widely accepted.

This chapter depends on the discussion of the principles of water balance techniques drawn from Chapter Six. To facilitate the development of a realistic and goal oriented management framework for the West Bank, a Focus Group has been assembled. This group is comprised of 12 individuals who are involved and interested in the various aspects of water resources development, planning, management, research, and utilisation in the West Bank. Accordingly, it includes representatives of Palestinian water institutions, universities, and research institutions, non-governmental organisations, and municipalities. The Focus Group involves professional hydrogeologists, environmental engineers, economists, a systems analyst, irrigation engineers, water resources engineers, and lawyers. The main activities of the group are to review the proposed methodology and criteria for screening and evaluating options of water resources development.

10.2 Projected water budget for West Bank for the year 2020

Projected municipal water consumption for the West Bank for year 2020 was projected in chapter eight, while projected agricultural water demand was projected in chapter nine. The waters of the shared Mountain Aquifer and the Jordan River were divided according to allocation outcomes presented in chapter seven. Combining the consumption and supply projections, the overall water budgets for the West Bank are presented in Table 10.1

Table 10.1

Consumption and Supply Balance for the year 2020 for West Bank

Domestic and industrial water demands	Irrigation and livestock water demands	Available from ground Water	Available from Jordan River	Deficit
Mcm/yr	Mcm/yr	Mcm/yr	Mcm/yr	Mcm/yr
322 (Section 8.3.2) *(page 77)*	118 (Section 9.5) *(pages 96 & 97)*	118 (Section 7.3.1) *(page 64)*	26.5 (Section 7.3.2) *(page 67)*	-295.5

As Table 10.1 demonstrates, assigning entitlements to shared water resources is not a panacea for the long-term water crises confronting the West Bank. Assuming that utilisation of the West Bank aquifers and the Jordan River basin is limited to each region's entitlement, West Bank still experience critical shortages in available supply and serious deficits. Action on a number of fronts is required to meet this challenge as shown in next sections of this chapter.

10.3 Options for closing supply demand gap for the West Bank

Annex D describes 20 different proposed options for matching supply and demand and improving water supply in the region in general and in the West Bank in particular (see accompanying text box as an example for an option). It should be noted that the Annex simply records what is available in the literature and was kept as brief as possible both to limit the length of the annex and to provide a quick, readable resume of the options. The Author has focused on options that have particular relevance to arid and semi-arid areas and especially to new, emerging technologies that become increasingly important as water supplies become scarce. Most of the options considered here already being practised somewhere in the region.

The Focus Group were asked to assign weightings to each of the criteria shown in Table 10.2. This table shows a summary of planning criteria and weights obtained from the Focus Group that will be used for evaluating and screening the options.

OPTION NO. 1

DEVELOPMENT OF LOCAL GROUNDWATER SOURCES

CONCEPT: The total potential renewable groundwater resource in the West Bank is 601Mcm/yr and 78 Mcm/yr of brackish water for further development.

TECHNOLOGY/IMPLEMENTATION: The technology for groundwater extraction is readily available.

COSTS: The unit production cost of local groundwater in the West Bank ranges between \$ 0.25 and \$0.30/m^3. Financing, distribution, and treatment would increase these costs (WESC, 1996).

SOURCE WATER: From the point of view of hydrologic uncertainty, the availability of the resource is reasonably well known and dependable. Production can be sustained up to the total renewable capacities of the aquifers.

POLITICAL: The Palestinian share of the groundwater resources in the West Bank in not yet defined. Therefore, the extent to which the Palestinians may develop these resources in the future is a function of the Final Status Negotiations. Utilisation of groundwater resources would provide Palestinians with a high degree of independence in the control of their water resources.

INSTITUTIONAL: Management institutions necessary for effective utilisation of groundwater resources would not have any out-of-the ordinary or exceptional staffing, training, or manpower requirements.

ENVIRONMENTAL: The development of conventional water sources must take into account the sustainability of these resources. Groundwater development must be performed so that safe yield of aquifers in not exceeded.

SOCIAL: Public acceptance of the use of additional groundwater supplies would be limited only by the price charged to water users.

Table10.2

Summary of planning criteria and weights

Criteria		Weights		
		Mean	Median	Range
Financial and economic viability		20	20	10 - 25
	Fundability	50	35	20 – 60
	Cost per unit of water	27	25	15 - 40
	Affordability	23	20	10 - 30
Technical viability		13.3	10	10 - 20
	Availability of technology	29.4	30	10 – 40
	Implementability	27.2	30	10 – 35
	Feasibility	24.5	30	15 – 40
	Flexibility and reliability of technology	18.9	20	15 – 30
Source viability		22.4	20	15 – 50
	Availability and hydrologic certainty	41.6	35	25 – 50
	Sustainability of quantity and quality	35	30	20 – 40
	Flexibility of supply development	23.4	20	10 – 35
Political viability		21	10	10 – 30
	Willingness of participant countries	29	40	15 - 50
	Political certainty of source country	30	40	20 - 60
	Compatibility with international laws	41	50	35 - 60
Institutional viability		7.1	5	4 - 12
	Availability and capacity of institutions	55.5	50	50 - 70
	Reliability of institutions	44.5	50	30 - 50
Environmental viability		8.8	7	4 - 20
	Impacts on the built environment	47.9	50	40 - 50
	Impacts on the physical and natural environment	52.1	50	50 - 60
Social viability		7.4	6	3 - 10
	Public acceptance	42.2	40	20 - 60
	Fulfilment of development needs	57.8	60	40 - 90

Using the methodology presented in chapter six, the options presented in Annex D were screened and rated using the criteria and weights presented in Table 10.2. These ratings were summed to obtain overall scores for each of the options detailed in Annex D. Options with higher scores are ranked higher, and considered more compatible with the planning criteria than those with lower scores. The results of this screening are presented in Table 10.3.

Table 10.3 displays the 20 options in rank order, from most favoured to least favoured. Options that are obviously favoured are those that rely upon development of local resources and improvements in the efficiency of the water delivery infrastructure (e.g., development of local groundwater and improvement of water supply systems in the domestic, industrial, and agricultural sectors). These are generally followed by options that are more costly and that will require more time to implement (e.g., wastewater reuse, brackish and sea water desalination, and institutional modifications to support such approaches as water pricing). Finally, options that are ranked lowest are those that generally require large-scale imports and regional and international co-operation in the movement of water from one country to another.

The extent to which each option could contribute to closing the supply/demand gap varies. Any estimate of the potential of each of the 20 options is difficult. Desalination, for example, could provide any amount of water, but at considerable cost. Cloud seeding on the other hand may make negligible contribution and the success of cloud seeding is unpredictable. Each option should be considered individually to assess the quantity of water available or saved. Such an assessment is beyond the scope of this study and would be carried out as part of the full feasibility study.

10.4 Development of scenarios from retained options

Options presented in Annex D describe possible water supplies can be viewed as components or building blocks of scenarios in accordance with its ranking. Scenarios consider taking some water from a selection of the options listed in Annex D. The most favoured can be combined or assembled in different ways to form individual and distinct scenarios for the development and management of water resources. The first

10 options that are obviously favoured and having a higher rank in Table 10.3 are common to all of the scenarios.

Strategic and feasibility studies preceding any final decisions to proceed should include quantification of benefits under option assumptions about the potential results of demand management. The following is a set of possible scenarios as examples and offers realistic, conceptual plans to achieve sustainable long-term water supply for the West Bank. These scenarios have been specifically formulated to meet the demands forecast for the year 2020. Each scenario is also evaluated by the Water Focus Group with respect to its consistency or compatibility with planning criteria presented in Table 10.2. A scale of 0 to 5 was used for qualitative rating, with 0 meaning inconsistent with the criterion, and 5 meaning entirely consistent with the criterion. These ratings were multiplied by their respective criteria weights, and the resulting products were added to obtain a composite score for each scenario. These calculations are summarised in Table 10.4, which show scenario 3 to be the scenario with the highest overall score.

Scenario 1

This scenario assumes that the entire future fresh water deficits will be filled by desalination. In addition to the common options, the following major sources are included in this scenario:

- Desalination facilities in the Gaza Strip, with a total capacity of 100 Mcm/yr.
- Four desalination plants constructed in Israel, each of 50 Mcm/yr capacity.

The conceptual locations for the desalination facilities are those proposed by Tahal (1996), which include Tel Aviv, Ashdod, Hadra, and Ashqelon in Israel and Gaza and Qatif in the Gaza Strip.

Scenario 2

This scenario differs from scenario 1 in the location of the desalination facilities. In addition to the common options, the following sources are included in this scenario:

- Desalination facilities in the Gaza Strip, with a total capacity of 100 Mcm/yr.
- Four desalination plants constructed in Egypt, each of 50 Mcm/yr capacity.

Table 10.3

Rank order of options

No.	Option	Score	Rank
1	Development of local groundwater sources	8587	1
17	Supply system improvements- municipal sector	8197	2
15	Water conservation –municipal sector	8139	3
18	Supply System improvement— agriculture sector	8018	4
16	Water conservation – Irrigated agriculture sector	7966	5
2	Development of local surface water resources	7771	6
6	Intensive watershed management	7563	7
20	Water pricing	7423	8
19	Intersectoral reallocation	7210	9
5	Wastewater reuse	6855	10
4	Desalination of brackish water	6465	11
3	Desalination of sea water	5907	12
11	Medusa bags	5474	13
12	Litani-to-Hasbani transfer	4998	14
7	Cloud seeding	4789	15
9	Mini peace pipeline	4766	16
10	Peace canal	4719	17
14	Mediterranean Sea-Dead Sea desalination	4702	18
13	Red Sea-Dead Sea desalination	4301	19
8	Peace pipeline	4201	20

Scenario 3

This scenario combines desalination and sea imports to meet fresh water deficits. In addition to the common options, the following facilities would be built:

- Desalination facilities in the Gaza Strip, with a total capacity of 100 Mcm/yr.
- A 200 Mcm/yr unloading facility for sea imports in Gaza.

This scenario assumes the use of new tankers for sea import from the mouth of the Manavgat River in Turkey. Construction of transmission facilities to convey sufficient quantities of water inland from Gaza to the West Bank is included in this scenario.

An overall comparison of the three scenarios is presented in Table 10.4. As stated previously scenario 3 has the highest score and has support. From the information presented in the table, the following observations can be made:

- Demand management, through pricing, implementation of a plumbing code that calls for flow limiting devices, limiting the use of potable water for certain uses (such as urban and agricultural irrigation), maintenance of water meters, and implementation of water loss-reduction programs, will be an important element of any proposed scenario.

- Scenarios that rely on sea imports are preferred to those that rely on desalination to supply additional water to the region. Moreover, scenarios that use a combination of desalination and sea imports are preferred to those that do not employ a combination.

- Regardless of the type of non-conventional technology used to supply additional water (i.e., desalination or sea imports), locating that technology in Egypt is preferred to locating it in Israel.

Table 10.4

Summary and Comparison of Scenarios

Scenario	Criteria, Weights, and Ratings							
	Financi-al	Source viability	Techn-ical	Politi-cal	Institut-ional	Enviro-nmental	Social	Score
	20%	22.4%	13.3%	21%	7.1%	8.8%	7.4%	
Scenario 1	2	4	3	2	3	2	2	265
Scenario 2	2	4	3	3	3	2	2	286
Scenario 3	3	4	3	3	3	3	3	322

CHAPTER 11

INSTITUTIONAL REQUIREMENTS FOR THE WEST BANK

11.1 Introduction

Institutional support will be required to implement any of the management options included in the comprehensive management framework. Ideally, the responsibility of the required support will reside with one entity. Only with strong, clearly defined lines of responsibility can a comprehensive program of the magnitude of the management options proposed in the previous chapters be implemented in an efficient manner.

An institutional framework for the management of water resources is presented in this chapter along with the areas of support that must be provided by these institutions for the implementation of water resources development plan. Management and implementation activities associated with the support areas are discussed. Although no attempt is made to assign responsibility to a specific institution, whether existing or planned, certain areas of responsibility that relate specifically to the comprehensive management framework are addressed. Finally, suggestions are given for the continued development of the institutional framework.

11.2 Proposed institutional framework for the West Bank

At present, the recently established Palestinian Water Authority (PWA), municipal water departments, village councils, Mekorot, UNRWA, and regional utilities accomplish the management of water resources. The proposed framework consists of the PWA, a national water supply utility, and a series of regional utilities. According to the proposal, the PWA is responsible for the management and allocation of all of water resources with the objective of achieving social, economic, and environmental goals. The national water supply utility would be responsible for providing sufficient quantities of water, and the regional utilities would be responsible for delivering the water.

The PWA has four departments: Water Resources and Planning, Regulatory, Technical, and Administrative. The basic organizational structure was developed with assistance from an international institutional development team and represents a suitable organizational structure for the existing and anticipated condition in the West Bank (CDM 1997). There have been no conclusions drawn from this Research that would suggest any modifications to this structure.

11.3 Basic requirements

There are certain basic requirements for which there is an immediate all-encompassing need regardless of the institution associated with the furtherance of any of the concepts of the comprehensive management policy. These requirements are being met for some of the existing institutions to different degrees and include:

- Organizational structure
- Position qualifications and job descriptions
- Management system: data management, financial, and reporting
- Public education and public relations
- Personal training in modern technology of water management tools.

11.4 Institutional activities

Institutional activities represent the general support areas that must be available prior to or early in an implementation program. These activities can generally be assigned to the national organizations. As they relate to any of the development plans in the planning framework, these activities include the following:

- Setting policy, establishing regulations, and proposing legislation
- Prioritizing projects
- Negotiating treaties for the purchase or exchange of water
- Setting standards and establishing codes
- Coordination with donor agencies
- Project funding and financial planning
- Strategic development planning.

As most of the existing policy has been established by Israeli institutions, once the responsibility for policy is turned completely over the Palestinians, much work needs to be done. Some of the most urgent areas where policy decision will be required include the following:

- Water rights
- Unregistered connections
- Pricing and subsides
- Water saving devices
- Treatment of water reuse
- Plumbing codes
- Private development.

The regional entities are charged with the enforcement of policy decisions, the collection of data, or the performance of studies to support policy, and regional planning. Some of the most important institutional activities of the regional entities for which a capability must be developed include:

- Operation and maintenance of water and wastewater systems
- Billing and collection.

11.5 Management and implementation activities

Four management and implementation activities are especially important for the successful implementation and operation of the facilities and actions associated in the management strategy. These activities are negotiation, coordination with donor agencies, planning and technical support, and construction surveillance.

11.5.1 Negotiation

All of the resource augmentation elements require a negotiation capability. First and foremost, the capability is required in dealing with the Israel Civil Administration to secure the permits associated with the construction and operation of the well and transmission system. Second, a negotiation capability will be required to arrange for financing from donor countries, as it is unlikely that the Palestinians will be able to fund the required water infrastructure.

11.5.2 Coordinating with international donor agencies and consultants

It is recognised that many donor agencies come into a country with predetermined ideas of what they want to fund. Institutionally, information should be available to enable the co-ordinating entity to indicate what assistance is needed to convince the donor agency that the assistance is need and that it is worthwhile.

11.5.3 Planning and technical support

The planing studies start with the development of national and regional water plans, and proceed to the assessment of the economic and financial feasibility of any of the courses of action recommended in the water plans.

From the feasibility stage, the implementation would require the preparation of designs and contract documents. Associated with this step is the need to pre-qualify contractors, evaluate bids, award contracts, and, for the next step, supervise construction, administer the contract, and resolve claims.

While it is anticipated that much of technical assistance will be provided by local and international consultants, it is still a necessity to have an organisation to work with the consultants, to offer comments and suggestions, and to review the consultant's result. This could be a Palestinian entity or a Program Management Consultant.

The technical support requirements at a national level may include support for the establishment of standards, a research and development program, and the development of building, land use, zoning, and other type of codes. At the regional level, an inventory of the resources is needed which will include data collection and analysis, creation of a database, and program monitoring.

11.5.4 Contract administration and construction surveillance

This can be accomplished through a construction management consultant or by Palestinian staff. Depending on the approach, different type and degrees of institutional support will be required. In any event, any decision with respect to the selection of contractors, claim, and the acceptance of the final product will reside with the appropriate Palestinian agency.

11.6 Assignment of responsibility

In addition to the identification of required areas of support and the capabilities needed to provide this support, there are still many questions related to how the process will work. Many of these questions concern the assignment of responsibility for performing an action or activity. Once the responsibility is assigned, an organizational structure can be developed. It is not the intention of this research to suggest where the responsibility should lie or to propose an organization within which these activities could be accomplished. In this section, certain questions are posed in relation to the activities associated with the management policy. The answers to these questions can form the basis for the assignment of responsibility and the development of an appropriate organization.

Who will:

- Negotiate with Israel for the purchase or exchange water?
- Implement local, regional or international water resources projects?
- Prioritize areas to be developed?
- Operate and manage water transmission facilities?
- Monitor agricultural runoff?
- Collect and treat wastewater?
- Have overall responsibility for the quality of the water resources?

The implementation of the PWA is a good start. It establishes the keystone that permits the continuation of institutional development. However, implementation of the proposed or other institutional framework is recommended to provide the complete institutional capability required implementing the development plans.

CHAPTER 12

CONCLUSIONS AND RECOMMENDATIONS

This concluding chapter brings together thoughts, ideas, and proposals that have been explicit or implicit in the preceding chapters. In effect, it provides a set of recommendations that are intended as steps toward alleviating the water crises in the West Bank. Many of these recommendations could apply to many countries in arid and semi-arid areas; others, however, are unique to the situation in which Israelis and Palestinians find themselves, and to the history and geography that they share.

As stated in chapter one, the discussion on the nature and scope of the problem under investigation has led to propose and formulate the following hypothesis:

"A water resources and water demand management model can be developed applicable to locations which experience specific constraints such as rapid population growth, limited water resources and political disputes over water resources."

None of the models reviewed in the literature, however, provides a means of managing water resources considering the various limiting factors and that can readily be applied to locations which experience the above specific constraints. This thesis has proved the above hypothesis as far as possible and has achieved such a model but it needs to be applied and implemented if it is to be proven conclusively. Fig 3.1 that show a general flow chart of the model has also proved useful in this research.

To test the above hypothesis, the West Bank was chosen as a case study. The results of this research will assist water managers and engineers to formulate a water resources management framework and initiate actions (that are environmentally, socially, politically, economically sustainable) to improve and manage the water sector.

The Researcher believes that the case study of this research has suggested a paradigm for a comprehensive management framework for large-scale water management problems in arid and semi-arid areas. This management framework can help to achieve sustainable water resources for meeting water demand and preventing the gridlock and excessive legal expense of uncoordinated and conflict-filled decision processes.

The attributes of the management framework (some well known and others not so familiar) begin with inclusion; that is, the framework should be comprehensive, with extensive stakeholder involvement and collaboration. The decision processes should be clear, action oriented, and adaptive. Other desirable qualities of the framework include a focus on environmental integrity, technical aspects, financial aspects, social implications, institutional aspects, political implications and use of proven management practices.

Establishing Priorities

Before considering recommendations that can begin to deal with the quantity, and geopolitical dimensions of the water crisis, it is necessary to establish priorities for action. Arid and semi-arid countries can and should take the initial steps toward mitigating the water crises in areas clearly within their own jurisdictions. Regional agreements for sharing water and joint responsibility for water management are probably the best long-term solutions.

Therefore, the following are the proposed priorities toward resolution of water problems in the West Bank. The Researcher advances them with considerable confidence that they apply as well to other countries in the Jordan River Basin and throughout arid and semi-arid countries.

Priority 1: Moderating Water Demand

First, priority must be accorded to policies and programs for attaining greater efficiency in the use of water, including both micro options aimed at the point of use and macro options in selecting among uses for water. Support of this priority includes not only formal regulations and improved technology, but also education and awareness campaigns. Support of this priority also includes what is perhaps the most important change in the short run: better designed pricing systems that not only cover costs but also build in incentives to conserve. Demand management is, very often, the most economic "source" of water, being in many cases a preferred alternative means in order to respond to increasing water demand.

Priority 2: Improved Water Institutions

The second priority must be the development of local and national institutions that can deal with both water supply and water demand. This priority is closely linked to the first. As stated by the former Executive Director of UNEP *"The major constraint on efficient water management is the weakness of the institutions concerned"* (Tolba, 1994).

Priority 3: Augmenting Local Water Supply

The third priority should be to promote measures to identify, develop, and manage alternative, local sources of water supply.

Priority 4: Building Regional Water Institutions

The fourth priority focuses on international, but still interregional, agreements and institutions for managing water, for sharing supplies, for creating markets to exchange or sell water, and for avoiding or mitigating water quality problems.

Priority 5: Augmenting Regional Water Supply

Only fifth should consideration be given to inter-basin transfers of water or water imports and to capital intensive mega-projects such as large scale desalination.

This research does not maintain that this order of priorities must be followed in every case or every locale. The Gaza Strip, for example, may already be experiencing such excessive demands on its water resources that only the fourth and fifth options have any significant potential. Many analysts would accept the above ordering of priorities, but they would argue that we should move sooner rather than later toward options lower down the list. Nevertheless, the above given order represents a starting point from which any nation in the region, and indeed each village, neighbourhood, and sector, can begin taking control of water management.

The guiding principles and recommendations from international water conferences have stimulated the international debate, and proposed concerted action to implement. Moreover, those principles have formulated the first steps in this research. Conferences set recommendations for action at local, national, and international levels based on four guiding principles listed in chapter two.

In order to achieve efficient use of water a complete "package" of the following recommendations should be applied:

Water Disputes Recommendations

Today's international legislative structure is incapable of solving complex water disputes. Present international law provides only guidelines for sharing water resources rather than a clear-cut basis. This research introduces one such multi-criteria decision tool for quantification of water resources rights.

For illustrative purposes, it is presented in terms of the water-sharing problem facing Israel and the Palestinians. The approach presented in this Thesis should be seen as a first step in grappling with the problem of trans-boundary water resources rather than as the final word. The methodology is based upon the several factors identified by the International Law Commission (ILC) in its draft articles on the non-navigational uses of international watercourses. Although seemingly reasonable in principle, this provision can be troublesome in practice. Questions (and controversies) soon arise over the appropriate weight to assign to the various factors.

The satisfactory resolution of water disputes requires both improved conflict resolution methods and innovative measures such as water marketing and conservation. This combination of decision-making processes and technical or policy solutions is critically important to creating workable solutions to controversial water resource problems.

Domestic Recommendations

The development of a broad and enforceable strategy for domestic water conservation should be the first step toward reducing water scarcity. This strategy should include information programs to promote awareness of the growing water shortage, minimum efficiency standards, and regulation.

Based on the available studies several parameters appear to have greater influence on domestic demands. However, the inter-relationships of these parameters appearing in the developed model for the case study of this research and their relative importance would vary from one environmental setting to another. Consequently the findings of a study in one area cannot be directly applied elsewhere. This emphasises the need to carry out domestic water use studies for individual areas in order to make a rational prediction of domestic demands. Models should be generated from available data to provide clear insight of the different factors that can be used as effective managing tools.

Introducing appropriate pricing of water will encourage efficiency in allocation and use in all sectors, together with the reduction or elimination of subsidies. The results of this study indicate that water utility authorities can use price as a tool to ration or discourage water consumption in the households. Obviously, this is an acceptable practice and water resources will be conserved if it is applied in an appropriate way as shown in chapter eight.

Working toward reducing water loss in supply systems throughout the West Bank is urgently required. Faulty infrastructure, faulty metering, inadequate monitoring, and water theft are problems that must be addressed.

Agricultural Recommendations

Continue the trend toward full use of recycled water for agriculture or for recharging aquifers in parallel with investing in modern sewage systems wherever they do not now exist.

A guide should be prepared for establishing and operating an irrigation scheduling service. Crops with low transpiration rates or crops that produce high dry matter yield per unit of water transpired should be selected. New economic crops, cash crops such as avocadoes, and flowers, which bring high prices and have low production costs, should be introduced.

Reallocation of water from irrigation holds little promise for the West Bank and would run counter to a national policy to increase food production and promote a greater self-sufficiency. Furthermore, present agricultural water use is not as large in volume compared to municipal uses.

Institutional Structures

Institutional support will be required to implement any of the management options included in the comprehensive management framework.

The implementation of the PWA is a good start. It establishes the keystone that permits the continuation of institutional development. However, implementation of the proposed or other institutional framework is recommended to provide the complete institutional capability required implementing the development plans.

Four management and implementation activities are especially important for the successful implementation and operation of the facilities and actions associated in the management strategy. These activities are negotiation, coordination with donor agencies, planning and technical support, and construction surveillance.

Regional Recommendations

In the future, as the various parties build enough confidence in their own abilities and those of their neighbours to think about substantive cooperation, a regional water institution for the Jordan River Basin will have to be established. It should, as a start, have a limited mandate, acting largely as an information clearinghouse.

Modern computerised data processing systems need to be installed, with the training and manpower development programs that they imply, for water data base development, and for timely dissemination of information. This will also support and facilitate the research agenda discussed below.

Modelling Water Demands Recommendations

The process of projecting water demands should be directed towards analytical modelling approaches such as statistical techniques and mathematical programming if reliable and valid data are available.

Based on the nature use of activities, mathematical programming as a planning tool seems well suited for the analysis of a wide range of demand forecasting problems in the agricultural and industrial activities. On the other hand, the statistical approach appears to be most promising for modelling domestic water demands. A combination of two is therefore appropriate for modelling overall demands.

Water Balance Recommendations

The options for closing the gap between supply and demand in arid and semi-arid areas should consider various means of matching supply and demand, and of satisfying environmental concerns. Besides demand management possibilities the strategic options should include: broad technical arrangements needed to meet physical developments of water resources, options for institutional and human resource arrangements, environmental and health protection measures.

The manager should in any event avoid producing a list of options and recommendations that is a "wish-list", divorced from practical considerations of the resources available to implement a water resources strategy.

Planning criteria must serve as a tool and set the framework for decision making regarding the development and selection of different options. The criteria can be classified into the following categories: technical, financial, environmental, social, institutional, and political.

Implication for future research

As regards priorities for the research, the following are suggested:

Further research on factors affecting domestic water demand is needed. The domestic water use model developed in this study is likely to provide stimulus to new thinking and innovative research in this area. Greater emphasis should be put on knowing the aggregate impact of all the factors and their relative importance than on studying the effect of isolated factors.

An appraisal of the need for community participation is not an end in itself. Innovative ideas and research on how to involve the community in water resources management have ever increasing importance.

The magnitude and cost of potential water savings from existing uses, and the impact of increased water use efficiency on food production are likewise poorly understood. What would be the impact on food production and food security of transfers of saved water out of agriculture? Research is urgently needed to understand on a global basis the relationships between water scarcity, food production, food security and environmental sustainability. Understanding the contributions of water management and investment policies to future food security would provide important guidance to national and international policy makers, and could generate large benefits for food producers and consumers.

There is a need for economic and hydrological research, data exchange, and circulation of information for debate and discussion.

Following on the recognition of water as an economic good, research is needed to establish better the actual economic value and productivity of water in different places and applications. Different forms of irrigation, different crops, different treatment and distribution systems have different cost/benefit profiles, which must be worked out. Estimates from such analysis must be disseminated for debate, and to increase the public's awareness that various water uses have specific costs and returns.

It is necessary to establish in one of the countries that suffer from water shortage a strong research centre to develop the scientific and practical methods of water resources protection and development.

Finally, in the words of Kenneth Boulding (1964):

Water is far from a simple commodity;
Water's a sociological oddity.
Water's a pasture for science to forage in;
Water's a mark of our dubious origin.
Water's a link with a distant futurity;
Water's a symbol of ritual purity.
Water is politics, water's religion;
Water is just about anyone's pigeon.
Water is frightening, water's endearing;
Water is more than mere engineering.
Water is tragical, water is comical;
Water is far from the Pure Economical.
So studies of water, though free from aridity;
Are apt to produce a good deal of turbidity

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ANNEX A

Questionnaire on Water Supply and Demand Study

QUESTIONNAIRE ON WATER SUPPLY AND DEMAND STUDY

Name of department or utility: ....

Location: ....   Date: /   / 1997

Service area (km^2): ....

Administrative type of utility:

Regional Utility	Municipal Department	Village Council	Water Committee	Other	Water Only	Water & Wastewater

I - Infrastructures

A. Network

Average age	
Overall condition [1]	
Total estimated value ($)	

(1) Overall condition: 1= excellent, 2 = V. Good, 3 = good 4 = fair, 5 = bad

B. Pumping Stations

Unit	Age year	Working Conditions [2]	Capacity m^3/hr	Type [3]	Head (m)	Total pumping Cost $ / m^3

(2) Working condition: 1= excellent, 2 = V. Good, 3 = good 4 = fair, 5 = bad

(3) Type: D = diesel, E= electric

(4) Pumping Cost = Energy + (O& M) + Depreciation + Other costs

C. Pipe Length Breakdown

Diameter, inch	½	1	2	3	4	5	6	8	10	12
Length, m										
Material of Pipe [5]										

(5) Materials: C = Concrete, AC= Asbest-Cement, S= Steel

II. Water Sources

Source Name	Type	Ownership[6]	Capacity	Production			Remarks
				1985	1990	1996	

[6] Ownership: 1=Owned by utility, 2= Rented by utility, 3= Bought from private sources, 4= Bought from Mekorot, 5= Bought from ....

Storage Capacity

Reservoir	Type[7]	Material	Shape[8]	Capacity (m^3)	Present condition[9]

[7] Type: E= elevated, G = ground, U = underground

[8] Shape: R= rectangular or cube, C= cylindrical

[9] Present condition: 1= excellent, 2 = V. Good, 3 = good, 4 = fair, 5 = bad

III. Inventory of Equipment and Staff

A. Inventory of Equipment's

Type of equipment	No.	Ownership type [10]

[10] Ownership: 1=Owned by utility, 2 = Rented by utility, 3= Bought from private sources 4= Bought from Mekorot, 5= Bought from ....

B. Inventory of Working Staff

Staff	Number					
	1996					
Qualification PhD Bsc 2 or 3 yr Secondary school Less	Managers	Engineers	Forenames	Technicians	Workers	Accounting
Major Civil Eng. Electrical Mechanical Buss/Manag. Others						

IV. Water Consumption

Water use	Total water consumed (Mcm/yr)									
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Domestic										
Agricultural										
Industrial										
Truism										
Recreation										
Total										

Water use	Total number of connections									
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Domestic										
Agricultural										
Industrial										
Truism										
Total										

Water use	Total number of consumers served									
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Domestic										

Water Supply

Year	Total water Supplied by The system	Total water Metered at Consumer's Connection	Net sales m^3	% Unaccounted for water	Remarks
1987					
1988					
1989					
1990					
1991					
1992					
1993					
1994					
1995					
1996					

V. Water Tariff

Water amount range m^3	Price $/m^3$	Remarks

* Does the water tariff include any waste water tax of cast? ....

VI. Unserved Localities

Name of locality	Estimated population

VII. Current Water Supply Projects

Type of project	Total budget	% of Utility's participation

VIII. Waste Water Infrastructure

1. Collection system

Size	6"	8"	10"	12"	14"
Length (km)					

2. Percent coverage .... %
3. Number of manholes ....
4. Booster stations: Capacity .... m^3 /h Capital cost .... $
5. Treatment plant (if existed) : Cost ....$

IX. Issues Related to Future Activities

- List alternative water supply sources that can feasibly be connected to your system with their expected capacity:

- List major water supply /demand problems that the utility or department is facing:

- List needed projects or activities related to the enhancement of the water supply/demand within your service area:

ANNEX B

The Domestic Survey Questionnaire

THE DOMESTIC SURVEY QUESTIONNAIRE

Please " × " or put numbers where applicable.

A. Sample information

[ ] A.1 Sample No.

[ ] A.2 Average annual water consumption in m^3/ y from Water Supply Agency records

B. Call Record

a. Call Number	1	2	3	4	5	6
b. Time of day						
c. Month and date						
d. Day of week						
e.Result (abbreviate)(1)						

(1) NAH No one at home at time of call — RA Respondent absent at time of call

INT Interview taken — APPT Appointment made

REF Refusal — HV House vacant

C. Household variables

[ ] C.1 Number of occupants per dwelling

[ ] C.2 Number of children (less than 15 years)

[ ] C.3 Monthly income in US $

[ ] C.4 Lot size in sequre meter

[ ] C.5 Number of rooms

[ ] C.6 Sprinkling area in sequre meter

[ ] C.7 Number of cars

[ ] C.8 Number of flush toilets & Arabic toilets

[ ] C.10 Number of showers

[ ] C.11 Number of washhand basins

[ ] C.12 Number of sinks

[ ] C.13 Number of dishwashers

[ ] C.14 Number of taps in the courtyard

[ ] C.15 Number of washing machines

[ ] **Total No. of taps**

Your comments and amplifications, please.

THANK YOU

ANNEX C

Summary Output Tables of the CROPWAT Software

Table C1

Mean monthly climatic parameters and reference crop evapotranspiration for Bethlehem District

Month	Max. Tem. C°	Min. Tem. C°	R.H. (%)	Wind (Km/day)	Sunshine (hr)	Rad. $MJ/M^2/day$	ET_O Penman (mm/day)
Jan.	14.3	7.8	57.0	222	5.4	10.2	2.16
Feb.	12.9	6.1	60.0	260	7.1	14.1	2.50
Mar.	15.8	7.7	89.0	222	7.4	17.4	2.23
Apr.	26.0	14.9	69.0	226	9.4	22.6	4.47
May	26.4	14.7	59.0	295	11.4	26.7	6.06
June	29.5	17.8	45.0	302	12.4	28.5	7.41
July	29.5	20.3	31.0	359	12.1	27.8	8.56
Aug.	32.8	21.4	22.0	233	11.8	26.3	7.68
Sep.	31.3	20.0	54.0	181	10.1	21.7	5.39
Oct.	28.4	18.0	66.0	180	7.3	15.2	3.72
Nov.	19.2	11.7	75.0	175	5.0	10.3	2.14
Dec.	17.6	10.7	81.0	141	5.9	10.1	1.46
Avg./Total	23.6	14.3	59.0	233	8.8	19.2	1640

Table C2

Mean monthly climatic parameters and reference crop evapotranspiration for Jericho District

Month	Max. Tem. C°	Min. Tem. C°	R.H. (%)	Wind (Km/day)	Sunshine (hr)	Rad. $MJ/M^2/day$	ET_O Penman (mm/day)
Jan.	19.2	7.4	69.8	214	5.0	9.7	2.20
Feb.	20.9	8.3	65.4	249	5.4	12.2	2.98
Mar.	24.3	10.5	57.2	314	7.9	18.0	4.70
Apr.	29.3	14.2	44.6	389	8.7	21.5	7.18
May	33.7	17.6	38.1	380	10.0	24.7	8.92
June	36.7	20.4	38.2	368	11.5	27.2	9.86
July	37.8	22.1	40.5	384	11.8	27.4	10.21
Aug.	37.6	22.4	44.0	353	11.5	25.8	9.33
Sep.	36.1	21.1	47.2	301	10.1	21.7	7.61
Oct.	32.3	17.9	51.2	225	8.9	17.1	5.28
Nov.	26.4	12.9	59.5	187	7.1	12.4	3.33
Dec.	20.5	9.0	70.2	176	5.1	9.2	2.15
Avg./Total	29.6	15.3	52.0	295	8.6	18.9	2249

Table C3

Summary of the reference crop evapotranspiration for districts in the West Bank planted in open fields in mm/day

Month	Hebron	Bethlehem	Jenin	Tulkarem	Nablus	Rammallah	Jericho	Jerusalem
Jan.	1.64	2.16	1.7	1.30	1.80	2.00	2.20	2.10
Feb.	1.94	2.50	2.0	1.60	2.20	2.60	2.98	2.60
Mar.	2.87	2.23	3.0	2.30	3.10	3.40	4.70	3.70
Apr.	4.27	4.47	4.6	3.30	4.50	5.70	7.18	5.50
May	5.18	6.06	6.7	4.20	5.60	7.20	8.92	7.00
June	5.43	7.41	6.7	4.80	6.00	7.20	9.86	7.80
July	5.61	8.56	6.7	4.80	6.20	6.80	10.21	7.70
Aug.	5.48	7.68	6.1	4.50	6.00	6.30	9.33	7.10
Sep.	4.61	5.39	5.2	3.80	5.10	5.40	7.61	6.00
Oct.	3.70	3.72	3.7	2.90	4.00	3.80	5.28	4.40
Nov.	2.45	2.14	2.7	2.10	2.70	2.80	3.33	3.20
Dec.	1.65	1.46	1.9	1.40	1.80	2.80	2.15	2.30
Total	1367	1640	1556	1128	1490	1706	2249	1806

Table C4

Summary of the reference crop evapotranspiration for districts in the West Bank under plastic houses in mm/day

Month	Hebron	Bethlehem	Jenin	Tulkarem	Nablus	Rammallah	Jericho	Jerusalem
Jan.	1.80	1.90	1.9	1.80	1.80	1.90	1.80	1.90
Feb.	2.20	2.60	2.3	2.30	2.10	2.60	2.30	2.60
Mar.	3.00	3.30	3.1	3.00	3.00	3.30	3.40	3.30
Apr.	3.90	4.20	3.8	3.80	3.90	4.20	4.00	4.20
May	4.30	5.00	4.5	4.30	4.30	5.00	4.60	5.00
June	4.20	5.30	5.0	4.80	4.20	5.30	5.10	5.30
July	4.50	5.20	4.9	4.50	4.50	5.20	5.10	5.20
Aug.	4.70	4.90	4.4	4.10	4.70	4.90	4.80	4.90
Sep.	4.10	4.10	3.8	3.60	4.10	4.00	4.10	4.10
Oct.	3.40	2.80	3.0	2.90	3.40	2.80	3.00	2.80
Nov.	2.30	1.90	2.2	2.20	2.30	1.90	2.30	1.90
Dec.	1.70	1.90	1.8	1.80	1.70	1.90	1.70	1.90
Total	1222	1313	1240	1191	1219	1310	1292	1313

Table C5

Monthly crop water requirements in mm for crops in Bethlehem planted in open field

Crop	Plant Date	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Beets	Oct.	*	*	*	*	*	*	*	*	*	46	49	43	138
Spinach	Oct.	*	*	*	*	*	*	*	*	*	48	55	43	146
Garlic	Nov.	60	69	65	125	165	125	*	*	*	8	29	36	674
Turnips	Nov.	*	*	*	*	*	*	*	*	*	*	43	36	79
Radishes	Nov.	*	*	*	*	*	*	*	*	*	*	43	23	66
Baroadbeans	Nov.	60	46	*	*	*	*	*	*	*	*	22	37	165
Cauliflower's	Nov.	60	69	65	123	50	*	*	*	*	*	27	29	423
Peas	Nov.	67	78	*	*	*	*	*	*	*	*	29	43	217
Lettuce	Nov.	60	34	*	*	*	*	*	*	*	*	29	40	163
Onions (Dry)	Nov.	60	34	*	*	*	*	*	*	*	*	29	36	674
Onions (Green)	Dec.	45	69	29	*	*	*	*	*	*	*	*	19	163
Fennel	Dec.	61	73	66	29	*	*	*	*	*	*	*	21	250
Parsley	Feb.	*	33	65	132	181	222	158	*	*	*	*	*	791
Eggplants	Mar.	*	*	27	83	180	233	268	239	172	118	64	*	1384
Cucumbers	Mar.	*	*	30	111	172	205	*	*	*	*	*	*	518
Squash	Mar.	*	*	30	111	172	131	*	*	*	*	*	*	444
Beans	Mar.	*	*	24	108	170	*	*	*	*	*	*	*	302
Pumpkins	Mar.	*	*	30	111	172	126	*	*	*	*	*	*	439
Melon	Mar.	*	*	28	96	172	199	*	*	*	*	*	*	495
Jews' mallows	Apr.	*	*	*	64	158	211	77	*	*	*	*	*	510

Table C6

Monthly crop water requirements in mm for crops in Jericho planted in open field

Crop	Plant Date	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Eggplants	Sep.	72	95	151	224	249	*	*	*	90	96	101	70	1148
Squash	Sep.	*	*	*	*	*	*	*	*	97	130	97	22	346
Tomatoes	Sep.	72	86	*	*	*	*	*	*	90	100	104	70	522
Pumpkins	Sep.	*	*	*	*	*	*	*	*	97	130	96	21	344
Cucumbers	Oct.	40	*	*	*	*	*	*	*	*	68	83	63	254
Beans	Oct.	*	*	*	*	*	*	*	*	*	63	92	32	188
Corn	Oct.	69	*	*	*	*	*	*	*	*	54	89	70	282
Cabbage	Oct.	65	86	132	*	*	*	*	*	*	64	67	63	477
Spinach	Nov.	20	*	*	*	*	*	*	*	*	*	45	60	125
Radishes	Nov.	*	*	*	*	*	*	*	*	*	*	66	33	99
Broadbeans	Nov.	65	25	*	*	*	*	*	*	*	*	34	53	177
Lettuce	Nov.	65	25	*	*	*	*	*	*	*	*	45	60	195
Parsley	Dec.	65	90	144	213	159	*	*	*	*	*	*	30	701
Potatoes	Oct.	69	23	*	*	*	*	*	*	*	66	81	70	310
Jews' Mallows	Feb.	*	45	131	200	*	*	*	*	*	*	*	*	376
Okra	Feb.	*	41	137	224	130	*	*	*	*	*	*	*	532

Table C7

Summary of yearly crop water requirements in mm for crops in the Districts of the West Bank

Crop	Plant Date	Hebron	Bethlehem	Jenin	Tulkarem	Nablus	Rammallah	Jerusalem	Jericho
Beets	Oct.	149	138	163	126	161	199	192	193
Spinach	Oct.	157	146	171	132	170	199	201	125
Garlic	Nov.	614	674	706	224	665	813	815	*
Turnips	Nov.	90	79	100	78	97	123	119	119
Radishes	Nov.	76	66	82	64	81	98	98	99
Cauliflowe	Nov.	412	423	451	356	446	537	538	*
Peas	Nov.	197	217	*	165	214	262	259	*
Lettuce	Nov.	150	163	161	126	164	199	197	*
Onions	Nov.	614	674	706	504	665	813	815	*
Onions (Green)	Dec.	152	163	161	126	166	197	200	210
Fennel	Dec.	*	250	259	200	267	313	320	*
Parsley	Feb.	657	791	1034	544	713	860	889	701
Eggplants	Mar.	1114	1384	1290	921	1217	1366	1477	1148
Cucumbers	Mar.	440	518	532	364	478	587	594	254
Squash	Mar.	388	444	468	318	420	521	520	346
Beans	Mar.	277	302	333	223	299	375	366	188
Pumpkins	Mar.	375	439	494	315	416	515	515	344
Melon	Mar.	401	495	510	347	456	*	568	741
Jews' mallows	Apr.	401	510	494	336	436	534	550	376
Tomatoes	Mar.	763	*	*	636	832	971	1034	522

Table C8

Summary of yearly crop water requirements in mm for crops in the Districts of the West Bank under plastic houses

Crop	Plant Date	Hebron	Jericho	Plant Date	Tulkarem	Nablus	Rammallah	Jerusalem	Beth-lehem	Jenin
Beans	Oct.	623	352	Mar.	622	623	710	710	710	654
Cucumber	Oct.	830	591	Mar.	804	830	901	903	903	844
Tomatoes	Oct.	923	706	Mar.	893	923	1002	1006	1006	937
Eggplants	Oct.	310	810	Mar.	710	1000	1064	353	1069	323
Peppers	Oct.	724	446	Mar.	314	724	811	812	812	748

Table C9

Monthly effective average rainfall in mm for the West Bank's Districts

Month	Hebron	Bethlehem	Jenin	Tulkarem	Nablus	Rammallah	Jericho	Jerusalem
Jan.	91.1	69.8	51.2	97.5	94.3	11.8	11.4	89.5
Feb.	80.0	80.9	28.3	62.8	86.4	50.7	8.4	69.2
Mar.	46.7	49.2	26.1	36.8	56.0	12.6	5.2	51.9
Apr.	11.3	1.4	4.1	4.7	9.4	9.8	0.0	6.1
May	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
June	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
July	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sep.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct.	0.0	0.0	0.1	6.1	1.1	0.4	0.0	0.2
Nov.	27.8	22.8	16.8	52.4	34.9	188.8	3.1	28.3
Dec.	67.9	46.2	45.0	111.1	89.6	131.5	9.8	67.3
Total	324.8	270.3	171.6	371.4	371.7	405.6	37.9	312.5

Table C10

Irrigation scheduling for Tomatoes planted in open field in Jericho, without LR

No. of iirigation	Interval period (days)	Date of irrigation turn	Crop stage in each irrigation turn occures	Depltion (%)	Net Gift (mm)	Gross Gift (mm)
1	1	1 Sep.	A	60	19.0	25.3
2	2	3 Sep.	A	23	8.0	10.7
3	2	5 Sep.	A	22	8.0	10.7
4	3	8 Sep.	A	29	12.0	16.0
5	3	11 Sep.	A	26	11.8	15.7
6	3	14 Sep.	A	22	11.3	15.1
7	3	17 Sep.	A	21	11.3	15.1
8	4	21 Sep.	A	24	14.8	19.7
9	4	25 Sep.	A	20	13.4	17.9
10	5	1 Oct.	A	23	16.9	22.5
11	5	5 Oct.	B	22	17.4	23.2
12	6	11 Oct.	B	24	21.6	28.8
13	5	16 Oct.	B	20	19.5	26.0
14	6	22 Oct.	B	23	24.3	32.4
15	7	29 Oct.	B	24	27.3	36.4
16	7	6 Nov.	B	23	29.2	38.9
17	9	15 Nov.	C	22	28.7	38.3
18	11	26 Nov.	C	21	28.1	37.5
19	15	11 Dec.	C	20	26.5	35.3
20	22	3 Jan.	C	21	27.2	36.3
21	19	22 Jan.	C	20	26.6	35.5
22	15	7 Feb.	C	20	26.5	35.3
23	13	20 Feb.	D	20	26.6	35.5
Final	11	1 Mar.	D	15	0.0	0.0
Total					456	608

Table C11

Irrigation scheduling for tomatoes planted under plastic houses in Jericho

No. of irrigation	Interval period (days)	Date of irrigation turn	Crop stage in each irrigation turn occurs	Depletion level (%)	Net Gift (mm)	Gross Gift (mm)
1	1	1 Oct.	A	54	17.4	23.20
2	4	5 Oct.	A	24	9.8	13.07
3	4	9 Oct.	A	20	9.8	13.07
4	5	14 Oct.	A	20	11.7	15.60
5	7	21 Oct.	B	23	16.4	21.87
6	7	28 Oct.	B	20	17.6	23.47
7	8	6 Nov.	B	22	22.6	30.13
8	8	14 Nov.	B	20	24.5	32.67
9	10	24 Nov.	C	20	27	36.00
10	13	7 Dec.	C	21	27.2	36.27
11	15	22 Dec.	C	21	27.5	36.67
12	15	7 Jan.	C	21	27.5	36.67
13	14	21 Jan.	C	20	26.5	35.33
14	13	4 Feb.	C	21	27.5	36.67
15	12	16 Feb.	C	21	27.9	37.20
16	10	26 Feb.	C	20	26.5	35.33
17	9	5 Mar.	C	21	27.1	36.13
18	8	13 Mar.	C	20	26.6	35.47
19	8	21 Mar.	C	22	28.8	38.40
20	7	28 Mar.	C	20	26.5	35.33
21	7	5 Apr.	C	21	27.5	36.67
22	7	12 Apr.	C	21	28.4	37.87
23	7	19 Apr.	C	22	29.4	39.20
24	7	26 Apr.	C	23	30.7	40.93
25	6	2 May	C	20	26.9	35.87
26	6	8 May	C	21	27.7	36.93
27	6	14 May	C	21	28.1	37.47
28	6	20 May	D	21	28.3	37.73
29	6	26 May	D	21	27.2	36.27
30	6	2 June	D	20	26.5	35.33
31	7	9 June	D	22	29.4	39.20
Final	2	11 June	D	3		
Total					767	1022

Table C12

Irrigation scheduling for cucumbers planted in open field in Jericho, without LR

No. of the irrigation turn	Interval period (days)	Date of irrigation turn	Crop stage in each irrigation turn occures	Deplition level (%)	Net Gift (mm)	Gross Gift (mm)
1	1	1 Oct.	A	60	14.2	18.9
2	3	4 Oct.	A	32	9.3	12.4
3	3	7 Oct.	A	29	10.1	13.5
4	3	10 Oct.	A	25	10	13.3
5	5	15 Oct.	A	28	14	18.7
6	6	21 Oct.	B	28	17.2	22.9
7	7	28 Oct.	B	25	18.4	24.5
8	7	5 Nov.	B	25	21.6	28.8
9	8	13 Nov.	B	26	26.6	35.5
10	13	26 Nov.	C	27	30.7	40.9
11	21	17 Dec.	C	25	28.8	38.4
12	26	13 Jan.	D	26	29.4	39.2
Final	8	21 Jan.	D	7		
Total					230	307

Table C13

Irrigation scheduling for cucumbers planted under plastic houses in Jericho, without LR

No. of the irrigation turn	Interval period (days)	Date of irrigation turn	Crop stage in each irrigation turn occures	Deplition level (%)	Net Gift (mm)	Gross Gift (mm)
1	1	1 Oct.	A	56	13.0	17.3
2	4	5 Oct.	A	30	8.7	11.6
3	5	10 Oct.	A	30	11.0	14.6
4	6	16 Oct.	A	27	12.4	16.5
5	7	23 Oct.	B	26	14.7	19.6
6	8	1 Nov.	B	25	17.3	23.1
7	9	10 Nov.	B	26	21.2	28.3
8	10	20 Nov.	B	25	24.9	33.2
9	12	2 Dec.	C	26	29.2	38.9
10	17	19 Dec.	C	25	29.0	38.6
11	18	7 Jan.	C	26	29.9	39.8
12	17	24 Jan.	C	26	29.6	39.5
13	15	9 Feb.	C	26	29.5	39.3
14	13	22 Feb.	C	25	29.0	38.6
14	11	3 Mar.	C	25	28.9	38.5
16	10	13 Mar.	C	26	29.9	39.8
17	9	22 Mar.	C	26	29.5	39.3
18	9	1 Apr.	C	27	31.0	41.3
19	8	9 Apr.	C	25	28.9	38.5
20	8	17 Apr.	C	26	30.2	40.3
21	8	25 Apr.	C	27	31.4	41.8
22	8	03-May	D	28	32.2	42.9
23	8	11-May	D	29	32.6	43.4
23	8	19-May	D	28	32.2	42.9
25	8	27-May	D	28	31.6	42.1
Final	4	1 Jun.	D	10		
Total					637	850

Table C14
Optimal agricultural water requirements for irrigated crops under various agricultural patterns, Jericho District

Crop	ET crop (mm)	Net Gift (mm)	LR (fraction)	Gross Irrigation (mm)	Total Area (1000m^2)	Optimal Water Use (Mcm)	
						without LR	with LR
Eggplants	1148	1081	0.226	1862	1155	1.6647	2.1508
Squash	346	351	0.045	468	1860	0.8705	0.8705
Tomatoes	522	456	0.088	608	2680	1.6294	1.6294
Pumpkins	344	359	0	479	8	0.0038	0.0038
Cucumbers	254	230	0.088	307	1305	0.4006	0.4006
Beans	188	186	0.254	332	545	0.1352	0.1812
Yellow Beans	249	213	0.254	381	35	0.0099	0.0133
Corn	282	210	0.135	324	1125	0.3150	0.3642
Sweet pepper	641	563	0.156	889	73	0.0548	0.0649
Chili peppers	641	563	0.156	889	410	0.3078	0.3647
Cauliflower's	477	388	0	592	670	0.3966	0.3966
Cabbage	477	388	0.127	592	205	0.1059	0.1214
Onions (dry)	816	783	0.203	1310	205	0.2140	0.2685
Spinach	125	127	0.113	191	29	0.0049	0.0055
Anchusa	125	127	0.113	191	3	0.0005	0.0006
Garlic	816	783	0.073	1044	57	0.0595	0.0595
Artichokes	1722	1629	0	2172	4	0.0087	0.0087
Radishes	99	95	0.203	159	15	0.0019	0.0024
Broadbeans	177	135	0.145	211	235	0.0423	0.0495
Lettuce	195	138	0.185	226	29	0.0053	0.0065
Parsley	701	621	0	828	17	0.0141	0.0141
Cowpeas	235	188	0.185	308	3	0.0008	0.0009
Snake cucuml	254	230	0	307	26	0.0080	0.0080
Potatoes	310	281	0.135	433	454	0.1701	0.1966
Jew's Mallows	376	379	0	505	1423	0.7191	0.7191
Okra	532	514	0	685	11	0.0075	0.0075
Sub-total					**12582**	**7.1511**	**7.9090**
Wheat	755	671	0.035	895	655	0.5860	0.5862
Barley	341	259	0.026	345	410	0.1416	0.1416
Green Forage	1634	1556	0.113	2339	380	0.7884	0.8888
Sub-total					1445	1.5160	1.6166
Fruit trees							
Citrus	1492	1414	0.135	2180	1369	2.5810	2.9838
Bananas	1633	1530	0.254	2735	5600	11.4240	15.3137
Bananas	1450	1376	0.254	2458	5600	10.2685	13.7648
Date Palms	1548	1501	0.0543	2001	570	1.1408	1.1408
Olives	884	783	0.081	1044	39	0.0407	0.0407
Vines	1088	1117	0.156	1765	103	0.1534	0.1818
Loquats	939	855	0.081	1765	30	0.0342	0.0342
Sub-total					**13311**	**25.6427**	**33.4598**
Plastic Houses							
Cucumbers	591	637	0.088	850	9	0.0076	0.0077
Tomatoes	706	767	0.088	1022	10	0.0102	0.0102
Jew's mallows	177	201	0	268	6	0.0016	0.0016
Eggplants	810	862	0.226	1485	6	0.0069	0.0089
Green beans	352	375	0.254	627	9	0.0045	0.0056
Sub-total					**40**	**0.0308**	**0.0340**

Continue next page ....

Table C14 (cont.)

Crop	ET crop (mm)	Net Gift (mm)	LR (fraction)	Gross Irrigation (mm)	Total Area (1000m^2)	Optimal Water (Mcm) Use	
						witout LR	with LR
Low plastic Tunnels							
Squash	346	351	0.045	468	760	0.3557	0.3557
Tomatoes	522	456	0.088	608	322	0.1958	0.1958
Watermelons	741	696	0	928	750	0.6960	0.6960
Green beans	188	186	0.254	332	315	0.0781	0.1047
Eggplants	148	1081	0.226	1862	85	0.1225	0.1583
Chili peppers	641	563	0.156	890	45	0.0338	0.0401
Sweet pepper	641	563	0	890	80	0.0601	0.0601
Sweet melons	741	696	0	928	16	0.0148	0.0148
Cucumbers	254	230	0.088	307	12	0.0037	0.0037
Yellow beans	249	213	0	381	9	0.0026	0.0026
Sub-total					**2394**	**1.5632**	**1.6317**
High Plastic Tunnels							
Cucumbers	591	637	0.088	849	2	0.0017	0.0017
Sweet pepper	446	480	0.156	758	11	0.0070	0.0083
Chili peppers	446	480	0.156	758	9	0.0058	0.0068
Sub-total					**22**	**0.0145**	**0.0169**
Grand Total					**24194**	**35.8700**	**44.6800**

Table C 15

Optimal agricutural water requirements for irrigated crops under various agricultural patterns, Bethlehem District

Crop	ET crop (mm)	Net Gift (mm)	LR (fraction)	Gross Irrigation (mm)	Total Area (1000m^2)	Optimal Water (Mcm) Use	
						witout LR	with LR
Spinach	146	133	0.035	177	35	0.0060	0.0060
Turnips	79	17	0.082	23	80	0.0020	0.0020
Cauliflowers	423	154	0	205	65	0.0130	0.0130
Cabbage	423	154	0.039	205	102	0.0210	0.0210
Lettuce	163	87	0.055	116	30	0.0030	0.0030
Onions (dry)	674	532	0.06	709	68	0.0480	0.0480
Onions (green	163	80	0.06	107	38	0.0040	0.0040
Barley	791	691	0	921	22	0.0200	0.0200
Eggplants	1384	1278	0.066	1704	129	0.2200	0.2200
Cucumbers	518	458	0.028	611	56	0.0340	0.0340
Squash	444	406	0.015	541	22	0.0120	0.0120
Beans	302	250	0.073	333	95	0.0320	0.0320
Chili peppers	927	893	0.048	1191	6	0.0070	0.0070
Sweet Pepper	927	893	0.048	1191	9	0.0110	0.0110
Pumpkins	439	426	0	568	3	0.0020	0.0020
Radishes	66	38	0.06	51	47	0.0020	0.0020
Sub-total					**807**	**0.4370**	**0.4370**
Plastic Houses							
Cucumbers	903	975	0.028	1300	2	0.0030	0.0030
Tomatoes	1006	1104	0.028	1472	4	0.0060	0.0060
Green beans	710	746	0.073	995	1	0.0010	0.0010
Sub-total					**7**	**0.0010**	**0.0100**
Grand Total					**814**	**0.4470**	**0.4470**

Table C16

Livestock water consumption (m^3/y)

District	Cows		Steers		Goats		Chicken-Broiler		Chicken-Layer		Total water consumption m^3/y
	Number	Quantity	Number	Quantity	Number	Quantity	Number	Quantity	Number	Quantity	
Hebron	1008	20160	440	4400	280500	1402500	6937875	624409	345000	34500	2085969
Bethlehem	328	6560	440	4400	76500	382500	991125	89201	22500	2250	484911
Jenin	1944	38880	1120	11200	153000	765000	6387250	574853	135000	13500	1403433
Tulkarem	1048	20960	480	4800	25500	127500	1762000	158580	540000	54000	365840
Nablus	3000	60000	880	8800	153000	765000	2092375	188314	90000	9000	1031114
Rammallah	336	6720	360	3600	127500	637500	3303750	297338	360000	36000	981158
Jericho	304	6080	280	2800	34000	170000	550625	49556	7500	750	229186
Total	7968	159360	4000	40000	850000	4250000	22025000	1982250	1500000	150000	6581610

Source: Ministry of Agricultural

The per animal water consumption (m^3/y) is as follows:

Type	Cows	Goats	Steers	'Chicken-Broiler	Chicken-Layer
Per animal water consumpti	20	5	10	90 per 1000	101 per 1000

Table C 17

Output of GAMS Software for Bethlehem District (Optimal Production)

Crop	ET crop (mm)	Gross Irrigation (mm)	Total Area ($1000m^2$)	Costs ($\$/1000m^2$)	Production (ton)
Beans	302	333	95	252	75.6
Cabbage	423	205	102	231	204
Cauliflowers	423	205	65	231	103
Cucumbers	518	611	56	294	89.6
Eggplants	1384	1704	129	294	129
Lettuce	163	116	30	224	45
Onions (dry)	674	709	68	210	57
Pumpkins	439	568	3	224	6
Spinach	146	177	35	189	70
Squash	444	541	22	273	35
Plastic Houses					
Cucumbers	903	1300	2	1372	16
Tomatoes	1006	1472	4	1407	48
Green beans	710	995	1	868	1.5

ANNEX D

Major Options for Closing Supply-Demand Gap

Options can be viewed as components or building blocks of scenarios. They can be combined or assembled in different ways to form individual and distinct scenarios for the development and management of water resources. This Annex provides a brief description of each of 20 major options that are being considered for closing supply-demand gap.

OPTION NO. 1

DEVELOPMENT OF LOCAL GROUNDWATER SOURCES

CONCEPT: The total potential renewable groundwater resource in the West Bank is 601Mcm/yr and 78 Mcm/yr of brackish water for further development.

TECHNOLOGY/IMPLEMENTATION: The technology for groundwater extraction is readily available.

COSTS: The unit production cost of local groundwater in the West Bank ranges between $ 0.25 and $0.30/m^3. Financing, distribution, and treatment would increase these costs (WESC 1996).

SOURCE WATER: From the point of view of hydrologic uncertainty, the availability of the resource is reasonably well known and dependable. Production can be sustained up to the total renewable capacities of the aquifers.

POLITICAL: The Palestinian share of the groundwater resources in the West Bank in not yet defined. Therefore, the extent to which the Palestinians may develop these resources in the future is a function of the Final Status Negotiations. Utilisation of groundwater resources would provide Palestinians with a high degree of independence in the control of their water resources.

INSTITUTIONAL: Management institutions necessary for effective utilisation of groundwater resources would not have any out-of-the ordinary or exceptional staffing, training, or manpower requirements.

ENVIRONMENTAL: The development of conventional water sources must take into account the sustainability of these resources. Groundwater development must be performed so that safe yield of aquifers in not exceeded.

SOCIAL: Public acceptance of the use of additional groundwater supplies would be limited only by the price charged to water users.

OPTION NO. 2

DEVELOPMENT OF LOCAL SURFACE WATER RESOURCES

CONCEPT: The only major surface water source in the region is the Jordan River. However, the Palestinian share of the Jordan River is yet to be defined.

TECHNOLOGY/IMPLEMENTATION: The technology for diversion, storage, and conveyance of surface water is well known, relatively easily constructed, and readily available.

COSTS: Costs for surface water exploitation would be highly variable, depending on the specific water resource and the types and capacities of the storage and conveyance systems involved.

SOURCE WATER: If Palestinian entitlements to the Jordan River and other surface sources could be recognised, and if appropriate storage and conveyance structures could be built, the hydrologic certainty of the source could be maximised.

POLITICAl: The extent to which these resources many be developed by the Palestinians in the future is a function of both the Final Status Negotiations and the negotiation of further agreements with the other Jordan Basin nations. Utilisation of local surface waters would provide Palestinians with a high degree of independence in the control of their water supplies.

INSTITUTIONAL: Management institutions necessary for effective utilisation of surface water resources would not have out-of-the-ordinary or exceptional staffing.

ENVIRONMENTAL: Surface water development might have some impact on aquatic habitats in the Jordan Basin, and might also influence the hydrologic budget of the Dead Sea.

SOCIAL: Public acceptance of the use of additional groundwater supplies would be limited only by the price charged to water users.

OPTION NO. 3

DESALINATION OF SEA WATER

CONCEPT: Desalination of seawater is a proven technology that has the potential to supply unlimited quantities of high-quality fresh water. The principal drawback to desalination is its high cost. Desalination of seawater has been used for decades to augment water supplies in areas where fresh water in limited. Large-scale commercial plants normally operate in the 20,000 to 40,000 m^3 /day range (Hoffman 1992).

TECHNOLOGY/IMPLEMENTATION: The technologies exist for large-scale desalination of sea water, and ongoing research into improving these technologies will lead to lower production costs in the future.

COSTS: The cost of desalinated water ranges widely, depending on the quality of the source water, the type of technology used in the desalination process, and the cost of energy. The cost of desalinated seawater may reach \$0.6-\$0.8/m^3 (Hoffman 1992).

SOURCE WATER: Use of seawater for desalination would provide an unlimited supply of very high quality water.

POLITICAL: This aspect of the technology minimises the need for international agreements and co-operation and thereby reduces the uncertainty of ability of the technology to deliver fresh water. Desalination of seawater would provide near total control over the water source with virtually no reason for international opposition.

INSTITUTIONAL: Additional capabilities would have to be provided within Palestinian water supply institutions for the operation and maintenance of desalination plants.

ENVIRONMENTAL: If natural currents did not dilute brine concentrations, there could be adverse effects to sea life in the area.

SOCIAL: The principal drawback to the wide scale use of desalination is its cost. The price of water might be unacceptable to the general public.

Option No. 4

Desalination of Brackish Water

Concept: Desalination of brackish water can be done with the same technologies as those used for seawater.

Technology/Implementation: Desalination technologies appropriate for brackish water is well understood and readily available.

Costs: In comparison to desalination of seawater, utilising brackish water as the source reduces costs dramatically. For a 20000 m^3/day by reverse osmosis plant, the unit cost of brackish water desalination is between $0.3 and $0.4/$m^3$ (Hoffman 1992).

Sources of Water: Use of brackish water for desalination would be limited only by the quantity of water available. The location and magnitudes of such waters in the West Bank are relatively well known.

Political: Brackish water desalination plants would give near total control of the resource to the Palestinian Water Authority and local water managers. This aspect would minimise the need for international agreements and cooperation. The only constraining factors on this use of the resource would be the renewable capacity of the resource and other potential hydrologic limitations if the brackish supply is hydraulically connected to a freshwater resource.

Institutional: Additional capabilities would have to be provided within Palestinian water supply institutions for the operation and maintenance of desalination facilities.

Environmental: Disposal of the brine waste stream produced by a desalination plant would be the major environmental issue to address. The brine would have to be properly handled to ensure that freshwater aquifers would not be polluted and that the brine would not otherwise harm the environment.

Social: The principal drawback to the wide scale use of desalination is its cost

OPTION NO. 5

WASTEWATER REUSE

CONCEPT: The collection, treatment, storage, and reuse of wastewater for suitable purposes in the West Bank represents a potential "new" source of water as well as improving public health conditions.

TECHNOLOGY/IMPLEMENTATION: Technology for the collection and treatment of domestic and industrial wastewater is readily available.

COSTS: The treatment of domestic sewage ranges in cost from \$0.15 to \$0.25/m^3 for large wastewater stabilisation ponds and similar systems to about \$1.00 to \$1.4/m^3 for more sophisticated tertiary treatment technologies (CDM 1997).

SOURCE WATER: There would be minimal uncertainty relative to the quantity and quality of the source water.

POLITICAL: The reuse of domestic wastewater is generally within the domain of a single urban jurisdiction. Reuse of treated wastewater could potentially minimise reliance on imports from other countries.

INSTITUTIONAL: Additional capabilities would have to be developed within Palestinian water supply and wastewater treatment institutions for the operation and maintenance of wastewater collection and treatment facilities. Water quality standards will have to be set, and programs of monitoring and control would have to be established.

ENVIRONMENTAL: Treatment of wastewater has beneficial impacts on public health and economy of a region.

SOCIAL: Social acceptance of the use of treated wastewater would be limited by the cost to the user (relative to other available water sources) and traditional culture norms regarding the handling of human wastes.

OPTION NO. 6

INTENSIVE WATERSHED MANAGEMENT

CONCEPT: In locations where the hydrologic and geologic conditions are appropriate, it is possible to harvest rainfall and store it in surface reservoirs, or increase groundwater storage and recharge through a variety of mechanisms. These range from roof collection systems with storage in cisterns, to artificial recharge of groundwater.

TECHNOLOGY/IMPLEMENTATION: The technology for these systems is generally very simple and readily available.

COSTS: Costs of these technologies are highly variable and dependent upon local conditions. Water harvested from greenhouse roofs in the West Bank has been estimated to cost about \$ 0.15/m^3 (Alhmaidi 1992).

SOURCE WATER: Runoff from high precipitation events would be the primary source of water. This, of course, is subject to the hydrologic uncertainties of weather.

POLITICAL: Local watershed and groundwater management techniques will generally have no international implications. Exceptions to this might involve internationally shared water resources. For example, artificial recharge of an aquifer that is shared by two or more political entities would be of concern to all parties.

INSTITUTIONAL: Institutions for providing financial and technical assistance in establishing and managing different types of facilities might also be necessary.

ENVIRONMENTAL: The environmental impacts of these systems are quite limited, and generally associated with local modifications in the hydrologic cycle.

SOCIAL: Since the bulk of construction, maintenance, and management activities for these facilities would be done locally, there should be wide social support for their implementation, provided, of course, that the cost of water to the user is not prohibitive.

OPTION NO. 7

CLOUD SEEDING

CONCEPT: The main purposes of cloud seeding would be to increase the quantity of water available to rain-fed agriculture. Additional benefits might be realised if intensive watershed management and storm water harvesting methods were also employed. Cloud seeding is accomplished by introducing a chemical ice-nucleating agent (as silver iodide agent) into a cloud system by ground-based generators or airborne systems.

TECHNOLOGY / IMPLEMENTATION: Cloud seeding technology is well understood, but it is a sophisticated method requiring a well-established scientific management organisation. Even with this, the results of cloud seeding are highly unpredictable.

COSTS: The cost of additional water provided by cloud seeding has been estimated at \$0.02 to \$0.05/m^3 (Tahboub 1992).

SOURCE WATER: The availability of the source water is dependent upon the weather and is therefore hydologically uncertain.

POLITICAL: If carefully done on a local scale, cloud seeding would have minimal geopolitical implications. Within the West Bank, however, it would be very difficult to operate an effective cloud seeding program without full participation of the Israeli government.

INSTITUTIONAL: Use of cloud seeding methodology would require a sophisticated technical and scientific institution.

ENVIRONMENTAL: Even with extensive studies conducted in the United States, no negative environmental impacts have been reported from cloud seeding.

SOCIAL: There should be no problem with social acceptance of the technology.

Option No. 8

Peace Pipeline

Concept: The "Peace Pipeline" is one of several proposed import schemes that would take advantage of Turkey's current water surplus. The concept of the Peace Pipeline is to transfer water from Turkey along the Mediterranean coast to Mecca (Wachtel 1992).

Technology / Implementation: The technology to implement the project exists and is well known. Construction could probably be completed in 7 to 10 years.

Costs: The total cost of the Peace Pipeline was estimated to be about US $21 billion. The average cost of water delivered to user countries would be about $\$0.84/m^3$.

Source Water: The long-tem availability of the source water would be subject to arrangements made with the Turkish government.

Political: Construction of the pipelines would require political and financial agreements among as many as ten countries. Given the existing friction between Syria and Turkey regarding Euphrates River water, as well as long-standing water resources disputes among other countries in the region over other shared water resources, the potential international political difficulties to be surmounted by any plan that includes the Peace Pipeline are very substantial.

Institutional: Palestinians would have to participate in the creation and operation of international institutions that would be required for operation and maintenance.

Environmental: Transporting and introducing large and small organisms from one basin into another could have impacts on the environment.

Social: The main problem associated with local acceptance of this scheme would be related to the cost of water to the user.

OPTION NO. 9

MINI PEACE PIPELINE

CONCEPT: The "mini-pipeline" would convey approximately 600 Mcm/yr from the Ceyhan and Seyhan Rivers in Turkey through Syria to Jordan, terminating near Amman. The quantities of water that could be made available for Palestinian use from this scheme have not been estimated (Gruen 1992).

TECHNOLOGY/IMPLEMENTATION: The technology to implement the project exists and is well known.

COSTS: No cost estimates are available for the Mini Peace Pipeline, except as an extrapolation of those for the Peace Pipeline. This would imply an approximate average cost of about $0.84/m^3$ (Kally 1992).

SOURCE WATER: Characteristics and concerns regarding the long-term availability and quality of the source water would be the same as those of the Peace Pipeline.

POLITICAL: Regional political concerns are similar to those of the Peace Pipeline.

INSTITUTIONAL: Institutional issues that would have to be resolved would be the same as those for the Peace Pipeline.

ENVIRONMENTAL: The potential environmental impacts for the Mini Peace Pipeline would be similar to those for the Peace Pipeline, though on a smaller scale.

SOCIAL: The main problem associated with local acceptance of this scheme would be related to the cost of water to the user.

Option No. 10

Peace Canal

Concept: This scheme would import water from Turkey from the Euphrates River. Water would be diverted from Lake Ataturk through a tunnel through the mountains southwest of the lake. Pipelines would be constructed south through Syria to the Golan Heights. At the Syrian-Israeli border, the pipelines would terminate, and an open canal would then convey the water for 60 km across the Golan Heights. The canal would branch in the southern of the Golan, with one branch feeding a smaller canal to the Yarmouk River. The project would make available approximately 1,100 Mcm/yr to Syria, Jordan, Israel, and the West Bank (Gruen 1992).

Technology/Implementation: The technology to implement the project exists and is well known.

Costs: Preliminary estimates of the construction cost of the Peace Canal range between US$5 and US$7 billion.

Source Water: Characteristics and concerns regarding the long-term availability and quality of the source water would be similar to those of the Peace Pipeline.

Political: The regional political considerations of the Peace Canal would be very similar to those of the Peace Pipeline.

Institutional: Institutional issues that would have to be resolved would be the same as those for the Peace Pipeline.

Environmental: Though no specific information is available, the potential environmental impacts for the Peace Canal would be similar to the Peace Pipeline, but on a smaller scale.

Social: The main problem associated with local acceptance of this scheme would be related to the cost of water to the user.

OPTION NO. 11

MEDUSA BAGS

CONCEPT: The bags would be capable of transporting 1.5 Mcm at a time, towed by a tug at a speed of about two knots. The most seriously studied plan for this scheme would derive the source water from the Manav Gat River in Turkey and deliver water to southern Israel. Alternatively, water could be unloaded at the Gaza Strip. This scheme could deliver 250 Mcm/yr to southern Israel and West Bank (Gruen 1992).

TECHNOLOGY/IMPLEMENTATION: This scheme is still in the pre-feasibility stage and many technical problems remain to be solved. Estimates of costs and technical capabilities are therefore uncertain at this time.

COSTS: The cost of water would be about $0.20/m^3. These cost estimates do not include the purchase price at the source.

SOURCE WATER: The scheme could deliver a variable quantity of water, depending upon the capacity of facilities, the number of Medusa Bags developed, and the availability of water from the source river.

POLITICAL: The international political considerations associated with Medusa Bags scheme would be relatively minor.

INSTITUTIONAL: Institutions would have to be created to maintain and operate loading and unloading facilities at the necessary Mediterranean ports.

ENVIRONMENTAL: Impacts associated with the Medusa Bag scheme include environmental and public health implications of transporting and introducing large and small organisms from one basin into another and disturbance during construction of port and related facilities.

SOCIAL: There should be no difficulties with social acceptance of this water source, provided its costs remain within the users' ability to pay.

OPTION NO. 12

LITANI-TO-HASBANI TRANSFER

CONCEPT: The Litani River in Lebanon is not fully utilised, and Lebanon has no foreseeable water shortage. At one point the Latani is approximately eight kilometres from the Hasbani River, a tributary and of the Jordan River.

TECHNOLOGY/IMPLEMENTATION: The technology to implement the project exists. A construction time of three to five years would be reasonable.

COSTS: The total cost of the project is estimated at about US$24 million. The average cost of water delivered is estimated to be about $0.14/m^3$ (CDM 1997).

SOURCE OF WATER: High annual variation in stream flow in the Litani might preclude diversions to the Hasbani in dry seasons, thus making the availability of water unpredictable under this project and therefore less acceptable.

POLITICAL: The scheme would require co-operation of Lebanon, Israel, Jordan, and the Palestinians. Because of the political relationship between Lebanon and Syria, Syrian interests would also have to be addressed.

INSTITUTIONAL: Apart from limited additional requirements for operation and maintenance requirements for the import structures, no substantial new institutional capabilities would be required for this scheme.

ENVIRONMENTAL: Little information on environmental impacts is available.

SOCIAL: This scheme would have social acceptance limitations similar to that of the Peace Pipeline. The main potential problem would be related to the cost of water to the user.

OPTION NO. 13

RED SEA-DEAD SEA DESALINATION

CONCEPT: There is approximately a 400 m difference in the elevations of the Red Sea and Dead Sea, and it is technologically feasible to exploit the elevation difference to produce hydropower by making water flow from the Red Sea to the Dead Sea. The power could be used in any manner, including desalination of seawater.

TECHNOLOGY/IMPLEMENTATION: The technology to implement this scheme exists. Implementation would require approximately seven years.

COST: Cost estimates for the Red-Dead proposal is highly variable and depend upon assumptions regarding the capacity of the project and types of desalination technologies employed. It is estimated that such a scheme would product approximately 100 Mcm/yr at a unit cost of approximately \$0.63 to \$0.69/m^3.

SOURCE WATER: The supply of source water would be very certain, as would its long-term quantity and quality sustainability.

POLITICAL: Such a project would require cooperation among Jordan, Israel, and the Palestinians.

INSTITUTIONAL: Since the actual operation of the Red-Dead diversion, hydropower, and desalination facilities would probably be in the hands of Jordanian or Israeli agencies, this proposal would require relatively little expansion of the capabilities of the Palestinian water institutions.

ENVIRONMENTAL: The diversion of a significant amount of sea water from the Red Sea would lower the mineral concentration of the Dead Sea which, in turn, might have impacts on the economics of the existing mineral industries in the Dead Sea region.

SOCIAL: The most probable constraints on the social acceptance of this scheme would be the cost of water to the user, which is likely to be quite high.

OPTION NO. 14

MEDITERRANEAN SEA-DEAD SEA DESALINATION

CONCEPT: The Mediterranean Sea-Dead Sea scheme is similar in concept to the Red Sea-Dead Sea proposal (Gross and Zahazi 1985).

TECHNOLOGY/IMPLEMENTATION: The technology to implement this scheme is exists.

COSTS: Construction costs for a pure, Med-Dead hydropower scheme have been estimated at approximately US$ 1.4 billion. Estimates of annual costs are not available. The unit cost for desalinated water of $0.83 to $0.89/m^3 (CDM 1997).

SOURCE WATER: The supply of source water would be very certain, as would its long-term quantity and quality sustainability.

POLITICAL: The project would be wholly constructed in Israel, except for an initial link to the Dead Sea across the Gaza Strip. The project would require cooperation among Jordan, Israel, and the Palestinians. As with the "Red-Dead" option, industrial and tourist developments on both shores of the Dead Sea could be impacted.

INSTITUTIONAL: While the diversion facilities might be under Palestinian control, it is likely that most of the actual operation of the Med-Dead hydropower and desalination facilities would be the responsibility of Israeli and Jordanian agencies. Therefore, this proposal would require relatively little expansion of the capabilities of Palestinian water institutions.

ENVIRONMENTAL: Several environmental questions have been raised relative to this scheme. Diluting the salinity of the Dead Sea may affect mineral extraction works industries in both Israel and Jordan and raising the level of the Dead Sea might affect the location of resort areas which have been developed on both shores.

SOCIAL: The most probably constraint on the social acceptance of this scheme would be the cost of water to the user, which is likely to be quite high.

OPTION NO. 15

WATER CONSERVATION –MUNICIPAL SECTOR

CONCEPT: In the domestic sector, significant gains can be achieved from the use of simple technologies and minor changes in habits that affect how people use water. Low-flow faucets, showerheads, and toilets can be installed at relatively small costs (Hills 1995; Laohasiripanya 1996; Hodges 1998).

TECHNOLOGY /IMPLEMENTATION: The water conservation technology for domestic and commercial uses is readily implemented.

COSTS: Costs of water conservation technologies are variable, but generally low. Typically, water-conserving fixtures appropriate for domestic applications cost little more than regular fixtures.

SOURCE WATER: Water conservation measures provide direct savings of local water. The amount of such savings depends upon the extent of the conservation measures put into place.

POLITICAL: There should be no political implications associated with domestic, commercial and industrial conservation. Significant water conservation measures would also place more control over the remaining water resources into the hands of local utilities.

INSTITUTIONAL: Effective water conservation measures would require Palestinian agencies to adopt and enforce policies to encourage the installation of new fixtures.

ENVIRONMENTAL: No significant environment consequences would result from use of water conservation methods

SOCIAL: Water conservation would require that the general populace be made more aware of how water is used and more willing to participate in conservation measures and activities. Generally, these things should not meet with social resistance.

OPTION NO. 16

WATER CONSERVATION – IRRIGATED AGRICULTURE SECTOR

CONCEPT: Improvements at the farm level are possible through changes in irrigation technologies. It is also possible to achieve a reduction in agricultural water use through shifts in crop types.

TECHNOLOGY/IMPLEMENTATION: The technology for implementing on farm conservation and water savings policies is well understood and readily available.

COSTS: The capital outlay for these approaches is significant, ranging from US$ 1500 to US$3000 per hectare or higher, depending on the type of crop and production technology.

SOURCE WATER: Water conservation measures provide a direct saving of local water. The amount of such savings depends upon the extent of the conservation measures put into place.

POLITICAL: There should be no political implications associated with domestic, commercial and industrial conservation.

INSTITUTIONAL: A significant effort will be required on the part of Palestinian water management institutions to get farmers to convert their present irrigation practices to more efficient systems. Economic incentives might be required, and training programs in the installation and operation of new technologies would be necessary.

ENVIRONMENTAL: One potential environmental impacts associated with improvements in on-farm efficiencies would be a reduction in percolation of irrigation waters into aquifers and a reduction of return flows to stream channels.

SOCIAL: There might be resistance among the farming community to adopt new irrigation techniques, especially if there is no direct net benefit to the farmers involved.

OPTION NO. 17

SUPPLY SYSTEM IMPROVEMENTS- MUNICIPAL SECTOR

CONCEPT: Across all water-using sectors, substantial water savings can be achieved by improvements in the maintenance, operation, and management of conveyance and distribution systems.

TECHNOLOGY/IMPLEMENTATION: The technology for the detection of leaks, repair of aging pipelines, and management of supply systems to detect and eliminate illegal hookups is readily available and inexpensive.

COSTS: Costs are variable and depend upon the extent of repairs require to fix leakage.

SOURCE WATER: In a manner similar to water conservation measures, supply system improvements provide direct savings of local water. The amount of such savings depends upon the extent of the measures put into place.

POLITICAL: No political implications would be expected from supply system improvements. Significant water savings achieved through system improvements would place more control over the remaining water resources into the hands of local utilities.

INSTITUTIONAL: To enact effective programs for achieving significant water savings through system improvements, Palestinian utilities and water management agencies must be equipped with appropriate technology, trained in its use, and must have the financial resources to implement necessary and periodic repairs throughout the supply system.

ENVIRONMENTAL: No significant environmental consequences would result from water system improvements and intensive management.

SOCIAL: There may be local resistance to termination of illegal hookups.

OPTION NO. 18

SUPPLY SYSTEM IMPROVEMENT— IRRIGATED AGRICULTURE SECTOR

CONCEPT: In irrigation sector, losses from storage and conveyance systems can be very large. Even if on-farm water efficiencies are very high, conveyance system losses can reduce overall system efficiencies to less than 50 percent. Lining of canals and can significantly reduce system losses.

TECHNOLOGY/IMPLEMENTATION: The technologies for irrigation sector system improvements are well known and readily available.

COSTS: Costs are variable and dependent upon local conditions and types of approaches used.

SOURCE WATER: Supply system improvements provide direct savings of local water. The amount of such savings depends upon the extent of the measures put into place.

POLITICAL: No political implications would be expected from supply system improvements.

INSTITUTIONAL: Effective programs for achieving water savings through irrigation distribution system improvements will require than Palestinian water management agencies have the financial resources to construct new conveyance systems, and implement necessary and periodic repairs throughout the supply system.

ENVIRONMENTAL: Aside from possible changes in quantities of water lost from canals into the groundwater systems, no significant environmental consequences would result from water system improvements.

SOCIAL: There may be local resistance to irrigation sector system improvements depending upon how the costs of such interventions are shared.

OPTION NO. 19

INTERSECTORAL REALLOCATION

CONCEPT: Efficient use of water in arid regions where water shortages are chronic is best achieved when market mechanisms are in place that provide the capability for water to move from one sector to another, depending on where water is most valuable. The market is used to enable water to move from relatively low-valued uses (such as irrigation) to higher-valued uses (such as domestic or industrial supply).

TECHNOLOGY/IMPLEMENTATION: Intersectoral water reallocation requires little in the way of technology. Instead, it requires development of political, managerial, and economic institutions to allow it to happen.

COSTS: Costs associated with efficient water reallocation are minimal and borne by the parties engaged in the transfer.

SOURCE WATER: Intersectoral reallocation promotes efficiency in the water sector and, to an extent, would have the same source water implications as water conservation programs.

POLITICAL: No political implications would be expected from intersectoral reallocation as long as the resulting changes in water use had no downstream implications for other users.

INSTITUTIONAL: New institutions and capabilities would have to be created in the Palestinian water sector to manage market-based intersectoral water transfers.

SOCIAL: Creation of the institutional capability to foster intersectoral reallocation of water resources would probably be met with some resistance from various group, especially those who felt that their traditional water rights might be threatened by such policies and markets.

OPTION NO. 20

WATER PRICING

CONCEPT: The consensus among experts is that price mechanisms play a central role in managing demand.

TECHNOLOGY/IMPLEMENTATION: Water pricing requires little in the way of technology.

COSTS: Costs associated with water pricing programs are variable and chiefly related to the installation and periodic reading of meters, and the management of a billing and fee collection system.

SOURCE WATER: Effective water pricing results in water conservation and, as a result, has the same source water implications as water conservation programs.

POLITICAL: No significant political implications would arise from water pricing programs. Water pricing is instituted to encourage efficiency in water use, and hence reduce pressures on major sources. It therefore increases flexibility in local control of the water source.

INSTITUTIONAL: Water pricing requires development of political, management, and fiscal institutions to allow it to happen. Policies regarding the establishment of water rates for different users would be required, and mechanisms for public review and input to decisions on rate changes would have to be put in place. Timely and accurate programs for metering and billing would have to be established in water utilities.

ENVIRONMENTAL: No significant environmental impacts would be expected from water pricing programs beyond conservation of the resource.

SOCIAL: There would be resistance to implementation of pricing policies to achieve conservation aims, especially in the agricultural sector wherein the most significant gains could be obtained.