COMMUNITY PARTICIPATION

AND

LOW-COST DRAINAGE

TRAINING MODULE

United Nations Centre for Human Settlements (Habitat)

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CONTENTS

GUIDELINES FOR THE INSTRUCTOR

The guidelines (blue), for the instructor only, explain the use of the course module in the training session. They list the material required, outline the timing and organization of the session, and explain how the instructor has to prepare the training.

COURSE PAPER

The course paper (white), for distribution to the trainees, describes the various aspects of community participation in the execution of low-cost drainage projects. It cites examples from various parts of the world and it raises issues which have to be resolved for successful community participation in the execution of such projects.

The training module starts with an introduction describing drainage problems in low-income urban settlements. Then, it discusses motivation of the low-income groups who are to benefit from drainage systems and discusses how community participation can be generated.

The following chapter explains some basic principles of drainage and outlines design options for low-cost drainage systems.

The next three chapters describe actual participation in planning, construction and use/maintenance of a drainage system.

Each chapter is followed by questions that can be used to test the student's comprehension.

A glossary in an annex at the end of the paper explains the technical terms used in the overview.

For reasons of copyright, it is not possible to add case studies in the form of articles or chapters from books to this module. Therefore, a bibliography (yellow) listing titles of articles and books on low-cost drainage has been annexed to the course paper.

A third annex to the course paper provides some basic calculation methods for drainage. This part of the module is optional. Its main purpose is to give the interested course participant some insight to the design process.

GUIDELINES FOR THE INSTRUCTOR

This course module has been prepared as a general module for a training course on community participation in the execution of low-cost drainage projects. The module gives a framework for the course, but it is the responsibility of the instructor to provide additional and detailed information and to adjust the course to local conditions.

Target group	Project staff (project managers and staff involved in community participation).
Number of participants	10 - 20 persons.
Duration	Two or three days.
Location	Easy access to a sites-and-services scheme, a squatter settlement or a squatter settlement upgrading project is desirable.
Equipment	Blackboard or newsprint and, if possible, a film projector or video equipment.
Relevant films	Contact UNCHS (Habitat).
Preparation	In order to link the training to the situation in which the trainees are or will be working, the instructor has to prepare a background paper before the start of the training session. The paper should provide data on planned and ongoing low-cost drainage projects and list the principles for their execution. It should document local experiences with community participation and drainage projects, if any. A day before the session starts, the instructor distributes the course paper, the background paper and any other relevant material to the trainees, so that they have the opportunity to read them.
Training session (half a day)	The instructor and the trainees read together through the course paper and discuss the opportunities and limitations of community participation in the execution of low-cost drainage. At the end of each chapter, questions related to the issues raised in the chapter have been listed. These questions can be used during the session for discussion of the material.

Fieldwork (one or two days)	For this purpose, the trainees are divided into groups of three to five persons. Each group is assigned the task of preparing answers to issues raised in the course paper, using local drainage projects as their reference. Depending on the number of participants, groups can be formed around such topics as: <u>Characteristics of the target group</u> Where and how do the target groups of the low-cost drainage project live? Are they able and willing to maintain the system? <u>Community organization</u> Are there any community organizations among the target groups which served as channels for community participation? Were the target groups involved in the planning of the project? How were the users organized at neighbourhood level? Was maintenance organized by the community? <u>Communication with users</u> When and how have the users been briefed about the project? What did the users have to know in each phase of project execution? What documents were prepared for the users? What tools were used to explain the design of the drainage system to the users? <u>Procedures for community participation</u> What procedures existed for the involvement of the users in project implementation? Were these procedures suitable for the involvement of low-income groups? If not, what kind of procedures would be useful?
Review session (max. one day)	Each group has to present the results of its fieldwork at a plenary session, so that the work can be examined by all participants, the instructor and, if possible, some government officials.
Evaluation	The trainees and the instructor evaluate the training session.

SUMMARY

More than any other infrastructural provision for neighbourhoods, drainage has to be developed in co-ordination with other neighbourhoods and areas of the city.
For the development of a drainage plan, a considerable amount of physical data is required, and the technical skills for data collection mostly will have to be sought outside the community. There are however possibilities of involving community members in data collection, for instance by having them interpret and comment on aerial photographs taken at low altitudes. The actual design of drainage systems requires engineering skills and is thus not a suitable area for community participation.

Communities can play a role in the implementation of drainage projects: the digging of drains and prefabrication of drain components are common community contributions.

The most important area of community participation in drainage is in the field of maintenance. The regular inspection and cleaning of drains are an important task that communities can perform without specialized skills. They require supervision, timing, inspection, and a system for reporting (and repairs in response to these reports), while a good working relationship with the municipal authorities is also essential. The maintenance and cleaning of drainage systems are not very demanding and can have a positive impact on the living conditions in a neighbourhood.

Cleaning drains in good time and preserving vegetation cover along drains is more essential than the building of a sophisticated drainage system. The key to effective low-cost drainage is therefore community organization and the allocation of certain basic tasks to specific community members. This can be achieved by establishing a special drainage committee in the neighbourhood.
An active committee, overseeing very simple drain-cleaning and vegetation-planting routines before rains come, means much more to effective drainage than great efforts to repair damage after rains have done destructive work.

I. INTRODUCTION

Drainage problems

Low-income residential areas usually lack adequate infrastructure and have little or no maintenance service.
In many cities in developing countries, huge areas exist where neighbourhoods are flooded once or twice a year and people have to live with water inside the dwelling. It has become a way of life for squatters living on flood-prone marginal lands.

The flooding of neighbourhoods and the serious damage it can cause often occur on either very steep or very flat sites. Moderately sloping sites provide natural drainage that does not create much damage. Very steep sites are difficult because of the great speed and force that stormwater develops, destroying buildings and eroding the land. Very flat areas, such as river deltas, cause problems because water may rise without being able to escape.

It is not unusual that low-lying areas which did not show any signs of flooding before people settled on them, become flood-prone after a few years of construction activity. The reason for this may be that:

- constructions have cut off the original water runoff pattern;
- new traffic in the area has changed the composition of the top soil thus rendering it impermeable;
- covered areas (paved and roofed surfaces) have reduced the open land surface and thus its absorption capacity;
- people and cattle have destroyed vegetation and reduced the absorption capacity of the soil;

The residents of flood-prone areas often have to accept special hardships in order to cope with regular inundation of their neighbourhoods. In Maputo, Mozambique, seasonal evacuation to high ground was necessary for the residents of some flood-prone areas. Industrial workers living in such areas near the industrial zone had a second house outside the city, from which they commuted to the factories during the rainy season, returning to the shantytown around the industries as soon as the floods receded.

In Bangkok, Thailand, and Guayaquil, Ecuador, for instance, many houses in flood-prone areas near the river and harbour and even along the main drainage channels are built on stilts so that the dwelling is not affected by regular inundations. The houses are connected by elevated pathways, but construction is rickety, and it is very easy to lose one's balance and fall into the muddy, stagnant water underneath. Although the residents of these areas use latrines of the cesspool type, they cannot prevent the waste water from penetrating the soil and mixing with the natural water in the area. Flood-prone areas therefore become health hazards as well.

The steep slopes surrounding a number of large cities in developing countries have been used by squatters to develop their settlements. High densities result in minimal absorption of rain by the soil, while the lack of vegetation and natural drainage opportunities lead to wild and destructive torrents of water. The settlement itself often forms a barrier to natural drainage, and blocking of water runoff results in catastrophic mudslides that can take hundreds of dwellings along in their wake.

Drainage difficulties are sometimes related to overall topographic conditions in the city, sometimes to the complete absence of any drainage provision and sometimes to a combination of such factors. Difficulties can also be the result of the development of an area. It is not uncommon to find that the construction of a road through an area later causes inundations, because the natural drainage of the area has been cut off by the construction. The intensification of density of an area has direct implications for drainage conditions. All buildings and paved areas reduce the capacity of the ground to absorb stormwater, and the quantities that have to be handled by the drainage system may then become more than it can cope with. In other cases, drainage in one area is improved without building off-site drainage to take the extra water out of the area. The result is either flooding in a neighbouring area or flooding in the improved area.

The case of Manzese

The Manzese area in Dar es Salaam, United Republic of Tanzania, is an example of several of these factors. The squatter settlement had

been selected for upgrading, and a drainage system was being designed as part of the work. The consultants first designed a complete drainage scheme for the area, on the assumption that the normal infrastructural standards for residential neighbourhoods would be applied. Financial constraints however led to a much simplified version that was installed by contractors without much consultation with the community. As a result of the upgrading, new squatters settled in the area, but intensification of density was unplanned and came very quickly, increasing the quantities of runoff water in the area. When the quantities of water increased, the speed of the runoff water increased as well. Water sometimes poured out of the drains and caused severe erosion, and this was aggravated by blockages at some points caused by garbage. The erosion became so severe that some houses were undermined and had to be demolished. In the end, inundations and standing water in large pools became common. Finally, a totally new drainage system had to be developed.
The construction of a minimum drainage system had created problems more serious than those that existed before, and one of the causes might have been the lack of consultation with the community and the absence of maintenance and repair provisions.

Community participation

Community participation has a considerable role to play in improving infrastructural services such as drainage, but it is not a spontaneous and automatic process. It requires initiative, management and a certain technical capacity. Two factors have until now stood in the way of effective community participation in drainage:

1. When drainage problems occur, the reaction and mobilization usually come after the harm has been done. By then, the problem seems so complex that the residents of the neighbourhood feel incapable of doing something about it. Thus the people just suffer or move out of the area.

2. Drainage problems are not confined to a single area. A problem in one area can be caused by a problem in another area. Also, solution of the problem in one area can easily lead to other problems in an adjacent area.

It cannot be expected that a neighbourhood solve drainage problems itself, but effective measures exist for solving drainage problems that are well within the reach of the community.
Co-ordination between the community and the municipal authorities is absolutely essential, but has been haphazard at best in most countries. In all cases, participation in drainage requires planning and co-ordination, because the individual action of a few people will not solve anything.
Community participation in drainage has to be institutionalized, meaning that certain responsibilities and specific tasks are vested with the community, while others belong to the domain of municipal authority. Without such a partnership, attempts to solve drainage problems will meet with little success.

Generating participation

The successful construction of a drainage system in a neighbourhood does not guarantee a successful drainage project.
Users have to be aware of operation and maintenance requirements at the neighbourhood level.
The experiences of the past decade clearly show that user involvement at various stages of project planning and implementation is basic to the success of drainage projects. The main reasons for the failure of water supply and sanitation projects in general (including drainage) are:

1. The choice of technically or socially inappropriate systems.

2. Failure to involve the users in project planning and implementation, resulting in lack of motivation and skills for the upkeep of the system.

Too often, project staff members assume that the community (the users) has the same motives with regard to improving drainage conditions as they have themselves, but this is seldom the case. The planning of a drainage project should be based on some understanding of what motivates people to act in a certain way.

Motives that can contribute to participation in a drainage project are:

- Group pressure;
- Drive for modernization;
- Comfort and safety;
- Affordability and profit;

Group pressure
There is little doubt that group pressure is the most important motivating factor for participation in drainage. When a massive campaign addresses itself to the entire population in a certain neighbourhood, different forms of group pressure will emerge.

Group pressure can take the form of political pressure whereby the authorities make regular checks on project progress. In each community, considerable internal pressure exists to comply with decisions taken by its leaders after consultation with the community. So, even if the individual community member may not understand all of the decisions taken, it will not be easy to disobey and face questions by others.

Group pressure may also arise among the community members themselves. The mere fact that the others participate constitutes a psychological pressure on the individual to conform. Those who have complied will remind the other of it, and in the end the latecomers may find the price for staying behind too high.

Schoolchildren play an important role in influencing the parents. Parents will find the appeal by their children (not to lag behind and to be a progressive community member) a strong form of group pressure.

It is therefore advisable to avoid rushing decisions and to give the community time to discuss and consider the merits of the drainage project.

If, after some time, the leadership agrees to carry on with it, most community members will be inclined to obey whether they understand the project or not.

Modernization
The wish to modernize and to give the neighbourhood the appeal of a high-income settlement can become a motive to participate in the project.

Comfort and safety
An effective sales argument for drainage is the prospect of not having to wade through pools of stagnant water anymore, or to have no more collapsing houses and mudslides.

Affordability and profit
The economic benefit of a drainage system may be difficult to establish, as it can only be stated in general terms such as "improved health conditions" (which saves on health care), "improved safety" (which saves on hospital bills) and "added value to private property" (which makes the house profitable to sell or to sublet). If convincing facts and figures can be provided to demonstrate that the drainage project is affordable to the community and gives economic returns, they will be a very effective motivation factor.

Drainage projects will only generate community participation and will only meet with success if motivation is so strong that drainage becomes a priority to the community. If people cannot be sold on the idea that drainage is a priority, a drainage project is doomed to fail.

The basis of a successful project is sound knowledge about the future users of the drainage system. This knowledge can be acquired through socio-economic surveys, and such surveys should collect information about the prevailing opinions, attitudes, motivations and skills of the users.

QUESTIONS

1. To what factors can drainage problems in low-income settlements be attributed?

2. Some drainage problems are avoidable and others unavoidable for low-income settlements. List which are which.

3. For drainage problems which are avoidable, how can community participation help in preventing the problem before it occurs <u>or</u> help in solving it after it arises?

II. DRAINAGE OPTIONS

Hierarchy of systems

The drainage problems of one single neighbourhood cannot be solved in isolation because they are part of a hierarchy of problems related to the drainage system of the entire city. If this fact is not taken into account, the solution for surface drainage problems in one area becomes the cause of flooding in another.

It is therefore necessary to understand the hierarchy of drainage in the whole urban area to be able to solve the problems of a single neighbourhood.

The **primary system** is the ultimate "recipient" - the river, lake or sea which will absorb all of the surface drainage water from the entire area. Usually this primary system has a water level that at all times is below the average water level of the urban area. This is not, however, always the case. There can be seasonal fluctuations which prevent a direct discharge into the primary system. This can be the case with seasonal high water in rivers or with daily high tides along low-lying seaboards. In these cases, discharges may have to be regulated to coincide with the occurrence of a suitable water level.

The **secondary system** or "collector" is the drain which leads the neighbourhood's water to the primary system. In many towns, these are man-made drains which, to a large extent, determine the groundwater level in the flat land of the town. In very flat areas, as in the case of delta areas, such drains can only be emptied during certain periods when the primary system is at a sufficiently low level. The drains serve in the meantime as retention basins.

The collector can also take the form of a retention area (a pond, basin or park area) which stores the water during peak periods and drains it thereafter into the primary system.

The **tertiary system** or 'neighbourhood network' is the basic system of the hierarchy. It can consist of:

- Natural runoff from buildings, paved areas and vegetation cover;

- Natural runoff through permeable soil layers;

- Open drains (ditches, channels, trenches, gutters);

- Closed drains (pipes, conduits, ducts, culverts);

- A polder system that artificially controls the groundwater level.

This tertiary system unloads its water into the secondary system.

This paper only deals with tertiary systems, that is, drainage at the neighbourhood level. Drainage will not be much of a problem in low-density, gently sloping neighbourhoods, because, in such areas, drainage can take its natural course. It becomes a problem, however, when slopes become either too flat or too steep.

Design principles

The idea of a good drainage system is that it is able to handle normal as well as heavy rains. For that reason, drains usually have a _/ section. When little water is flowing through the drain, only the narrow bottom of the drain is used. When the water rises higher, a larger section of the drain is used. The advantage is that the water will have a steady flow speed and will keep the channel clean whether the water level in the drain is low or high. The _/ section comes close to the ideal parabolic drain section in which water flows most evenly, reducing deposits of dirt to a minimum. The parabolic shape, however, is difficult and expensive to make.

The only reason for using drains with a |_| section instead of a _/ section is lack of space. The staight drains use less than half the surface that the _/ drains use.

In principle, there is no reason to drain all water out of the neighbourhood as quickly as possible. The soil should be allowed to absorb part of the rainfall, as this will benefit the growth of trees and gardens. This is especially important in neighbourhoods with a low groundwater table. In neighbourhoods with a permanently high water table, rainwater should be allowed to run off as quickly as possible.

In moderately dense neighbourhoods on gently sloping terrain, drains can be designed as flat as possible and be unlined to allow rainwater to be absorbed into the soil.

In high-density settlements, where almost all surfaces are covered with roofs, footpaths and roads, all water can be expected to run off. The small patches of soil remaining are usually clogged by household waste that renders the soil impermeable. In such settlements, very little can be done to keep water in the ground for tree-growing.

On very steep terrain, water can only be kept in the soil by artificial reduction of the slope. Various methods of terracing exist, but they can only be applied if the neighbourhood has not already been fully built up.

As for roads, municipalities prefer high standards of design and execution for drainage, in order to reduce the annual cost of maintenance. When dealing with low-income communities, municipalities will have to compromise, in order to make the cost of the neighbourhood system affordable to its inhabitants. Design standards can be reduced by:

- Dimensioning the neighbourhood system for average rainfall and not for the occasional peak rainfall. This will considerably reduce the size and, thus, the cost of the system. Occasional overflowing of the system at the neighbourhood level is considered acceptable, as it will not result in much damage. However, the secondary and primary systems have to be dimensioned for peak loads, as the accumulated peak volumes of water from all tertiary systems together will cause great damage when led into a secondary system of insufficient capacity.

- Selecting cheap design solutions, such as a low number of unlined drains instead of a dense network of lined drains. As the use of cheap solutions will result in high maintenance costs (unlined drains have to be cleaned and remodelled often), the community will have to take care of maintenance. The system's design will therefore have to strike a balance between what the community is able and willing to do on the one hand and what it can afford on the other hand.

Steep slope drainage

Steep slopes are not attractive as land for housing, because they create many technical and practical problems. Steep slopes are prone to erosion and landslides, have difficult access, are expensive to build on and are inconvenient to use. The cost of building on slopes increases when density becomes high. From the point of urban land use, slopes are considered marginal lands, and this is the reason why many low-income areas are built on hillsides and suffer from the ill-effects of erosion.

Sloping land easily suffers from erosion when the vegetation cover is damaged and when intensive land use bares the soil. It is therefore important to prevent water from rushing down in uncontrolled flows that may undermine houses and erode the soil.

As a rule of thumb, slopes of more than 5 per cent are considered steep slopes, and drainage design for such slopes should attempt to reduce the slope to something near 1 per cent.

Different methods exist for leading the water down gradually and in manageable quantities:

1. Diverting the water horizontally through sideways drains, thus reducing water speed (page 13);

2. Stepping the drains to form a series of almost horizontal sections (page 14);

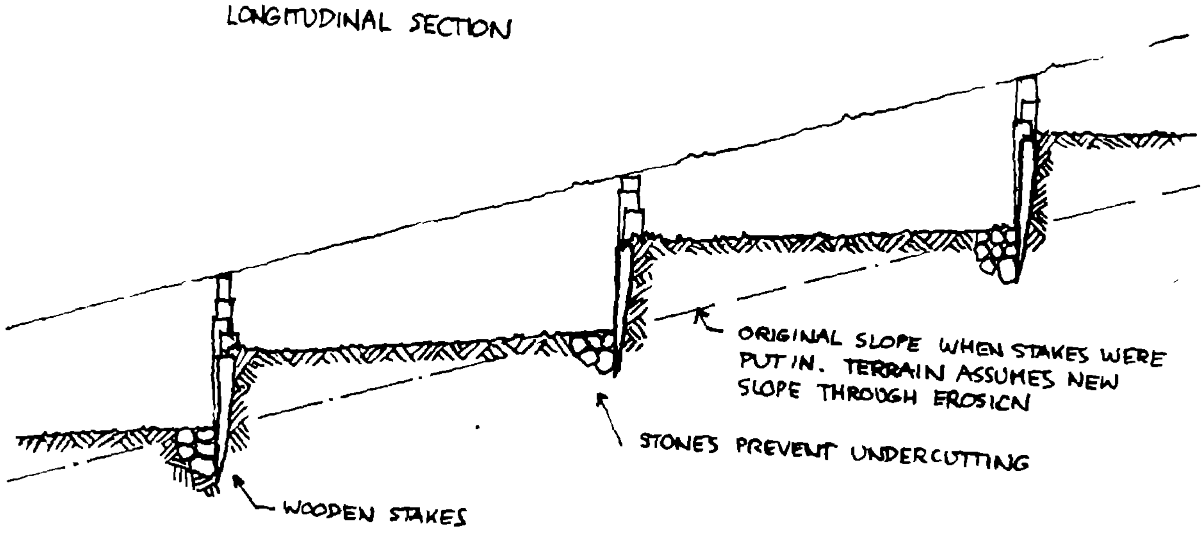
3. Leading the water in a controlled zigzag manner through baffles built into drains (page 14);

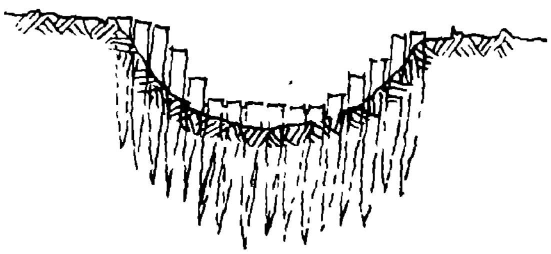
4. Combining 2 and 3, so that the soil settles behind the baffles and gradually builds a stepped drain (page 15).

Although these measures help reduce water speed and increase absorption into the ground, most of rainwater will have to be led down the slope at the same rate as the rain reaches the ground. The disposal of water at the bottom of the slope requires a recipient of large retention capacity, and lack of such capacity may lead to severe problems in still lower areas.

REDUCTION OF SLOPES (GRADIENTS)

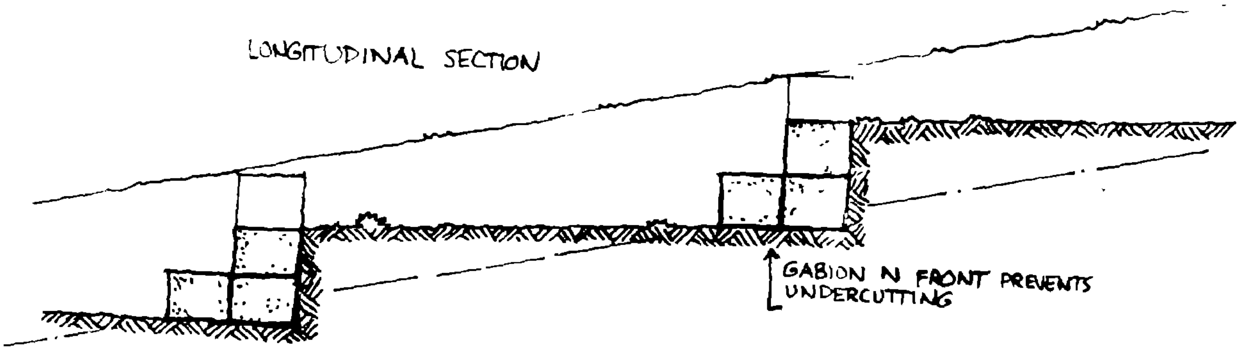
LONGITUDINAL SECTION

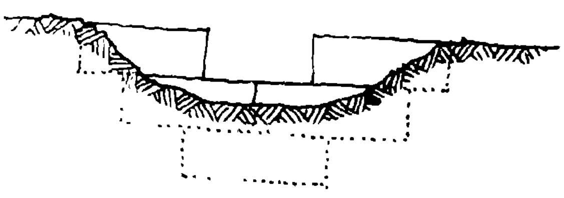




CROSS SECTION

LONGITUDINAL SECTION





CROSS SECTION

On very steep slopes, roadside ditches have a very high water-runoff speed (flow velocity), but gentle side drains can lead the drainage water away from the road.

Stepping the ditch might be a cheaper solution than this in high-density settlements. The control of the runoff system on sloping sites is always difficult, but, in spontaneous dense settlements, it may require large engineering works to which the communities themselves usually have little to contribute.

Flat land drainage

There are different methods to achieve a satisfactory groundwater level in flood prone areas:

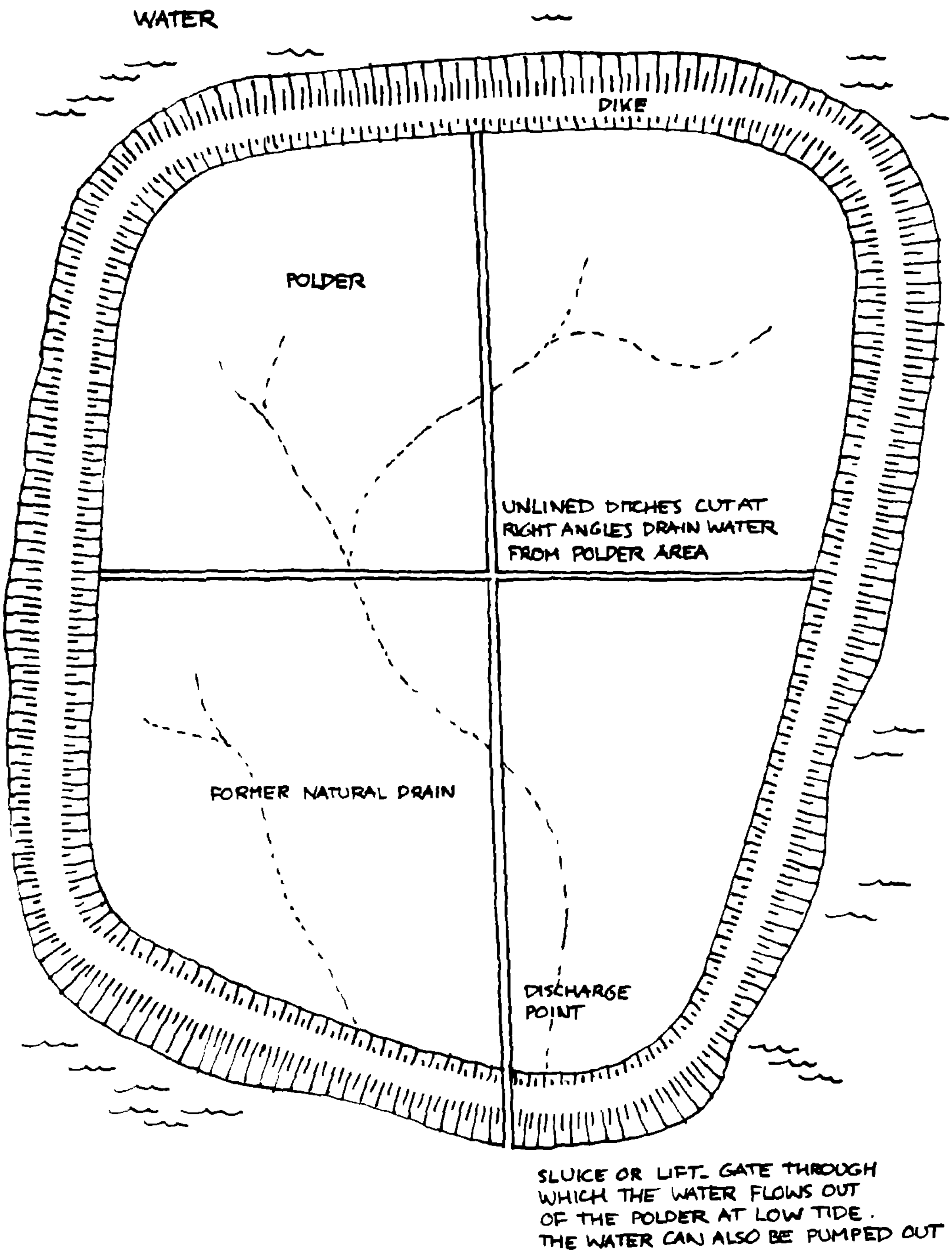
1. Ditches (unlined drains) to lead surface water to lower ground can be constructed. If there are lower areas to which the water can be led, this method can be used to control the flooding effects of sudden storms. Lower land, lakes or rivers are suitable recipients for the water from ditches. Their suitability depends to a large extent on the slope of the terrain.

2. If the land is quite flat, a low-lying retention area (where a sudden inflow of water can be stored) has to be found, until natural runoff can take care of the excess water.

3. The development of polder units can be a solution in extremely flat areas, such as large river deltas. A polder is a land area protected by a dike and/or a deep ditch all around. The groundwater level within the dikes is controlled by pumping the water out from the polder area into a higher canal outside the dike. Polders are not effective in very sandy soils because the groundwater returns as soon as it is pumped out (page 17).

4. If control of the groundwater level is very difficult, landfill may offer a solution. This can be done either by raising the entire surface of the area or just part of the area.

THE POLDER SYSTEM



5. If none of the above options is possible, as may be the case in some coastal swamp areas, it may be necessary to have all the houses built on stilts and to build elevated roads and pathways for access. It is, however, very difficult to maintain acceptable living conditions in such areas. It may be better to move the settlement to high ground. If this is not possible, great care has to be given to environmental conditions, especially proper waste water disposal.

The Thai example

The "Building Together" project in Bangkok is a good example of polder technology in a low-income housing area.

The housing project was developed for slum dwellers from nearby areas and had to be accessible for people of their income level.

The site that was made available was located in a very swampy area, and the environmental conditions necessitated special drainage provisions before construction could take place. The whole area was therefore surrounded by a stone/earth dike and drained from its lowest point by pumps. The water was discharged at the other side of the dike.

Access to the area was restricted to one or two roads going over the surrounding dike. Although the system required high investments and high maintenance and operating costs, it was justified because a large number of people benefited from it and co-operated to keep costs down. The maintenance staff of the area often doubled as security personnel.

The polder system is only workable if very regular maintenance and management can be guaranteed. The pumps have to be serviced and operated professionally, the dikes need inspection and repair, and the internal drainage system needs cleaning. The system in Bangkok worked because it was part of the whole neighbourhood management system which functions as an internal government, involving all the households. It governs task distribution, inspections and taxes, and others full accountability before the community.

The polder system proved to be quite economical, and, in spite of the severe floods that hit Bangkok several times after completion of the system, the "Building Together" project did not suffer from inundations as did the rest of the city.

The "Building Together" case demonstrates that a high level of community participation is possible in low-income areas. The extreme consequences of a failing drainage system are clear to all dwellers, and co-operation is therefore recognized as an essential element in achieving decent housing conditions.

Drain design

The drainage system that is built in an area is usually based on a network of drains that can be unlined, lined or partially lined (page 20).

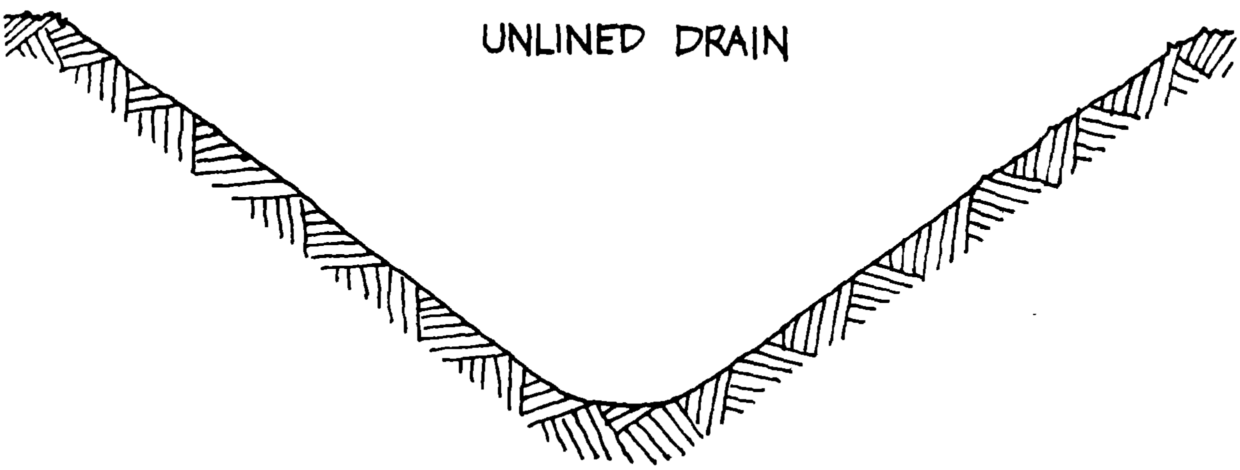
Unlined drains
Unlined drains or ditches can be made with the help of tractors or manually excavated with hoes, picks and shovels. Unlined drains can only be built on land with gentle slopes. If the slope is more than 1 per cent, the water speed in the drain will become higher than 0.5 metres per second, and the drain is likely to be damaged by scouring. The speed of the water can be reduced by growing grass on the inside of the drain or by stepping the drain (stone or brick steps at the bottom of the ditch so as to decrease its slope).
Open, unlined drains also need to be wide. The slope or angle of uncovered sides should be about 1 measure vertical to 2 measures horizontal (1:2), but, if grass-lined, sides can be as steep as 1:1.

Partially lined drains
For slopes between 1 and 5 per cent, water speed increases from 1 to 5 metres per second. This makes lining necessary. Partial lining of drains is less expensive than complete lining, and it protects the drain from scouring at the most vulnerable points, such as:

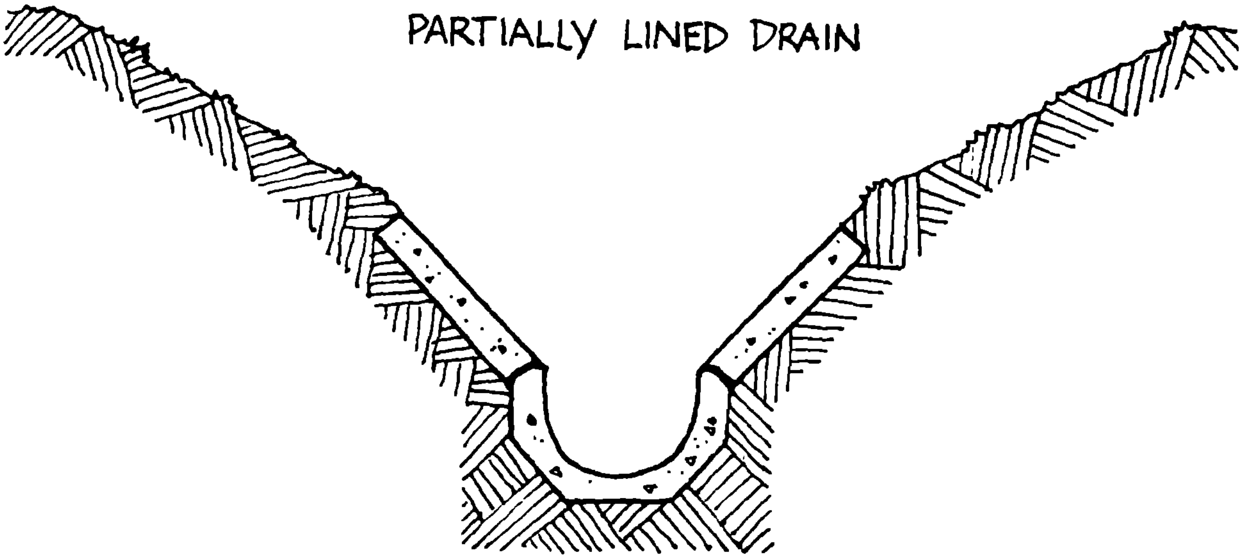
- Culverts
- Drain junctions
- Sharp bends
- Steep sections.

For these slopes, lining does not have to be made of solid masonry. A compacted gravel or stone layer will be sufficient.

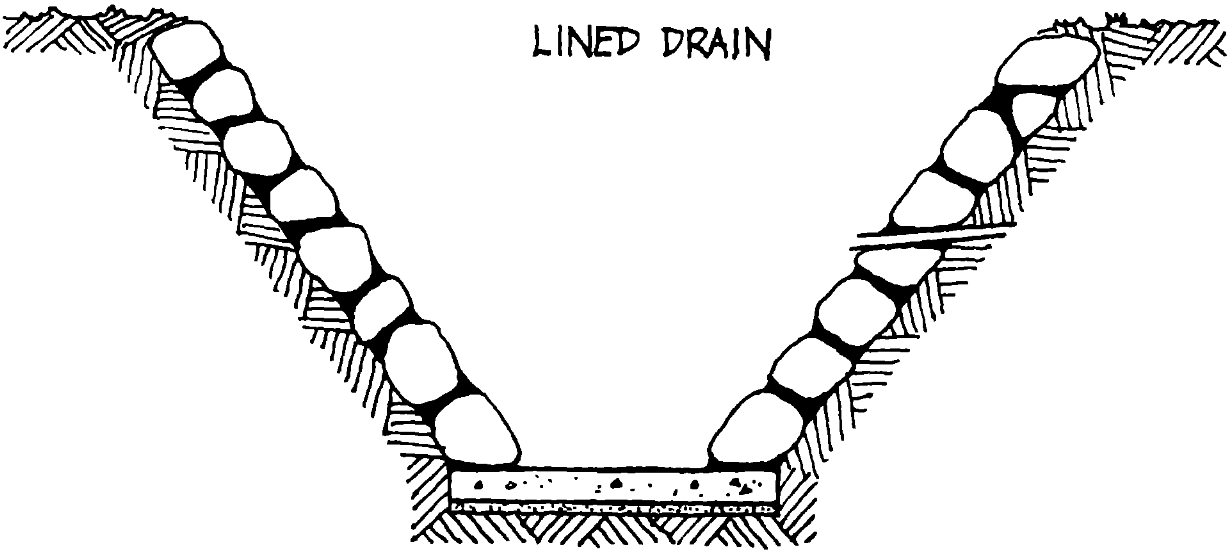
UNLINED DRAIN



PARTIALLY LINED DRAIN



LINED DRAIN



Lined drains
Fully lined drains are used as soon as the slope exceeds 3 per cent, or water speed exceeds 2 metres per second. In that case, loose lining with stones will not be enough, because the water will wash out the joints rapidly. Drains can be lined in several ways:

- Stabilization with bitumen, cement or lime - a cheap but not very durable solution, requiring much maintenance;

- Paving with stones, bricks or cement slabs;

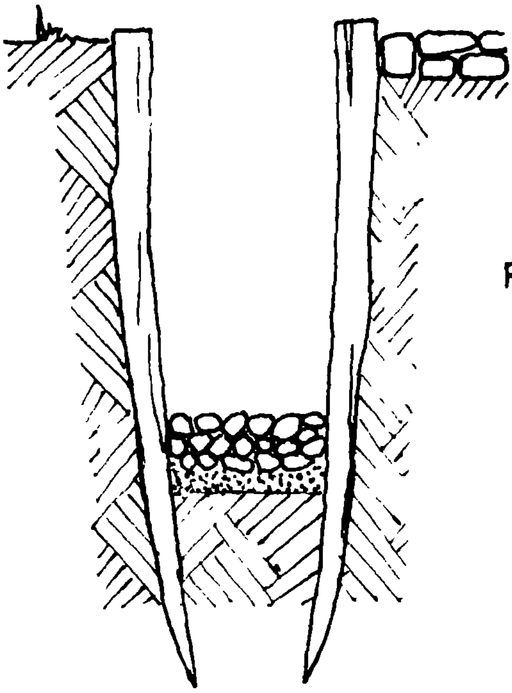
- Paving with concrete drain elements, either prefabricated or cast on the site.

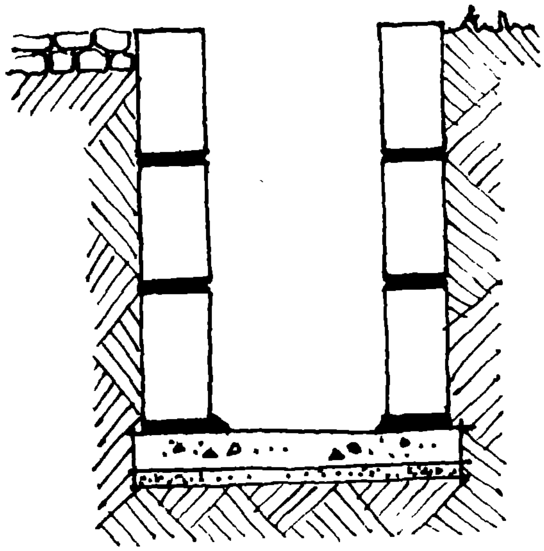
|_| shaped drains are always lined because the vertical walls are vulnerable to scouring and traffic damage. As this type of drain is only used when space is in short supply and drains have to pass close to houses, the lining also protects the foundations of houses against erosion (page 22).

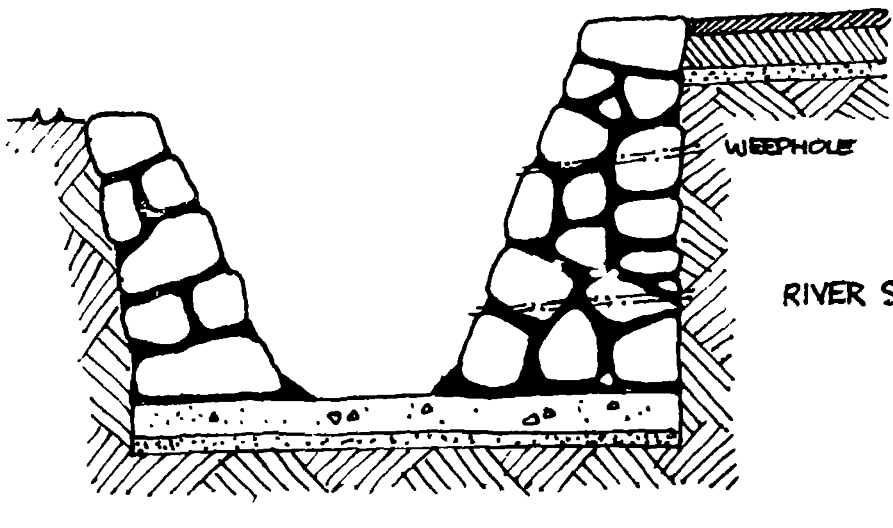
Roadside drainage
Drainage of roads is the most essential aspect of road maintenance. Without drainage along the road, water enters the road base and destabilizes it. The amount of traffic a road can take depends on the bearing capacity of the road and on the stability of the road base. Erosion of the road base may be caused by water entering from the road top (when unpaved) or through cracks in its facing. It can also enter the road base from the sides if there is no road drainage. In both cases, the bearing capacity can rapidly disappear, leading to collapse of the road's surface.

The construction of open roadside drains is an economic method to ensure the stability of the road and to drain the adjacent land at the same time. The correct positioning of roads can therefore effectively control erosion. If the road reserve is large enough, drains on both sides are preferable, but, if this is not possible (as in very dense neighbourhoods), a drain can be made on one side only. In this case, care must be taken that surface water from the other side easily flows over the road into the ditch without penetrating the road base.

LINED DRAINS USING LITTLE SPACE







Where drains have to cross roads, culverts are built which lead the water underneath the road. Culverts can be made of reinforced concrete pipes which can take heavy traffic loads but are expensive to make. Galvanized corrugated iron sheet culverts are cheap but need to be placed deep under the road (as deep as the culvert is wide) in order to avoid flattening by traffic load.

The problem with deep culverts is that they can easily become clogged by deposits. Building the road higher than the surrounding terrain does not always eliminate the problem because the road can act as a dike, keeping water from running off and thus creating pools of stagnant water.

In very dense neighbourhoods, roads and drains are sometimes combined in one. Two methods are used (page 24):

1) The drain is built underneath the road and covered by concrete slabs which allow for traffic load.

2) The road has a double function as a stormwater drain (this can only be done if the slope of the terrain does not exceed 5 per cent and if the surface of the road is compacted with gravel or stone to prevent washing out).

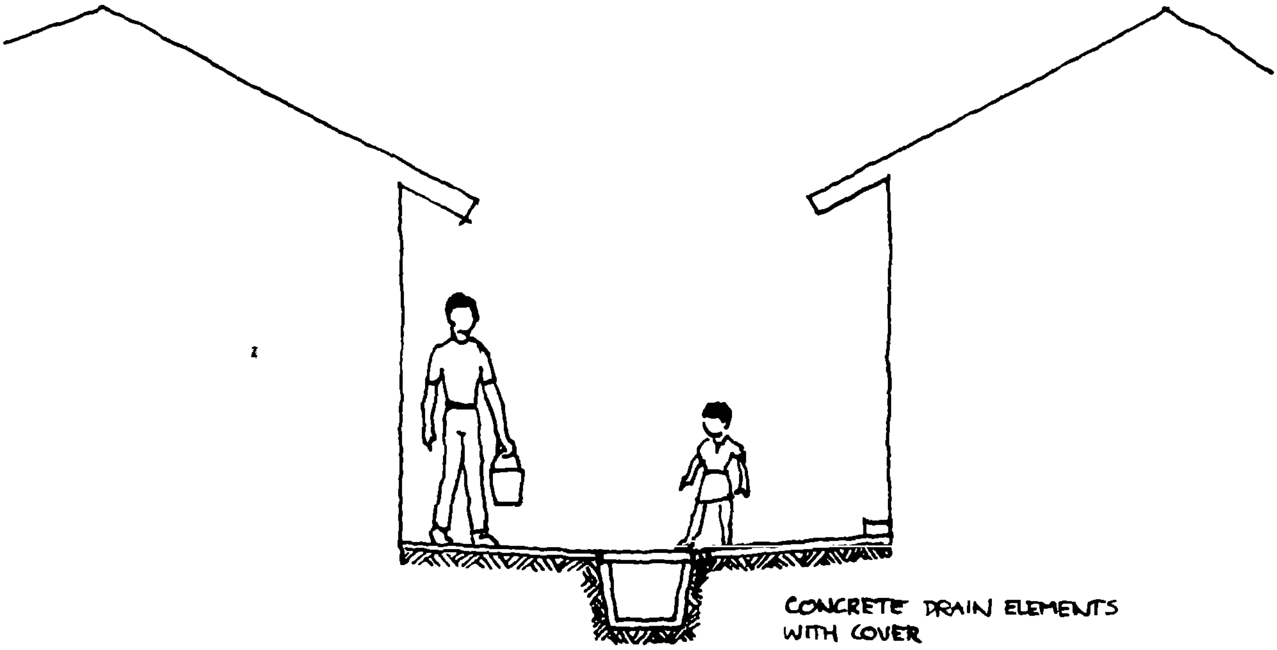
Gabions

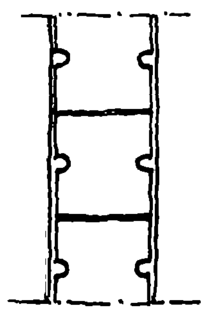
Gabions are packs of big stones held together by heavy galvanized wire mesh. They have a rectangular shape and can be as big as 1 cubic metre.

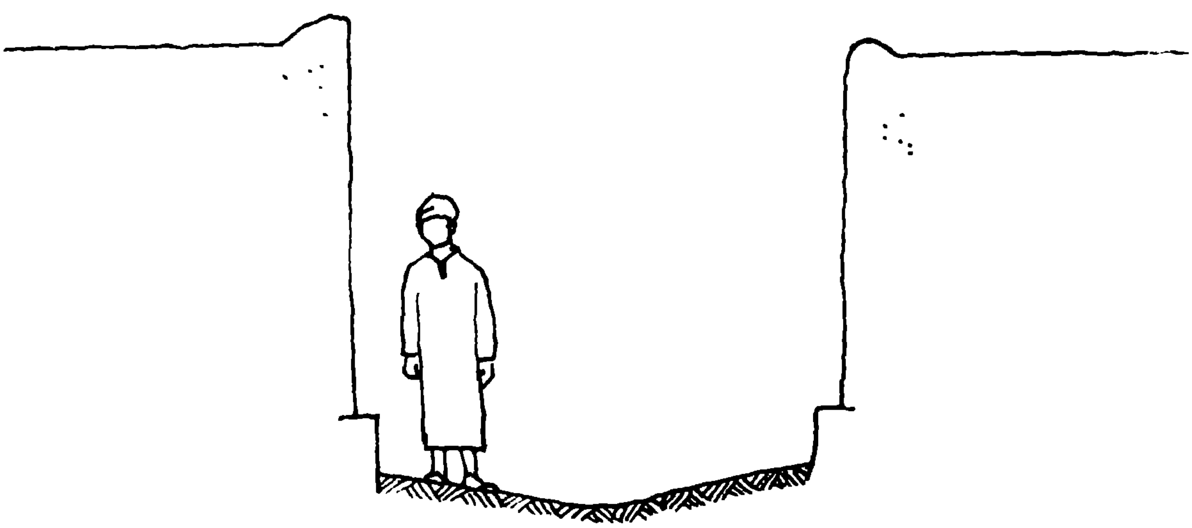
Gabions can be used to:

- Protect vulnerable places such as bends in unlined drains and outlets of culverts;
- Protect steep slopes from erosion by transforming the slope into a number of terraces;
- Protect vertical parts of the terrain from collapsing or sliding down by forming an embankment (page 25);
- Protect steep drains against scouring by forming barriers or baffles (page 25);

COMBINED DRAINS AND PATHWAYS

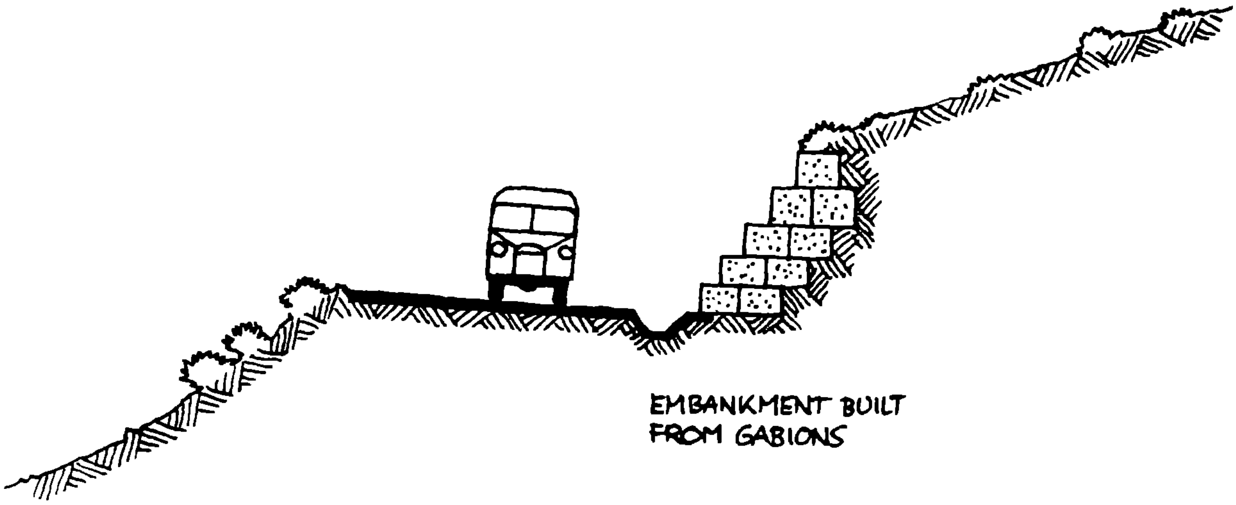




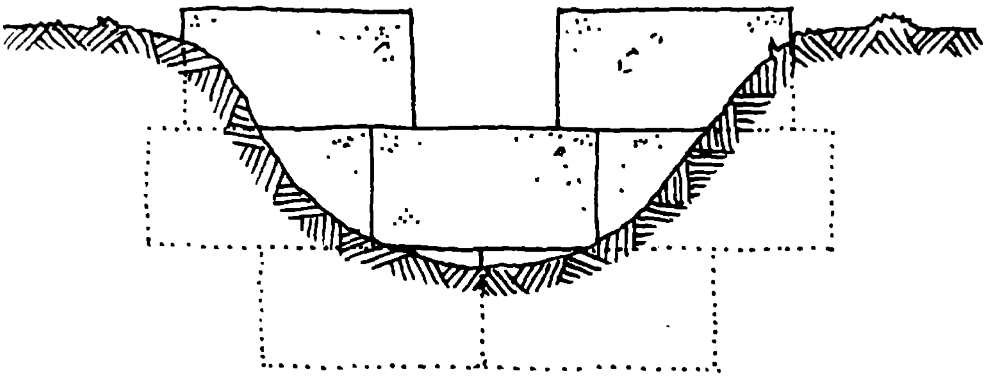


ROAD AND DRAIN IN ONE: ROAD COMPACTED WITH
STONE AND GRAVEL, SLOPE MAX .5 PER CENT

THE USE OF GABIONS



EMBANKMENT BUILT FROM GABIONS



BAFFLE BUILT FROM GABIONS WITH OUTLET ON TOP

Depressions

Depressions are low-lying parts of the terrain which collect rainwater. In small neighbourhoods, they are easy to identify, but, in large slums or squatter settlements, residents will have to assist in identifying all the trouble spots. Identification can also be made by aerial survey, with a small plane and a 35mm handheld camera, after one day of heavy rain. The standing water pools visible in the pictures can then be drawn on a map of the area. This is usually easy because the pools stand out clearly and coincide with the contours on the map. Ground checks will yield all the other necessary data and plans can then be drafted accordingly.

To deal with depressions, three courses of action are possible:

- Build a drain from the lowest point of the depression and connect it with the overall drainage system (this means cutting a deep channel through high surrounding land or putting in a pipe);

- Designate the depression as the retention area, with a permanent pond in the middle into which water from the catchment area is led;

- Build soakage pits into the depression.

Soakages may consist of deep boreholes filled with stones, which will lead surface water through impermeable ground layers into the groundwater. Boreholes drilled with hand augers to a depth of 3-5 metres have solved the problem in a number of cases.

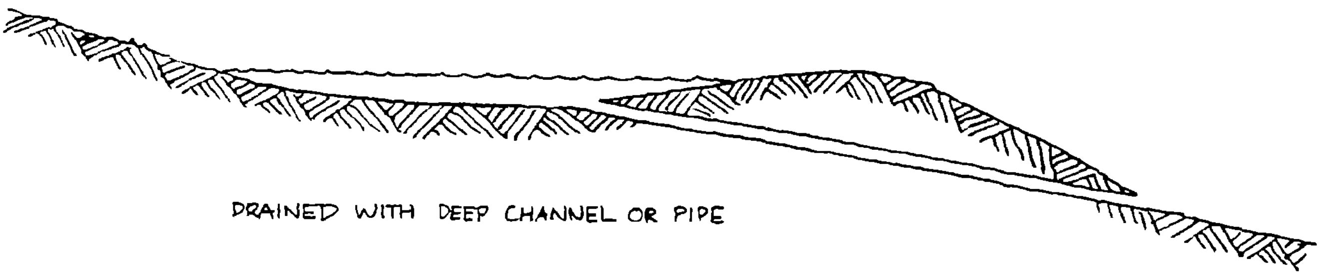
Clogging of the soakage may, however, occur, and it may be necessary to build a serviceable filter at the top of the soakage (page 27).

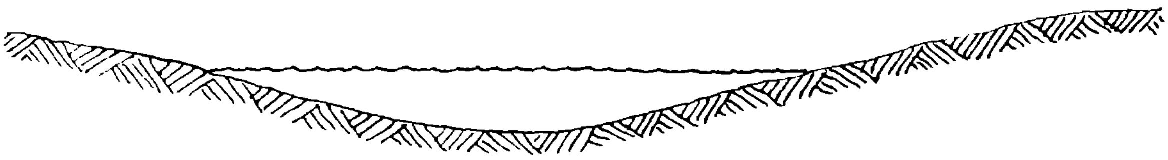
QUESTIONS

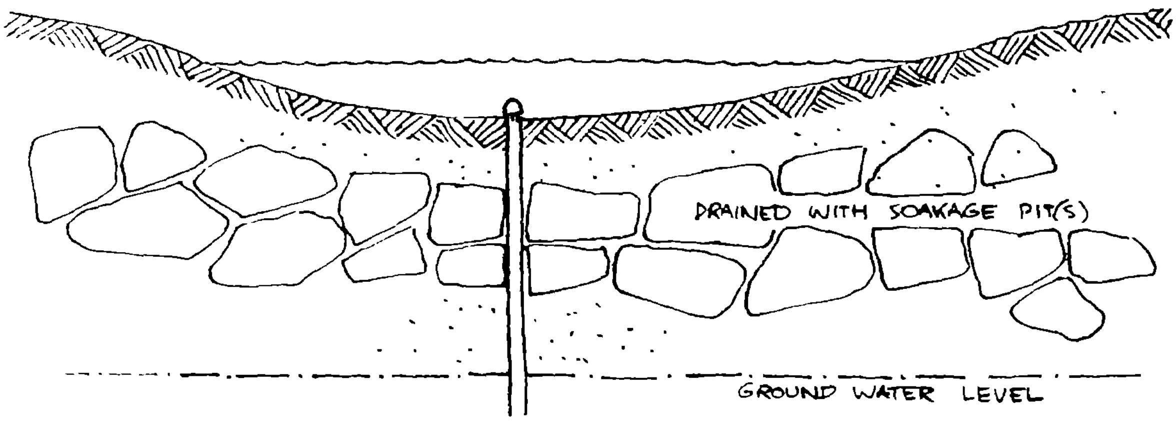
1. For a settlement in this town chosen by the workshop, which drainage options appear most feasible? Why?

2. Who is going to decide which option is most suitable, and how will such a decision be taken?

DEPRESSIONS







III. PARTICIPATION IN PLANNING

The drainage committee

Although the design and execution of a drainage system are professional tasks, community participation is important in order to keep the system in good working order once the project is completed. Community participation may be motivated/stimulated when municipal authorities are not able, for whatever reasons, to provide or maintain a drainage system in the neighbourhood.

A system developed in collaboration with the community is much more likely to be kept in good shape by the community members than a system imposed on them. The issue is especially sensitive when improvements done for one area require works to be executed in another as yet unimproved neighbourhood.

The foundation for community participation is a drainage committee, with representatives from the community and the municipal authorities. It should be created at the start of a project. Community representatives will have to be selected who are prepared to spend time and energy for this purpose.

In some cases, it may be on a totally voluntary basis, but it is most likely that a certain remuneration for the work done in drainage committees is justified. This is especially the case when the government department dealing with this matter has a shortage of material and human resources.

The first task of the drainage committee is to participate in the planning process.

Planning is above all a decision-making process, and the following important decisions will have to be made with regard to the drainage project:

1. What will the community do in the planning stage;

2. What will the community do in the construction stage;

3. What will the community do in the use/maintenance stage;

It means that during the planning stage, the community will have to decide what it is going to do in the future. It is essential for project staff to exploit the potential for decision-making in the planning stage, as it is likely to determine failure or success of the project. The more decisions can be taken in the planning stage, the better it is for the future of the project.

In the planning stage, the drainage committee can make the following contributions:

- Data collection, on the basis of which design decisions can be made;

- Implementation agreements, on the basis of which construction can be scheduled and carried out;

- Use and maintenance agreements, on the basis of which maintenance of the system can be scheduled and carried out.

Data collection

Before a drainage system is designed for a neighbourhood, the following research should be done:

(a) Identify the natural drainage system of the whole town, especially the location and the characteristics of the recipient in relation to the neighbourhood;

(b) Determine the catchment area for the neighbourhood and obtain a map of the area;

(c) Determine the direction of the surface runoff by looking at the natural erosion gutters in the area;

(d) Identify the areas where water remains standing for long periods after the rains;

(e) Put the contours on the map and mark the gradients along which the rainwater has to be drained;

(f) Combine the location of drains with the desired location of roads;

(g) Identify all points where drainage systems and roads will have to cross, so that culverts can be built at those points in advance;

(h) Combine the desired location of roads with the location of pathway crossings, taking into account where crossings will develop spontaneously, since at these crossings, small bridges will have to be built;

(i) Find out whether any other neighbourhoods are discharging their rainwater into the neighbourhood to be drained;

(j) Determine suitable release points where the neighbourhood can discharge its water (these points should be located in the lowest part of the area to be drained).

The next stage is the actual design of the drainage system. There is little the community can contribute to design, but it is the project staff's duty to make the community fully aware of its implications.*

Community self-surveys can simplify much of the data-collection work required and is a very productive form of participation. There are two data collection activities to which the community can contribute in the planning stage:

- Ground survey;
- Aerial survey.

Community participation in those two activities is useful, because the technicians can benefit from the community's intimate knowledge of the area it lives in.

Ground survey
This consists of a systematic collection of local data over a period of time and the relay of these data on to a map. Much of this information can well be collected by non-technicians and will concentrate on the following:

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* The annex to this paper explains basic design and calculation principles.

- Runoff patterns or the directions in which the water flows;

- The occurrence and level of standing pools after heavy rains.

Simple maps or, even better, aerial photographs showing such data, as well as markers on the ground, will enable the engineer to prepare the basic design for the drainage system.

Aerial survey
A map consisting of a collage of aerial photographs on a small scale (e.g. 1:1000) is an implement easily understood by community members. It does not take a long time to recognize familiar areas and, with little training, they will be able to use such a map for data-collection or surveying purposes. The use of Small Format Aerial Photographs (SFAP) has, in recent years, developed into a very effective tool for the planning of infrastructure in existing settlements. A small aeroplane (an ultralight for instance), flying at a height of about 600 metres can, with an ordinary camera, map the area on a practical scale.

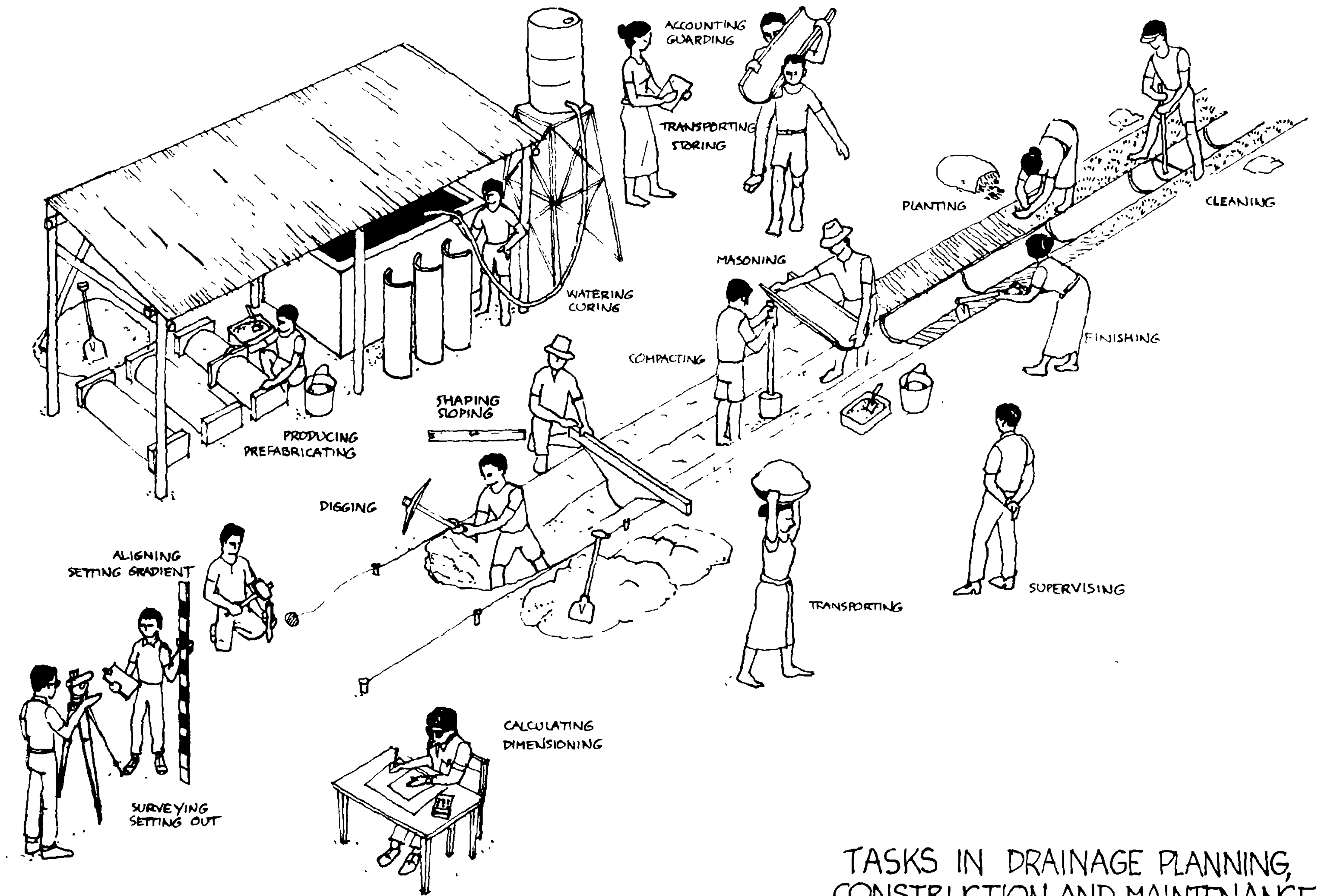
At this low altitude, survey flights can be done under any reasonable weather conditions. The shadows cast by clouds will not interfere with interpretation of the photographs.

Low-cost mosaic maps not only lend themselves to the rapid drawing of runoff patterns but are easy to read for non-technicians. Ground verification by community members using these photographs as maps is an effective method of data collection. Even for interpretation, community members are very helpful because of their great local knowledge. They can be asked to go out and check the conditions of a certain section of the drainage system, mark on the photograph the extent of the flooding, the occurrence of blockages in a drain etc.

Community self-surveying works only if it is planned in co-operation with professionals who are involved in the actual design work.

Implementation agreements

The implementation of a drainage project takes place at three levels:



TASKS IN DRAINAGE PLANNING, CONSTRUCTION AND MAINTENANCE

- Engineering work;
- Construction work;
- Supportive work.

Each level requires different skills and know-how. The following tasks are done at each of these levels (on page 33):

Engineering:	- Calculating, dimensioning; surveying, setting out; aligning, setting gradient; supervising.
Construction:	- Shaping, sloping, paving; prefabricating, supervising.
Supporting:	- Digging, compacting; watering, curing, cleaning; transporting, storing; accounting, guarding; planting, finishing; supervising.

The community will, during the planning stage, decide to undertake a number of the above tasks in agreement with project staff. It is the responsibility of project staff not only to make clear what each task means in terms of time and effort but also to provide the necessary training for proper implementation of such tasks.

The implementation agreements will specify:

- The quality standard of the work to be done;

- Labour conditions;

- Building material cost and supply specifications.

Chapter IV will discuss what distribution of tasks is possible in order to have effective community participation in project implementation.

Use and maintenance agreements

The community will assume its share of responsibility in the use and maintenance of the drainage system. This will determine, to a large extent, the cost of operation of the system. Whether individual community members will be responsible for taking care of that part of a drain which is on their plot or whether collective arrangements are made, the necessary agreements should already be reached in the planning stage.

For instance, car drivers dislike drains because they block access to plots. As a result, drains are often bridged with all sorts of materials, defeating their purpose. Ditches located close to houses are often built over when people want to add a room to their house. As a result, the drain becomes impossible to clean.

Use and maintenance agreements therefore have to specify:

- Bye-laws with regard to the use of drains;

- Pre-rain inspection schedules;

- Post-rain repair schedules;

- Reporting procedures for defects, blockages and so on.

Chapter V will discuss what distribution of tasks is possible in order to have effective community participation in use and maintenance.

QUESTIONS

1. There can be considerable constraints on community participation in planning. Make a list of constraints you expect can occur.
(A particular settlement should be selected for consideration, and the main concern should be how the problems and constraints regarding participation can be overcome and what cannot be overcome. In the latter case, an alternative must be suggested.

2. It is clear that both community and project staff have roles to play together for the planning of the project. It is not clear, however, how they start planning together. Make a list of who should do what to get project staff and community members together to plan the project.

IV. PARTICIPATION IN CONSTRUCTION

Scope for participation

Although implementation of a drainage system should always be co-ordinated byprofessionals, some of the tasks described in the previous chapter can be done by the community. They include the following:

- Excavation work (digging)
- Transport of soil, water, sand, cement
- Compacting of soil in drain foundation
- Prefabrication of drain elements
- Watering and curing of drain elements
- Transport and storage of drain elements
- Accounting and guarding of elements
- Finishing and planting of embankments

Most of these tasks require little special skill and can be done after an hour of instruction. The only task requiring real training is the production of prefabricated drain elements.

The prefabrication of drain elements can easily be learnt by semi-skilled community members and may also prove to be an attractive method of income generation. In many cities there is a ready market for prefabricated elements of this type.

The reasons for using prefabricated drain elements rather than *in situ* drains are mainly the following:

- Construction of a drainage system can be very disruptive to local traffic as it may block the roads for a considerable length of time. Masonry drains take a long time to construct, while concrete poured in place requires at least a week for the setting and curing of the concrete.

- Construction methods depend also on the availability of building materials, on-site water and the absence of rain. Masonry drains can only be properly executed when there is enough water available on-site to keep fresh masonry wet during curing time; also, work should be done completely outside the rainy season, because sudden downpours can easily ruin fresh masonry. When weather conditions are unpredictable and no regular supply of building water can be secured, it is best to produce prefabricated drain elements in covered workshops, for use as and when required.

There are two types of drain elements that can be prefabricated:

- Deep, narrow drain elements where no space is available;

- Shallow drain elements (for partially unlined ditches with grass embankments) where enough space is available.

For both types, simple designs have been developed that are appropriate for community production. The deep drains can be made in sections as long as four metres, but the shallow elements are usually not longer than two metres.

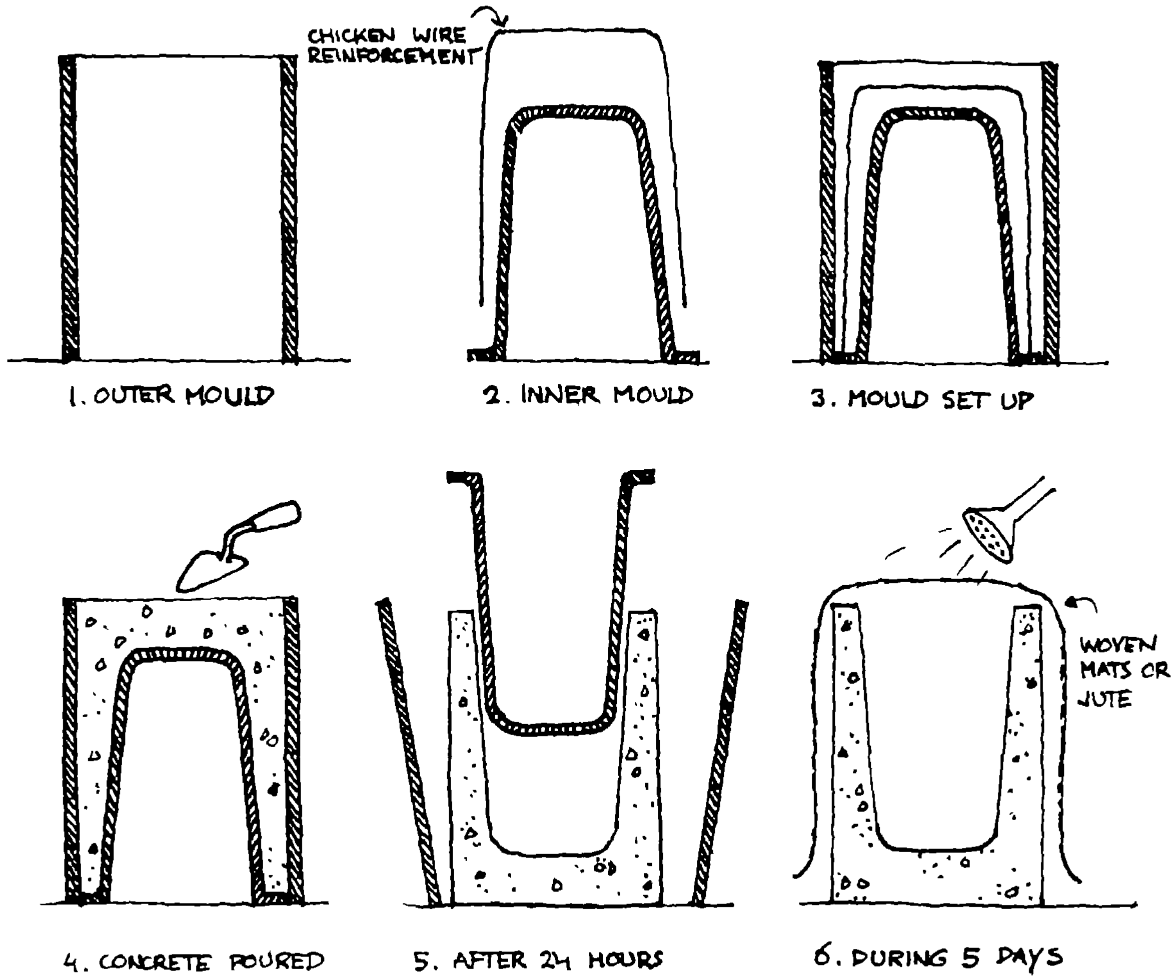
The production of drain elements requires moulds, storage space and basic concrete-mixing facilities. The prefabrication of elements has the advantage that quality control is easier and better than in conventional construction work. A practical requirement for prefabricated elements is that they have to be light enough to be carried by two persons (max. 50 kg).

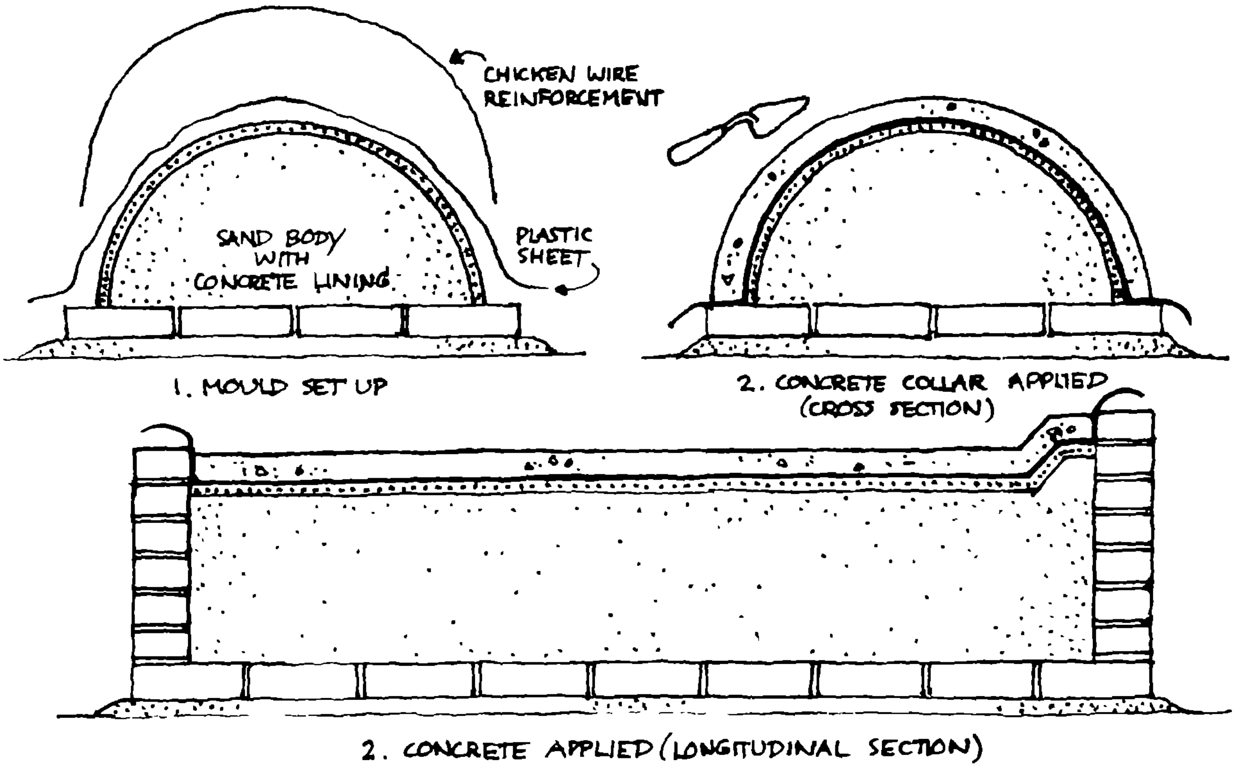
The Thai example

The National Housing Authority (NHA) of Thailand developed a simple prefabricated system of ferro-cement drain elements that could be produced in field workshops (page 39). After testing, the system was offered to small contractors who soon learnt how to set up efficient production units which produced channels either within the upgrading areas or in a central workshop. By producing the channels off-site and sending them to the construction site before the excavation work began, traffic disturbance in the area was minimized.

The Thai contractors taking up the NHA production methods soon found that there was a ready market for their products.

THE BANGKOK DRAIN ELEMENT





THE ROORKEE DRAIN ELEMENT

The Indian example

For the bottom part of shallow, partially lined drains, the Roorkee Research Centre in India developed a very simple system to produce ferro-cement elements using inverted moulds (page 39). The mould is made of a clay or sand ridge in the desired shape, covered by a thin concrete layer. Before preparing the element, this mould is covered by plastic sheeting or oiled newspapers. The drain element is made from a layer of cement mortar reinforced with chicken wire applied on top of the mould.

After two days of setting, the element is lifted off and cured for two weeks. During the first week, curing is done in a basin filled with water. During the second week, the element can be stored vertically and covered by mats which are sprayed with water in the evening. After that, the element is ready for use and can be taken to the site and fixed in position. A bitumen coating may be applied as a finish. The embankments of the drain should be stabilized by smoothing and compacting, while a grass cover should be grown and maintained to give the drain a greater capacity to deal with heavy rains.

The shallow drain is a pleasant green element in the neighbourhood but is only suitable if the embankments are kept free of traffic and if there is enough space in the area for this type of drain.

Some considerations

Although the community, can in principle, implement the tasks described above, participation in construction work should be given careful consideration.

Experience has shown that organization of the community for construction-related tasks can consume considerable amounts of project staff's time and energy. Especially when the work is not remunerated, it is not easy at all to get construction crews together at the time set for it by project staff.

If a contractor has been engaged to do the actual construction work, he might prefer to do the excavation and prefabrication of channel elements himself in order to remain in control of his construction schedule. If he has to wait for a community to get organized while his contractual schedule is already running, he will charge the delays as overheads to the project.

Community participation should be not a risk factor but a way to let the community directly benefit from a project. Viewing the community only as a source of free labour to bring down (theoretically) the cost of drainage construction should be avoided.

Instead, a contractor could be awarded the contract with the obligation of employing only unskilled and semi-skilled labour from the community concerned and of including a training programme for drainage masons and for the creation of a drain-element production enterprise, to be left behind as a permanent fixture after completion of the contract.

Although the contract cost will be incurred because of the employment and training clauses, project management will be eased, since the role of the community is clearly defined.

The advantage of community participation in construction is, above all, that the users, through their construction activity, learn what is required to maintain and repair the system. Construction not only improves building skills but also gives a sense of responsibility for what has been built.

QUESTIONS

1. What can the drainage committee do for the construction stage of the drainage project? Make a list of activities for this committee and mention whether the committee has to learn any new skills to carry out such activities.

2. Assuming that a contractor and the drainage committee have to work together to build a drain, who will have the last word on the time schedule - the contractor or the drainage committee? In your deliberations, consider social as well as technical aspects.

V. PARTICIPATION IN USE AND MAINTENANCE

Drainage failure

Drainage maintenance is necessary to avoid blockage or collapse.
The collapse of drains may occur through:

- Erosion of the bottom and sides of the drain (scouring);
- Root growth through the drain's walls;
- Excessive pressure on the drain's sides (vehicles, expanding or shrinking clay).

The causes of blockage can be:

- Accumulation of refuse, leaves and earth in the drain;
- Excessive vegetation growth in the drain;
- Soil deposits in low sections such as culverts.

Maintenance of drainage will include:

- Frequent cleaning of the drains;
- Periodic rehabilitation of the banks and slopes along the drains;
- Occasional repair of the drains and connected works.

Scope for participation

Community participation in maintenance takes place at two levels:

(a) A specialized team must repair the drains and connected works and may also have to check and maintain the main drain outside the neighbourhood that leads the water away from the area;

(b) The community must take part in the regular checking and cleaning of the drains.

One of the most important elements in any maintenance system is its regularity which can only be maintained if there is good co-ordination and a clear division of labour. It is certainly recommended that a neighbourhood appoint a standing drainage committee to plan and supervise maintenance work.

Inspection, cleaning and repair procedures will have to be institutionalized to become useful. If damages or blockages have been reported by a community member, there should be a maintenance crew on hand to respond. If such a community-based group can be organized, the community will care and will feel responsible for proper upkeep.

Prior to any rainy season, a systematic and general preventive inspection should take place. The drainage committee should look at four things:

(a) The state of the channels and culverts, in order to determine the extent of the cleaning required;

(b) The state of the masonry work and road-sides, including checks on erosion and water penetration that can undermine the structures;

(c) The state of the vegetation and grass cover on the bank of the drains;

(d) The state of planned and spontaneous pathway crossings over drains.

Project staff should make inspection sheets for this purpose. The sheets should clearly indicate what the inspection team has to look for and how they must do the inspection. Therefore each drain should be a separate inspection.

Then inspection sheets of each drain form the basis for the repair and maintenance schedule that will be given to the repair team and to the community for general pre-rain cleaning action. It is essential that there be a reporting procedure so that all the problems in the drainage system are centrally registered with the committee controlling the maintenance.

If community members have agreed to be responsible for the drain passing through or in front of their plots, most maintenance work can be done on a voluntary basis, but some construction work should be done by paid community workers. The drainage committee should also liaise with the neighbourhood and with the municipality, to ensure the unhampered discharge of the stormwater into the secondary system linking the neighbourhood with the water recipient.

The best maintenance is ordinary cleaning, as leaves, earth, stones, garbage etc. may fall into the drain and block it. The first effect of this is small pools of standing, muddy water in various places in the drain, which can offer breeding grounds for mosquitoes. Later, blockages may become serious and cause the drains to overflow and erode the surrounding ground.

Cleaning is usually done manually, with the help of spades, hoes, shovels and scoops. Such tools should be given to the drainage committee, and repair and replacement should become the committee's responsibility.

The cleaning of drains can be a disagreeable and back-breaking work if it is done with the wrong tools. Stones and earth in the drains may require shovelling and lifting that are quite tiresome if there are no proper tools and the drains are deep. It is worthwhile to have some special tools that can clean the drains over the whole length, such as shovels that just fit into the drain.

One tool which has proved to be useful is the standard agricultural hoe with an extra long handle for cleaning deep and narrow drains (page 46).

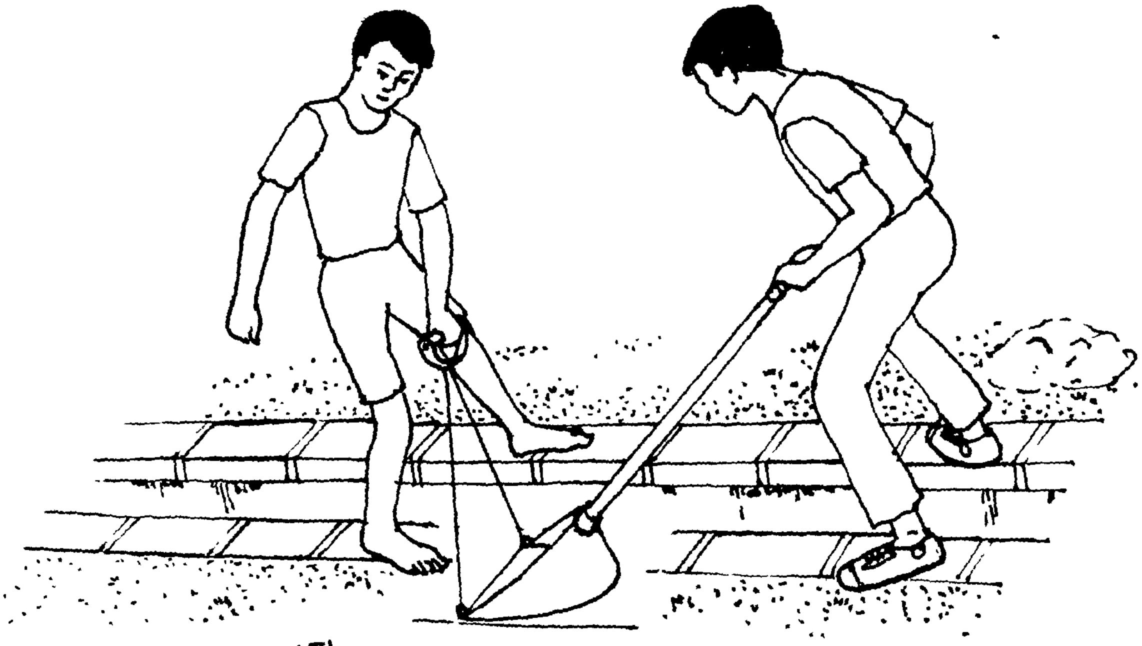
The Tunisian example

Difficulties in neighbourhood drains in Tunis, Tunisia, were related to the depth and the profile of the drains, and the effort required to lift unwanted material out of these drains proved to be too much for the residents. The problems were solved with the development of the Ahmed-Davis shovel which allowed pushing and shovelling deep into the drains by pulling the shovel forward and up with steel strings from its front end. The dimensions and shape of this tool were determined by the shape of the drains. The simple tool suddenly made the cleaning operation easy, and the impact on the maintenance of the drains was dramatic: it reduced cleaning time by 30 per cent (page 46).

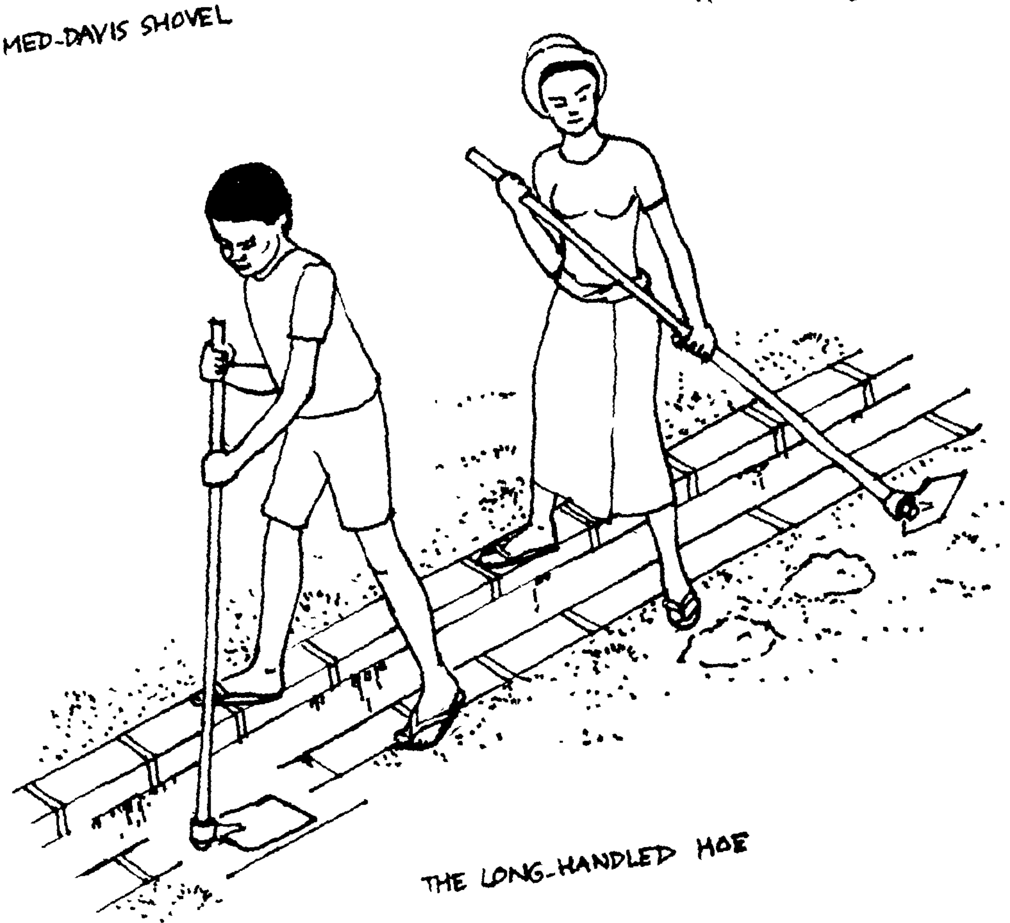
The Indonesian example

As part of a self-help upgrading scheme in Bandung, Indonesia, houseowners were made responsible for the daily cleaning of the drains in front of their houses. A neighbourhood co-ordinator inspected the drains twice a week and recorded his findings.

CLEANING DRAINS



THE AHMED-DAVIS SHOVEL



THE LONG-HANDLED HOE

The response to the friendly inspections was very good, and the inspector assisted in the manufacturing of simple scoops and scrapers to facilitate the cleaning of the small culverts under the house entrances. Soon, it became a daily routine that each self-respecting household performed.

The people in the area appeared more conscious of the improved tidiness of the streets than the long-term benefit of improved drainage, but the result was the same.

A turning point came when the municipality failed to clean a drainage channel outside the neighbourhood which was blocked and caused a heavy backflow of dirty water into the area. Much of the gain achieved by participation was lost when people realized that their efforts were negated by factors beyond their control.

The example shows that stormwater cannot just be dumped into the next neighbourhood and an adequate drainage solution cannot be developed without guidance from the city government about correct discharge points. When neighbourhoods are prepared to handle the tertiary drainage system, the municipality can not afford to neglect the secondary and primary systems.

Conclusion

Both examples demonstrate that some basic planning makes much difference for the organization of participatory work. A proper analysis of the tasks that the community is to fulfil and a proper planning of the work can persuade the community that participation is not just an unpleasant burden.

Cleaning the entire drainage system of the city is costly, and part of the responsibility should be taken over by residents of neighbourhoods. However, this will only be sustainable if the municipality is doing its job outside the neighbourhoods well. Failing to do so will destroy community participation.

QUESTIONS

1. It is often asked why the community should undertake maintenance activities in drainage. State a case in favour of it and a case against it.

2. Draw a "matrix" of responsibilities for the various "actors" in the municipal drainage system. Make a column for each actor you can identify. Make a row for each responsibility you can identify. Match each actor with the corresponding responsibilities.

Annex I

GLOSSARY

Alignment	The horizontal direction of a road, ditch or other structure as shown on a plan.
Auger	A drilling tool to scoop up soil from a deep and narrow hole in the ground.
Backfill	Earth fill surrounding a structure and providing support for the sides.
Baffle	A slab or board partly closing a channel to divert or slow down a water flow.
Bitumen	A general term used to indicate a material containing asphalt or tar.
Catchment area	The total area surface from which any given point in a certain area receives runoff water.
Cross drain	A drain which carries water from a roadside drain to the opposite side of the road.
Culvert	A drain for carrying water underneath a road.
Deposition	Accumulation of soil and/or debris deposited by a waterstream into a drain.
Depression	A basin, dip or otherwise low-lying area to which the runoff water flows.
Ditch	An unlined drain.
Drain	(In this paper) All natural or man-made arrangements to carry water, sewage and other unwanted liquids. They can take the form of natural slopes, pipes, ditches, channels, trenches, throughs, dips, soakage pits etc.
Drainage	Structures and facilities for collecting and carrying away water. Also the water that is carried away.
Drained area	The total area surface serviced by the drainage system.
Erosion	Removal of topsoil by the action of water and wind.
Flow velocity	Speed of runoff water in metres per second.
Gradient	Amount of slope, inclination to the horizontal. The gradient of a surface can be

expressed as the rate between vertical and horizontal distance (for instance 1:400). It can also be expressed in percentage points: 100 per cent slope is a vertical wall, a 0 per cent slope is a flat surface. It can also be expressed in degrees: a 90 degrees slope is a vertical wall, a 0 degrees slope is a flat surface.

Groundwater level	The elevation to which the water surface will rise in a well.
Headroom	The distance from the top of a pipe or other structure to the road surface.
Impervious	A property of soil or other material which prevents or inhibits the flow of water through the material.
Permeable or porous	A property of soil or other material which permits the flow of water through the material.
Profile	The vertical direction of a road, ditch, or other structure; a view of a vertical section of the structure.
Retention capacity	The amount of water a low-lying area (depression) can hold.
Runoff ratio or coefficient	That part of the total quantity of rainwater that does not evaporate or soak into the ground but runs off to lower areas. Expressed as a number between zero and one.
Scouring	The washing away of soil around and beneath a structure.
Slope	Difference in level between two ends of a drain, road or other object.
Soakage point	A place where water can penetrate the ground which is otherwise impervious in order to reach the groundwater level.
Subdrain or underdrain	A structure beneath the ground surface for collecting underground water and carrying it to an outlet.
Surface drainage	Collection and removal of water from the surface of the road and the ground.
Vegetation cover	A continuous growth of grass, shrubs or other plants which protects surface soil from washing or blowing away.

Annex II

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Annex III

BASIC CALCULATIONS

Introduction

It should be recognized that maximum rainfall in any area usually greatly exceeds the average. In most cases it is economically not possible to develop a drainage system that can effectively deal with those peak periods. The consequences of an economic system based on average rainfall is that, during occasional peak rains, the system will overflow.

The water that must be drained away originates from the rainfall in the area itself, but, in addition to that, some may come from higher grounds that drain into this area. The drainage area to be determined is therefore the catchment area, unless a peripheral drain prevents higher grounds from discharging their water into this area.

The dimensions of the drainage system have to be such that it can evacuate the quantities of water running off in the area, but, in addition, it has to do so in a controlled manner. The flow velocities are of great importance. Large quantities of water moving at high speed have an incredible destructive power and can cause great damage to the neighbourhood the drainage system is intended to serve. The drainage system's gradients determine runoff speed. If the site has a moderate slope, water can be intercepted at suitable spots by ditches - for instance, along roads - before entering the regulated drainage system.

Bare soil is subject to erosion, but areas with a good vegetation cover will drain without a significant loss of soil. Slopes between 1 and 5 per cent allow a good natural drainage, but steeper slopes than these are vulnerable to erosion or scouring.

Areas of less than a 1 per cent slope do not drain easily. In this case, a fine network of drains (unlined ditches) should lead the water through the area to collector channels in which the level of the water is controlled.

Within the tertiary system, the drainage velocity has to be controlled to avoid damage as well as clogging. At a speed of 0.45 m/sec, sedimentation is avoided, and the channels clean themselves. The scour velocity for sandy soils is 1.5 m/sec, and higher speeds than that require lined channels.

The runoff is determined by:

- The volume of rain falling per hour;
- Duration of rainfall in hours;
- The size of the catchment area;
- The absorption capacity of the soil in the catchment area;
- The rate of evaporation of water from the surface of the catchment area.

Metereological data can be requested from the local metereological service. The catchment area can be read off a contoured map of the area. The next data which have to be determined are the permeability of the soil (which determines the amount of water that can be absorbed in the soil before it starts running off on the surface) and the land use of the area.

A runoff coefficient will then be chosen.

Design procedure

The design procedure is as follows:

- Calculate the volume of water running of per hour during average rainfalls;
- Determine the runoff coefficient based on soil permeability and the percentage of the neighbourhood already covered with roofs and pavements;
- Determine whether the secondary system can take the calculated extra discharge;
- Decide how dense the drainage network will have to be to cope with the surface water;
- Determine the necessary dimensions of the channels;
- Check the expected water velocities in the system and select construction methods accordingly.

Runoff ratio or coefficient

The runoff coefficient is that part of the total water coming down in the catchment area that runs off. It is expressed as a number between zero and one. If it is zero, all water is absorbed into the ground or evaporates, and no water runs off at all.

If the coefficient is one, all water is assumed to run off the catchment area into another area.

The real situation is normally somewhere between those extremes.

The following runoff coefficients (P) are commonly used for drainage calculations:

Commercial and industrial	0.75- 1.0
High-density residential	0.5 - 0.6
Low-density residential	0.3 - 0.4
Open space	0.2

Prolonged rains, however, saturate surface soil. As a result, no more rain is at all absorbed. The same happens in dense slum areas where the little remaining open space is often blocked by household waste. In both cases, the runoff coefficient becomes equal to 1.

After determining the total surface of the catchment area in hectares (A) and the rainfall in mm/hour (i), one can calculate the volume of water to be drained off per second (Q) as follows:

$$Q = \frac{A \times P \times i}{360}$$

The symbols have the following meaning:

Q = The water throughput in m^3 per second
A = The catchment area in hectares
i = Rainfall in millimetres per hour
P = Runoff ratio or coefficient

This calculation is only valid for limited periods of moderate rain, say one or two days. During prolonged rains, the surface soil gets saturated and loses its permeability. The runoff coefficient then increases to 1.0. This means that all the water that comes down will run off.

Example:
Take a standard heavy shower producing 50 mm

of rain per hour.
It falls on 1 hectare of high-density settlement which is already saturated with rains from the previous days. Therefore assume a runoff ratio of 1.
The calculation is as follows:

$$Q = \frac{1 \times 1 \times 50}{360} = 0.1388 \text{ m}^3 \text{ per second}$$

This is rounded off to 0.140.

$0.140m^3$ equals 140 litres (140 dm^3).

Drain cross-section

Once the quantity of water to be drained per second has been determined, one can read the total required drain cross-section from the chart on page 58.

However, to use the chart, two more facts have to be known:

- The slope (pitch, gradient) of the drain (in percentage)

- The type of drain as determined by its friction, that is, the resistance the drain surface gives to water flowing through it. Three types of drain are distinguished by the chart:

  (a) Drains covered with vegetation (turf) which slow water speed most;
  (b) Unlined straight earth drains which are average;
  (c) Drains lined with stone masonry or concrete which slows water speed least.

Continuing with the above example, we now assume that the slope of the drain is 1 per cent and that it is going to be an unlined straight earth drain.

On the left side of the chart, find the 1 per cent slope, while on the bottom of the chart, find the 140 litres per second capacity for unlined (earth) drains, just left of the 150 mark.

Roughly where the corresponding horizontal and vertical lines cross each other can be read off the expected water speed in the drain (on the diagonal dotted line going downwards) in metres per second: about 1 metre per second, which is acceptable.

Roughly where the horizontal and vertical lines cross, can also be found a diagonal line going upwards which shows the required width and depth of the drain: B=10 cm and D=25 cm. Note that the calculation is valid for drains with sides having a pitch of 1:2 (one measure vertically to two measures horizontally). It means that the total section of the drain is a wide trapezium with a section of 1500 cm^2.

The straight earth drain, 10 cm wide and 25 cm deep (in which both sides of the drain have a low pitch), will take 150 litres of rain per second when its slope is 1 per cent. This is slightly more than we need for a shower of 50 mm per hour.

If a drain with pitches of 1:2 is not wanted, but one with steeper or even vertical sides, calculate the total section of the original drain, which is 1500 cm^2.
A drain with a rectangular shape can be chosen, as long as it has approximately the same total section as our original drain. Worked-out examples are provided on page 59.
It should be noted, however, that unlined drains with sides steeper than 1:2 cannot be made. The shape transformation is mainly useful when an existing earth drain is replaced by a lined drain of the same capacity.

On the basis of the above calculations, decisions will have to be made that determine the cost and performance of the drainage system:

- The extent and type of links between roads, pathways and drains;

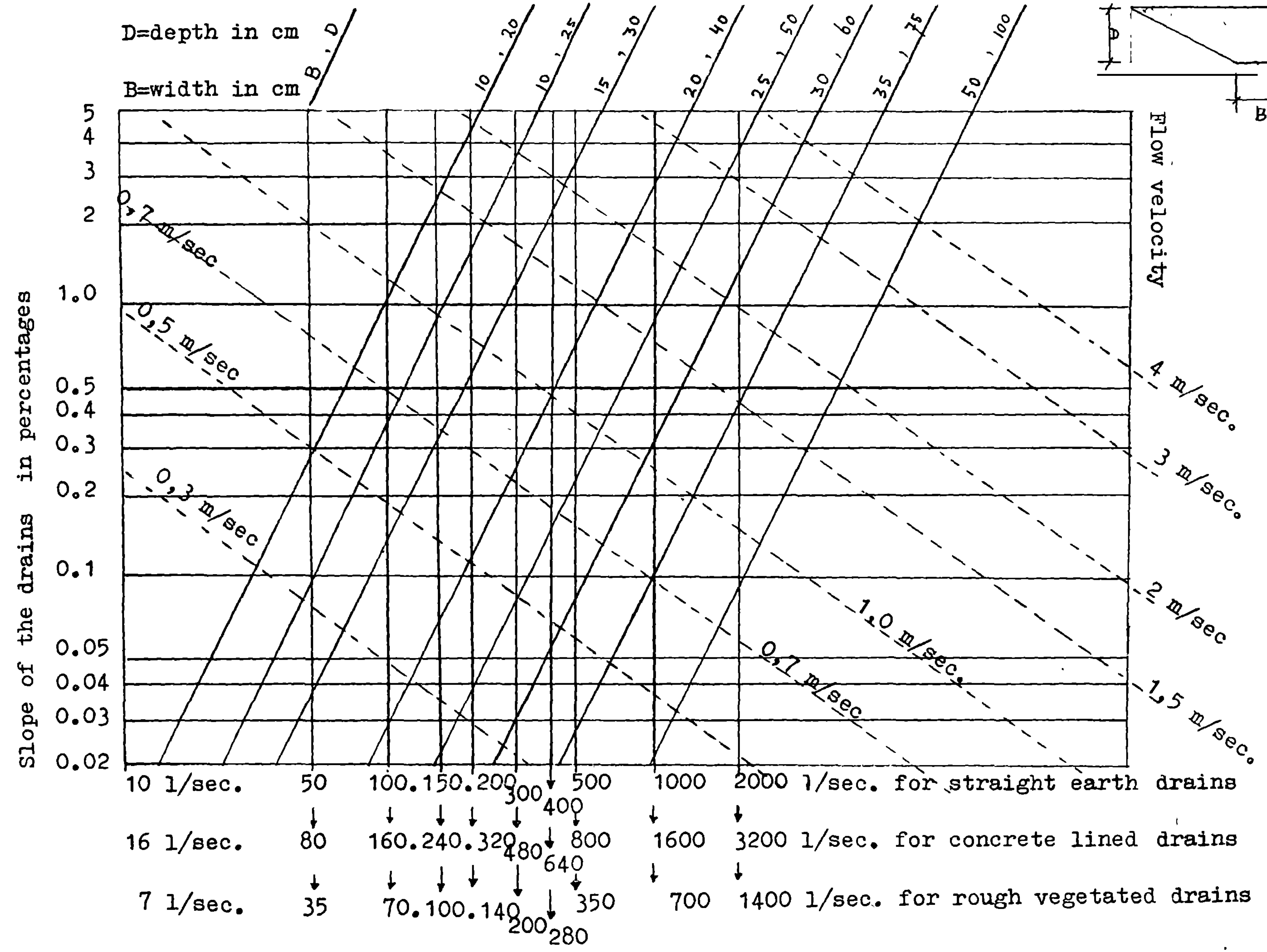
- The choice between shallow or deep drains, depending on available space, cost and maintenance requirements;

- The choice of the location of the drains, especially if roads are to be part of the system.

- The amount of space to be ceded by community members on their plots to lay drains.

The chart on page 58 has been adapted from: Stern, P, Small-scale Irrigation, (London, Intermediate Technology Publications Ltd, International Irrigation Information Centre, 1985)

Design chart for small drains



Alternative designs for calculated drains