# Key points about drainage

- The objective of drainage improvements is to contain and limit flooding so that it causes minimal damage and disruption.

- The raising of road surfaces above the plinth levels of nearby houses should always be avoided.

- Where off site drainage systems are inadequate, try to develop drainage schemes which retain water locally in order to reduce the rate of runoff.

- Wherever possible, design streets to act as drains. In general, the run-off from areas up to about 5 hectares in area can be carried on the street surface where the annual rainfall is in the range 500-1000 mm/yr.

- Drainage schemes in informal areas should normally be designed for a return period of 1 year or less. In the absence of local information, a rainfall intensity in the range 50-100mm per hour can be assumed.

- Both open and covered drains give rise to maintenance problems and their total length should be minimised.

- Unlined ditches have limited uses in upgrading schemes because of their need for constant maintenance.

- Covered drains should not be smaller than about 500mm square in cross-section.

# Section 4a

# Drainage

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## Tool D1 Drainage: Objectives and options

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## Objectives

The objective of drainage is to remove unwanted water from the neighbourhood in a controlled and hygienic manner in order to minimise public health hazards, inconvenience to residents and the deterioration of other infrastructure. This requires:

- the removal of sullage, that is, household wastewater which has been used for washing, cooking or cleaning purposes but which does not contain excreta; and
- the removal of surface water, that is, water which runs off the land and buildings as a result of rainfall.

More specifically, we need to consider:

- minimising the incidence of flooding of houses;
- preventing erosion and the consequent risk of damage to property;
- eliminating standing water and the consequent danger from mosquito-carried diseases; and
- reducing the extent and duration of flooding of streets and rights of way to acceptable levels.

It is necessary to define what constitutes acceptable levels of flooding. Ideally, the drainage system should prevent flooding completely in all but the most severe storms. However, this ideal will be unattainable in many informal areas. In general, some flooding of streets and public spaces can be tolerated if:

- the flooding does not prevent movement of pedestrians and vehicles;
- flood levels are below most house plinth and yard levels;
- the flooding clears quickly, say within 30 minutes of the ending of heavy rainfall; and
- the flood water does not include sewage.

## Sullage drainage systems

The problems resulting from inadequate disposal of sullage tend to be indirect, rather than due to the actual quality of the wastewater itself, although there is likely to be a significant amount of organic matter in water which has been used for food preparation and cleaning cooking utensils. Pools of sullage become breeding grounds for flies; a generally insanitary environment results, in which certain pathogens, such as worm eggs, can survive.

The quantity of sullage generated varies with the quantity of water supplied and local bathing practices; between 50 and 80% of the water supplied may end up as sullage. The provision of individual household water connections significantly increases the volume of sullage to be disposed of. The use of large quantities of water for bathing at communal standposts or wells can create highly insanitary conditions if the drainage is inadequate.

There are three options available for the disposal of sullage:

- on-plot;
- surface water drains; and
- sewerage.

### On-plot disposal

On-plot disposal of sullage can be through garden watering, or by allowing percolation through the soil by means of a soakage pit. Key factors are the quantity of sullage, the plot size, and the permeability of the ground. Garden watering is only appropriate if plots are large. If the ground is very sandy and highly permeable, it may be feasible to dispose of household sullage into a

Figure D1. Soakage pit (after Indian Standards Institution)
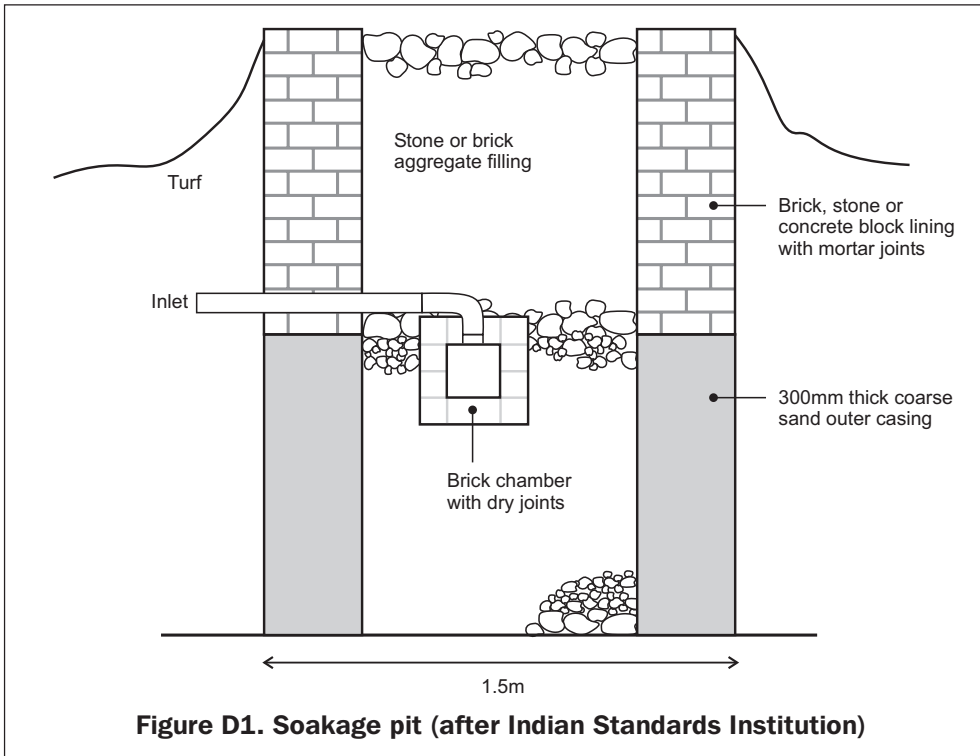
soakage pit; such a pit could handle the sullage arising from a household of about six people having a per capita water supply of approximately 40 litres per day. An example is shown in Figure D1. If the ground is only slightly permeable, or is waterlogged during the wet season, soakage pits will not work. On-plot disposal may be feasible where water is being fetched from a public water supply point. However, where the houses have individual water connections it is unlikely to be appropriate unless the ground is very permeable or the plots are very large.

## Surface water drains

It is very common for sullage to be disposed of to surface water drains; however, there is a health risk associated with this as sullage often contains high numbers of disease-causing organisms. The surface water drains must satisfactorily carry:

■ the high flows resulting from intense rainfall; and

■ very low flows of sullage at a velocity sufficiently high to prevent deposition of solids.

## Sewerage

If a sewerage system exists, sullage should be discharged into it. This is probably the most convenient option for the householders and generally creates the least problems on the site as a whole, although it is likely to be expensive.

# Surface water drainage systems

There are several different approaches to the design of a surface water drainage system:

- rapid removal of surface water using a network of open channels, or occasionally buried pipelines;
- storage on site; and
- temporary retention.

## Rapid removal

This is by far the most common method; the surface runoff resulting from a particular rainfall event is calculated and the drains are designed to be able to carry this flow away from the site as rapidly as possible. The main problems with this approach are:

- it depends upon the existence of an adequate secondary drainage system, off-site;
- it requires a high degree of coordination and planning to ensure compatibility with the secondary system, particularly if community action is envisaged; and
- maintenance is a problem and blockages can cause the system to cease to function.

## Storage on site

Storage on site holds water and allows it to percolate away through soakaways or evaporate from holding areas after a storm. Whilst it is not dependent on off-site facilities it has the following serious limitations:

- systems will not deal with more than one storm in quick succession;
- they are not suitable if combined sullage and surface water flows exist;
- the capacity of the system reduces with time as the surfaces clog with silt; and
- land is required for holding areas.

## Temporary retention

Temporary retention allows some water to be held and allows the remainder to drain away in a controlled manner. The advantage is that the storage reduces the magnitude of the peak flows and therefore the capacity of the off-site drainage system is less critical. The main drawback is that land is required for the storage.

Storage on site is unlikely to be feasible in most circumstances; the possibility of temporary retention in conjunction with removal by surface water drains is attractive and should be investigated.


# Removal of surface water

## The total system

The drainage problems of a small area cannot be solved in isolation. As with sewerage there is an important hierarchy in drainage systems:

- *Tertiary drains* are those drains at the neighbourhood level which collect and deliver drained water to one or more outfall points at the site boundary, as shown in Figure D2.
- *Secondary drains* running past the site into which the tertiary site drains discharge.
- *Primary drains* such as a large drainage canal, stream or river into which the secondary drains discharge.

There are two main causes of flooding by stormwater:

- inundation from a surrounding area, for example from a river or canal which is flowing at an abnormally high level; and
- inability of the drainage system to remove the required quantity of stormwater resulting from intense rainfall.

It is important to realise that the drainage problem does not end once a drainage network has been designed for the site in question. The drainage water which has been collected from the site discharges into a nearby secondary drain; if this has insufficient capacity to cope with the additional flows, its water level rises, and water cannot escape from the site drains. Flooding occurs on the site, and the fundamental problem has not been solved. Consideration must always be given to that part of the main drainage system which is 'downstream' of the outfall point of the site drains.

| | |
|---|---|
| ▢ | Site |
| → | Tertiary drains |
| ➡ | Secondary drain |
| o | 'Outfall' of the site drainage |
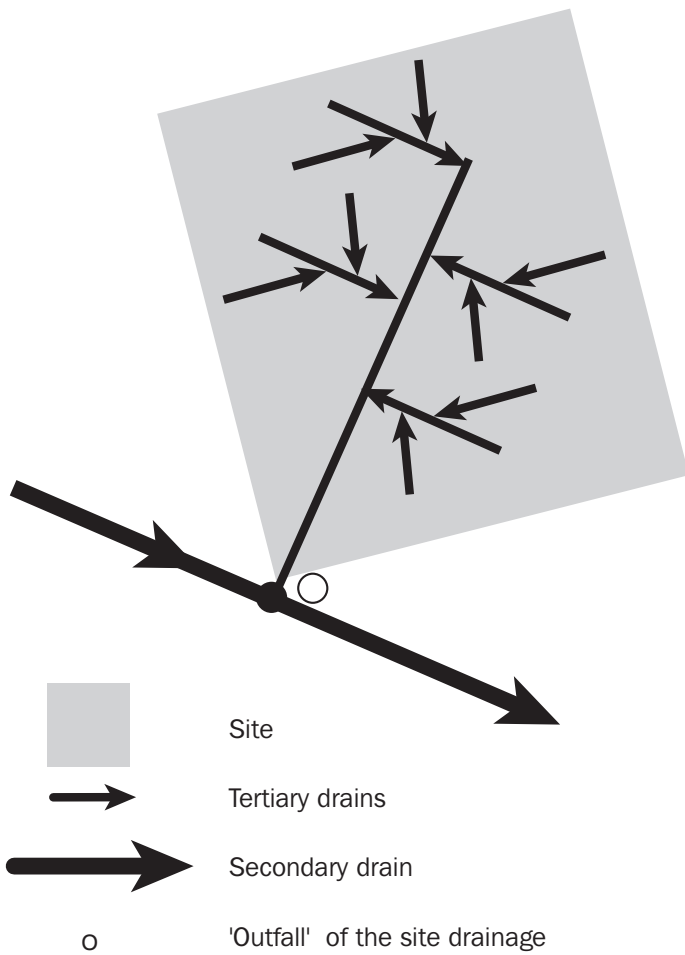
**Figure D2. Site drainage outfall**

*Open channel drainage networks* are relatively simple to construct and maintain. They occupy space and pose a hazard to road users, especially if the drain is very wide or deep, or passes along a busy thoroughfare. In such cases the drains can be covered with removable slabs.

*Road-as-drain*. In some densely populated settlements, paved roadways and alleys are used to carry stormwater short distances to drainage channels; that is, water is deliberately allowed to flow along the paved surface and there are no channels alongside (see Figure D3). This works where the surfaces are fully paved and well maintained and is only applicable if adequate sullage disposal facilities exist. It is cost effective and is recommended wherever possible.

*Buried pipeline* systems have regularly spaced inlets or 'gullies' along the roadside, through which surface water enters the drains. This option, which is commonly used in many western towns and cities, requires the roads to be constructed and surfaced to a high standard. Serious problems arise if the pipelines become blocked.

*Difficult Situations*. The principal problems in the design and implementation of drainage relate to the slope of the ground. Difficulties are encountered on ground which is either flat or excessively steep.
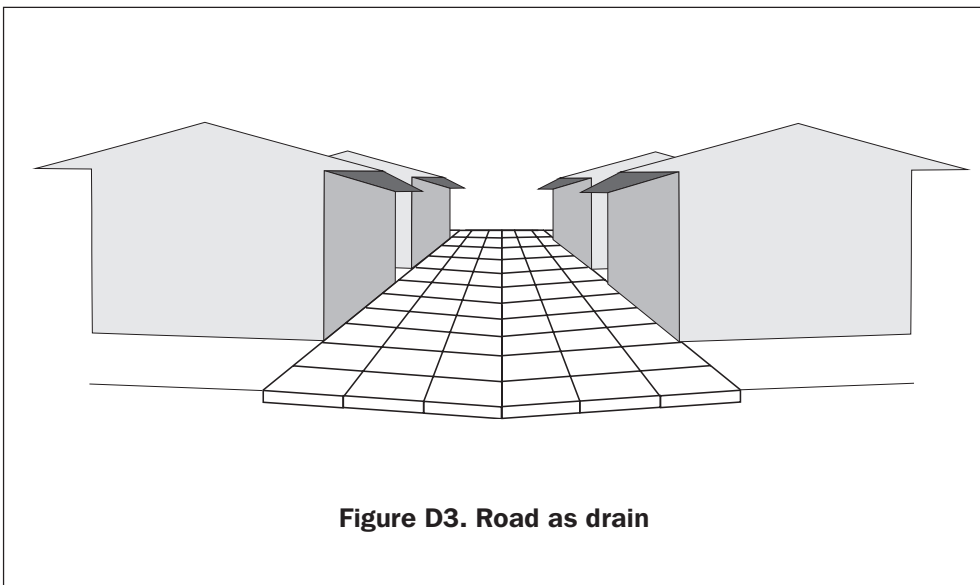
**Figure D3. Road as drain**

***Flat ground***. Positive drainage by gravity implies that all drains must slope downhill; this is achieved by following natural contours. On low-lying or flat sites which are being redeveloped it is difficult to create the required gradient, ground preparation must ensure adequate contouring of the ground to permit positive drainage to occur. The available options include:

- filling and contouring;
- moving the outfall closer to the site by means of a canal; and
- constructing the outfall drain as a buried pipeline.

***Steep ground***. Hydraulic problems occur if drains are very steep. On steep sites it is likely that the ground will be terraced for housing construction. Drains should follow a path parallel to the contours for short distances to help reduce the flow velocity. Where the drains run steeply downhill, a series of downward steps can be built.

# Tool D2 Drainage: Planning

## Initial appraisal

The aim of initial appraisal is to establish the extent and capacity of existing facilities and to identify problems and their causes. A plan of the area under consideration is required at a scale between 1:2000 and 1:5000. Overall drainage plans should be consulted where they are available.

A visual survey of the site should be made in order to:

■ establish existing drainage routes and boundaries;

■ identify the places where flooding is a problem; and

■ identify any restrictions and encroachments that restrict the capacity of main drainage routes.

In the case of flooding, it will usually be necessary to obtain information by talking to local people and officials. This may be done formally using in-depth interviews and focus group discussions.

The likely causes of flooding are likely to be found among the following:

■ inadequacy of main drains;

■ reduced capacity of main drains due to encroachments, restrictions or lack of maintenance;

■ unplanned development which allows storm and foul water drains to flow into low lying areas; and

■ inadequacies in local drainage.

In many cases, this initial survey will provide a clear indication that existing main drains are inadequate. In other cases, it will be necessary to produce calculations to determine their capacity in relation to design flows. The important things from the point of view of upgrading are to establish whether a problem exists and to ensure that appropriate action is taken by the concerned agency.

As far as local problems are concerned, the links between causes and effects will usually be fairly obvious and so there should be a basis for deciding on remedial action.

## Drainage layout

The drainage layout may be affected by the approach adopted; for instance, a layout that incorporates local storage/infiltration basins may be different from that for a conventional system. Nevertheless, the principles that follow can be employed for all but the most self-contained drainage systems.

The drainage layout is largely determined by topography. A good guide to the likely drainage layout can be obtained from existing drainage routes but it is preferable to base layout decisions on survey levels, particularly in flat areas. Longitudinal sections should be drawn along the routes of collector drains. Typical scales for these sections should be in the range 1:1000-1:2500 horizontally with a 10 to 20 times vertical exaggeration. (Normal practice is to use a vertical exaggeration of 10 but a greater amount may be justified in flat areas). There will be some places, for instance where an existing inadequate drain runs in a narrow right of way between plots, where a new drain cannot be located along the lowest possible route. In such cases, it should be located as closely as possible to the lowest route.

The length of drains should be reduced as far as is possible by allowing water to be held and/or drain on the surface for some distance before entering the drain. In places with annual rainfalls between 500mm and 1000mm, it is reasonable to assume that drains will only be required for areas greater than about 5ha. This assumes that streets can be graded to provide a slope, no matter how small, to the drains and that some temporary flooding of access streets and lanes is permissible. It is reasonable to allow larger areas without formal drains in dryer areas, providing that streets and lanes are designed to deal with stormwater. To avoid erosion problems, this approach should be used with some caution where not all the right of way is paved and average falls are greater than about 1:100.

Any low-lying areas which might be retained and used to hold stormwater and thus reduce run-off should be identified at the planning stage. The scope for providing temporary storage in shallow ditches, infiltration trenches and depressed areas should also be assessed.

The decision on the approach to be adopted will depend on both the topography and the adequacy or otherwise of main drains. Where either the average ground slope is less than about 1:500 or main drains are inadequate, the aim should be to hold stormwater within the area for as long as possible.
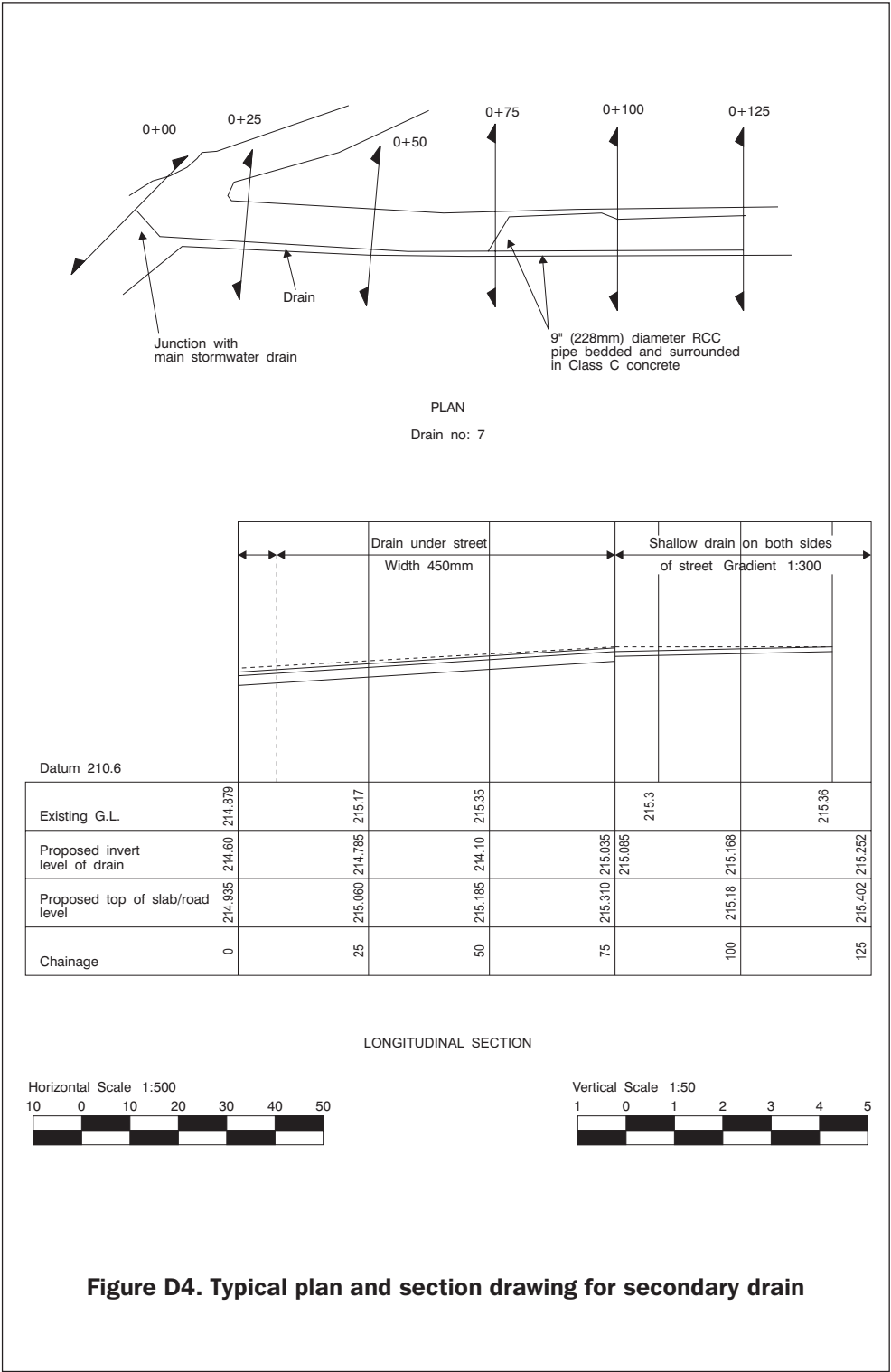
Pumping of stormwater should be avoided except where there is absolutely no other option. Where it cannot be avoided, stormwater should be collected in a holding pond connected to the pumping station sump. This will have two benefits; it will balance flows so that the required pumping rate can be less than the peak discharge rate and it will settle any solids and thus reduce the likelihood of pumps being blocked.

## Preparing plans for drainage schemes

Information on the route and levels of drains should be provided on drawings, each showing a plan of a length of drain under which is a longitudinal section of that length. It is important to show plan and section on the same drawing. By providing standard cross-sections, including both the drain and the street surface, it will often be possible to use one drawing to show levels for both the drain and the street. The normal procedure will be first to construct the drain to the levels shown on the drawings and then to relate levels across the street cross-section to the drain levels. Additional levels may be shown on the plan at points where the arrangement diverges from a simple cross-section, for instance where the drain crosses from one side of the street to the other. Figure D4 shows a typical plan and section for a length of drain.

Construction details for drains are provided by standard cross-sections and details of features such as access arrangements for covered drains. These should normally be produced at a scale of about 1:20.

PLAN

Drain no: 7

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Drain under street Width 450mm | | | | Shallow drain on both sides of street  Gradient 1:300 | | | | |

Datum 210.6

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Existing G.L. | 214.879 | | 215.17 | | 215.35 | | 215.3 | | | 215.36 |
| Proposed invert level of drain | 214.60 | | 214.785 | | 214.10 | | 215.035 215.085 | 215.168 | | 215.252 |
| Proposed top of slab/road level | 214.935 | | 215.060 | | 215.185 | | 215.310 | 215.18 | | 215.402 215.252 |
| Chainage | 0 | | 25 | | 50 | | 75 | 100 | | 125 |

LONGITUDINAL SECTION

Horizontal Scale  1:500

10  0  10  20  30  40  50

Vertical Scale  1:50

1  0  1  2  3  4  5

**Figure D4. Typical plan and section drawing for secondary drain**

4.16

# Tool D3 Drainage: Design

## Estimating surface water runoff

The design procedure involves calculation of the quantity of surface water or 'runoff' which is likely to result from rainfall.

### Drainage catchment

The boundaries of drainage catchments can be defined using a contoured plan of the site, given that in a gravity flow drainage system water flows downhill from a higher elevation to a lower elevation. This is illustrated in Figure D5.

Site boundary

Fall

Fall  High point  Fall

Contour

Fall
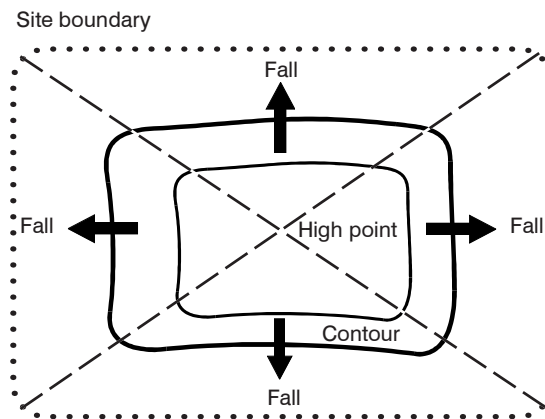
Key:

— — —  Catchment boundary

··········  Site boundary

**Figure D5. Identifying catchment boundaries from site contours**

## Calculation of runoff

The simplest way of calculating the runoff from a given catchment is by the 'rational method' which states that:

Q = 2.78 CIA    where

Q = runoff in litres per second

C = volumetric runoff coefficient

I = rainfall intensity of the storm in mm per hour

A = total area drained in hectares ( 1 hectare = 10 000 m²)

Table D1 gives appropriate values for 'C'. It is assumed that the area is fully developed, that road surfaces are impermeable and that plots are generally above the level of the roads. A reduction of 20% can be applied to these values if the road surfaces are semi-permeable (such as sand-grouted bricks or blocks, or unbound gravel). Note that we are using population density as an indicator of housing density, which in turn affects the impermeable area of a settlement.

| Table D1  Runoff coefficients | | | |
|---|---|---|---|
| **Average plot size** | **Population per hectare** | **Average ground slope** | **Typical run-off coefficient** |
| < 100m² | 400 and over | <1:500 | 0.65 |
| | | 1:500 - 1:200 | 0.70 |
| | | >1:200 | 0.80 |
| 100-250m² | 200 - 400 | <1:500 | 0.50 |
| | | 1:500 - 1:200 | 0.55 |
| | | >1:200 | 0.65 |
| 250m² | 50 - 200 | | 0.45 |

## Rainfall intensity

The rainfall intensity represents a rate of rainfall, and its magnitude depends upon the storm duration (that is, the length of time for which rain is falling in a particular storm) and the return period of the rainfall intensity (that is, the number of years on average between the rainfall intensity being greater than or equal to a specified intensity). The selection of a suitable return period for the design storm is usually arbitrarily taken to be once in one year.

Rainfall intensity reduces as the duration of the storm increases; examples of intensity/duration curves for several return periods from Lahore are shown in Figure D6.



**Figure D6. Rainfall intensity-duration curves for Lahore**
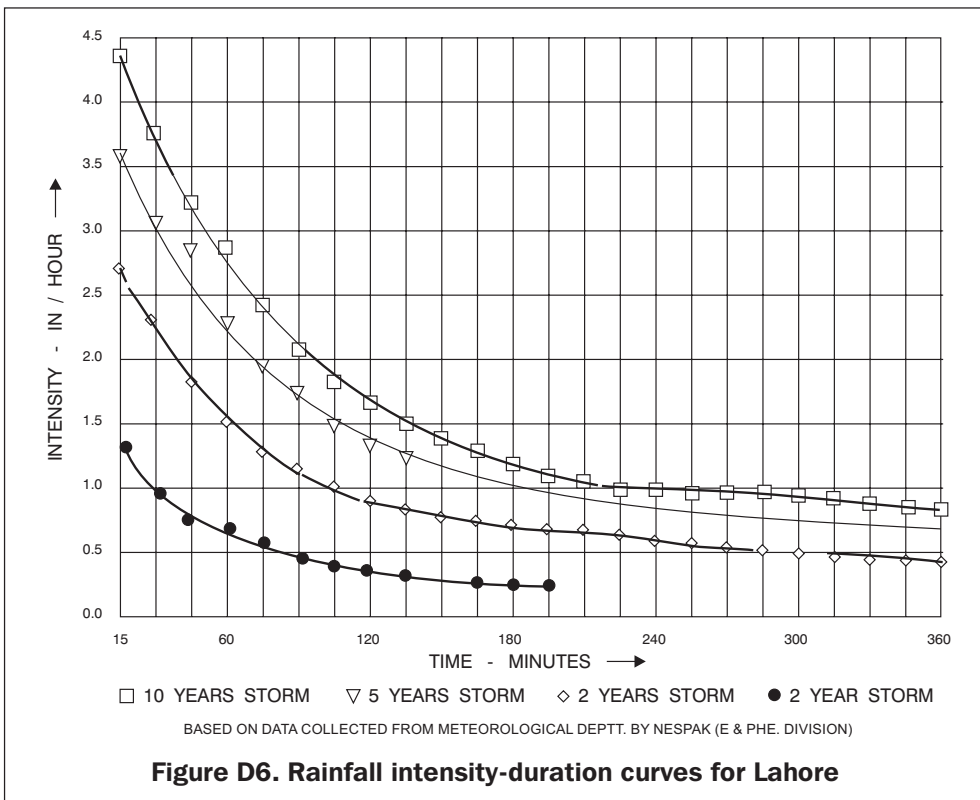
The rational method assumes that the storm duration which is appropriate for a particular drainage catchment equals the total time it takes for rain falling on the most distant part of the catchment to flow down to the outfall point of that catchment. This is defined as the 'time of concentration', where

time of concentration = time of entry + time of flow

The time of entry is the time taken for rain falling on the ground or a building to flow into the nearest drain; the time of flow is the time taken for that water to flow from its entry point into the drain to the outfall point.

$$\text{time of flow} = \frac{\text{length of drain}}{\text{velocity of flow}}$$

The length of the drain is obtained from the proposed site drainage plan; the flow velocity can be assumed to be 0.7 metres per second as a first estimate, and the time of concentration determined.

The duration of the storm appropriate to the catchment is equal to the time of concentration; thus the appropriate rainfall intensity can be found from the rainfall intensity/duration curve for the location in question.

The runoff from the catchment under consideration is then calculated using the rational formula.

## Design intensities for small areas

It can be seen from Figure D6 that design rainfall intensity decreases with increased duration. This means in effect that the smaller the drainage area, the larger the intensity assumed in design. In practice, the run-off from short periods of rainfall will usually be less than that predicted using the intensity obtained from the intensity/duration curve with a constant run-off coefficient. This is because water gathers in small depressions in the surface and thus reduces the short-term run-off coefficient. To allow for this effect, a constant intensity can be assumed for times of concentration of 15 minutes and less. (In effect, the adjustment for the reduced run-off is then made in the intensity assumed rather than the run-off coefficient). In practice, this generally applies to catchment areas of about 15ha. and less, in other words for tertiary level facilities.

Rainfall intensity/duration data is often not readily available; a very useful guide to developing these curves from standard rainfall data is given by Kolsky (1998). In the event of there not being any information, a reasonable value for a rainfall intensity having a one year return period is likely to be in the range 50-100 millimetres per hour; this could be applied to tertiary level catchments.

## Effect of storage on run-off

The Rational Formula is intended for use with conventional schemes in which the aim is to remove water from the site as quickly as possible. It does not allow for storage of water in the drainage system and therefore tends to overestimate run-off, particularly in flat, slow-draining areas. In areas with average slopes less than about 1:250, the effect of storage on road surfaces will be significant but this effect cannot be quantified simply.

It is probable that the best way to deal with this situation will be to use reduced run-off coefficients to compensate for storage and this is the approach which is followed here. Table D1 gives suggested relationships between run-off coefficients and average ground slope. However, it must be emphasised that these figures are estimates only and more research is needed on this subject.
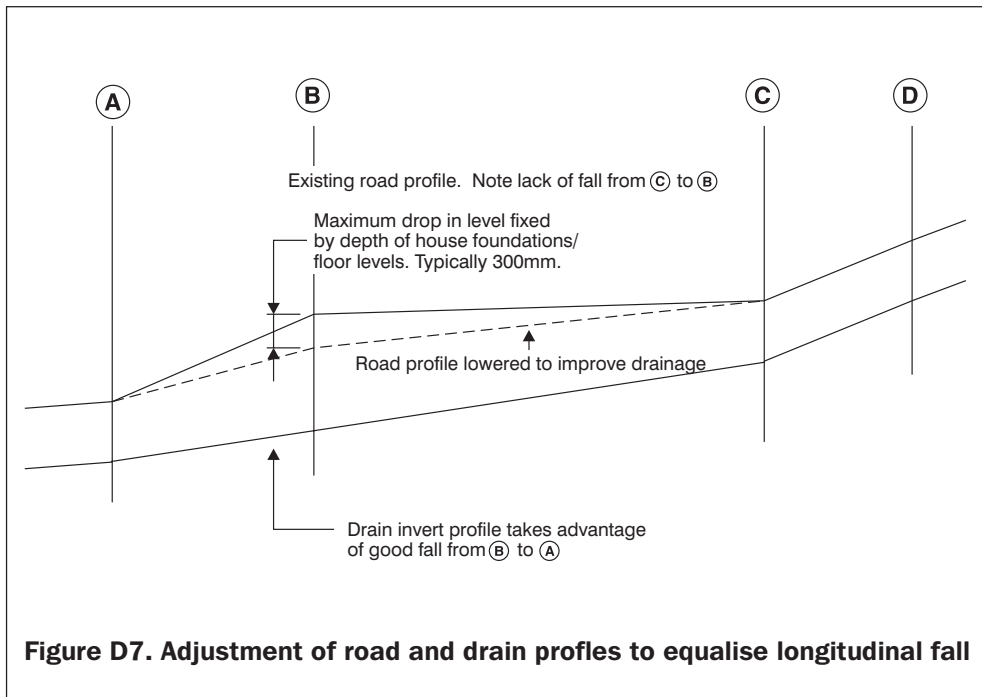
For wholly on-site and hybrid systems that rely heavily on storage, the critical factor is not so much the instantaneous run-off flow as the total volume of run-off. Analysis of these systems is complex, indeed the necessary theory is not available in any simple usable form. If a site contains a substantial area of potential stormwater storage, for instance a low-lying park or playing field area, the advice of a specialist drainage engineer should be obtained.

## Estimation of available falls

The first step in estimating available falls is to prepare longitudinal sections of the main drainage routes, showing existing ground levels and noting the bed levels and top water levels of receiving drains or watercourses. Sections already prepared when deciding the drainage layout may be used. Possible drain profiles can then be added to these sections, together with road profiles where it is planned that the road may occasionally carry stormwater. (This will be the case in most informal areas.) When planning street and drain profiles, the following rules should be observed:

- Raising of road surfaces along primary and secondary drainage routes should be avoided.
- Variations in longitudinal fall that result in flat lengths of street and drain should be smoothed out. This will be particularly important where a flat length of street is located upstream of a length with a good fall. This point is illustrated in Figure D7.
- The aim should always be to slope tertiary streets towards drainage routes.

- Covered drains and storm sewers should have sufficient fall to ensure self-cleansing velocities. This requirement is less important for open drains since they can be cleaned more easily; nevertheless, it should be achieved where possible.



Existing road profile. Note lack of fall from ©C to ©B

Maximum drop in level fixed by depth of house foundations/ floor levels. Typically 300mm.

Road profile lowered to improve drainage

Drain invert profile takes advantage of good fall from ©B to ©A

**Figure D7. Adjustment of road and drain profiles to equalise longitudinal fall**

# Drain design

## Tertiary drainage routes

Specific design calculations are not required for individual tertiary drainage routes where the best option is to use the road-as-drain, which has minimal maintenance requirements. Tertiary areas up to about 15 hectares can be treated in this way. The important point is to determine where water from different parts of the site will drain to, so that the runoff into the secondary drains can be correctly estimated. If conventional open channel drains are used in tertiary areas, the drain size is often determined by the available space and access widths. Table D2 gives the capacity of different drain sizes for different longitudinal slopes.

| Table D2. Drain capacities in litres per second | | | | | |
|---|---|---|---|---|---|
| n= | 0.018 | | | | |
| **Bed slope** | **S** | **Drain Size (width \* depth) in mm** | | | |
| | Width | 1000 | 750 | 500 | 250 |
| | Depth | 500 | 375 | 250 | 125 |
| 1:100 | 0.0100 | 1097.3 | 509.0 | 172.4 | 27.1 |
| 1:150 | 0.0067 | 895.9 | 415.6 | 140.8 | 22.1 |
| 1:200 | 0.0050 | 775.9 | 359.9 | 121.9 | 19.2 |
| 1:250 | 0.0040 | 694.0 | 321.9 | 109.0 | 17.1 |
| 1:300 | 0.0033 | 633.5 | 293.9 | 99.5 | 15.6 |
| 1:350 | 0.0029 | 586.5 | 272.1 | 92.2 | 14.5 |
| 1:400 | 0.0025 | 548.6 | 254.5 | 86.2 | 13.5 |
| 1:450 | 0.0022 | 517.3 | 240.0 | 81.3 | 12.8 |
| 1:500 | 0.0020 | 490.7 | 227.6 | 77.1 | 12.1 |

## Primary/secondary drain capacity

A suitable drain size must be specified which can carry the required surface runoff from tertiary areas. If the capacity of an existing drain is being checked, then it is essential to go to the site and measure the width, available depth and bed slope of the drain. Note that solids and debris on the bed of the drain reduce the available depth of flow; the capacity should be calculated for two cases:

- assuming the depth and slope measured to the channel invert; and
- assuming the depth and slope measured to the solid deposits rather than to the channel invert (after Kolsky 1998).

After doing these calculations the importance of drain cleaning becomes readily apparent.

The capacity of an open channel can be calculated from the Manning equation.

$$Q = \frac{1000 * AR^{0.67}S^{0.5}}{n}$$

where        Q = capacity in litres per second
A = cross sectional area of flow in metres squared
S = longitudinal bed slope of the channel
n = Manning's channel roughness coefficient
R = hydraulic radius of channel in metres

where        $$R = \frac{A}{Width + 2 * Depth}$$

for a rectangular channel.

Table D3 gives some typical 'n' values.

| Table D3. Manning's roughness coefficient 'n' | |
| --- | --- |
| **Material** | **Manning's coefficient** |
| Earth | 0.025 |
| Brick - unrendered | 0.018 |
| Brick - smooth rendered | 0.015 |
| Concrete - smooth finish | 0.015 |
| Concrete - very rough finish | 0.020 |
| Solids on bed and smooth side walls | approx. 0.023 |

The optimum shape for a rectangular cross section drain is for the width to be twice the depth; thus the capacity (Q) can be calculated for a given drain size, slope and roughness using the Manning equation. However, in practice restrictions on available width mean that the section may be square.

The drain capacity is then compared with the runoff which it is required to carry and the size of the drain is adjusted until its capacity is within say 10% of the runoff. Calculate the velocity of flow in the drain using

Velocity = Capacity/Cross sectional area

If it is not equal to 0.7 metres per second (that is, the value assumed in order to find the time of concentration and rainfall intensity), recalculate the time of flow based upon this recalculated value of velocity.

In practice it is usual to standardise on a limited number of drain sizes in order to simplify construction. Small drains easily become blocked and a minimum width of 300 mm is suggested.
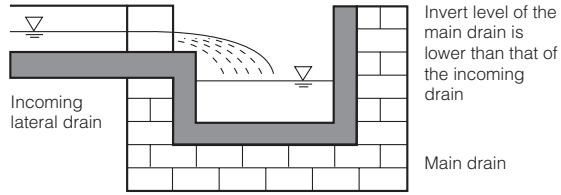
At the junction of two drains, the invert level of the minor drain should be above that of the major drain which it is joining as shown in Figure D8. This prevents backflow of water up the minor drain.

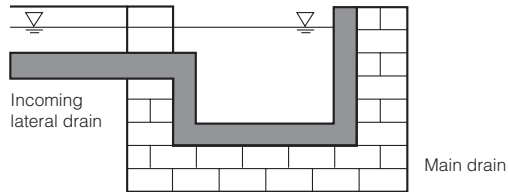Step Height = Depth in major drain - Depth in minor drain

Note that for sheet flow on street pavements, the value of the hydraulic radius (R) approximates to the average depth, measured in metres.

It is normal to carry out calculations for secondary drains on standard sheets such as that shown in Figure D9. Columns 1-13 of the sheet are concerned with the calculation of design flows in the drain. Columns 8-12 are concerned with the calculation of the rainfall intensity, using rainfall intensity/ duration curves such as that given in Figure D6. For areas up to about 15 ha, the procedure may be simplified by assuming a constant rainfall intensity. Columns 14-24 are concerned with the calculation of the velocity and quantity of flow in the drain. For each drain leg, starting at the head of the system, the design flow is calculated, drain dimensions are assumed and the drain full flow velocity and quantity are calculated. Calculation is an iterative process. If the velocity obtained in column 23 is too low, a greater drain slope must be assumed. If the capacity calculated in column 24 differs by more than 10% from that obtained from column 13, revised drain dimensions or slope should be tried. If the calculated velocity obtained in column 23 differs by more than about 20% from that assumed in column 9, it may be necessary to recalculate the rainfall intensity based on a revised time of concentration. Once the design of a drain leg has been satisfactorily completed, the designer inputs the data obtained on time and quantity of flow into the design of the next downstream leg.

**a: Low flow**

Incoming lateral drain

Invert level of the main drain is lower than that of the incoming drain

Main drain

**b: Maximum flow**

Incoming lateral drain

Main drain

**Figure D8. Drain invert levels**



| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drain leg | Upstream node | Area contributing over leg (ha.) | Run-off coefficient | Effective contributing area (ha) | Effective area at u/s node (ha) | Effective area at d/s node (ha) | Distance from previous point (m) | Assumed V (m/sec) | Time from u/s node (min) | Time of conc. (min) | I (mm/hr) | Required drain capacity (l/sec) | Av slope on drain | Drain width (mm) | Drain height (mm) | Cross-sectional area, A (m²) | Wetted perimeter P (m) | R = A/P | $R^{2/3}$ | $S^{1/2}$ | Mannings $n$ | $V = \dfrac{R^{2/3}S^{1/2}}{n}$ (m/sec) | Q = VA x 1000 |

**Figure D9. Typical calculation sheet for secondary drains**

# Types of drain

### Unlined ditches

Unlined ditches are the cheapest form of drain to construct. However, they require constant maintenance and this limits their usefulness in informal areas. They are not suitable for carrying sullage flows and should therefore only be considered in sewered areas. In practice, they will only be an option in the rare situations in which streets are at least 7 metres wide. The slope on unlined drains should not be greater than about 1% (1 in 100) to avoid scouring. The side slopes should normally be about 1 in 1.5 except in particularly sandy soils where flatter side slopes are required. An example is shown in Figure D10.
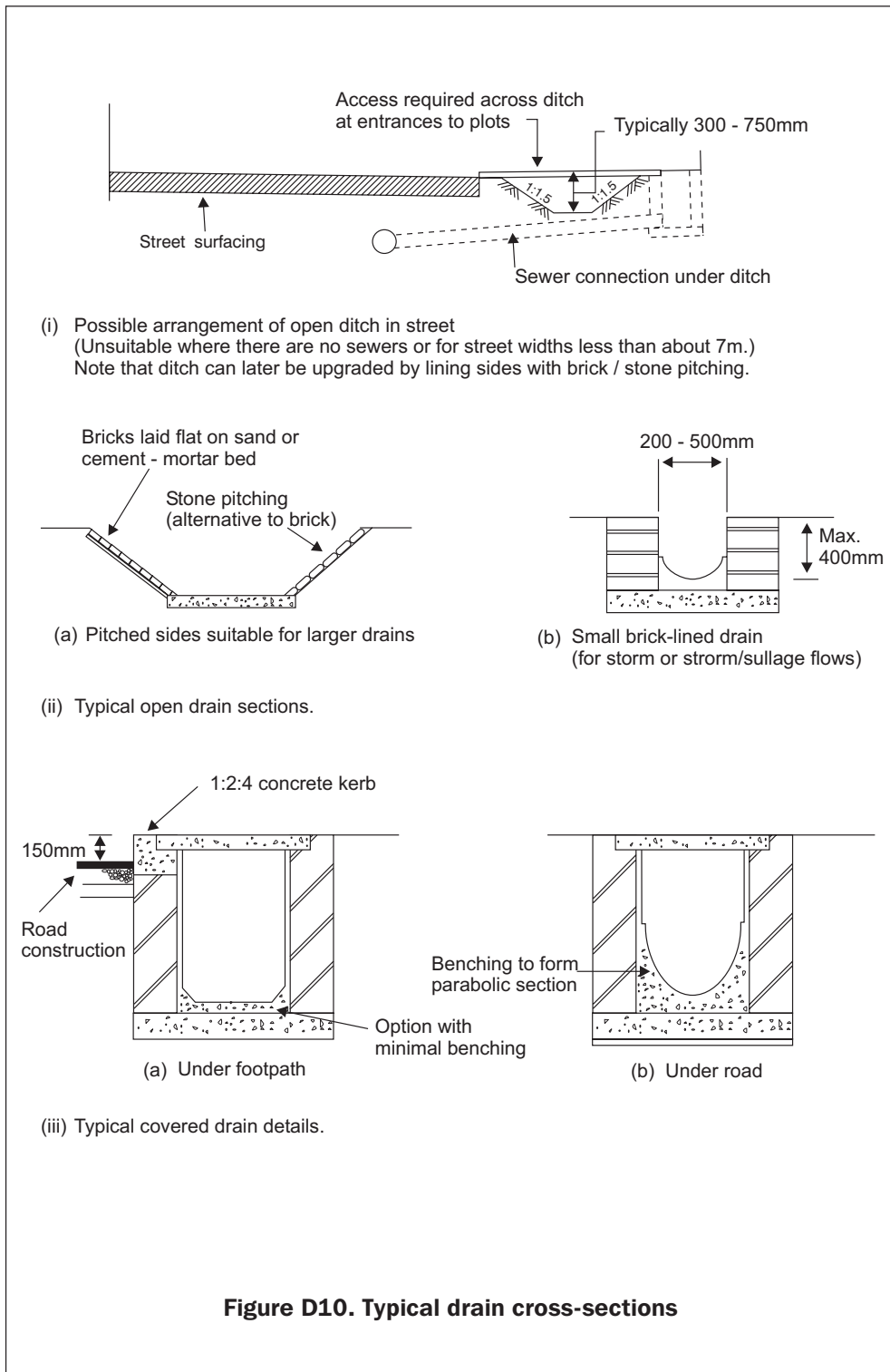
### Open drains

Brick-lined open drains intended to carry both storm and sullage flows are widely used. Their main disadvantage is that it is easy to throw rubbish into them, reducing their capacity and eventually blocking the flow. On the other hand, they are much easier to clean than covered drains and the equipment presently used by municipality sweepers is intended for use with them. Open drains over about 400mm deep are a hazard, particularly to children who may fall and injure themselves. Large open drains may be appropriate where space is available so that sides can be pitched or where access can be restricted. For main drains, access may be restricted by providing walls on either side of the drain.

The most common cross sectional shape is rectangular; this gives rise to very low flow velocities when the discharge is small and is thus unsuitable for sullage flows. This can be overcome by using parabolic or half-round invert profiles as shown in Figure D10, or the compound section shown in Figure D11. This ensures that an acceptable velocity and depth of flow are maintained during low flows, with the overall capacity sufficient to carry the required storm discharges.
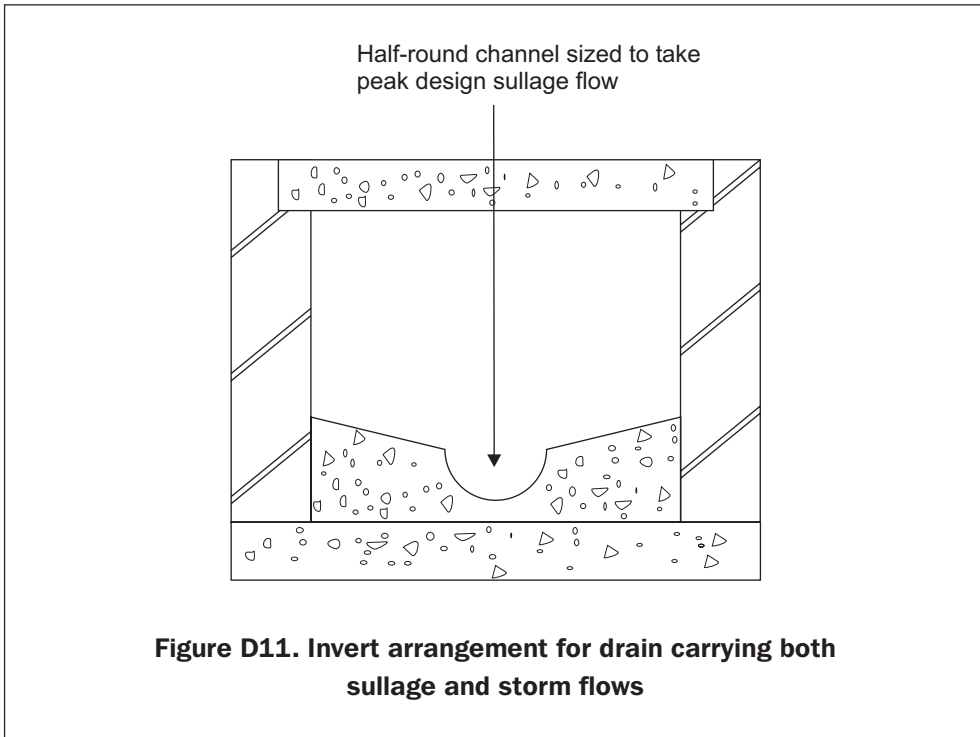
### Covered drains

It is more difficult to gain access to covered drains than to open drains. This means that it is more difficult to throw solid waste into them so that they do not become blocked as quickly. Conversely, it means that they are more difficult to clean and experience shows that municipalities are often not equipped or prepared to clean them.

Access required across ditch
at entrances to plots

Typically 300 - 750mm

Street surfacing

1:1.5    1:1.5

Sewer connection under ditch

(i)  Possible arrangement of open ditch in street
     (Unsuitable where there are no sewers or for street widths less than about 7m.)
     Note that ditch can later be upgraded by lining sides with brick / stone pitching.

Bricks laid flat on sand or
cement - mortar bed

Stone pitching
(alternative to brick)

200 - 500mm

Max.
400mm

(a)  Pitched sides suitable for larger drains

(b)  Small brick-lined drain
     (for storm or strorm/sullage flows)

(ii)  Typical open drain sections.

1:2:4 concrete kerb

150mm

Road
construction

Option with
minimal benching

Benching to form
parabolic section

(a)  Under footpath

(b)  Under road

(iii) Typical covered drain details.

**Figure D10. Typical drain cross-sections**

Half-round channel sized to take
peak design sullage flow

**Figure D11. Invert arrangement for drain carrying both
sullage and storm flows**

An advantage of covered drains is that it is possible to use the area above them. This may be important where the available right of way is limited. For larger covered drains, the cover slab can have an important structural effect, converting the walls from cantilevers to propped cantilevers and reducing the wall thickness required. This will partly offset the additional cost of covering the drain.

As a general rule, drains smaller than about 500mm x 500mm should not be covered. Larger drains should be covered except where access to them can be prevented.

## Road as drains

Tertiary drains can be eliminated by designing streets and lanes to carry stormwater. This reduces both the capital cost of drainage and the need for maintenance and the approach should therefore be used in upgrading schemes wherever possible. Most of the typical street and lane cross-sections given allow for stormwater to be drained on the surface. Where streets are designed to act as drains, surfacing materials such as brick and concrete, which are not damaged by stormwater, should be used.

The most important factor is to ensure that the paved areas and roads have a positive slope so that the water drains into secondary drains at a known number of outfall points. This requires attention to detail at the planning stage. The road should slope longitudinally and also have a cross-fall unless:

■ the street is less than about 2 metres wide; or

■ the longitudinal fall is less than about 1 in 300.

For narrow lanes, the benefits derived from a cross-fall are not great enough to justify its provision.  Where there is little longitudinal fall and the surface is impervious, irregularities in the surface will result in standing water after rain, The water will remain for longer if it is concentrated in one spot by the cross-fall, especially where infrequent street cleaning allows dirt and rubbish to gather at the low point of the cross-section.  With a flat cross-section, water will stand over a wider area but the depth will be less and the speed with which the water will either evaporate or percolate away will be greater.

In flat areas it may be permissible to allow streets to flood temporarily to a depth of say 150mm providing that the water drains away rapidly after the storm. Street levels must be sufficiently far below the plot levels to prevent flooding of properties. This retention of floodwater will have important benefits for the secondary drains, as it serves to reduce the peak outflow, thereby reducing the risk of overloading these drains.

## References

Kolsky, P. (1998) *Storm Drainage,* Intermediate Technology Publications London.

# Tool D4 Drainage: Handy Tips

## Drainage: Some general operation and maintenance tips

- Construction debris is a major problem; clean out all debris from the drains when construction is completed.

- Regular unblocking and solid waste removal is required.

- Small drains may need to be desilted on a monthly basis.

- Desilting of primary and secondary drains is essential prior to the rainy season.

- Road crossings and culverts are subject to frequent blockages and need particular attention.

- Proper tools are required for removal of waste from drains.

- Drain waste should not be stacked alongside the drain; the management challenge is to organise desilting and lifting in one operation with subsequent removal to the disposal site.

- Municipally managed drain cleaning is labour intensive and consumes considerable resources; larger drains may increasingly be cleaned using mechanical plant.

- Cleaning of local drains can be community-managed.

- Regular spraying of street drains with pesticides to reduce mosquito breeding is important.

## Earth drains: where to use them

- Not generally suitable for drainage channels in densely populated areas.

- Do not use for carrying sullage or foul sewage.

- Often used for large primary drainage channels and for ultimate disposal of stormwater.

- During the urbanisation process, old earthen irrigation channels are used as tertiary and secondary drains.

- For temporary purposes such as diversion or pumping out of drainage water, e.g. where there are site disputes on the proposed permanent alignment.

- Problems include: low velocity due to high roughness and irregular shape; mosquito menace as there is a possibility of weed growth.

## Earth drain: construction tips

- Inexpensive and simple to construct; lines and levels need careful setting out and control by a surveyor.

- Use trapezoidal sections to minimise scour.

- On relatively steep ground, increase the length of the drain by following a zig-zag route to reduce velocity - ultimately to reduce scouring by having a flatter slope.

- Use excavated earth (spoil) for embankments on larger drains.

- In certain cases, larger drains may need approach roads for undertaking maintenance.

- Requires cohesive soils for greater stability of excavated section; not good in sandy soils.

- Suitable for community based works; excavation can be done by unskilled labour.

## Earth drain: operation and maintenance tips

- *See general operation and maintenance tips.*

- Maintenance intensive compared with other options.

- Frequent desilting and unblocking required; this may lead to the bed profile being disturbed.

- Periodic realignment is necessary; depth, width and slope are fixed initially but change in the course of time, as the channel flows 'in regime'.

- Suitable for community based works.

- Care should be taken when there is a roadway on its embankment, as slips are common.

- Unexpected flooding from adjacent catchments areas can cause major damage.

## Brick masonry drain: where to use them

- Very common and appropriate for tertiary and secondary drains using bricks or cement blocks.

- Resistant to settlements and associated cracks as the section is strong.

- An increasingly expensive option for larger drains due to the continuing rise in the cost of bricks.

## Brick masonry drain: construction tips

- Accurate measurement of levels and falls is essential.

- A good quality smooth cement plaster to cover the bricks is necessary to ensure good flow characteristics.

- Side walls have varying depths governed by the longitudinal bed slope and the road levels.

- Use a template or former to produce the required cross sectional profiles for non-rectangular sections; half-round and parabolic benching for small drains can be produced in-situ using a wooden hand-held former up to about one metre long.

- Use good quality bricks which are well-burnt and have good water resistance.

- At road crossings, side walls need to be strong enough to take traffic loading; in this situation and with deep sections sidewalls are designed as small retaining walls.

- Consider the type of tools used for drain cleaning when specifying the cross sectional shape

- Requires skilled labour other than for trench excavation.

## Brick masonry drain: operation and maintenance tips

- *See general operation and maintenance tips.*

- Suitable for community management using only basic tools.

## Cement concrete drains: where to use them

- Convenient if cement concrete paving is used; construction can be done at the same time.

- Construction is relatively simple and quicker than brick lining.

- Cost comparisons depend primarily on the local costs of procuring materials and their quality.

- Used mostly for tertiary street drains.

- For medium to large sized secondary and primary drains concrete reinforcement is required.

- Useful if access is very restricted because the wall thickness is less than for brick drains and a marginally wider pathway is available.

- Resistant to scour by high velocities such as occurs in steeply sloping areas.

- Good where rainfall is high; concrete deteriorates less than brick under submerged conditions.

## Cement concrete drains: construction tips

- Accurate measurement of levels and falls is essential; the bed alignment needs to be carefully prepared following the required slope before concreting.

- Good quality formwork is necessary to obtain the desired cross section.

- Small drains may need plastering to ensure good flow characteristics.

- Use coarse aggregate of less than 20 mm size for small drains.

- Rectangular or box drains may need tie beams at top between two walls to improve stability against collapse due to moving loads (such as traffic).

- Machine mixed concrete is preferable.

- Construction is more difficult when the depth of the sidewall varies due to problems with formwork.

- Requires skilled labour other than for trench excavation.

## Cement concrete drains: operation and maintenance tips

- *See general operation and maintenance tips.*

- Longer life than brick drains, but cracks develop if there is any ground settlement.

- Repair and patching cost is slightly less than for brick lined drains.

- Durability of the surface means that heavier tools can be used for cleaning.

## Precast concrete drains: where to use them

- Appropriate for small tertiary drains.

- Useful as a temporary measure to relieve immediate problems.

- Relatively cheap to construct but experience shows that it is not a long lasting solution.

- Difficult to use in situations where depths vary over short distances and where there are frequent changes in alignment.

## Precast concrete drains: construction tips

- Accurate measurement of levels and falls is essential in preparing the trench profile.

- Casting can be centralised, offering the opportunity for closer quality control.

- It is possible to remove and refix sections.

- Concrete should be vibrated and cured properly at the casting yard; care needs to be taken to avoid damage when the units are transported to site.

- Take particular care when making cement mortar joints; use a strong mortar mix.

- Suitable for small enterprise development.

## Precast concrete drains: operation and maintenance tips

- *See general operation and maintenance tips.*

- Uneven joints pose problems when moving cleaning tools along the drain.

- Settlement opens up joints and subsequent leakage can create localised pools of water.

- Refixing and replacement need to be carried out on a regular basis as the pre-cast sections are disturbed relatively easily.

## Stone/block/rubble lined drains: where to use them

- Suitable for larger secondary and primary drains and main outfalls; commonly used as a means of improving existing large unlined channels.

- Provides a stable section by lining the sidewalls; the bed need not necessarily be lined for larger main drains.

- Cost effective if local materials such as stones, stone flags and 'random rubble' are used for pitching the sides.

- Difficult to provide any covering over drain for safety and access.

- Susceptible to accidents through people, particularly children, falling in.

## Stone/block/rubble lined drains: construction tips

- Accurate measurement of levels and falls is essential for new drains; large drains tend to have flatter slopes.

- Simple to construct; sidewalls can be vertical, sloped or stepped and should be designed as retaining walls allowing for nearby traffic loading.

- Requires a mix of unskilled and skilled labour.

- Sidewall/revetment lining can be either mortar jointed or without jointing material; open joints allow some percolation.

- Use a cement concrete 'capping' for the tops of side walls to impart extra strength against wearing.

- Cross drainage works are complicated involving culverts and possibly bridges; planning needs to be integrated with wider, long term drainage needs.

- Adequate safety measures need to be taken during construction within developed housing areas as walls of nearby buildings are prone to cracking or even collapse.

- Water and sewer line crossings create major problems if encountered during construction; it is essential to work out what to do at the planning stage.

## Stone/block/rubble lined drains: operation and maintenance tips

- *See general operation and maintenance tips.*

- Stones and blocks have some salvage value.

- Settlement can cause cracks in the lining; some sections may need periodic refixing.

- Care must be taken when heavy equipment is used for desilting to avoid disturbing the stone pitching on the revetment.

- Weeds such as water hyacinth can severely restrict flows; removal is a major operation once the weeds take hold.