STORMWATER DRAINAGE AND LAND RECLAMATION FOR URBAN DEVELOPMENT

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CONTENTS

Annex

FOREWORD

The potential socioeconomic benefits of urban stormwater drainage are huge: improved health and quality of life in existing low income human settlements, and the availability of additional usable urban land reclaimed by drainage projects which can be used for human settlements or industry and commerce. Properly designed and maintained stormwater drainage projects almost always increase substantially land values.

This report has been prepared in response to the increasing need for those involved in urban land use and management to develop efficient and cost-effective urban stormwater drainage programmes. It focuses specifically on the socioeconomic and engineering factors involved in such programmes, with special emphasis on appropriate strategies for proper operation and maintenance, as well as providing sound advice on planning and design. Operation and maintenance of stormwater drainage projects has all too often been neglected in the past - frequently it has been done only in response to emergency situations: this is both costly and inefficient. Detailed engineering advice is given in the annex to the report; this is basically a stormwater design manual.

The very rapid increase in urbanization that is currently occurring in developing countries is an irreversible fact of life facing urban planners and city engineers. The demand for urban land is correspondingly enormous and I am confident that this publication will be invaluable to those professionals involved in urban land management and urban stormwater drainage. These two disciplines together have the ability to regenerate vast areas of land in developing country cities, land that is currently unable to be fully utilized due to inadequate or non-existent stormwater drainage. I hope therefore that this report will serve as a useful starting point in increasing awareness of the need for appropriate strategies for urban stormwater drainage, so that the supply of usable urban land increases.

I gratefully acknowledge the contribution of Mr John Macklin in providing specific inputs to UNCHS (Habitat)'s present research efforts leading to the completion of this report.

Dr Arcot Ramachandran
Under-Secretary-General
Executive Director

INTRODUCTION

A. Background

The management of rainfall and the resulting stormwater flows is an essential feature of healthy cities. This is best illustrated by considering an urban area devoid of any such management practices: during times of intensive rainfall two events commonly occur - flooding of low-lying areas, and landslides on steep slopes which have been denuded of their natural protective vegetation in order to provide space for human settlements. The latter is perhaps the more dramatic: the shacks of the poor are demolished by the landslide which generally continues downhill to damage seriously the houses of richer communities. However, the health, both physical and mental, of those living in flooded low-lying areas is often much more adversely affected: vector-borne diseases (such as urban malaria, filariasis, even schistosomiasis and yellow fever) become established as the open waters provide opportunity for the vectors to breed very rapidly; and diarrhoeal diseases - together with malaria, a major killer of children - and geohelminthic infections also become endemic. Urban communities living in such settlements have a very poor health profile, and their productivity is correspondingly low. This is not only to their personal disadvantage but, on a strictly commercial basis, is detrimental to the local industries and businesses that employ them. While stormwater management is not a magic panacea, it is an essential component of urban development in general and of urban health in particular.

Land subject to regular flooding or landslides has a relatively low value. Stormwater management increases the value of land as it then becomes available either for improved - healthier - human settlements or for more economically productive uses such as industry and commerce. The increases in land values are usually, at least in properly planned and implemented schemes, quite substantial: this benefit alone is economic justification enough for stormwater management projects to proceed.

B. Purpose of the report

This publication is intended to assist those who management. It seeks to promote the role of stormwater drainage in the production of urban land particularly for human settlements, but also for commerce and industry, through the stabilization or reclamation of land that is currently unsuitable for such use because it is subject to permanent, seasonal or freak flooding. Specifically the purposes of the report are:

(a) To create awareness amongst urban land use planners and municipal engineers in developing countries of the economic and social benefits of the provision of good urban stormwater drainage;

(b) To provide technical information on the design of urban stormwater systems and land reclamation techniques, so that currently unsuitable urban land that is low-lying and subject to inundation, or on hillsides subject to storm-induced landslides, may be converted into safe land that can be used for low-income human settlements or for industry and commerce.

C. Scope of the report

Chapter I discusses current trends in urbanization and the effects these have on land prices and the consequent necessity for the urban poor to settle on marginal land that is subject to flooding. It also discusses the major health problems faced by those living in these settlements. Chapter II identifies the potential impacts of urban stormwater drainage and consequent land stabilization and reclamation - the implications for urban land-use planning, effects on health and the resulting socioeconomic benefits. Chapter III addresses the engineering factors involved in urban stormwater drainage and land reclamation and stabilization, with emphasis not only on appropriate planning and design (details of the latter are presented in the annex) but also, in chapter IV, on operation and maintenance which is all too frequently done inadequately so that the full potential benefits of urban drainage projects are not realised. Chapter V provides guidance for the appraisal of urban stormwater drainage projects and, finally, chapter VI identifies areas for further action and research.

I. URBANIZATION AND THE DEMAND FOR URBAN LAND

A. *Current trends in urban growth*

The current position and trends in urbanization in developing countries have recently been summarized in a UNDP Strategy Paper (see box I.1). This rapid and sustained growth in the size of cities and towns creates a correspondingly huge demand for and pressure on land, principally but not exclusively for housing. In addition to land for housing, however, there is a need for land for urban infrastructure - roads, drainage and utilities - and for commercial, industrial and recreational purposes. While there is such a need for land and while in practice, as will be noted below, land is being used for urban purposes, there is in many respects a crisis in urban land-use policy in many cities around the world - a crisis that has been caused by a desperate mismatch between the official supply of land and the demand for it. The root cause of this crisis must briefly be outlined.

The root of the current crisis is that, usually with the best of intentions, governments have adopted policies which have unfortunately and far too frequently contributed to land shortages rather than land availability. These policies have emphasised control and regulation over land use and its supply, rather than enabling and facilitating its release. These policies generally stress the maintenance of inappropriate standards - standards often inherited and accepted uncritically from former colonial powers - rather than focus on the appropriateness and affordability of such standards. Government policies have also either shied away from, or attempted to impose inappropriate legal regimes on, traditional land-tenure practices which have consequently inhibited the release of land with clear titles for urban use. Finally, these policies generally place too much emphasis on public ownership, management and development of urban land, and the resulting heavy bureaucracy normally impedes the release of land. Some examples of these defective policies are given below.

Control and regulation of supply and use

There are few better examples of attempts to control the supply and price of urban land than the Urban Land (Ceiling and Regulation) Act 1976 of India. A respected commentator has this to say about the Act and its operation:

> This Act was aimed at socializing all land in excess of a given quantum on payments of a nominal amount, thus making available large chunks of strategically located land for use by the common man. Exemptions can be granted from the operation of the Act. The phenomenon of granting exemptions to large property owners, bogus cooperative societies who enter into agreements to purchase land, commercial builders etc. is universal with the result that the very purpose of the Act has been defeated.

The National Commission on Urbanization has likewise concluded that the Act has failed to achieve any of its objectives. This has not, however, prevented a very rapid rise in urban land prices all over India and a concomittant shortage of affordable land for housing for the urban poor.

Nigeria may be instanced as another country where similar legislation - the Land Use Act of 1978 - has done nothing to bring more land forward for urban development, but which has created yet another layer of bureaucracy and corrupt practices which must be overcome before land can be developed.

Even where the supply of land is not controlled, its use too often is. Inappropriate metropolitan models of town and country planning legislation (some of them dating back 70 or more years with emphasis on control of development, and the obligation to seek, via official forms, permission to build a house) simply render the self-build efforts of the poor illegal and liable to demolition.

The maintenance of inappropriate standards

Two aspects of this deficiency are plot size and building regulations. Over-large plot size

Box I.1. Current urbanization trends in developing countries

The relentless growth of cities is inevitable and irreversible. Standing at 2.4 billion in 1990, the world's urban population will rise to 3.2 billion in 2000 and 5.5 billion in 2025. The developing countries' share in these totals - 63 per cent in 1990 - will rise to 71 per cent in 2000 and 80 per cent in 2025. By the end of the 1990s, Mexico City will have almost 22 million residents. Calcutta, Shanghai and Bombay will each have more than 15 million, and 13 other cities in developing countries will have more than 10 million: Seoul, Cairo, Dakar, Delhi, Lagos, Beijing, Bangkok, Manila, Jakarta, Karachi, Tianjin, Buenos Aires and Rio de Janeiro. In addition to the growth of these megacities, the growth of small and medium-sized cities will also continue.

For decades this growth was seen as inimical to human development. Cities already benefited disproportionately from national development efforts, urban development was more costly than rural development and the growth of cities merely added to unemployment - these were the prevailing views. So, government policy and international assistance gave greater attention to the countryside.

Today the growth of cities is seen increasingly as essential for human development. The GNP per capita numbers are much higher in countries with more of their people in cities. The economies of scale in large cities generate goods and services far in excess of their share of the total population. This higher productivity of urban labour means that wages are higher and unemployment opportunities greater, especially for women. Cities also give their residents the knowledge and skills to become more productive - a propitious cycle. Cities promote the modernization of agriculture, provide markets for farm goods and reduce pressure on land.

Despite the obvious efficiency advantages of cities, the negative consequences of urbanization for low-income groups are overwhelming. Simply, many city dwellers in developing countries live in crushing poverty - more than 300 million, or a quarter of all those in urban areas. That number promises to swell. By 2000 more than half the developing countries' poor will be in cities and towns: 90 per cent in Latin America, 45 per cent in Asia and 40 per cent in Africa. Their living conditions are alarming, for their numbers far outstrip the supplies of water, waste removal, transport and clinics. Nor do they and their richer neighbours help the environment using natural resources and discharging wastes in disturbing quantity, with all the predictable effects.

Source: Cities, People and Poverty (New York, United Nations Development Programme, 1991) severely handicapped efforts to develop low-cost housing until a downturn in the economy caused the plot owners themselves to see the good sense of subdividing their plots in order to increase their income and also to reduce building costs. Many site-and-service schemes have been beyond the reach of the urban poor simply because the price of the large plots has been beyond their capacity to pay, and the high costs of running services to the plots have further raised prices.

Few countries have yet made any effort to revise their building regulations to allow for more appropriate standards. In some countries and cities the building regulations are more than 50 years old and are still legally in operation. For example, in Nairobi insistence of antiquated standards in the regulations held up the commencement of a major site-and-service project; and in Madras official refusal to allow low-cost unconventional materials and practices to be used in site-and-service schemes effectively prevented the urban poor from benefiting from them.

Customary tenure

The African continent has many examples of inappropriate efforts to grapple with customary tenure. For example, in urban Lesotho, a World Bank land-reform programme broke down because of suspicions that it was designed to facilitate foreigners acquiring choice urban plots under a law which only they could understand. In the United Republic of Tanzania and in Zambia, a refusal to permit an officially recognised market in land led to the development of a vigorous alternative market, with major problems of security of tenure due to the consequent absence of any official documentation relating to title. In Nigeria, the imposition of public controls on an evolving market in land merely inhibited the evolution of the market without providing any positive benefit.

Public ownership and management

A favourite device is the creationof an urban development authority which is empowered both to purchase land in advance of use (and release it in due course for use by the urban poor) and to develop land itself. The example of the Delhi whatever the theoretical merits of the policy, in practice it can have disastrous results. In Delhi 20,000 hectares of land were notified for compulsory acquisition and frozen for private development, and the DDA, in order to balance its accounts, has allocated nearly 50 per cent of the land it has released to the urban rich and less than 10 per cent to the urban poor. Land prices have at the same time rocketed. According to a commentator:

> ... regarding of its efficacy in serving desired goals, the fact remains that this policy for Delhi, supported by hefty financial aid from government was sought to be replicated in other states with calamitous results ... Funds or the expertise to assess needs, plan and execute development programmes or to manage the land were not provided.

Urban development and capital development authorities in Brazil, Pakistan, Nigeria and the United Republic of Tanzania have a similarly dismal record of providing affordable land for the urban poor, many of whom labour to construct buildings they will never be able to afford to use.

What might be the results of continuing with such inadequate policies? The following are suggested as the more likely outcomes.

(a) Land prices will continue to accelerate and there will be a corresponding decline in the number of people who will be able to purchase or rent houses or building plots;

(b) There will be a continuing increase in urban slums. People will not cease to come to cities, but they will cease to be able to do other than slot into already overcrowded squatter settlements or take part in land invasions;

(c) The development of ever larger squatter settlements without adequate services or infrastructure will cause major urban health problems and a rapid deterioration of the urban environment;

(d) Large cities, full of the unemployed and the poor (too few of whom will have a stake in the system through the ownership or secure possession of land or regular employment), will deal with and may begin to pose problems to the security of the State and the stability of the local political system.

B. Increases in land prices and the use of marginal land

As a result of these mistaken policies and institutional developments, two interlinked phenomena have become increasingly apparent: rapid rises in land prices, and unauthorized developments of marginal lands. We have already noted how the urban ceiling legislation in India brought about a rapid increase in urban land prices. It has also brought a rapid increase in urban development on ecologically sensitive land outside city boundaries where such land escapes the reach of the urban ceiling legislation. In the United Republic of Tanzania, the inefficiencies of the allocation of public land has had the same two effects: dramatically high prices paid for officially allocated land when it is traded on the unofficial market, and land bought from traditional land holders on the outskirts of towns since no other land can be obtained (see box I.2).

Many commentators have noted the same phenomenon of high prices forcing low-income communities on to marginal land in Latin American and the Caribbean. In Trinidad and Tobago, for example, the hills around Port of Spain are being rapidly devèloped with unauthorized housing, much of which collapses during the rains so contributing to mudslides and the loss of topsoil. In an effort to overcome the shortage of "official" planned development land, a group of architects and planners instigated the Sou Sou Land movement, a venture which was designed to open up undeveloped land for lowcost housing. Inevitably the land so opened up included marginal land and no provision was made for drainage or sanitation. In Latin America, the urban poor often settle on steep hillsides, as in Rio de Janeiro, for example, with serious consequences of flood-induced mudslides (see box I.3).

Even where there is not the great pressure on land which migration to large cities causes, the same phenomenon of rapid use of agricultural and marginal land occurs. Box I.4 details the Indian

C. Specific problems of the urban poor

The problems of the lack of developable land being available at an equitable price or allocated in a fair and reasonable manner are overwhelmingly problems for the urban poor. It is they who get squeezed out of land near to places of work (unless, as in Bhopal, that land is unsafe for conventional housing). It is they who are not allocated land by the politicoadministrative process as they have neither the influence nor funds to smooth the land allocation process. There are few cities in the developing world where the plight of the urban poor is improving: in most their plight is actually getting worse.

There are various manifestations of this. Recent research has shown that increasingly the poor are renters and not buyers of accommodation. Their landlords are not usually the benevolent, if overbureaucratic, public authorities; the majority are private individuals. While many landlords are of the same social class as their tenants and are merely renting out a part of their own too-small accommodation, low-cost housing is increasingly becoming commercialized and large-scale landlords are moving into the sector, and they are simply intent on obtaining as large a return on their capital investment in as short a time as possible. This involves putting as large a number of people into as small a space as possible and cutting down on basic facilities and amenities. Inevitably this means that such matters as sanitation and drainage are neglected. Legislation imposing minimum standards on landlords may well exist, but it is rarely enforced - to the clear detriment of the poor (see box I.5).

To escape such conditions, the urban poor can and do retreat to the outskirts of towns where in terms of land use and environmental conditions, the situation may not be very different. In towns and cities in many countries in Africa, land on the urban periphery is still subject to customary tenure and any legal regulations and restrictions are, in practice, disregarded by traditional land holders. Thus in Maseru, Lesotho, local chiefs routinely ignore the provisions of the Land Act (1979) which imposes certain conditions on land to be used for urban purposes, and they grant

Box I.2. Prices paid for government land sold unofficially in some areas of Dar-es-Salaam, United Republic of Tanzania

Area	*Type of plot*	*Price (1988 Tshs.)*
Sinza/Kijitonyama	High density, bare	150,000 - 200,000
Sinza/Kijitonyama	High density, incomplete foundation	250,000 - 300,000
Sinza/Kijitonyama	High density, complete floor slab	350,000 - 400,000
Mikocheni	High density, bare	400,000 - 1,000, 000
Oysterbay	Low density, bare	2,000,000 - 7,000,000
Mbezi Beach	High density, bare	100,000 - 150,000
Mbezi Beach	Medium density, bare	200,000 - 300,000
Mbezi Beach	Low density, bare	500,000 - 1,000,000

Official exchange rate in December 1988: US$ 1 = TShs 122.72.

Source: J.M.L. Kironde, *"Land pricing and taxation in Tanzania"* (paper presented at the Tanzania National Land Policy Workshop, June 1991).

Box I.3. In Latin America, why do sqatters settle on hillsides?

"Hillsides provide readily available land and at essentially no cost. They offer land with limited competition from other sectors. The trade-off is between legal title and expensive land, and land of no cost and often with an advantageous location but with unclear tenure, more difficult construction methods, inconvenient access, and more problematic utility provision. The location is paramount: Hillsides that are centrally located are the most desirable and the ones most quickly settled because they provide access to central business areas with their vast opportunities for casual employment." The author goes on to comment that "in hillsides sites the threat of eviction is inherently less since there is little interest from developers or other potential users, particularly where the gradient is 35 percent or more.' Conversely the danger or erosion from mudslides increases as the squatter settlements are consolidated. Two reasons are noted. Firstly, the rainfall runoff increases as more surface area is covered by development, and secondly, as the dwellings become more permanent they gradually convert to brick construction and increase the load on the relatively unstable soils" ... More critical are the erosion problems at the community level, where the heavily used pedestrian walkways require a more organized input and the question is always, "how will the material be paid for, and who will do the work?"

Source: R. Goethert, "Lessons from squatters in Latin America: Housing on hillsides for low-income groups", *Regional Development Dialogue,* vol 12 (1991), no 2.

Box I.4 Urbanization in Visakhapatnam, Andhra Pradesh, India

"Visakhapatnam, one of the major ports of India, is a rapidly-growing city situated on the East Cost of India (Table A). Geographical modality seems to be a powerful factor in the growth of the town. It is bounded by two hill ranges of the Eastern Ghats - Kailasa range on the north and Yarada range on the south. The Bay of Bengal forms the eastern boundary of the town with a coastline of about nine kilometres in length running northeast to southwest. The western side is an extensive tidal basin, a major portion of which is being slowly reclaimed. Within the two dominating hill ranges, a vast expanse of lowlands and a number of hillocks provide a rugged appearance to the landscape.

"Every land-use pattern is the result of the functional integration of residential, commercial, industrial, transportation and community facility uses in harmony with the topographical features. The city of Visakhapatnam is constrained by physical barriers on all sides. Hence, the topography plays an important role in the spread of the city and the land-use pattern. The city can grow only along the major arteries of the highways towards northeastern, northwestern and southwestern corners of the plain in what may be visualised as a ginger-palm pattern. Table B shows a quantitative analysis of urban land use.

"By 1985 agricultural land was completely replaced by industrial and residential lands. The high percentage of land under industrial and institutional uses reveals the growing importance of industries and institutions inVisakhapatnam. Another important land-use change is the reduction of vacant land from 1965 to 1985. The vacant land has been converted into residential areas due to heavy pressure for residential use. The piedmont zone of the Kailasa hill ranges in the north is covered with mango and cashew orchards, which are also being cleared for industrial and residential purposes. The pressure on the population for minimum needs especially for shelter madethem to find new places and hence, the weaker section people who cannot afford to have houses within the town finding a place by encroaching the slopes of hill ranges ...

There is a vast tidal swamp on the western side of the town, which is slowly being reclaimed for port-based industries. Changes in land-use occur at highly variable rates from place to place. The reclamation of the marshy tidal basin provides an example of large-scale metamorphism of natural landscape by man ... The total area of marshy land was 2,590 hectares during 1933 which was reduced to 600 hectares in 1985. Approximately 80 percent of the total area has now been reclaimed and the remaining 20 percent of the area is also being slowly reclaimed. The swamp area is mainly destined for port-based industries. In addition to the port installations, the establishment of port-dependent industries has brought another fresh impulse for urban extension into the tidal basin, which is being reclaimed from all sides.

Source: S.S. Devi, "Urban land use changes with special reference to Visakhapatuan, India", in *Land Use in Change* (Hong Kong University Press, 1989).

Table A. Increases in built-up area and population in Visakhapatnam since 1920

Year	Built-up area (km^2)	Municipal area of the town (km^2)	Population
1920	1.88	15.62	44711
1942	3.97	5.62	70243
1961	7.78	29.14	182000
1975	20.50	76.33	450000
1985	47.79	76.33	710000

Table B. Urban land use in Visakhapatnam

	1965		1985	
Land Use	Area (in km^2)	Percentage of total area	Area (in km^2)	Percentage of total area
Residential	8.70	11.40	16.34	21.41
Industrial	5.20	6.81	6.30	8.25
Institutional	2.65	3.47	5.06	6.63
Roads and railways	3.60	4.72	5.15	6.75
Hills, scrub and water bodies	6.39	8.37	4.60	6.03
Commercial	0.35	0.46	0.87	1.14
Recreation	0.30	0.39	0.79	1.03
Agricultural	0.28	0.37	-	-
Harbour	28.94	37.91	28.94	37.91
Vacant	19.94	26.12	8.28	10.85
Total area	76.33		76.33	

Box I.5 Poor housing and ill health in Olayeye-Iponri, Lagos

Olaleye-Iponri originally consisted of two independent communities lying next to each other on a site of some 35 hectares. They are located primarily within the jurisdiction of the Lagos Mainland Local Government. The communities in their present location make up highly compact settlements whose expansion is limited by a series of natural and human-made barriers ... Olaleye-Iponri's central location within metropolitan Lagos and its contiguity to Alaka Estate makes it a valuable site for its inhabitants, despite the deficiencies of the site and infrastructure and service provision there ... most inhabitants are tenants who live within a household, sharing one small room, while most other inhabitants are small-scale landlords who have built the dwellings they rent out on land they have rented from absentee landowners.

There is very serious over-crowding in Olaleye-Iponri. The predominance of large households and the small sizes of rooms means that many households must live with less than one square metre per person for the whole plot. More than half of all households live in one room. Households occupying between two to three rooms account for about one-third of all responses. The most common room-size is between 2.4 by 1.8 m and 2.4 by 2.4 m. Occasionally larger rooms are 3 by 3.6 m and 3.6 by 3.6 m. Thus a common feature is to have households of five or more persons all living in a 2.4 by 1.8 m room.

In regard to excreta disposal, 28 percent of respondents have no access to toilet facilities. Most of those with toilet facilities only have access to the outhouse type and, with this, the use of bucket-latrines is predominant. About 88 percent of Olaleye respondents and 72 percent of Iponri respondents use bucket latrines. Next in importance is the use of pit latrines (or salgas), which account for about 12 percent in Olaleye and 7 percent in Iponri. Toilet facilities, as with bathroom facilities, are extensively shared; over 90 percent of respondents with access to toilets share these facilities. The pressure can be imagined particularly in cases where there is only one toilet serving a house with six or more households with an average household size of not less than five. It is not surprising that human waste is disposed of as a matter of routine in both the gutters around the houses, nearby bushes, the railway line and any other available discreet corner ...

In regard to sources of water, only a small proportion of residents have water piped to their living quarters. In Olaleye, 36 percent of respondents have water piped directly into the building in which they live but only 21 percent have it piped into their own living quarters. Another 15 percent rely mainly on water from wells in their buildings, while nearly a third purchase their water from water-hawkers who obtain the water either from wells or piped sources. For Iponri, about 71 percent of respondents claim they use piped water but only 36 percent have it piped into their living quarters; about 15 percent purchase water from private hawkers. Sources such as springs, streams and wells are not important (they are used by about four percent of the respondent). For those who obtain water from outside their living quarters, 52 percent of Olaleye respondents and 45 percent of those in Iponri claim they get water within 100 metres of their living quarters. The rest either use other means or get water from distances over 100 metres ...

Over a quarter of all houses had what the interviewers described as a foul smell arising from open drains, human waste, dead animals and overflowing garbage dumps. This is not surprising as most gutters and drains were blocked and not cleaned, and there is no systematic form of public-waste disposal. In Olaleye, about 96 percent of the drains are blocked with rubbish and not cleaned at all. In Iponri, 82 percent of the drains are recorded as blocked, while about 96 percent are recorded as not clean. Garbage disposal facilities within the vicinity of dwelling exist for 70 percent of Olaleye while in Iponri these exist in 59 percent of the cases ...

Source: Tade Akin Aina Housing and Health in Olaleye-Iponri, a Low Income Settlement in Lagos, Nigeria. In *The Poor Die Young* land without regard to any considerations of public health or the need for soil conservation, which is a pressing problem in Lesotho. In Mexico, the poor obtain accommodation on *ejido* land - rural land which in theory at least should remain in the perpetual ownership of peasant farmers. Since the transactions are not sanctioned, and the land is not subject to any public health regulations, the resulting informal and illegal subdivisions make little provision for drainage or sanitation. Similar conditions exist where the urban poor obtain land in Brazil and elsewhere in Latin America.

Living on marginal land gives rise to two principal sets of hazards; one natural and the other the result of human decisions and actions. The natural hazards tend to be floods or landslips (earthquakes are likely to affect all classes, but probably the urban poor will be the hardest hit since their homes are usually of the flimsiest materials). Human decisions and actions embrace fire and demolition or removal. While the former may be accidental, the latter is usually deliberate and is never less than traumatic, even when done for sound public health or ecological reasons. Two contrasting cases are given in boxes I.6 and I.7: the first from Barbados where care was taken to ensure that in so far as possible no one suffered unduly from relocation, and the second from Abuja, Nigeria, where relocation was carried out without sufficient care and so created major environmental and social problems.

D. Urban health in marginal settlements

The urban poor are at extreme risk from disease - principally water- and excreta-related diseases due to their inadequate water supplies and sanitation facilities, but also due to a lack of adequate stormwater drainage. Diarrhoea is extremely common, as is urban malaria and Bancroftian filariasis, with urban schistosomiasis becoming more common as the urban peripheries are pushed out into adjacent agricultural land. Good drainage, both sanitary and stormwater, can eliminate vector breeding sites. Conversely, poor or non-existent drainage actively promotes vector proliferation on a huge scale and so permits a correspondingly vast transmission of the diseases they carry. Box I.8 details the problems of Bancroftian filariasis, and box I.9 of urban malaria.

Mental ill-health in marginal settlements is a major public health issue that is only now beginning to be appreciated. Mental illness, especially minor psychiatric morbidity, is usually multi-faceted, but there can be no doubt that living in marginal settlements subject to flooding and mudslides is a significant contributory cause of chronic depression, anxiety and personality disorders, as well as of the acute water-related psychoses such as malarial psychosis and chronic neuroses such as filarial neurosis (depression induced by elephantiasis).

E. Conclusions

The developing world provides many examples of the same basic point: that the urban poor are driven increasingly on to marginal lands or to reside in conditions which provoke high levels of actual risk to their health. When they are relocated, their conditions may even be worsened. While in no way detracting from the human aspects of these appalling situations, it is necessary also to highlight their environmental consequences. Marginal or ecologically fragile lands often have certain positive environmental roles to play in urban development, quite apart from their recreational potential. Thus mangrove swamps play a vital role as a defence against high seas which may cause flooding of low-lying urban areas. Wooded hillsides may also offer protection against violent weather or alternatively be a vital factor in a microclimate which ensures rain and so sufficient water for an urban area. Streams and rivers running through a town are subject to multiple use; if one of those uses is as a sewer for industrial or domestic wastewaters, then other uses - for washing or drinking - becomes dangerous. It is the urban poor who suffer disproportionately from floods, landslides and poisoned watersources, so that there is, in fact, a close connection between the human and the environmental dimensions of the misuse of marginal urban lands. It is thus in the long-term interests of the urban poor that these lands are restored or returned to their proper environmental role and other land is released or reclaimed for urban use. Stormwater drainage has a major role in such land release and reclamation.

Box I.6 Resettlement in Emmerton, Barbados

Emmerton is an area of land immediately adjacent to Bridgetown, the capital of Barbados. The country's Physical Development Plan of 1971 deemed Emmerton as the city's worst slum area, and as a high priority for clearance and renewal. "It was thus not surprising that after exhaustive design development and economic considerations, the decision was taken to use five acres of the Emmerton area for the construction of the sewage (wastewater) treatment facility for the city's first sewerage system". There were at the time some 560 people living in the Emmerton area, predominantly in chattel houses, many of them in a dilapidated condition. Social surveys showed that a majority of the residents did not wish to leave Emmerton but "in general, the persons to be removed accepted it as a measure which the government had to take, but were insistent that uprooting them from their leisurely happy way of life should have its own compensations in better standards of living and the minimum dislocation from their livelihoods".

A loan for the construction of the sewerage system was to be provided by the Inter-American Development Bank, one of the conditions of which was that before any disbursement of the loan a programme and schedule for the relocation of persons from the site would be provided. The government selected a site two and a half miles from Emmerton and formed an inter-departmental committee of senior officials to plan the logistics of the clearing and the compensation "of landlords who may have suffered any loss as a result of clearance". The National Housing Corporation was designated as the agency to execute the relocation. This early planning for clearance and "rumours of crude methods to be employed by government in the implementation of the removal of residents brought very sharp, resentful and hostile reactions from the persons concerned in the removal as well as from several sectors of the Barbadian community".

Government recognised the need for a different approach. The Community Development Division was brought in, and a citizens' committee representing residents to be removed from Emmerton was established. The functions of the committee were to mobilize the entire community, learn their problems, needs and concerns, discuss government's plans with them and represent their views to Government. The Community Development Division's function was to "obtain the active and positive participation of the people of the Emmerton Community ..." and via in-depth interviews, become familiar with their concerns about moving. Government responded to the views and concerns expressed by the Citizens' Committee and, inter alia, agreed to provide improved amenities and utilities at the relocation site rather than, as had been initially determined, the same standards as existed at Emmerton. The conclusions of the commentators on the whole operation was that it "cannot be otherwise described but as a successful coordinated operation ..." even though surveys after the move showed some dissatisfaction with some aspects of it. However, overall, "the early recognition by the Government of Barbados that the people of Emmerton should become actively involved in the matters of resettlement which concerned and influenced their lives and welfare, contributed to the establishment of a harmonious relationship with widespread cooperation and the willingness by most to sacrifice some of their prejudged suspicious and recalcitrance.

The establishment of the Citizens' Committee helped to engender that feeling of belonging and participation in the sewerage cum resettlement project which helped both the Government and the residents affected in clarifying roles, solving problems and to prevent the spread of unfounded rumours and faulty beliefs among the residents. The interchange of ideas and goals led to more effective decision making by government".

Source: M. Alleyne, A. B. Archer and G. Walters, *The Resettlement of Residents from Emmerton, Bridgetown, Barbados.*

Box I.7 Resettlement in Abuja, Nigeria

Abuja was chosen as the new capital of Nigeria in 1976. The decision was taken to start the town without incorporating existing infrastructure and settlements. Existing land-use patterns consisted of dispersed clusters of dwellings with very light population density. "Land use was in equilibrium with the ecological capacity of the environment." The Federal Capital Authority was charged with the duty of resettling those people who wished to remain within the Federal Capital Territory.

A master plan for each resettlement area was prepared. It was proposed that "the population should be rehoused at minimum cost and the housing and the environment should be acceptable to the people ..." Practice, however, departed from the plan. Corrugated iron sheets instead of thatch were used on the roof of houses. "Since the houses were not adequately ventilated they are unbearably hot during the season of maximum insolation. In addition, the housing units are congested, with houses standing only about 10 metres apart. This pattern of housing has seriously eroded the privacy which the people highly regard. Population density within the small area of the housing units has been very much increased, thereby affecting land claims and land use in the resettled area. Households are restricted to minute holding which are usually insufficient for cultivating and grazing ... also, a serious omission in the housing arrangement was the lack of recognition of the differential status of households in the allocation of houses." Perhaps the most serious omission in the housing units is that there was no provision for granaries and animal shelters. Many households have suffered losses in grain as a result of inadequate arrangements for grain storage in the resettlement units. Consequently, the incidence of famine resulting from prolonged shortage of stored grains has been reported in the two settlement units. Villagers who are unable to tolerate this increased hardship have migrated or joined the nomadic group. The speed at which the resettlement programme is being carried out does not allow a thorough study of the ecological variations in the resettled areas in order to guard against their disruption.

When all factors are considered, the Abuja resettlement programme has not been able to provide an environment within which the peasants will quickly re-establish the ecological balance already attained in their previous settlements. This would require a greater involvement of the affected population in the decision-making process over matters affecting such issues as farm organisation, land allocation and design of dwelling units. Planning and implementation of any resettlement programme should be based on participation of the people involved.

Source: F. C. Okafor, "Resettlement and ecological disruption in Abuja, Nigeria," in *Land Use Policy*.

Box I.8 Urban health: Bancroftian filariasis

Bancroftian filariasis is a serious disease in urban areas. It is infection with the filarial worm *Wuchereria bancrofti*: the adult worms live in the human lymphatic system which, as a result of their presence, becomes blocked or partially blocked so impeding its free drainage. Swelling of the lower limbs and genitals then occurs and, in its clinical extreme, the disease is know as elephantiasis. People become infected through the bite of infected mosquitos belonging to the *Culex quinquefasciatus* complex of mosquitos, which breed preferentially in dirty water such as blocked stormwater drainage channels, marshy swamps, septic tanks and wet latrine pits - anywhere which becomes polluted. In this sense it is an urban disease caused by man: city authorities improve the water supply but make no or insufficient provision for the removal of the resulting wastewater. So unplanned rapid urbanization which results in sprawling slums and polluted water bodies leads to the creation of enormous breeding sites for the vector mosquito. Chemotherapy is available, but the only way in which transmission of the disease can be prevented is by improved sanitation and improved stormwater drainage, of which good operation and maintenance is essential for long-term control of the disease.

Box I.9 Urban health: malaria

Urban malaria is a major health problem throughout the developing world. Its mosquito vector is a species of the genus *Anopheles* and it is the local anopheline species and its preferred breeding habitats that determines, in any one place, whether urban malaria is related (in a similar way to Bancroftian filariasis) to inadequacies of sanitation and stormwater drainage. Thus *An. stephensi*, the main vector of urban malaria in Asia, generally breeds in household water storage containers, and so in Asia urban malaria is not so closely related to sanitation and drainage (although *An. stephensi* does occasionally breed in flooded borrow pits and blocked open drains). However in Africa and the Americas local vectors such as *An. gambiae* and *An. albimanus* breed in undrained water pools, marshes and rice paddies but also, and to a greater extent than *An. stepehensi*, in blocked drains (but not ones so polluted that they favour *Culex quinquefasciatus*).

II. POTENTIAL IMPACTS OF STORMWATER DRAINAGE AND LAND RECLAMATION PROJECTS

A. *Urban land-use planning*

Marginal urban lands subject to frequent flooding are generally left outside the scope of urban planning unless the urban authority has plans to reclaim the lands through stormwater drainage projects. Without such plans, the lands are in essence temporarily abandoned and often "invaded" by the landless urban poor. Such a situation is, from an urban planning viewpoint, most unwise since the lands, once reclaimed, may be better suited to urban uses other than low-income settlements - industrial or commercial developments, for example. Yet, once the land is invaded and settled, and however precarious the settlements, it becomes much more difficult in sociopolitical terms to clear the land of its human settlement and enhance it, by stormwater drainage, for an alternative use.

Thus, urban planning authorities must be aware of the potential benefits of draining marginal lands subject to flooding. They must plan for draining and reclaiming such land, and assign uses to the land so reclaimed, even though the reclamation project may not be realised in the short term. The land, in its unreclaimed state, must be protected. This will either mean providing alternative land for human settlements if the land to be reclaimed is to be used for another purpose; or it will mean allowing controlled development of the land for human settlement. Controlled development must include provision for stormwater drainage.

However, in such development programmes, there is a serious dichotomy: will the reclaimed land be too valuable to allocate it for a low-income human settlement? Urban planners must address questions such as this, and it is only through a fair and uncorruptible system of urban planning that the urban poor will be able to benefit from land drainage and reclamation projects. It needs to be remembered that the urban poor make up a large proportion of the urban population in most developing cities, and that businesses need a healthy workforce. Thus to continue to ignore the needs of the urban poor in the face of the demands of urban business and commercial sectors becomes, in the end, self-defeating. Both the sectors need land: stormwater drainage of marginal land can satisfy this need, and the resulting reclaimed land must be shared between them, for they are not mutually exclusive groups: they both need each other, and it is in the clear interest of the business and commercial sectors to see that the urban poor are provided with good land to settle on so that they have a good supply of fit and healthy labour. Urban planning, therefore, has to address this unequivocally.

B. *Urban health*

The principal immediate benefit resulting from the drainage of human settlements is improved environmental health. Vector-borne diseases will decrease substantially, as will faeco-oral diseases and geohelminthic infections if the settlement has an adequate water supply, adequate sanitation and adequate garbage collection. Given that the reclaimed land is valuable (see section C below), households have the incentive to invest further in their housing - so improvements in water supply, sanitation and garbage collection soon follow drainage improvements. Thus the cycle of urban ill-health can be broken: infrastructure improvements, starting with drainage, reduce disease; a less diseased workforce earns more money, and households with more money become healthier. The cycle of disease is replaced by a cycle of health. This is urban development at the human level.

C. *Socioeconomic benefits*

The principal socioeconomic benefit of urban drainage and land-reclamation projects is the increase in the value of land, although, as noted in section A above, if the urban planning process is not equitable, this can have a detrimental effect on the urban poor. Provided drainage and reclamation projects have been properly designed and executed, significant increases in the value of the land are basically inevitable, since land which is subject to frequent and serious flood inundation has very a low value compared with land which is protected or has a low risk factor associated with it. Improved drainage of this low-lying land can significantly increase the land values to the benefit due to the ability of local authorities to increase the valuation of the property tax base within the city.

Land which is subject to inundation is frequently low-lying and consequently the drainage investment required to protect it against a reasonable frequency of flooding is significant. It is often necessary to create artificial drainage patterns within the site so that the area can be drained for local storms and protected from major flows in the catchment waterways. A typical example, from Greater Manila, is given in box II.1. However, a surplus of economic benefits and financial viability cannot be taken for granted in any drainage and reclamation project. Careful analysis must be made of the costs of providing services at the appropriate levels and standards, together with conservative estimates of land values when the use is changed. It is essential that the environmental benefits and negative impacts be included in the equation, even though these are notoriously difficult to measure. In addition, the costs of correcting any external adverse effects must be included in the development costs. Further details are given in section V.C.

There are, it should be noted, serious economic disbenefits associated with forgetting about drainage. An example of this is to be found in the urban component of the Million Houses Programme in Sri Lanka. The Government was prepared to loan up to Rs 15,000 to plot holders to build a house, but it found it also had to spend an average of Rs 12,000 on plot preparation: this was not taken into account at the planning stage and so it ended up as a non-reclaimable government investment which was principally used to reclaim low-lying land designated for low-income housing or upgrading land already illegally occupied by the householders.

Box II.1 Drainage increases land values in Dagat Dagatan, Greater Manila

The site area in Dagat Dagatan was 410 hectares. The drainage component of the services/infrastructure provided represented 17 per cent of the total cost for off-site drainage work and 13 per cent for on-site drainage works. Out of a total cost (1978) of 452 million pesos, drainage costs therefore represented 229,000 pesos per hectare or 23 pesos per square metre. Land values increased from about 35 pesos per square metre to 94 pesos per square metre or 2.7 times due to the improvements and investment of infrastructure.

To make this land useful for urban purposes, reclamation was required to raise the site above the normal sea level and to grade the site to create local contours to provide the minor drainage system.

The economic analysis undertaken for the positive for three different land sale prices which were evaluated. Even at the price of 75 pesos per square metre there were positive benefits. In addition, there were substantial social benefits both on the site and off the site due to improvement of communication networks and locational advantages which could not be calculated in money terms but which were very real benefits. Additional social benefits noted in the economic analysis were the increased productivity of neighbouring land and improvements provided by the Dagat Datan development.

The reclamation significantly increased the productivity from the land due to the ability of the government agencies to consolidate a large number of small holdings into a single large parcel for redevelopment from fish ponds to urban use.

III. TECHNICAL OPTIONS FOR STORMWATER DRAINAGE AND LAND RECLAMATION

A. *Stormwater management*

Drainage systems in urban areas can be broadly divided into two types:

(a) *Combined systems,* where stormwater and wastewater (sewage) are combined together in one system to discharge into the watercourses which form the natural drainage system;

(b) *Separate systems,* where wastewater is diverted into a separate piped system to isolate it from stormwater flows.

In most cases, designers today prefer the use of separate systems, although in many developing countries where sewerage systems have not yet been provided the storm drainage system of necessity also carries urban wastewater. Conversion to a separate system can often be achieved in stages over time.

This report is principally concerned with the separate-system approach and with the provision of a system to collect, transport and dispose of the rainfall within a particular catchment. It is essential, however, that designers recognise the implications of low velocities which occur during dry weather in storm drains which also carry sewage. Low velocities can result in the deposition of silt and solids, so creating unsatisfactory sanitary and aesthetic conditions.

The main purpose of the urban drainage system is to convey stormwater to the receiving waters with a minimum of nuisance, danger and damage. Goals for urban drainage management are as follows:

(a) To ensure that floodwater inundation of residential commercial and industrial areas located in flood-prone landscape occurs only on rare occasions and that the velocity/depth conditions during these events are below prescribed limits;

(b) To provide convenience and safety for pedestrians and traffic by controlling stormwater flows within prescribed limits;

(c) To retain within each catchment as much incident rainfall and run-off as is possible given the planned use of the catchment terrain and its biotic and engineering characteristics.

The application of the first two goals within the drainage system of an urban area brings forward the concept of the major and minor drainage systems as part of the overall urban run off management.

This concept of urban run-off management can be considered as part of an overall strategy for water management within the city. The concept recognises that the total urban drainage system consists of a minor component which includes the network of pipes and surface channels capable of handling run-off from storms up to an agreed magnitude. Often, this magnitude of design frequency is chosen arbitrarily but, generally, it relates to the occupation of the land in the catchment and the potential damage which would follow inundation with floodwaters.

Larger storms than the adopted magnitude of design frequency for the minor system bring into play the major component of the drainage system. This is the route followed by storm flows which cannot be accommodated within the minor drainage system. This frequently involves the roads and other spaces naturally followed by floodwaters and is often not the result of deliberate design. It is an important objective of drainage design to ensure that adequate capacity is maintained in the path of the major drainage system without creating a hazard or threat of damage up to the design recurrence interval.

It is the recognition of these two major components which designers must keep uppermost in their minds when planning and designing a drainage system for an urbanized catchment. There is little benefit to be derived from increasing the capacity of the minor system without recognising the potential for using the major system. The logic of adopting this approach has been that increased capacity in the minor system will increase flood protection and reduce inconvenience. However, large storms will still achieved from the increased investment in the minor system may not be justified. There is a need to evaluate carefully the objectives of the minor system from a cost effectiveness standpoint and to recognise the value of the major system in coping with overflows from the minor system.

The design of a major drainage system implies the preservation of more open space. The control of development in the natural waterways and the preservation of natural channels in developed areas is preferable to a total commitment to storm drainage structures. This concept of a planned integration of permanent water areas in open spaces with provision for temporary flood storage can reduce drainage costs in two ways:

(a) Peak flood flows are attenuated, thereby reducing downstream drainage capacity requirements;

(b) Temporary storage, if properly designed, provides recreational and aesthetic benefits and, thereby, increases land values.

B. Drainage system components

Drainage systems, particularly in the minor system network, might include pipelines, open channels, natural surface channels and canals. The major drainage system would almost certainly include open channels and natural watercourses within an urbanized (or urbanizing) catchment.

Urban and rural development changes the preexisting natural drainage conditions. Agricultural development involves the clearing of the natural vegetation and replacement with pasture and harvested crops. This process usually increases surface water run-off, increases the rate of run-off and reduces the opportunities for infiltration, evaporation and transpiration which are critical components of the overall hydrological cycle. The methods of agricultural improvements to land include ploughing and grazing which can cause erosion, soil loss and sedimentation in streams thus further altering the natural environmental conditions.

Urban development has an even more marked effect than does agricultural development. By its very nature it covers a large proportion of the developed area with impervious surfaces including roads, footpaths, driveways, houses and outbuildings, commercial and industrial buildings and parking areas. Even parks and garden areas and sports fields are designed to be free-draining and avoid ponding and to shed the majority of storm rainfall by surface drainage and sub-surface pipe systems more quickly than the natural rate of infiltration will permit.

This more rapid surface drainage and the provision of lined drains and piping systems, besides increasing run-off, also removes opportunities for infiltration, evaporation and transpiration. It rapidly increases the rate of run-off concentrating it and aggravating flooding problems in downstream areas. An illustration of the rates of run-off changes due to increasing percentages of impervious cover as development increases is shown in figure 3.1. It can be seen that evapotranspiration decreases by some 25 per cent, but that surface run-off increases 4.5 times. Major losses also occur in infiltration, which is reduced by some 30 per cent. It is, therefore, of great importance in planning the design of a drainage system that areas of infiltration and storage either be retained or created within the major drainage network to attempt to mitigate against the impact of urbanisation on the run-off characteristics.

C. Storage: detention and retention

Any system of run-off involves some storage between rainfall and the collection of the run-off in a major watercourse or receiving waterbody. Natural storage occurs as wetting on natural vegetation and in surface depressions under conditions of overland flow. This is usually minor, depending on the configuration of the area concerned.

Where the area concerned contains larger depressions, major open drains or where the surface water recharges adjacent aquifers through major pervious soil areas, the natural storage may be much greater. The storage in pipes and streams themselves is of significance in the behaviour of the total drainage system. This storage acts to reduce the peak of the storm hydrograph by increasing the time of concentration and by varying and spreading the range of concentration times from the individual contributing areas. It therefore lessens downstream flooding and the size

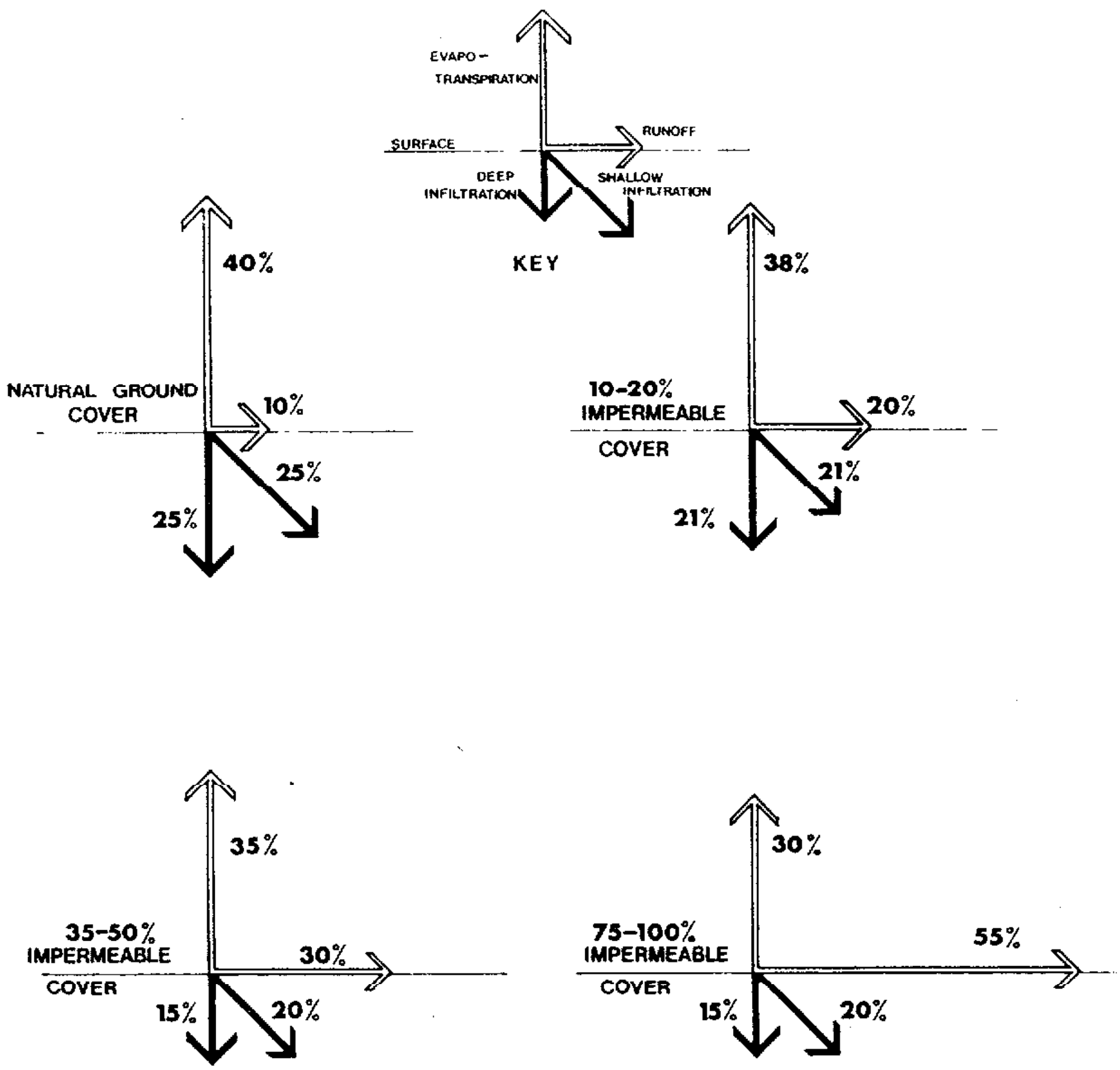


Figure 3.1. Runoff changes due to changes in impermeable cover in catchment

of the designed drainage system necessary to handle a given storm event.

Storage may be either temporary or permanent and may be designed into a development to replace the natural storage lost due to development or to augment insufficient natural storage to avoid aggravating inadequate downstream capacity. Storage may be designed to be concentrated or distributed, or it may be a combination of these to suit particular design parameters.

Further discussion on designed storage and its role in the control of run-off is given below. Despite its importance in understanding of stormwater management, it is not a universal solution. The physical characteristics and constraints in an urban catchment may preclude the provision of sufficient storage, or may make it uneconomic, even if it is technically feasible.

Detention

Detention is the technique of using temporary storage to collect and hold run-off for a short period of time and then release it through a controlled outlet into the normal drainage system at a reduced rate. The peak outflow is thus lessened and the drainage system downstream of the temporary storage is more easily able to carry the storm flow. Detention methods may be implemented at a local or regional level. The difference is really only one of scale, though they may conveniently be thought of as relating to stormwater drainage and regional flood control respectively.

In recent years there has been a substantial movement in the United States of America and other developed countries to require a developer to take steps to ensure that peak run-off rates from its development are not higher than those existing before the development.

Some techniques for providing detention include:

(a) *Rooftop detention.* In order to meet these requirements some developers of commercial and industrial properties have provided ponding on flat roofs to store stormwater and release it gradually into the drainage system. A typical detention ponding ring is shown in figure 3.2. This method of detention makes use of the substantial load carrying capacity of flat roofs which are designed for high live loads.

(b) *Parking areas.* Another method used to comply with these requirements of limited stormwater outflow from commercial properties is to construct parking areas with a large holding capacity and restricted outflow. Thus the parking area acts as a detention basin for some time after a sudden downpour. The large parking areas serving shoppers and sports areas makes this viable when other land is not readily available. Two general methods have been used in the United States of America. In one method the parking surface is graded to porous medians which act both as storage basins and seepage pits, so permitting the slow infiltration of stored water into the ground or the drainage system. The exact details will be site-specific and depend upon prevailing soil conditions including both the permeability and the susceptibility to siltation. A typical method is shown in figure 3.3. The surface should be graded to assist drainage to the porous median. Slopes between 1 and 4 per cent are generally recommended.

(c) *Tanks.* Some studies have shown that there could be overall economic benefits in residential development by introducing a fibre-glass tank detention system for each household in the development. The system consists of a conventional roof and downpipe system but with all downpipes being led to a single under-house fibre-glass tank which would receive and store the house stormwater drainage. Outlet from the tank would be choked and drained through a small diameter pipe to a reduced drainage system (figure 3.4). Since the tank in this system is to be placed at the very source of a major component of the stormwater run-off, the savings accrue to all components of the drainage system.

(d) *Retarding basins.* Beyond the local off-site detention areas, there are sometimes one or more major downstream detention basins, more often known simply as retarding basins. The key factor in detention is not a change in run-off quantity but a change in its discharge rate. Each area which is used for the temporary storage of run-off is designed to discharge its storage more slowly than the rate of inflow, thereby providing attenuation to the hydrograph as it passes through the storage. As a general guide, the rate of release should be

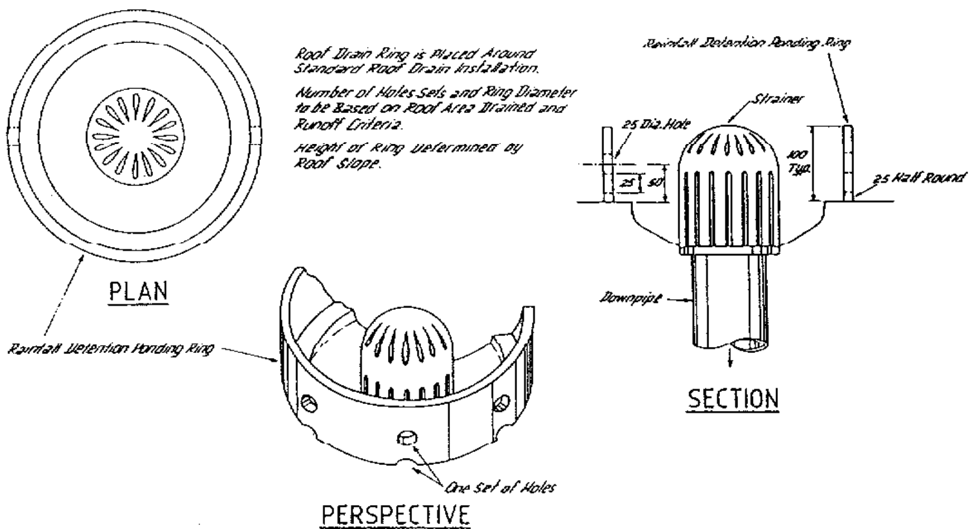


Figure 3.2. Detention ring for flat roofs

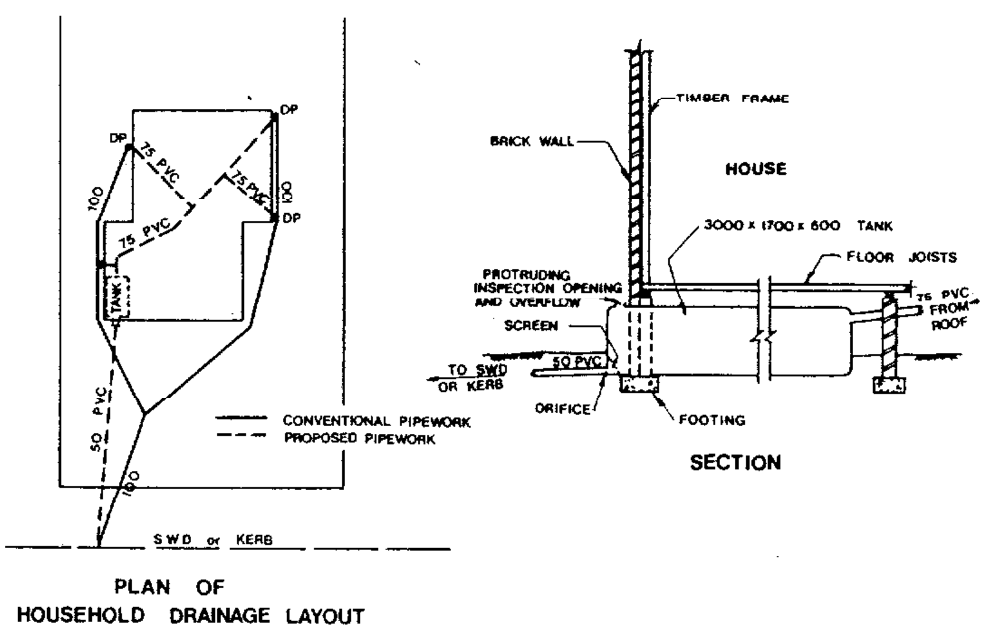
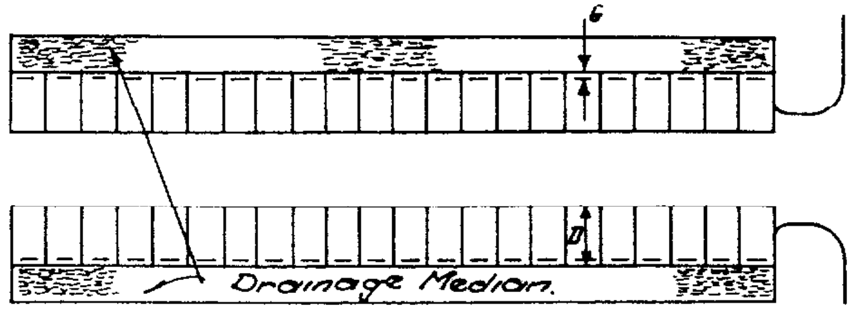
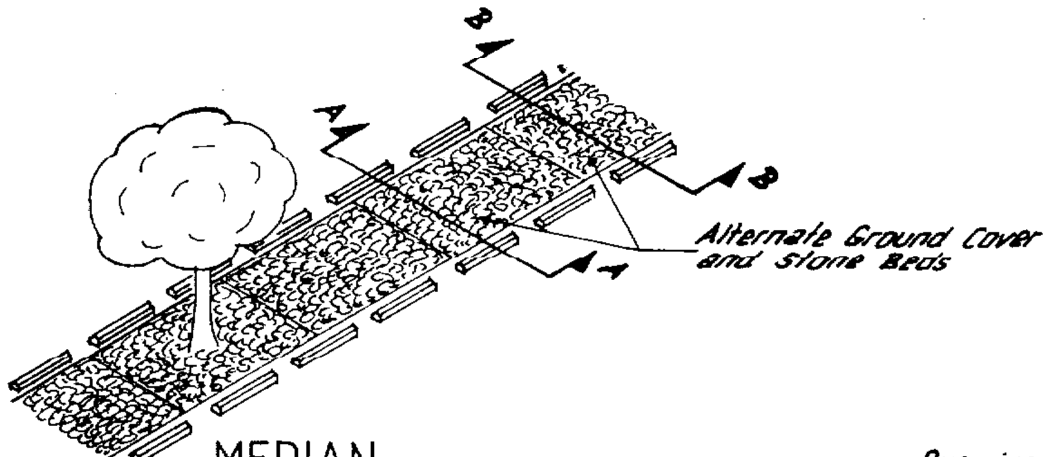


Figure 3.4. Household tank detention system

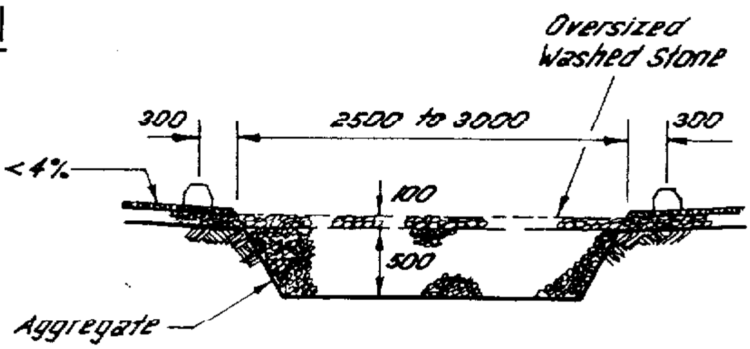


PARKING MODULE

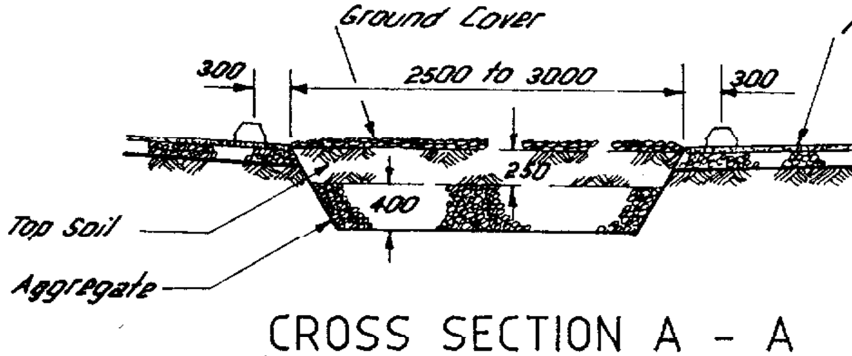
PERPENDICULAR PARKING



MEDIAN



CROSS SECTION B - B
AT STONE BED



CROSS SECTION A - A
AT GROUND COVER BED

less than or equal to the rate which would have applied to the natural system before development took place. The effectiveness of this approach, properly used, is illustrated in figure 3.5. However in a complex system of interconnected detention ponds and retarding basins it is necessary to verify that the resulting sub-catchment hydrographs do not accumulate in such a way as to affect the outflow hydrograph adversely. This possibility is illustrated in figure 3.6 for a very simple system. It shows how detention, although lowering the individual hydrograph peaks, could result in a net increase in the overall hydrograph peak due to the concurrence of the individual hydrographs. Such an example is artificial and unlikely to occur in practice, but the principle is important and the resulting hydrographs should always be checked.

D. Drainage system design

Factors affecting storm flows

The two principal factors affecting storm flows are rainfall and run-off. It is necessary, in designing storm drainage systems, to use rainfall data for the catchment under consideration. This leads to an estimation of the various stream flow characteristics and the run-off quantities to be coped with in the drainage system. It therefore follows that, for satisfactory drainage design, adequate rainfall data are essential. However the forms in which rainfall data are normally retained vary considerably, depending on the country and the purpose for which the rainfall data were originally measured. The commonly used forms of data for hydrological analysis include estimates of basin rainfall depth, rainfall intensity (the amount of rain falling at a certain point over a given period of time), rainfall duration and storm pattern characteristics.

It is common to try to classify rainfall information for drainage design into intensity-frequency-duration data and storm pattern data. In developed countries the meteorological agency which collects and records rainfall data at many locations throughout the country is able to produce rainfall intensity-frequency-duration curves for a particular location. However in developing countries the availability of data is often limited to daily rainfall information and a great deal of effort is needed to storm drainage design. Further details are given in the annex.

Run-off is that measure of the quantity of water which occurs from the rainfall events. The volume measurement of its estimation is the basis for drainage design. It is unusual to find sufficient information available in developing countries for the measurement of run-off in urban catchments, and thus estimating procedures must be used based on the rainfall intensity-duration-frequency curves generated from rainfall data. Run-off depends on a number of factors apart from rainfall, such as the rate at which the water flows across the surface of land and reaches the drain being designed. The nature of the ground will affect the eventual quantity of run-off. More porous catchment areas will provide more infiltration. Flat slopes will provide more areas for storage in low-lying areas in the catchment and consequently opportunities for transpiration, evaporation and infiltration. Catchments which are already wet (antecedent wetness) will have higher quantities of run-off for a particular storm.

The more of this rainfall which is lost during the run-off process, the lower will be the requirement for drainage capacity.

Estimation of flood flows

The processes involved in the transition from rainfall to run-off can be summarized as follows:

(a) Rain falls at a rate which varies with time and with the extent of area covered;

(b) Water runs off the different surfaces in the catchment, the latter flow being affected by retention on the surfaces by their relative distribution by infiltration and by the hydraulic characteristics of the surface channels and inlets;

(c) Once in the drain, the water flows at varying rates and the volume of water contained in the drain also varies with time.

Because of the inadequate records available for run-off, methods for designing storm drains have generally been based on rainfall records which are available at many more locations and for substantially longer periods than any run-off

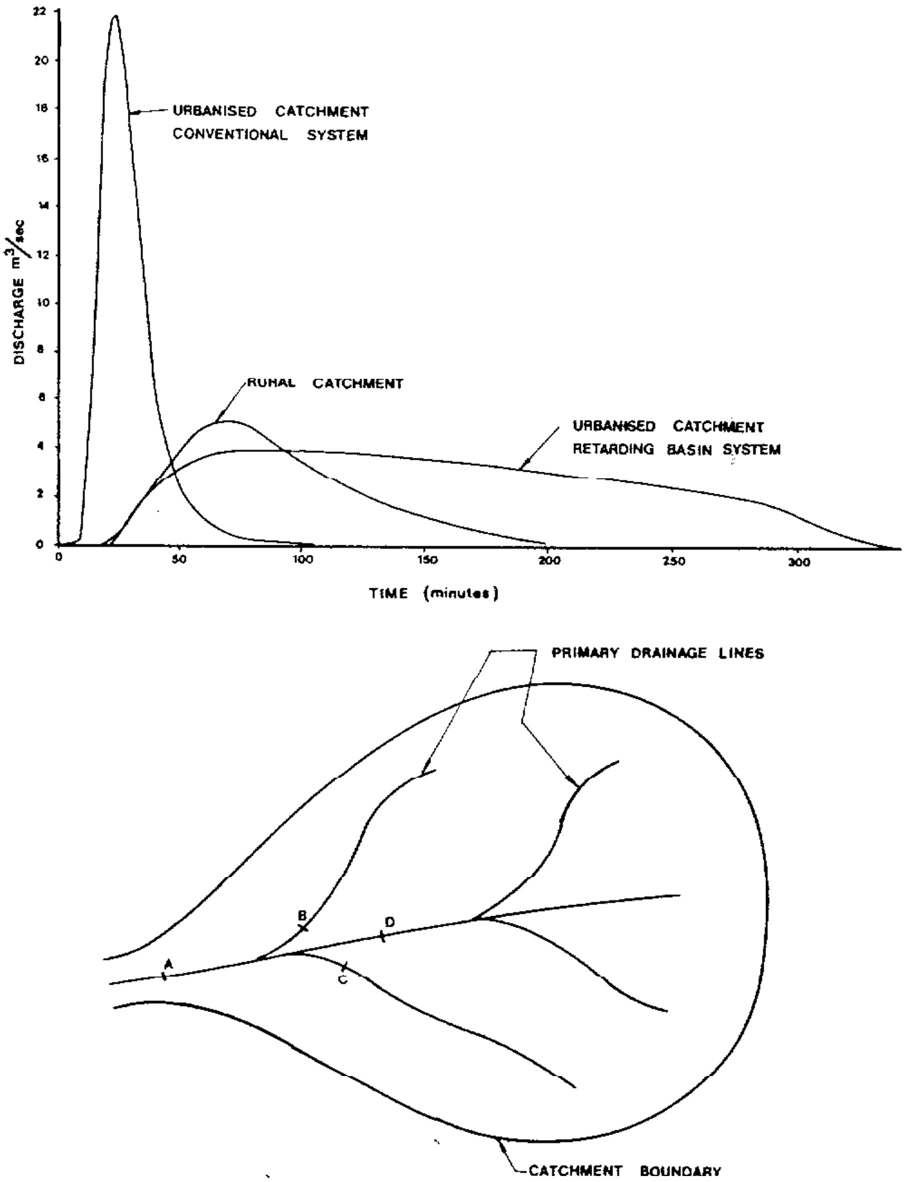
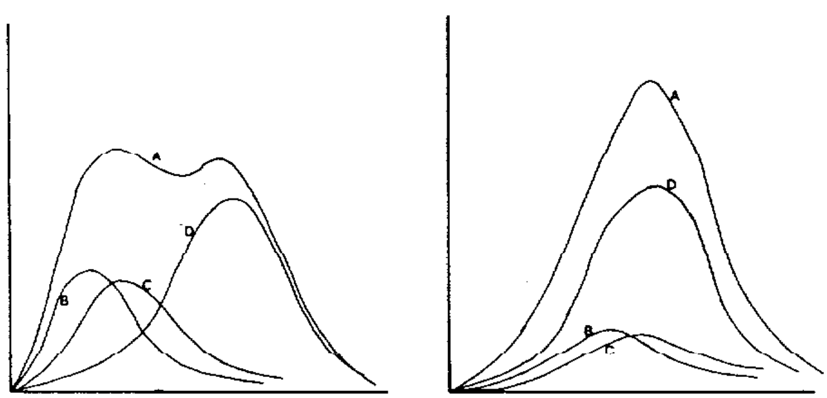


Figure 3.5. Effectiveness of retarding basin in an urbanised catchment



Run-off must be less than rainfall by an amount depending on the physical characteristics of the catchment.

Rational method

The simplest and most widely used example of this approach is the rational formula, which is based primarily upon the assumption that the maximum rate of run-off will be produced by the most intense rainfall that can be expected to occur over the basin for the period of time required for surface flow from the furthest part of the basin to reach the point at which the peak flow is being computed.

The simplicity of the formula and the clearly evident logic on which it is based have led to its widespread and continued use. Except in the case of urban areas for which it was originally developed, however, a number of important secondary assumptions implicit in the formula are seldom satisfied. The rational method is an adequate method of approximating the peak rate of run-off from a rainstorm in a given catchment. Its greatest drawback is that it normally provides only one point on the run-off hydrograph. When the catchments become complex and where subcatchments join, the rational method tends to overestimate the actual flow, so resulting in oversizing of the drainage components. The rational method provides no direct data to route hydrographs through the drainage facilities - that is, it takes no account of the storage and retention within the drainage system itself and consequently will tend to over-estimate both the run-off and peak flows.

One reason the rational method is normally limited to small areas is that good design practice requires routing of the flows for large catchment areas to achieve an economic design. There is, however, no agreement on the size of the catchment which should limit the use of the rational formula. Nonetheless it is reasonable to take 20 ha as a maximum area, and where urban catchments are larger they should be broken into sub-catchments of about this size.

One of the basic assumptions underlying the rational method is that run-off is a function of the average rainfall rate during the time required for water to flow from the most remote part of the drainage area under consideration to the point or design flow being calculated. However, in practice, the time of concentration can be an empirical barrier.

The TRRL method

This approach to the estimation of run-off was developed by the Transport and Road Research Laboratory in the United Kingdom to overcome the problems inherent in the rational method. The TRRL method is a hydrograph technique, which in its present form is implemented as follows:

(a) A hydrograph is constructed for a given pipe, using an area-time graph for the catchment area directly connected to the pipe and a rainfall profile;

(b) This hydrograph is added to the outfall (i.e., exit) hydrograph of the pipe immediately upstream of the one under consideration, displacing it by a time equal to the flow-time in the pipe being considered;

(c) The combined hydrograph is now routed through the reservoir formed by the pipe being considered, assuming instantaneous uniform proportional depth in the pipe under consideration to the given outfall hydrograph for it;

(d) This outfall hydrograph becomes the upstream (i.e., inflow or entry) hydrograph for the next pipe downstream, and so on.

The procedure is illustrated in figure 3.7, and the process is equally applicable to open channels, as well as to pipes. The method, which has been computerized and for which programs are commercially available, has been modified for tropical conditions where some account has to be made of the stormflow from unpaved areas.

E. *Land reclamation options*

Reclamation in areas already occupied

Most sites where extensive reclamation is contemplated are low-lying and swampy. Reclamation is seen as the appropriate means of increasing the value of the land by making it

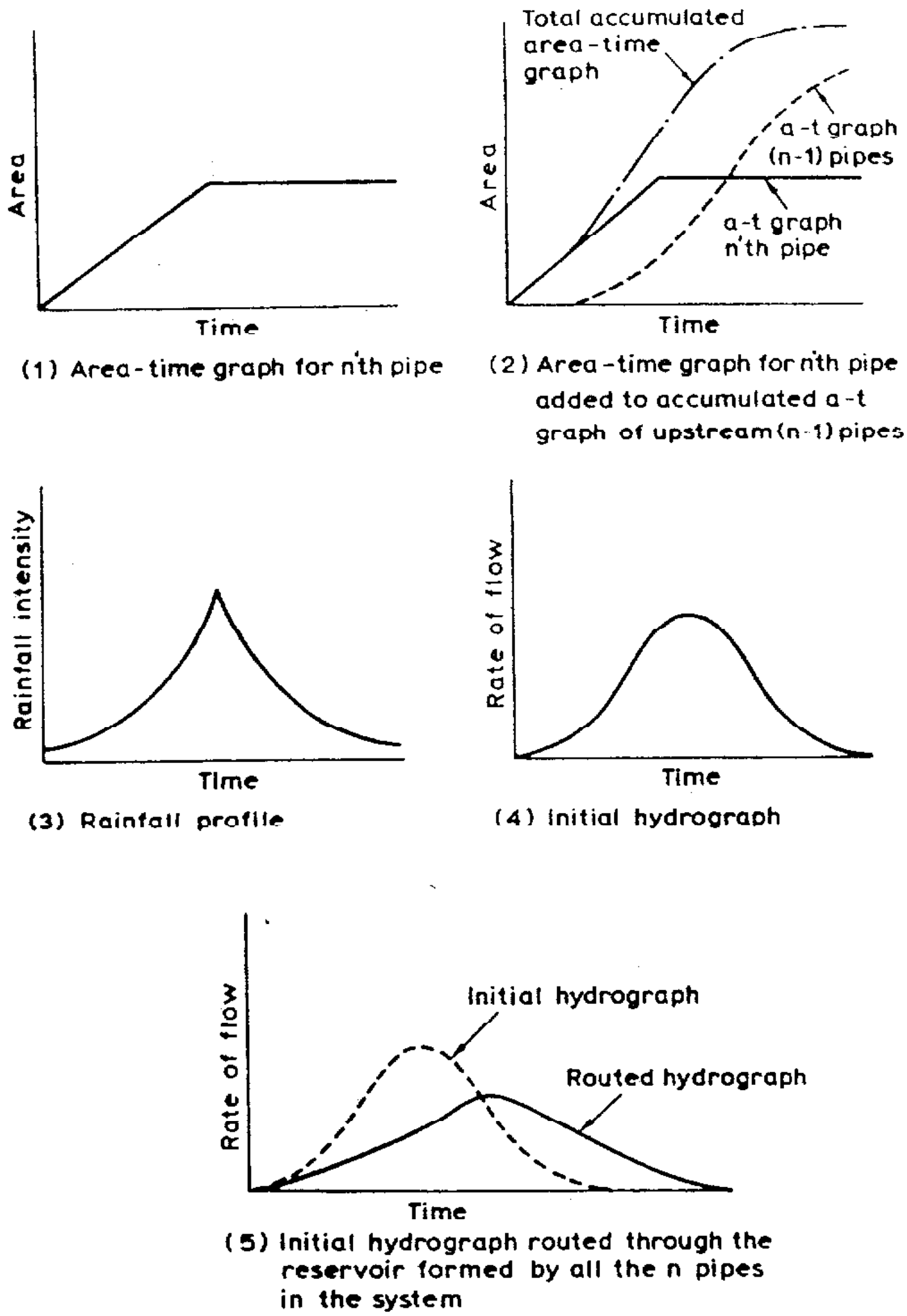


Figure 3.7. Steps in calculation of a hydrograph using the TRRL method

The cost of reclamation has to be balanced against the value added to the land. As the demand for urban land increases, the economics of reclaiming low-lying land becomes more attractive. As already noted, low-lying land located near existing urban centres often attracts squatters who build houses on the land, even into the water, simply because the land is vacant.

The main feature that most squatter colonies have in common is that the land is usually low-lying and even tidal: for example, areas of the Tondo in Greater Manila flooded twice a day with the high tide before reclamation of these areas was completed. Where squatters have occupied land, densities are often 150 houses per hectare. Drainage is normally non-existent. Roads are built above the level of the housing land, houses then being built with raised timber floors. Reclamation in this case is very difficult and can only be undertaken by manual techniques. Occupiers fill their land with solid waste and other fill materials as they become available. The whole reclamation procedure can take many years to complete before seeing the benefits to health from eliminating water under the dwellings and being able to dispose of stormwater and wastewater into a network of pipes and channels. Major programmes to hasten this improvement have been implemented - for example, the Zonal Improvement Programmes in the Philippines and the Kampung Improvement Programmes in Indonesia. Most other developing countries have, with the assistance of multilateral lending agencies, implemented similar slum-upgrading programme.

Reclamation methods for large-scale development

In other cases, housing authorities, faced with the enormous demand for low-cost public housing have undertaken major urban development projects as sites-and-services projects. These sites are most frequently provided with a sanitary core for each housing unit. If these housing estates are to be of maximum benefit to the target low-income families, they need to be located near industrial areas, ports etc. where work is available so that the journey to work is reduced to 1 or 2 km. The only land which will be vacant and meet this location criterion is often low-lying swamps which, without extensive reclamation, are unsuitable for housing.

In these cases, where the land is undeveloped, other method of reclamation, using mechanical means, are available to enable large volumes of fill material to be transported at a low unit cost. The cost of transport of fill is a direct function of the distance of the borrow pits. For coastal sites, off-shore dredging is a practical solution. The process is illustrated in the diagrams in figure 3.8. Two techniques are shown. For borrow sites less than 2 km offshore, sand fill can be dredged from the sea bottom and flushed to the fill site by pipeline. For distances greater than 2 km, dredges fill barges which discharge into a stockpile nearer to the shore and the fill is then dredged and transported from the stockpile to the fill site as in the first method.

On-shore borrow pits allow the use of mechanical equipment, excavators, loaders and trucks to carry the fill from the borrow pit to the fill site. An example of this is the Mirpur Project in Dhaka. In this case, there were several sites requiring fill. The largest site was filled by trucks transporting fill to the site and the fill was placed where needed by manual handling in baskets. Other areas required site excavation and the cut material was transported by hand to fill areas within the site (figure 3.9).

Some problems on reclaimed sites

The principal physical problem to be faced in sites which are deep filled is the settlement, both short-term and long-term. The short term settlement is largely a factor of the type of fill materials, and the degree of initial compaction effort applied. It is desirable for the benefit of structures and roads being built for the sites to be well compacted as filling proceeds in layers. This is often difficult where dredged materials are used off shore. In these cases it is almost always necessary to found important buildings on piles. Piles are often also required under major sewers and drains since these services must be constructed to grade and the continued effective operation depends on them retaining their gradelines.

Long-term settlement is a function of the base material in the areas being filled. Where the land is swampy, it will often contain substantial depths

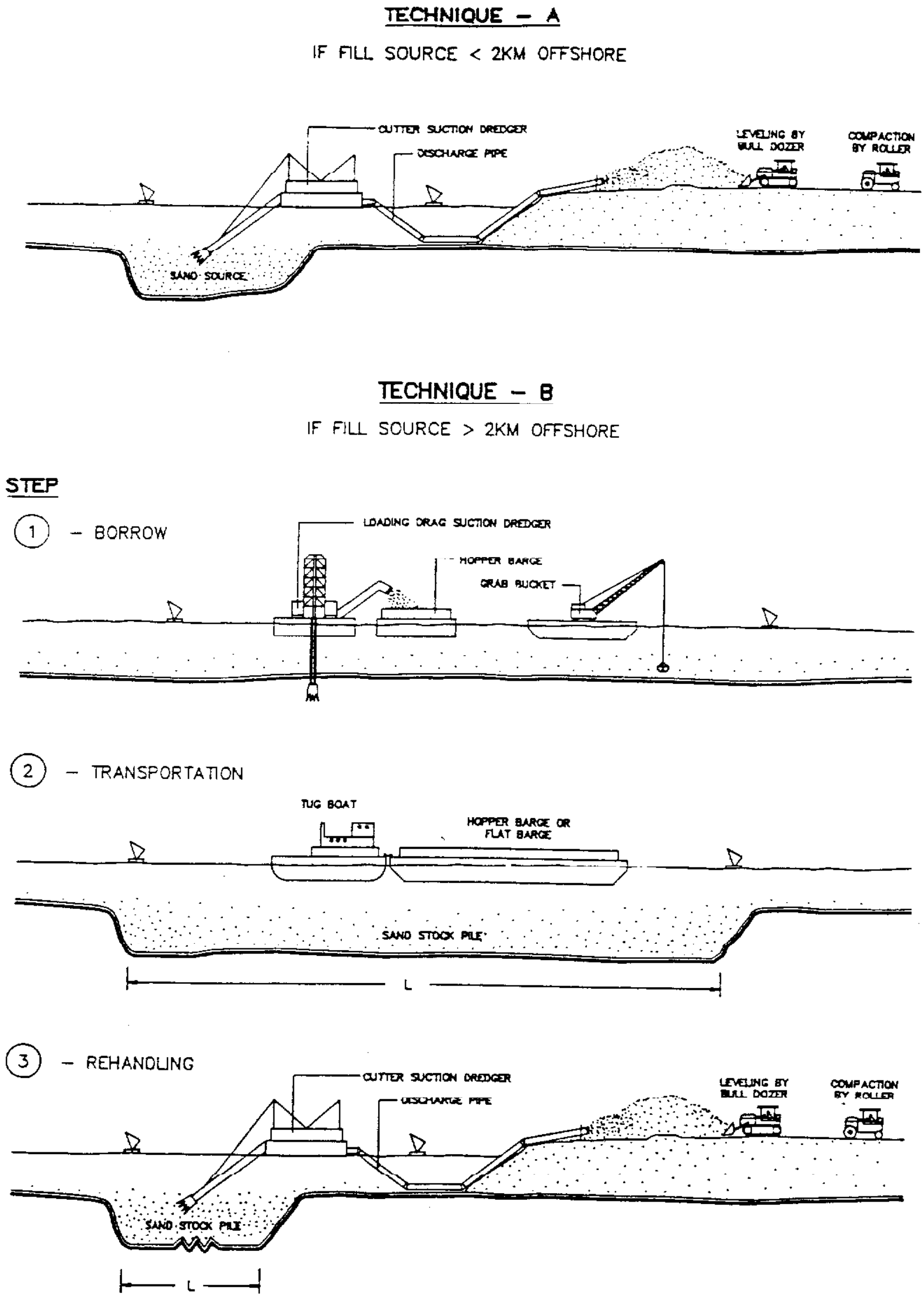


Figure 3.8. Alternative reclamation techniques from offshore

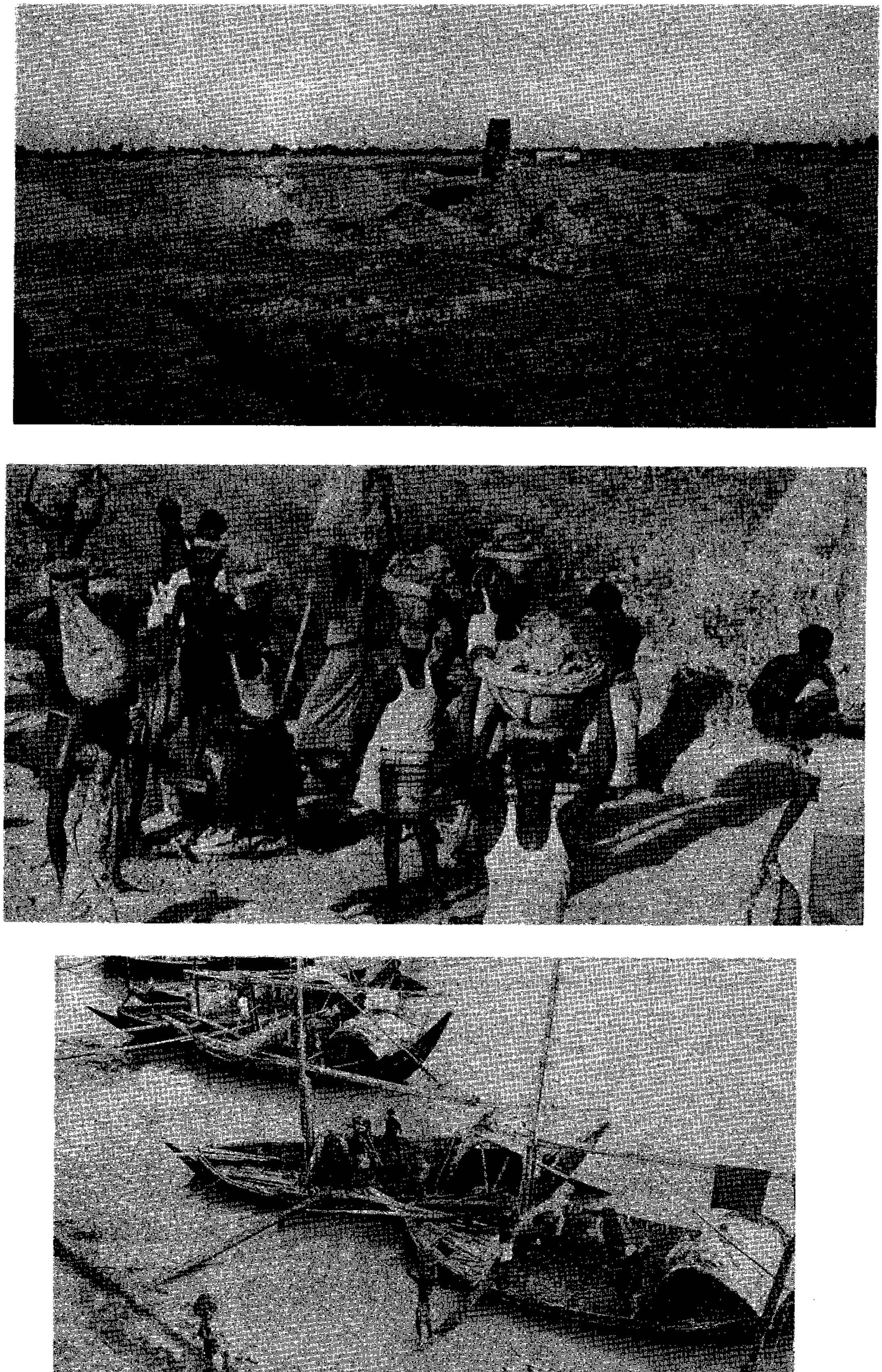


Figure 3.9. Filling techniques at Mirpur, Dhaka

of clay sediments which are soft and compressible. These will settle as the load of fill material is increased over the base sediments. Singapore provides a good example of the effect of placing deep fills of 6 m to 12 m over marine clays. The Geotechnic Division of the Singapore Public Works Department suggests that fill can continue to settle beyond 100 years. The curves in figure 3.10 show the anticipated settlement for a site reclaimed off-shore by sand dredging. Two curves show the settlement to be expected for one or two layers of fill.

The curves show that much of the settlement occurs in the first 10 years after fill. This experience suggests that:

(a) Potential reclamation sites should be filled several years before development occurs, if settlement is to be expected;

(b) Low profile small scale buildings are preferable to high rise and could be founded on short timber piles;

(c) More substantial buildings will require fully-piled foundations for stability.

F. *Land stabilization*

Where the land being reclaimed abuts the seaboard, special protection measures are required to maintain the stability of the site. The type of structure used for this purpose will depend on the availability of land. In Singapore, sea revetments are constructed on specially placed sand fill (see figure 3.11) with flat slopes. Excavation behind these revetments needs to be carefully considered due to the groundwater table associated with certain high tidal conditions.

Where space is a premium, a concrete or steel sheet piled wall can be built to protect the filled area from erosion and reduce the land loss from flat batters.

Seawall design is at a specialist function and required the consideration of a large number of complex interacting factors to ensure the wall is structurally stable and does not cause more erosion due to the change in the natural seaboard conditions.

Inland sites which are close to large rivers or require major drainage impose severe constraints on construction. It is generally necessary to construct the principal drainage channels before the filling of the site. One technique for doing this is illustrated in figure 3.12 where the walls of the channel are built "in the dry" and the waterway excavated by dragline or dredge depending on the drain dimensions.

As can be seen from the foregoing discussion, reclaiming land requires detailed engineering analysis in hydrology, soil mechanics, maritime engineering and construction techniques for successful implementation. Without this input, the results have a serious impact on land outside the site and result in unstable conditions within the site for many years.

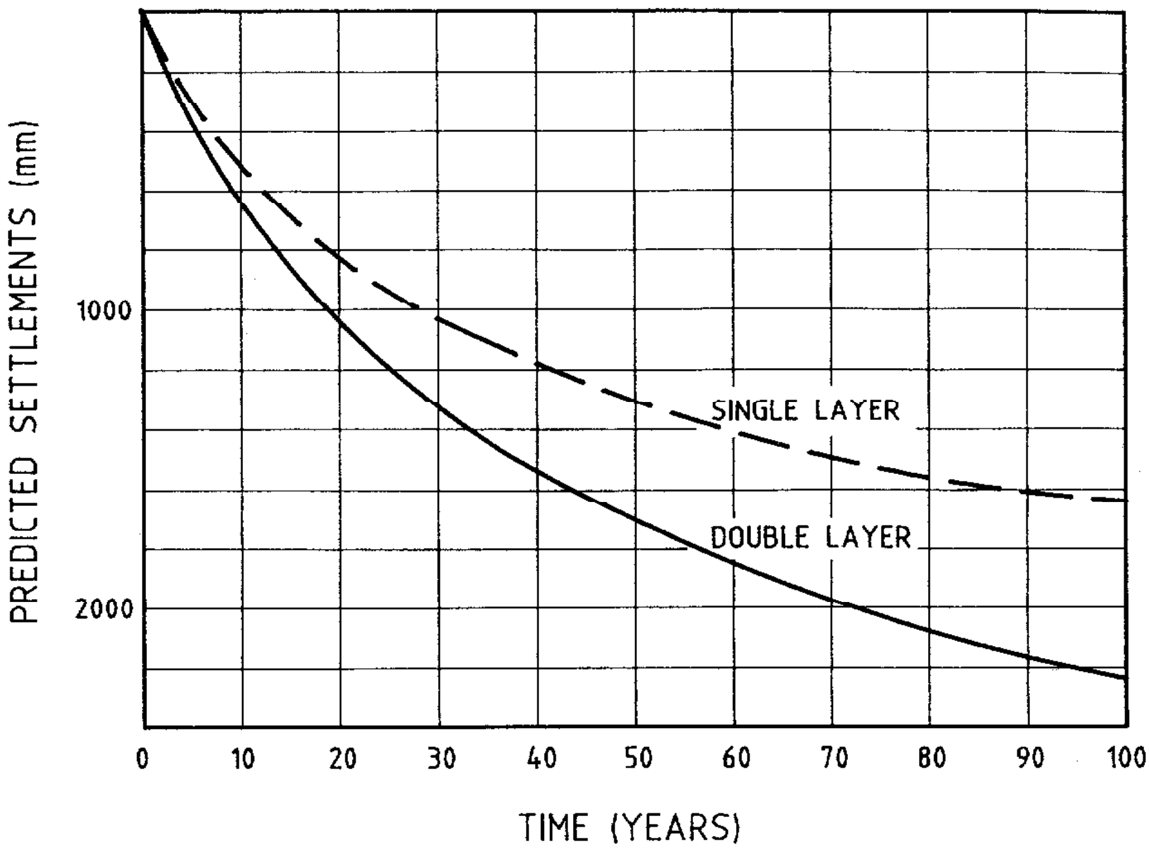


Figure 3.10. Predicted settlements in Singapore reclamation

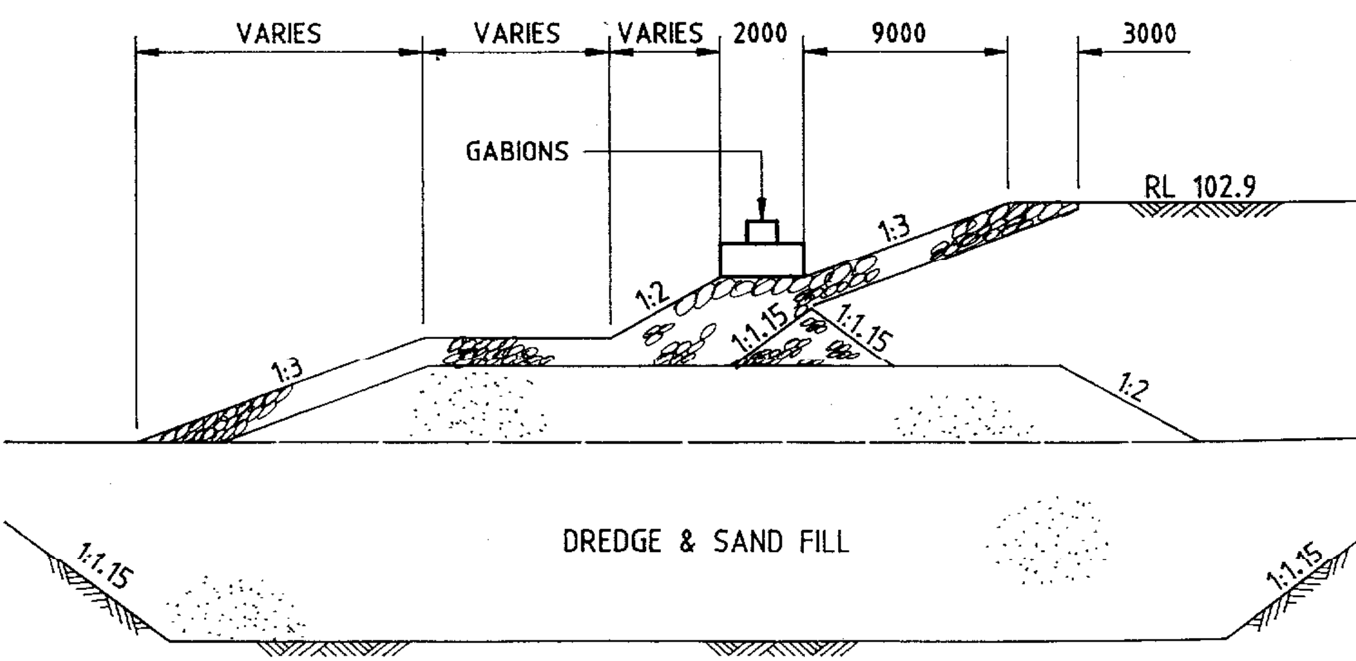


Figure 3.11. Revetment shore treatment, Singapore

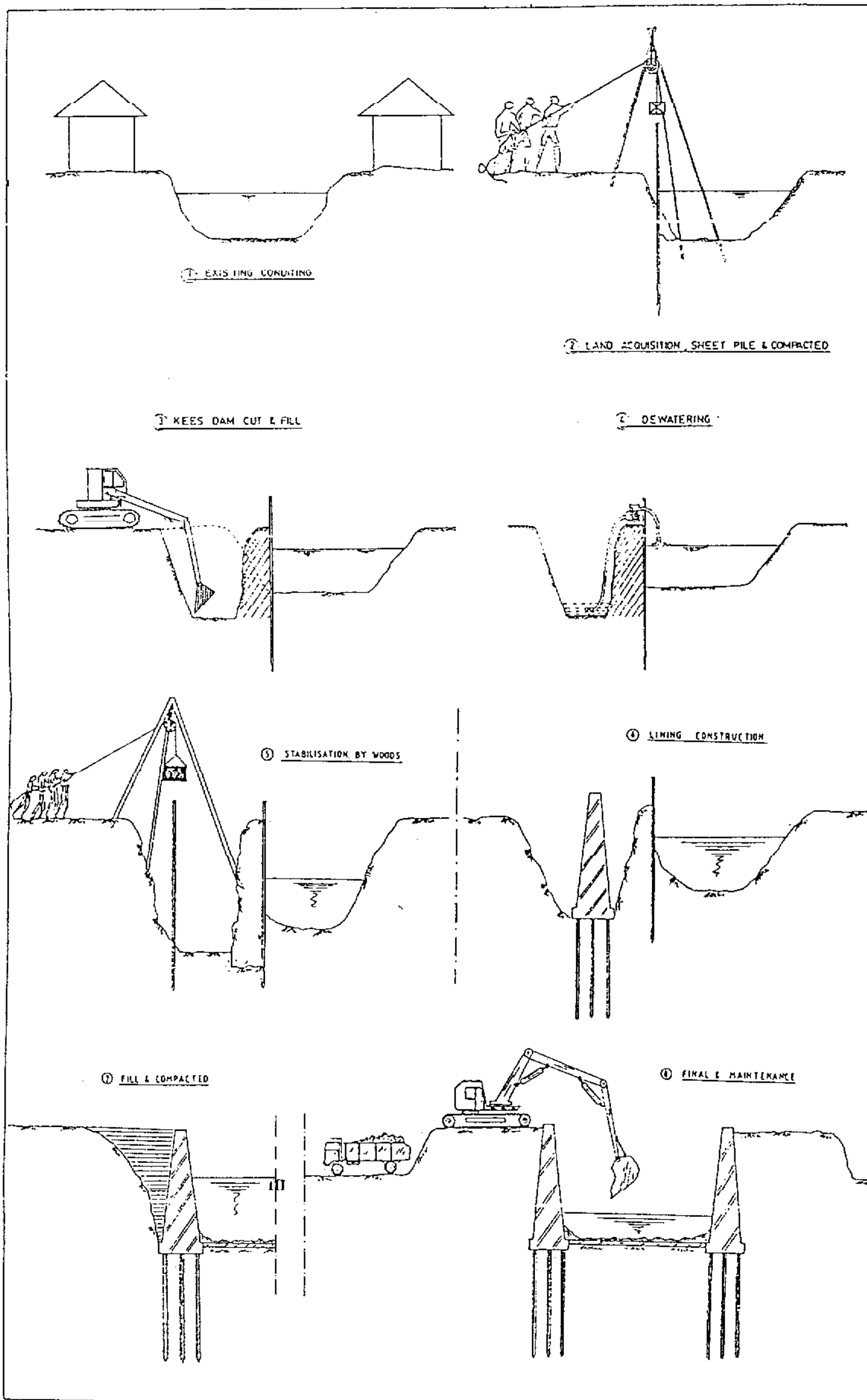


Figure 3.12. Technique for channel construction and land reclamation

IV. MAINTENANCE

A. *Maintenance objectives*

The importance of an adequate system for maintenance of the drainage system cannot be overemphasised if the system is to operate at its design capacity. If rubbish and silt are allowed to accumulate in channels and rivers, these facilities will not be capable of satisfactorily fulfilling their primary function - the removal of stormwater run-off. If the inlets into the drainage system from roads are not regularly cleared, they will become blocked and stormwater will be prevented from entering drains, so causing local flooding. The objective of a maintenance programme should, therefore, be to keep the drainage system operating dependably, at its design capacity, without breakdowns.

Protection of the capital investment in the drainage system necessitates a planned programme of inspection and routine clearing. Periodic, thorough and competent inspection while cleaning will reveal points at which damage begins to take place. Adequate financial and labour resources must be allocated to ensure successful drainage operation and maintenance. It is therefore necessary for drainage authorities, usually the local government, to ensure that maintenance is accorded a sufficiently high priority in the allocation of funds in annual budgets.

The objectives of carrying out the maintenance programme should be to:

(a) Keep the system operating at design standard at all times;

(b) Obtain the longest life and greatest use of the systems facilities by providing adequate maintenance and timely repairs;

(c) Achieve the foregoing two objectives at the lowest possible cost.

The history of drainage is full of examples of the difficulties which can occur when maintenance is neglected. Even the best constructed system will eventually fail if adequate maintenance is not undertaken.

Maintenance activity should begin the day the system is placed in operation or, under some circumstances, prior to completion of a system and before the system is placed into operation. Keeping maintenance work current on all facilities in a system is the keystone to any successful drainage enterprise.

There are two primary concepts of maintenance of public property, and most maintenance operations can be readily classified into one of these categories:

(a) Maintenance by necessity;

(b) Preventive maintenance.

"Maintenance by necessity" refers to the practice of "fixing it when it breaks down". Under this approach cleaning of drains is confined to the minimum necessary to satisfy complaints. Likewise, repair work is undertaken only when a condition becomes so bad that it must be corrected or repaired to restore service or for safety reasons. Unfortunately, this approach is all too common in rapidly growing cities where the funds for routine maintenance are inadequate.

"Preventive maintenance" is represented by a systematic programme of inspection, cleaning and repair that reduces breakdowns and complaints to a minimum. Preventive maintenance not only pays dividends in economical operation; a smooth working system also means uninterrupted removal of water at lower cost with reduced risk of damage from flooding as a result of design storms.

Preventive maintenance also has other distinct advantages:

(a) It can be scheduled and performed on a regular basis at times that least disrupt other operations functions;

(b) Pre-ordered parts can be made more readily available; they may not be so readily available under emergency conditions;

(c) Work can be carried out during normal working hours with less emphasis on extension of hours and weekend work;

(d) More experienced personnel can be used if the work is scheduled; they may not be available in emergencies;

(e) Special tasks of preventive maintenance may be contracted out to reduce the need to carry a specialist workforce.

B. The maintenance programme

All structures and facilities are subject to deterioration in varying degrees over time. Regular inspection therefore is necessary to detect and correct potentially unsafe or unsatisfactory conditions as they develop. Cracks in concrete or masonry, general erosion behind structures or settlement of an embankment can result in major failures if the cause is not identified and corrected or repaired without delay. Many problems that develop may not be of such a serious nature. In channels, the control of weeds, storm erosion of banks, seepage of water through banks and base, silting and accumulation of debris or solid waste may be less serious than structural failures, but they still require regular attention if efficiency of the system is to be maintained. Frequently these latter problems are more time-consuming and costly over the years and are more frequently neglected since they accumulate slowly.

The use of appropriate materials and methods for repair or replacement is important. This can include adequate attention to the quality of the concrete aggregate and cements used, and the characteristics of protective coatings used to meet environmental requirements. Staff responsible for drainage system operation and maintenance should always be alert to the development of new materials and products and their possible adoption for the solution of maintenance problems.

The application of the agreed maintenance procedures requires close supervision and the development of a range of skills in the maintenance workforce.

To accomplish the required maintenance, of materials, the need for lines of communication and access, and the personnel requirements to accomplish the work. Regular inspections and records of complaints will identify any components in the drainage systems which are not meeting the design criteria. If it is found that a structure or facility does not perform the purpose for which it was designed, the designer should be advised. In this regard, experienced operation and maintenance personnel can be of key assistance if they are given the opportunity to review system designs before a facility is constructed. In carrying out such reviews, they should consider designs and construction that will require the least maintenance consistent with budgetary constraints.

Obtaining the longest life and greatest use of drainage facilities can best be accomplished by providing good maintenance and a programme of systematic improvements and replacements. In many instances, it is hard to determine the point at which good maintenance ends and replacement begins. Good maintenance, for example, may necessitate the replacement of a gate leaf, later a gate shaft, and perhaps later still the lifting device itself.

As drainage works advance in age, a programme to replace worn out and obsolete structures is necessary to extend the useful life of the system. The essential requirement is to have a maintenance plan and programme.

C. Review of maintenance

The key to good maintenance is frequent inspection. Inspection followed by proper care of channels, structures and mechanical equipment will avoid major maintenance at a later date. Proper maintenance demands close and continuous examination of system facilities by experienced personnel, followed by timely repair and replacement programmes.

The timing of some recurring maintenance needs can sometimes be predicted. However, in general maintenance needs can only be determined by careful on-site observation. It is therefore necessary to arrange for periodic inspection of all system facilities at regular intervals. The results of these inspections must be recorded so that the computer technology and the development of smart software, this recording of information in databases for easy access and management reporting can expose trends in the extent of the maintenance effort required by various sections of the drainage system. This information system can then be used to direct the available maintenance funds to those areas.

As untreated or uncorrected minor maintenance needs can grow rapidly into major and costly maintenance problems, inspections should be made frequently. The interval between subsequent inspections may then be determined as performance dictates.

Three procedures which have been developed for the implementation of an inspection programme are:

(i) *Initial inspection.* When construction is essentially completed, a formal inspection of all work is made and any uncompleted items and deficiencies listed. This defines the work remaining to be accomplished and provides an opportunity for all concerned to be better informed on the condition of the system at the time control is taken over. The inspection should be made by a team representing the design, construction and operation and maintenance agencies.

(ii) *Operation and maintenance instructions and criteria.* A detailed manual for operation and maintenance of major structures covering all important features of the operation and maintenance of the structure should be prepared. The designers' operating criteria should be published to cover the technical operations of equipment and structures and the requirements for maintenance. This helps to ensure that the facilities will be operated as the designers intended, thus avoiding damage and extending the life of the facility.

(iii) *Periodic review of maintenance.* These reviews should be in the form of a thorough inspection of all facilities. The inspection team should include an engineer from the design organization, a senior representative from the operating agency, and key maintenance personnel. The principal purposes of the review determine the level of maintenance and conditions that might cause failure of operation; to note the extent of deterioration as a basis for planning maintenance, repair or rehabilitation work; and to obtain operating experience data for improvement of future design, construction, maintenance and operation practices.

Reports prepared for all review of maintenance inspection should include the current findings, comparisons with previous inspections, and a summary of conclusions and recommendations. To provide guidance in planning and performing repairs, they should also include adequate photographs and drawings to illustrate conditions found. It is suggested that recommended repairs and operating procedures be grouped into categories according to the importance of problems involved. These might be:

Category 1: recommendations involving matters of great importance which must be acted upon within a prescribed period;

Category 2: recommendations covering a wide range of important problems that should be solved;

Category 3: recommendations for modification of the inspection, operation and maintenance procedures.

D. Institutional arrangements for maintenance

The drainage system in a city falls into a distinct hierarchy. At the lowest level is the initial drainage system, the small drains along the edges of the roads and paths, and the kerbs and channels where rain falling on the roads and buildings will slow first. These channels convey water through inlets in the kerb or road edge to the minor drainage network.

The minor network of pipes and open channels are the second level in the hierarchy where the stormwater is collected and transported to discharge into the next tier, the major drainage system network of natural streams and watercourses.

It is not possible to set one single strategy for the will be suitable for all cities. Much depends on the overall institutional structure in the city: is it one municipality or is there more than one municipality with a regional authority with metro wide responsibilities for major drainage works? It is possible, however, to make some general assertions:

(a) The initial drainage system maintenance should be integrated with the maintenance of the local road network. These drains form an integral part of the road. Good drainage maintenance is an essential requirement of the protection of the road itself. The patrol gang responsible for the road maintenance should also ensure that the drains, culverts and entry points to the drains are clear, serviceable and able to function properly. In general, the public works department of the municipality would have this responsibility.

(b) Depending on the structure of the city government, the minor drainage system could also be maintained by this same public works agency. This will normally lead to efficient use of the agency's plant and equipment fleet and its labour force. In large cities this will be decentralized into districts where local depots would hold stores of materials, house equipment and provide servicing of the district's equipment. It also provides a local contact point for residents to lodge complaints. In some cities there is a division of responsibility for the construction and maintenance of the minor drainage system between the municipality and the metropolitan regional authority. For example, the regional authority might have responsibility for drains where the contributing catchment is greater in area than, say, 100 hectares. This has the advantage of locating the maintenance of these larger drains which frequently cross municipal boundaries with a single agency. This will lead to a consistent application of maintenance standards and design criteria.

(c) The major drainage system includes roads and landscape/park areas where excess stormwater from the minor system flows during heavy storms. These parts of the major drainage system are not formal drains and are used as overflows from the minor drains. Their maintenance needs careful attention so that they will properly fulfil this overflow role in times of

ambit of the municipality for routine maintenance. The other components of the main drainage system, the watercourses, streams and rivers, are clearly regional, traversing municipal boundaries. These are not only used to carry excess stormwater but may be used for recreation, transport, irrigation or water supply. Only a metropolitan-wide organization can successfully integrate these functions with the drainage function of the watercourse. Maintenance should therefore be the responsibility of this organization. If no metropolitan agency exists, the role will most likely fall to a provincial level of government.

The following are some of the key functions related to drainage maintenance:

(a) Programming and implementation of a regular inspection and maintenance programme of the drainage system;

(b) Collection and recording of rainfall and run-off data for all catchments in the area, if this is not available through a central agency;

(c) The establishment and maintenance of records of all drains in the system and the inspection and repair programme;

(d) The training of staff and operators;

(e) The protection of the public and employees by the development of safety programmes;

(f) Public communications to increase the awareness of the public of the importance of good drainage and the community's role in achieving this;

(g) Liaison with other agencies who may be affected, or whose functions affect, the drainage system;

(h) Consultation with the drainage design and construction agencies to ensure designs incorporate details to facilitate maintenance.

The form of organization for maintenance of urban drainage systems will vary by country and the government structures established in each country. The structure shown in figure 4.1 is the organization and the sections which are required to provide a comprehensive maintenance programme.

The key sections are:

(a) Safety office - separate from the operations sections to ensure this aspect retains its priority and status in the organization;

(b) Operations and maintenance;

(c) Inspection, records and survey;

(d) Sub-districts in larger cities with mobile gangs;

(e) Plant maintenance;

(f) Stores.

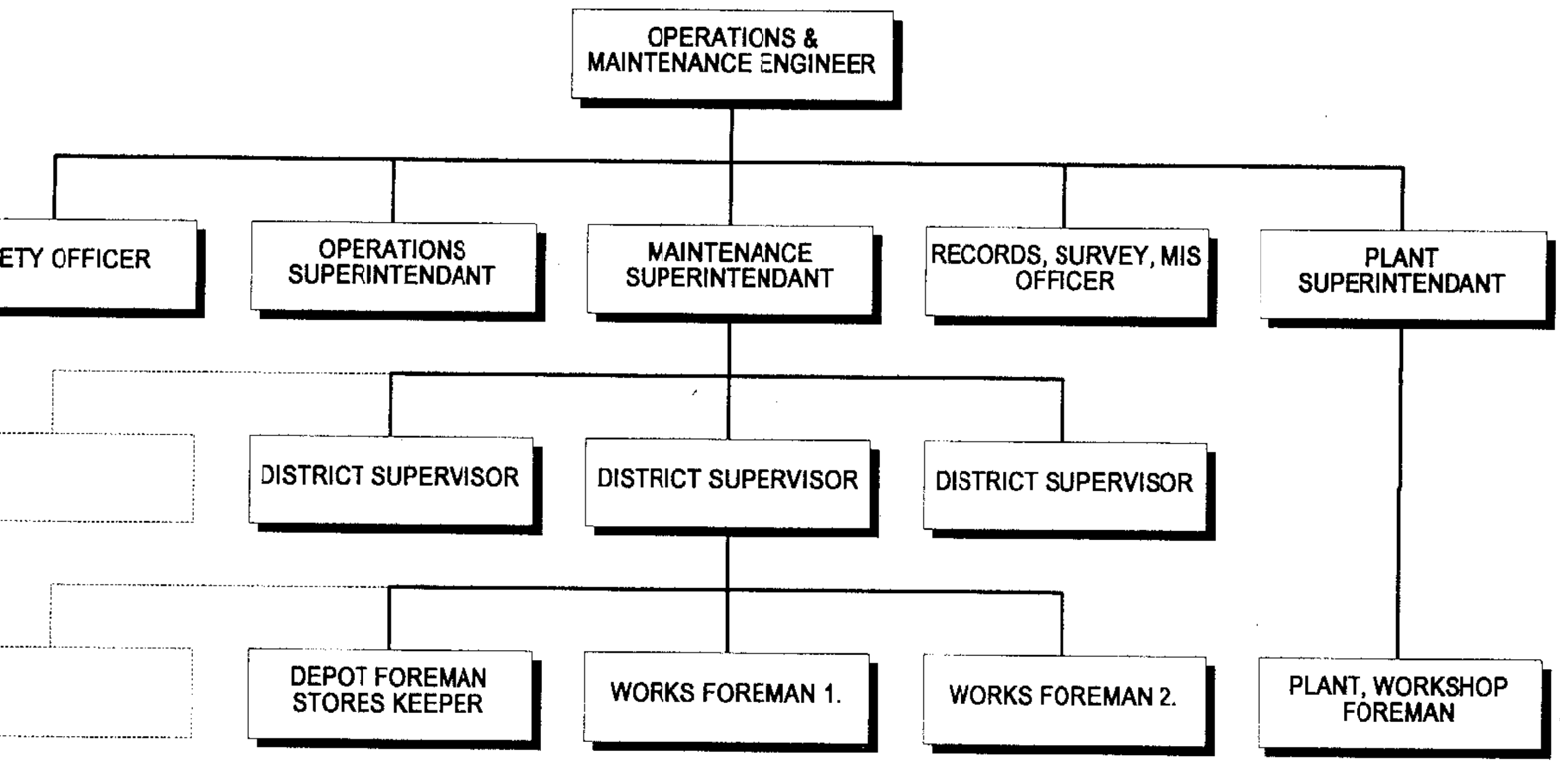


Figure 4.1. Organization chart for drainage operations and maintenance

V. PROJECT APPRAISAL

The appraisal of drainage and land-reclamation projects should follow the same procedures as for any other public sector project. This will include at least four types of review and analysis:

(a) Technical;

(b) Social and health impact;

(c) Economic and financial;

(d) Institutional.

The appraisal process requires a team with skills in a wide range of disciplines including urban planning, civil engineering, institution building, cost estimation, operations and maintenance, financial analysis and economic appraisal. For land reclamation, where lots are the product generated and these must be sold, skills in marketing, valuation, and estate management are also generally necessary.

A. *Technical appraisal*

The technical appraisal, or the engineering review, of the project will deal with such questions as:

(a) Are the physical scale and quantity of inputs (materials, labour and plant) appropriate for the development?

(b) Is the quality of materials proposed suitable?

(c) Are the design criteria based on sound planning and engineering principles?

(d) Does the level of service proposed meet the project objectives and affordability levels?

(e) Are the levels of technology to be adopted appropriate?

(f) Do the capital cost estimates meet budget provisions?

(g) Is there adequate access to the site, and are transport facilities satisfactory?

(h) Do the project procurement and project delivery procedures (including the implementation schedule) meet the phasing requirements of the project?

(i) Are the arrangements for stormwater disposal ecologically sound? Has a comprehensive environmental impact statement been prepared?

B. *Social and health impact appraisal*

The social and health impact appraisal is concerned with the effects of the project on people, and thus is concerned with such questions as:

(a) Does the project require any houses or other buildings to be demolished? If so, what arrangements have been made for relocation? Are these acceptable to those households to be relocated?

(b) What arrangements have been made for access during construction? Are these acceptable?

(c) Has a detailed health impact statement been prepared? Does it cover malaria, Bancroftian filariasis and schistosomiasis as well as faeco-oral and geohelminthic infections?

(d) Does the project create any new health hazards, including during the construction phase?

(e) What arrangements have been made for selling new plots to the urban poor? Can they afford them?

(f) Do the urban poor need special help to participate in, or benefit from, the project? If so, has it been provided?

(g) What legal safeguards have been incorporated into the project to protect the poor?

C. *Economic and financial appraisal*

There are basic differences between financial analysis and economic evaluation. Financial throughout the later stages of project preparation to refine design standards and test the financial implications of various implementation policies.

Economic appraisal attempts to reflect the effect of the project on the national economy and so must take a much wider view than financial analysis. The purpose of economic appraisal is to estimate the likely net impact on an investment project, in terms of national welfare. A good project will increase national income, undifferentiated by type of recipient. Income by itself does not create welfare, but leads to the consumption of goods and services and can serve as a proxy for such welfare-creating consumption. The viewpoint for the economic appraisal is that of a government official or agency concerned about the effect of a project on the overall economy.

The procedure for economic appraisal is complex and requires identification of the origin of the project inputs (labour, materials and plant) and the destination of outputs. An experienced economist is needed to prepare this analysis. In the words of the World Bank:

> Once a project's inputs and outputs have been classified as traded and nontraded, the procedure is straightforward. The cif or fob prices of the traded items are identified, along with the domestic costs of moving the items to the project site or domestic marketplace. Then the domestic market prices of the nontraded items are identified and converted into border-price equivalents. When all inputs and outputs have been expressed in border prices (including the domestic transfer costs), one simply inserts those values into the cashflow in place of the financial values and computes the economic rate of return.

To calculate the economic (internal) rate of return one can employ a trial-and-error method of finding the discount rate that reduces the net present value of the economic time series to zero. Ideally, this rate should equal or exceed the country's opportunity cost of capital.

A financial analysis is also required, and this has three main objectives:

(a) Confirm that an adequate financing plan exists to cover expenses during the investment phase of the project;

(b) To ensure that funds are likely to be available as needed during the operational phase of the project to pay for current operating and maintenance costs and to repay debt;

(c) To verify that sufficient surplus will be generated, under plausible assumptions about the future, to reward equity investors for bearing risk and putting savings into the project rather than elsewhere.

Investors can use a variety of techniques to measure the potential rewards of putting funds into one activity rather than another. The objective is usually the same: to maximize the return flow of income without exceeding some tolerable level of risk. A disciplined appraisal helps to focus on the nature and extent of risk as well as the likely amount of income to be expected.

The investor, be it a government agency or private developer, will have similar objectives, but the decision to proceed or not may be based on different criteria. The government agency may need to meet some social criteria to meet its political objectives. The private sector, unless subsidized by government, will evaluate the project on the basis that the project will show a superior return on investment than other potential investments available at the time.

Project timing and phasing are critical factors in determining the rate of return. The phasing will be affected by the need to meet market demand for the developed land. Development ahead of the market will mean an investment lying idle, so generating holding costs on capital. Development which is behind the market will be affected by competition from other developments.

Several techniques are used in testing the financial viability of a project. It is necessary, when comparing alternative scenarios, to establish the cash flow over the life of the project and to "discount" expenditure planned for the future to its present-day value. This discounted cash flow is dependent on the selection of a will need to adopt a different discount rate from the government investor because of their costs and their opportunities for alternative investment.

From most agencies' viewpoint, an after tax financial return to equity does not convey enough information. Analysts need to look into a project's fundamental strengths, without regard to specific financing considerations. They do not want to be misled by financial "gearing" and peculiar borrowing arrangements. For these reasons, the project's financial rate of return on all these resources, donated or borrowed, but before taxation, has to be determined.

Sensitivity testing. Testing variables and assumptions to determine their relative influence on the financial and economic rates of return should be done. The objective is to discover the impact on the internal rates of return by changes in the assumptions. Items that are normally significant include the cost of investment and the unit prices of major current cost components (for example, the purchase price of land and the sale prices of developed lots). Thus the question is asked, "What happens to the financial/economic rate of return if the sale price of the land is reduced by, say, 10 per cent?' Similar questions relating to increases in the cost of goods and the delay in completion of the project, and therefore the delay in the revenue stream, need to be answered. Generally, the greater relative importance of an item within the overall cashflow, the earlier it occurs in time and the more likely it will be to have an adverse impact on the internal rate of return.

It is also advisable to run the sensitivity analyses for simultaneous adjustment of several variables. The objective is to highlight the strengths and weaknesses of the project as an investment. It then may be possible to identify the potentially damaging factors and to apply appropriate measures to minimize their effects.

D. Institutional appraisal

The institutional appraisal considers topics such as:

(a) Land acquisition procedures and availability;

(b) Project ownership - public, private or mixed?

(c) Target population to be served;

(d) Community consultation;

(e) Operations and maintenance (O&M) of the project assets on completion;

(f) Executing agency capacity and capability and project implementation management;

(g) Levels of staffing for planning, implementation and operations and the scope and extent of the skills required for these functions;

(h) Staff training for on-going management (including O & M).

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. Urban stormwater management is an essential component of urban development programmes and, in particular, of urban health programmes. It can provide reclaimed, safe urban land for human settlements, industry and commerce. If the reclaimed land is used for human settlements, then these will be much healthier environments than undrained settlements, and significant reductions in vector-borne diseases, diarrhoeal diseases and geohelminthic infections will occur.

2. Effective stormwater management can protect not only low-lying areas from inundation, but also human settlements on steep hillsides where the threat of storm-induced landslips can be minimized or even obviated.

3. Stormwater management projects require careful appraisal, design, implementation, and operation and maintenance. All these project stages are vital to project success.

4. Properly implemented and maintained stormwater management projects may be expected to increase land values significantly. Such projects are almost inevitably highly cost-effective, but improperly developed schemes are likely to be economically, and possibly also ecologically, expensive, if not disastrous.

B. Recommendations

1. Governments in developing countries, both national and local, should become more aware of the potential socio-economic benefits - principally improved health and increased land values - of urban stormwater management programmes and projects.

2. Governments need to decide, in any one instance and always on the basis of socio-economic equity, how best to allocate urban land reclaimed by stormwater drainage to the competing sectors of housing, industry and commerce.

3. Local governments, which are normally responsible for the execution and operation of stormwater drainage projects, must not only ensure their proper design and implementation, but also make sound provision for their long-term successful operation, for which a programme of regular preventative maintenance is essential.

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Annex I

STORMWATER DRAINAGE DESIGN PROCEDURES

Contents ***Page***

A. Introduction

This Annex has been prepared to provide guidelines for urban drainage practice to agencies undertaking the planning of human settlements particularly in developing countries. It is not a regulatory code of practice, nor is it intended to be a comprehensive document providing detailed design steps for all possible drainage works. Rules and methods appropriate to various situations are presented, together with background information. Since drainage systems and problems are diverse, and related technology is changing, recommendations made herein should not be taken as binding. They should be considered in the light of other information and local experience when setting standards or regulations.

Drainage systems in developing countries have generally evolved from natural systems passing through significant changes as land uses change from low-density village settlements to gradually increasing higher densities of urban populations. The systems in most instances combine the functions of drainage of stormwater runoff with the disposal of wastewater generated by urban development. The result is a combined system which has not been designed to the more exacting standards of a sewerage system coping with lower-volume dry-weather flows and creating the problems of low velocities of flow in flat-graded channels or pipes with attendant problems of settlement of solids, anaerobic decomposition of the solids, and consequent odours and corrosion.

As the settlements grow and the net incomes of populations increase, the next step in the urban drainage process is to divert the wastewater ffom the drainage system into a separate foul-water sewerage system.

This Annex deals only with the design of the components in a stormwater drainage system and does not address the implications in design of a combined system.

A.1 *Drainage systems*

Stormwater drainage systems can be divided into the following parts, which are shown in figure A1:

- o Roof and property drainage;
- o Street drainage (including both piped and surface flows);
- o Trunk or major drainage (consisting of larger conduits, usually open channels located on roads or lands reserved for drainage purposes);
- o Receiving waters (a river, lake, groundwater storage or the sea).

A.2 *Aims and principles*

The main purpose of urban drainage system is to collect and convey stormwater to receiving waters, with safety and minimal damage. Other objectives are:

- o Limitation of adverse impacts of urbanization, such as pollution, erosion and sedimentation;
- o Water conservation in areas of low rainfall;

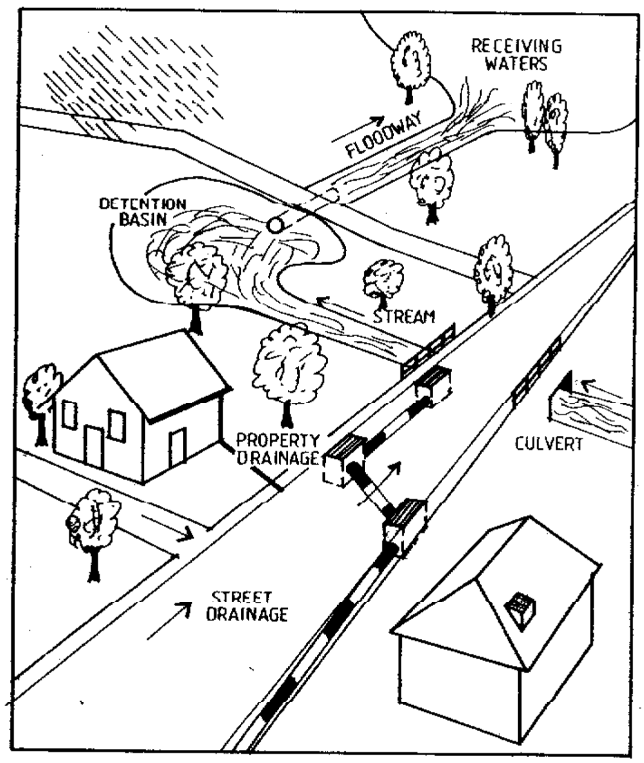


Figure A.1. Parts of an urban stormwater drainage system

- Integration of large-scale drainage works into overall town planning schemes, with multiple use of land for drainage, recreation or transportation.

Some principles which storm drainage planning and design should follow where possible are as follows:

- Analyses of stormwater drainage systems should be based on measured or observed real system behaviour. Reasonable or "logical" assumptions are inferior to hard evidence;
- Drainage systems must be planned in relation to the total urban system. Drainage works are built and operated within a social and economic framework. They are greatly influenced by local environmental planning processes, and must be integrated with other elements of the urban infrastructure. Professionals in the fields of planning, economics and sociology must be consulted by engineers in developing the most acceptable solutions;
- Drainage systems should be designed and operated to maximize benefits to the community. The good of the community, expressed through a concern for adequacy, safety and economy, is the basis for determining the type, performance, standard and scale of drainage works. Designers must strike a balance between the objectives of providing a high standard of performance and of minimizing costs;
- Designers should be influenced by professional considerations such as ethics, standardization and innovation. While there are benefits in following traditional methods of design and standardized procedures, users should question these and be ready to adopt new, improved procedures where justified. Reference to these basic principles is helpful in resolving uncertainties arising in design management of the systems.

B. Planning

B.1 *General*

Any landform includes a natural drainage system and planning and development of new areas should be in harmony with this system to preserve it in its natural state as far as possible.

All new development proposals should take account of:

(a) Possible flood hazards in the whole system;
(b) Possibility of upstream development;
(c) Erosion hazards;
(d) Runoff reduction as an objective.

B.2 *Multiple use*

When planning a new urban development, drainage facilities should be coordinated with open space and transport requirements.

o Open spaces

Significant social benefits at reduced land costs can be achieved by combining open space needs for recreation with major drainage works such as retarding or detention basins.

o Transport

The design and construction of new roads should be fully integrated with the drainage needs of the urban area. This results in better roads, better drainage, and minimization of flood hazards during major storms. Rainfall in excess of the design storm will generally be carried within the confines of the street, giving greater protection from flooding to private properties.

Similarly, where major transport routes cross significant drainage lines and flood plains of rivers and streams, design must account for runoff from the ultimate upstream development to protect the road or railway and ensure that urban flooding does not occur from inadequate provision of waterway under the embankment.

B.3 *Natural channels*

Natural water courses should be used for storm runoff waterways whenever possible. The use of natural waterways, with their generally slower flows will minimize peak flood flows in downstream areas. Lined channels and underground pipes are most costly, cause faster flow, increased peak flow rates, and can induce severe flooding if the downstream drainage system is inadequate. However, increased peak flows caused by higher and more rapid runoff from urban areas can increase velocities in the natural streams, possibly causing erosion and instability of land. It may be necessary to line the stream banks to reduce this erosion.

B.4 *Transfer of problems*

Planning and design of stormwater drainage should not be based on the premise that problems can be transferred from one area to another. Channel modifications which simply transfer problems downstream should be avoided unless they are part of a comprehensive upgrading of a particular drainage network. Such problems include erosion, sediment deposition, increased flooding, and debris transporting.

B.5 *Storage and reserves*

Stormwater runoff can be stored in detention ponds or retarding basins which reduce the downstream drainage capacity required, the amount of land acquisition and the expenditure on downstream works. Reserving major drainage ways from development as part of the urban land-use planning process will allow storm runoff to spread, so causing minimal damage to private property and be temporarily stored for slower discharge downstream. It is important in the planning stages of new developments to set aside areas that can be potential sites for the storage of stormwater runoff. Development of these areas should be restricted as the overall costs of drainage could be significantly increased in terms of new construction or

Storage is also an important factor to consider in the design of reclamation areas. Frequently, the area to be reclaimed forms part of the natural storage of flood waters caused by bank overflow of rivers or streams. Removal of this storage capacity from the floodplain can have serious effects on the river hydrology: flood levels may increase, so causing flooding of areas which would not normally be subject to inundation.

Storage provision is required in the design of polder schemes to buffer the pumping capacity provided and to limit the installation costs. In planning polder schemes, it is vital to allow sufficient storage volume.

C. Design criteria

C.1 *Procedures for design and analysis*

Design methods determine the arrangement of a drainage system and the characteristics and sizes of its components. They can involve full analysis or simplified procedures. Generally, the larger, more complex and expensive the project, the more elaborate the method to be used. Consequences of failure which involves an assessment of the resulting risk, should also influence the choice of method.

The many methods available are based on mathematical models of the physical processes involved. These are expressed as a set of calculations performed by hand, programmable calculator or computer program. They include:

(a) Hydrological models, which calculate appropriate peak flowrates, storage volumes or flow hydrographs for system components;
(b) Hydraulic models, which define sizes and other characteristics of components, or analyse system behaviour to define possible failures;
(c) Other models and calculations concerning water quality, structural adequacy of components, maintenance requirements and economics.

The rainfall/runoff relationship is a complex one, particularly in an urban environment. It involves applying a statistically-derived model of the infinite variations in rainfall patterns to land catchments with an almost chaotic distribution of features which sometimes impede and sometimes promote the passage of water.

To model such a process with any degree of validity requires the use of computers to deal with the extensive calculations involved. Until the widespread use of computers only a few years ago it was impractical to carry out routine designs on them, even if the programs that are now in use had been available.

Stormwater drainage design is continually changing. New problems are being encountered; tools and methods are evolving. Designers should aim to improve design processes, by assessing the performance of past designs and modifying the design approach if justified.

C.2 *Hydrological models*

Some of the hydrological models currently in use are shown in table C.1 in increasing order of complexity. Some can be combined in various ways with hydraulic models.

Urban area models are the same in principle as those applied to rural catchments. The rational method, unit hydrograph procedures and runoff routing models can all be employed where suitable data are available. There are also specialized urban catchment models.

In most developing countries, there are insufficient data to test and calibrate urban hydrological models on a wide scale. Rainfall-runoff models employing statistical design rainfall data should be used for most applications.

The **rational method** is the best-known of these, and has been the model most closely associated with urban drainage design. It uses the formula:

$$Q = C.I.A./360$$

where Q is the design flowrate (m^3/s)
C is a dimensionless runoff coefficient
I is a rainfall intensity (mm/h), corresponding to a particular storm duration and average recurrence interval, and
A is catchment area (ha)

The rational method has been the most popular design aid for urban drainage in the past and continues to be so today because of its ease of use and most designers are familiar with it. While the rational method has a place in design, it is important to understand its limitations.

The rational method does not model the rainfall/runoff process and does not simulate the effect of catchment characteristics on the response of the catchment to rainfall. Its real role is as a statistical tool which relates a few simple rainfall and catchment features to an expected peak discharge for that catchment.

The degree to which it works depends on how "average" the catchment is and, of course, on how extensive has been the data collection and statistical analysis. Unfortunately, there is wide variability of catchment types and a paucity of gauged catchments.

Of necessity, all drainage designs carried out more than a few years ago were based on some form of the rational method. Logically this should have resulted in many underdesigned as well as overdesigned systems. However, recent experience is suggesting a bias towards underdesigned systems.

Table C.1. Hydrological models for urban drainage design and analysis

Model	Model type	Appropriate uses	Degree of complexity	Major variations	Examples of models
Empirical equations	Peak flow	Estimation of design flows for very small catchments in property and road drainage.	Very simple		Rules for roof drainage design. Talbot's formula.
Rational method	Peak flow	Design of small and medium street drainage systems , and large property drainage systems. Only applicable to limited forms of analysis.	Simple to medium (use of computers optional)	(i) Accumulation of: flowrates, equivalent impervious areas, areas of different land-use types. (ii) Treatment of partial area effect.	
Unit hydrographs	Hydrograph	Design and analysis on large urban catchments, where data are available.	Medium (computers optional)		Synthetic unit hydrograph methods such as Snyder, Clark-Johnstone..
Time area (isochronal)	Hydrograph	Design or analysis of all sizes of system, including those involving storages.	Medium (computers required)	Linear or non-linear storages.	TRRL, ILLUDAS ILSAX
Storage routing	Hydrograph	Too complex for routine design at present. Used for detailed analysis of larger systems and scientific studies.	Medium to complex (computers required)		WASSP RORB, RAFTS
[illegible]	[illegible]		[illegible] required)		[illegible]
Physical process or soil moisture accounting models	Continuous hydrograph		Complex (computers required)		SWMM, HSPF

The rational method is a simple tool that attempts to model a complex process. It takes into account the following factors:

(a) Catchment area;

(b) A characteristic storm duration which is indexed to the catchment response time, using the time of concentration;

(c) Rainfall losses using a runoff coefficient to account for the combined effect of land cover, vegetation and soil type.

The rational method does not explicitly take into account a number of key characteristics such as distributed storage, rainfall temporal pattern, catchment shape and drainage network. As the method takes overall values for the runoff coefficient and time of concentration, it does not account for variations within the catchment of factors such as slope and land use. Estimates for runoff coefficient are arbitrary, while estimation of time of concentration becomes increasingly difficult as the catchment increases in size and complexity.

(c) The total storm duration equals or exceeds the time of concentration and rainfall is uniform over the entire storm, so that catchment shape does not affect the peak discharge;

(d) Reasonable estimates can be made for the runoff coefficient and time of concentration.

More complex models employ sets of equations and procedures requiring use of computers. Appropriate uses for hydrological models are set out in table C.1 and features of models are described below:

o Models can be divided into those which produce a peak flowrate and those which provide a full hydrograph. The former use rational assumptions based on statistical analysis of data to produce a "standard" design flowrate or discharge. Although they can be used to analyse individual pipe capacities, they cannot stimulate actual flow behaviour throughout a network.

o Runoff hydrographs may be generated by time-area procedures (combining a hyetograph with an assumed time-area diagram for each sub-area), by routing the hyetograph through a hypothetical linear or nonlinear reservoir, by kinematic wave routing, or by a soil moisture accounting model. All of these can be calibrated to appropriate data. Most hydrograph-producing models analyse isolated storm events, but the complex soil moisture storage models can produce continuous hydrographs spanning years of flows.

o Models suited to urban situations can deal with different degrees of by modelling changes to flow paths and conduits. Urban catchments must be subdivided in greater detail than rural ones, to determine flowrates at points throughout the catchment, rather than only at the outlet.

- Urban areas may have a higher density of raingauges and pluviometers than rural areas. Although urban catchments are relatively small, spatial and temporal rainfall variability is nevertheless a significant problem when modelling actual storm events. It is desirable to have a dense network of rain gauges for more accurate modelling of the actual rainfall distribution.

- A variety of loss models may be used. In the rational method, all losses are included in the runoff coefficient. More elaborate models use separate initial losses for pervious and impervious surfaces, and extended losses such as runoff coefficients, constant continuing loss rates or decreasing infiltration curves. Programs capable of continuous simulation use complex soil-moisture accounting models.

C.3 *Data*

Data are required to:

- Describe physical processes associated with drainage systems;
- Develop, calibrate and test models;
- Provide a basis for design of drainage works, such as design rainfall intensities and storm patterns;
- Monitor system operation, and such aspects as water pollution.

C3.1 Rainfall data

Measurement of rainfall is made in all developing countries now, but the length of the record, the spacial distribution of recording stations and the availability of data on rainfall events against time are very often limited in scope or even non-existent. It is necessary, therefore, to search diligently in the central and regional offices of the agencies responsible for meteorological records to locate the basic rainfall data upon which to base the design of drainage systems.

C.3.2 Runoff data

Very little information on the runoff of stormwater is available in urban areas in developing countries. It is usually possible, however, to obtain local information in small catchments by field measurement and gauging of principal components in the drainage system during storm events provided the designer has sufficient time for the development of the system design parameters.

Observation and experience by local residents and authorities can provide informal information on flood levels. These may be of considerable value in the absence of quantitative measurements, particularly where they are systematically recorded with rainfall data.

C.4 *Standards of performance*

C.4.1 Introduction

Drainage standards are influenced by many factors, including:

- o The level of hydraulic performance required;
- o Construction and operating costs;
- o Maintenance requirements;
- o Safety;
- o Aesthetics;
- o Regional planning goals;
- o Legal and statutory requirements.

They are usually expressed by an **average recurrence interval** (ARI). These measures determine the magnitude of a design rainfall or runoff event with which the system can cope. Past practice has often been based on one level of operation, but it is usually appropriate to design for several performance levels, which may include:

- o A maintenance requirement (frequent event), related to a short design ARI, perhaps less than one year;
- o A convenience or nuisance-reduction requirement (infrequent event), possibly a 1- 2- or 5-year ARI;
- o A flood damage prevention requirement, (severe or rare event), or about a 50- to 100-year ARI;
- o A disaster management requirement (extreme event), related to extreme events such as probable maximum floods.

The first two, possibly three, are relevant to minor drainage, and all but the second to major drains.

Methods for determining appropriate design standards are discussed in section C.4.2. Ideally, standards should be set after consideration of all effects arising from construction and operation of drainage works. Benefit-cost analysis usually has limited application, since the benefits of drainage systems are extremely difficult to measure. An approach in which costs of alternative standards are compared with some measure of "performance" is appropriate in most cases.

Several factors affect the accuracy of estimated flow rates or capacities for given average recurrence intervals. First, there is inherent variability in rainfall or runoff values obtained from fitted statistical distributions. Also, the ARI of the runoff derived from a rainfall-runoff model may differ from that of the rainfall input, due to differing antecedent conditions and nonlinear effects in the rainfall-runoff process.

C.4.2 Selection of average recurrence intervals

The selection of a suitable design ARI must be made by the designer in the light of economic and financial consideration of local conditions and requirements. It may be appropriate for designers to vary the standards applied to different points in a drainage system, depending on the perceived risks of failure. This is often related to the land use.

Estimation of costs of alternative designs is possible by hand calculations but is more easily done in computer-aided design procedures, which allow scope for sensitivity analysis. In general, drainage system costs increase by roughly 10 per cent for each doubling of the design ARI, but for particular designs, costs will vary with a range of parameters. For example, the cost implications of adopting a 2 year and 5 year ARI for residential and commercial/industrial areas for the design of the minor drainage system were investigated in Bandung, Indonesia: the analysis indicated that, for a cost increase of 11 per cent, a channel designed with ARI of 2 years would reduce the annual flood damage by 56 per cent over a channel designed on a 1-year ARI. To obtain a further 29 per cent reduction in average annual flood damage, a cost increase of 15 per cent would have been required for a 5-year ARI. An analysis of this type must be made in specific situations. No firm rule of benefit can be applied.

For major drainage systems the emphasis shifts to prevention of flood damages. Benefits are easier to quantify, and benefit-cost analyses can be conducted. Regardless of the economic outcome, it may be necessary to select a design ARI which conforms to community standards, particularly those pertaining to floodplain management.

In addition to the ARI used for design, the performance of larger trunk drainage systems should be evaluated for extreme events such as probable maximum floods. This is to ensure that systems will fail in a predictable and relatively safe manner in such events, although significant damages should be expected.

Standards may change. When a revised set of standards is introduced, they can be readily applied to new works after a transition period. However, there may be anomalies in connections to existing works built to older standards, and many existing drains may have insufficient capacity according to the new criteria. It is clearly not feasible to upgrade existing works in the shortterm. The new standards should be taken as an objective to be pursued in long-term (say 20-year) upgrading programmes.

Levels of service for the design of drainage works in developing countries is frequently based on affordability criteria and financial analysis. The design criteria set out in section 3.5 will, in most instances, be acceptable and will provide a significantly improved quality of living conditions in areas subject to frequent inundation by storm runoff.

C.5 *Basic design criteria*

C.5.1 Basis of design

Drainage design will be considered on the basis that two separate and distinct drainage systems exist. These are the *minor* or local drainage systems and the *major* drainage system.

(a) Minor drainage system

The minor drainage system is that part of the total drainage system which caters for the maximum runoff from the initial storm. Included in this system are: street gutters, roadside drainage channels and ditches, culverts, stormwater pipes, open channels, and any other features designed to handle runoff from the initial storm. All elements of the minor drainage system should be designed for at least the initial storm. The initial storm may have a design ARI of 2 years or 5 years depending on the adjacent land use.

(b) Major drainage system

Provision will also be made to provide capacity for the safe discharge of a 20-year return period flood in rivers and main canals with catchment areas in excess of 100 hectares. Provision should be made to minimize major property damage and prevent loss of life from the runoff expected from the flood of a 100-year return period. The major drainage system can include natural streams, rivers, floodplains, lined channels, major pipes, major roads.

C.5.2 Calculation of stormwater runoff

Runoff calculations for areas up to 500 hectares should be based on the Modified version of the rational formula as set out in section C.2. This method takes account of channel storage and gives the design hydrograph if required. Where the catchment area exceeds 500 hectares, the results determined by the modified rational method should be compared with the results obtained from the Snyder synthetic unit hydrograph method or a similar hydrograph model. In estimating the design discharge for complex drainage systems a flood hydrograph shall be prepared as set out in section D.3.

C.5.3 Design recurrence intervals

In some circumstances (e.g., where major works are proposed in a highly developed or capitalized area) a cost-benefit analysis which takes into account the socio-economic consequences of design flood exceedence may be appropriate in determining the design storm recurrence interval.

Runoff calculations for both initial and major storms are commonly based on design recurrence intervals shown in table C.2.

Table C.2. Design storm recurrence intervals

	Drainage system	**Return period (years)**
Minor	Residential land use	2
	Commercial land use	5
	Industrial land use	5
Major	All main water carriers with > 100 ha catchment.	20
	All uses checked and assessed for adequacy.	100

C.5.4 Calculation of capacity of stormwater drains

Manning's formulae for open channel flow should be used in calculating the capacity of existing and new stormwater drainage channels. The Colebrook-White equations should be used for the calculation of the flow in pipes.

C.5.5 Drainage reserves

Drainage reserves are necessary to prevent development encroaching on flood prone land and to give access for plant and machinery for maintenance and repair operations. Recommended reserve widths are shown in tables C.3 and C.4.

Table C.3. Reserve widths for catchments less than 50 ha

Drain	**Reserve width (m) for drainage areas of:**	
	0.50 ha	**5-50 ha**
Between building lots	Top width + 1 m	Top width +3 m
Alongside roads	Top width	Top width

Where downstream development is proposed in an undeveloped catchment, drainage reserve to accommodate the ultimate 1 in 100 year flood with its natural flood path should be reserved, or alternatively the reserve widths shown in table C.4 should be provided.

Table C.4. Reserve widths for catchments more than 50 ha

100 year discharge (m^3/s)	Reserve width (m)
30	30
30-100	40
100-200	75
200-300	90
300	Analyse separately

D. Flood estimation

D.1 *General*

The flood estimation procedures for urban drainage system design recommended in this manual have been selected from an assessment of the conditions likely to be found in developing countries where limited reliable statistical data are available and simplicity of application is warranted. The modified rational method has been developed to improve the accuracy of the standard rational method to take account of the variable runoff coefficients in the catchment and the losses in rainfall and storage in the system. It should be used for areas up to 500 hectares. Areas larger than 500 hectares should be calculated by both the modified rational method and the Snyders unit hydrograph method; for design, the higher figure is adopted.

D.2 *Modified rational method*

The formula for peak runoff estimation is:

$$Q = FCC_s IA \qquad (D.1)$$

where Q = the peak discharge in cubic metres per second of return period T years
I = the average intensity of rainfall in mm per hour for a duration equal to the time of concentration (t_c) and return period T year
A = the catchment area in hectares
C = coefficient of runoff
C_s = storage coefficient
F = factor of proportionality (= 0.00278 when A in hectares)

(a) Time of concentration

The time of concentration is the time required for water to flow from the most remote point of the catchment to the point being investigated. For urban stormwater drains, the time of concentration (t_c) consists of the time required for runoff to flow over the ground surface to the nearest drain (t_o) and the time of flow in the drain to the point under consideration (t_d):

$$t_c = t_o + t_d \qquad \text{(D.2)}$$

Overland flow time

The time for overland flow (t_o) should be estimated from figure D.1 using appropriate values of length, slope and runoff coefficient C (see table D.2 and figures D.2 and D.3 for values of C.)

Drain flow time

The time of flow in drains (t_d) is estimated from the hydraulic properties of the drain. In the case of natural streams where the hydraulic properties are difficult to determine the time of flow shall be estimated using the velocities shown in table D.1.

Table D.1. Approximate steam velocity

Average slope of Stream (percentage)	Average velocity (metres/second)
Less than 1	0.4
1 - 2	0.6
2 - 4	0.9
4 - 6	1.2
6 - 10	1.5
10 - 15	2.4

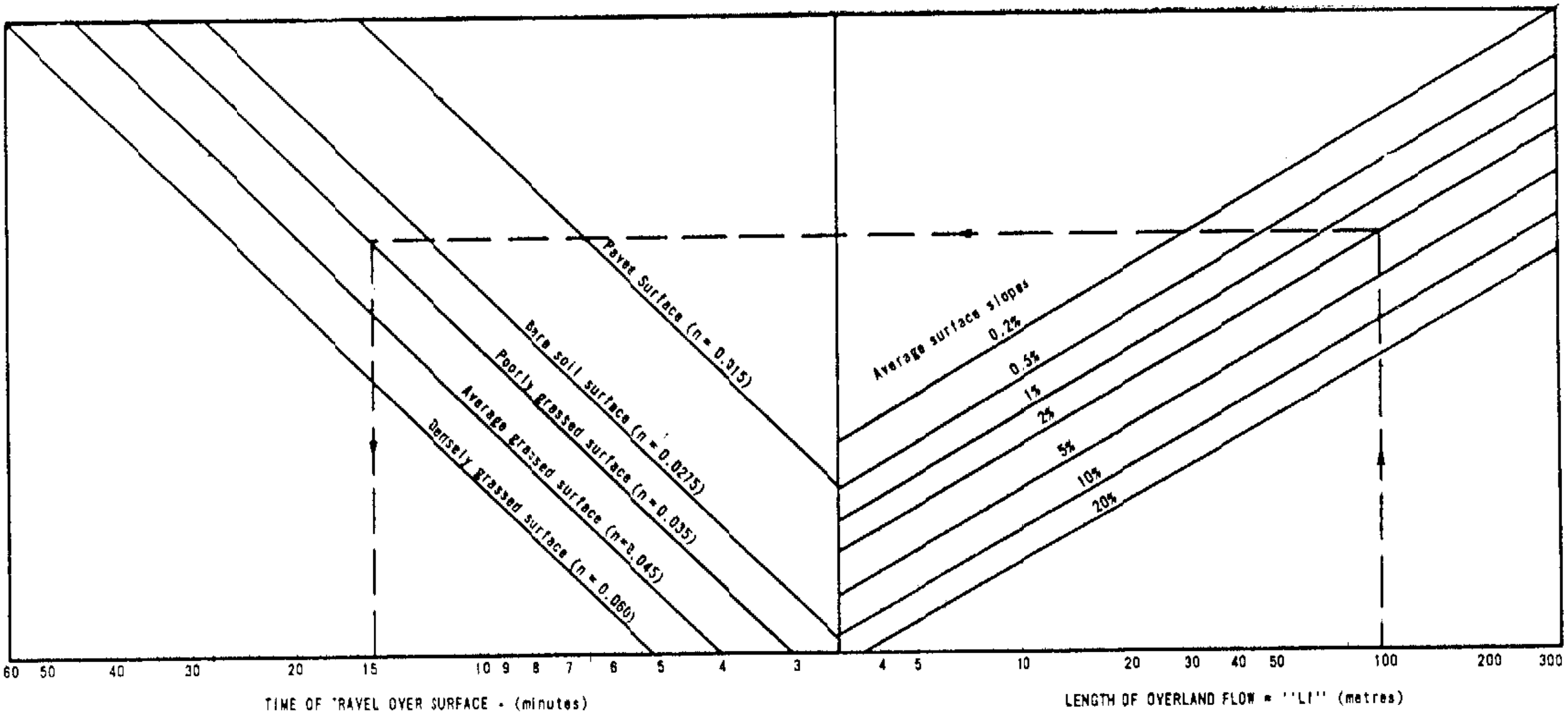
(b) Rainfall intensity

For a given storm recurrence interval, the rainfall intensity (I) is the average rate in millimetres per hour of precipitation from a storm having a duration equal to the time of concentration (t_c). Rainfall intensity - duration - frequency relationships must be derived for the locality.

(c) Runoff coefficient

The runoff coefficient C is difficult to determine precisely and can be interpreted in different ways. Engineering judgement is necessary in selecting the appropriate procedure. Coefficients for the modified rational method described above should be based on ultimate catchment development and weighted where more than one land use is likely.

A weighted coefficient (C_w) should be calculated where land uses vary or surface characteristics exist in the catchment:



FORMULA $t = \frac{108n \sqrt[3]{L_f}}{\sqrt[5]{s}}$ minutes

Where t = time of travel over surface in minutes

n = roughness coefficients for the surface

L_f = length of flow in metres

s = Slope of surface in %

EXAMPLE

Length of overland flow 100m

Average slope of surface 2%

Poorly grassed surface

Time of travel = 15 minutes.

Figure D.1. Surface flow times (time of concentration) for areas with sheet flow)

$$C_W = (A_1C_1 + A_2C_2 + \ldots + A_nC_n) \div A \qquad \text{(D.3)}$$

where A_1, A_2, A_n = n areas of relatively uniform land use or surface character comprising the total area A

C_1, C_2, C_n = corresponding runoff coefficients obtained from table D.2 (or from figures D.2 and D.3)

Table D.2: Rational method runoff coefficient

Land use			Runoff coefficient (c)
Urban			
Central commercial			0.90 - 0.95
Industrial			0.80 - 0.90
Residential			
- Low-density	20	houses/ha	0.25 - 0.40
- Medium-density	20-60	houses/ha	0.40 - 0.70
- High-density	60-160	houses/ha	0.70 - 0.80
Parks and recreation areas			0.20 - 0.30
Rural			
Steep slopes > 20 percent			0.50 - 0.60
Undulating slopes > 20 percent			0.40 - 0.50
Terraced slopes			0.25 - 0.35
Irrigated ricefields and pasture			0.45 - 0.55

(d) Storage coefficient

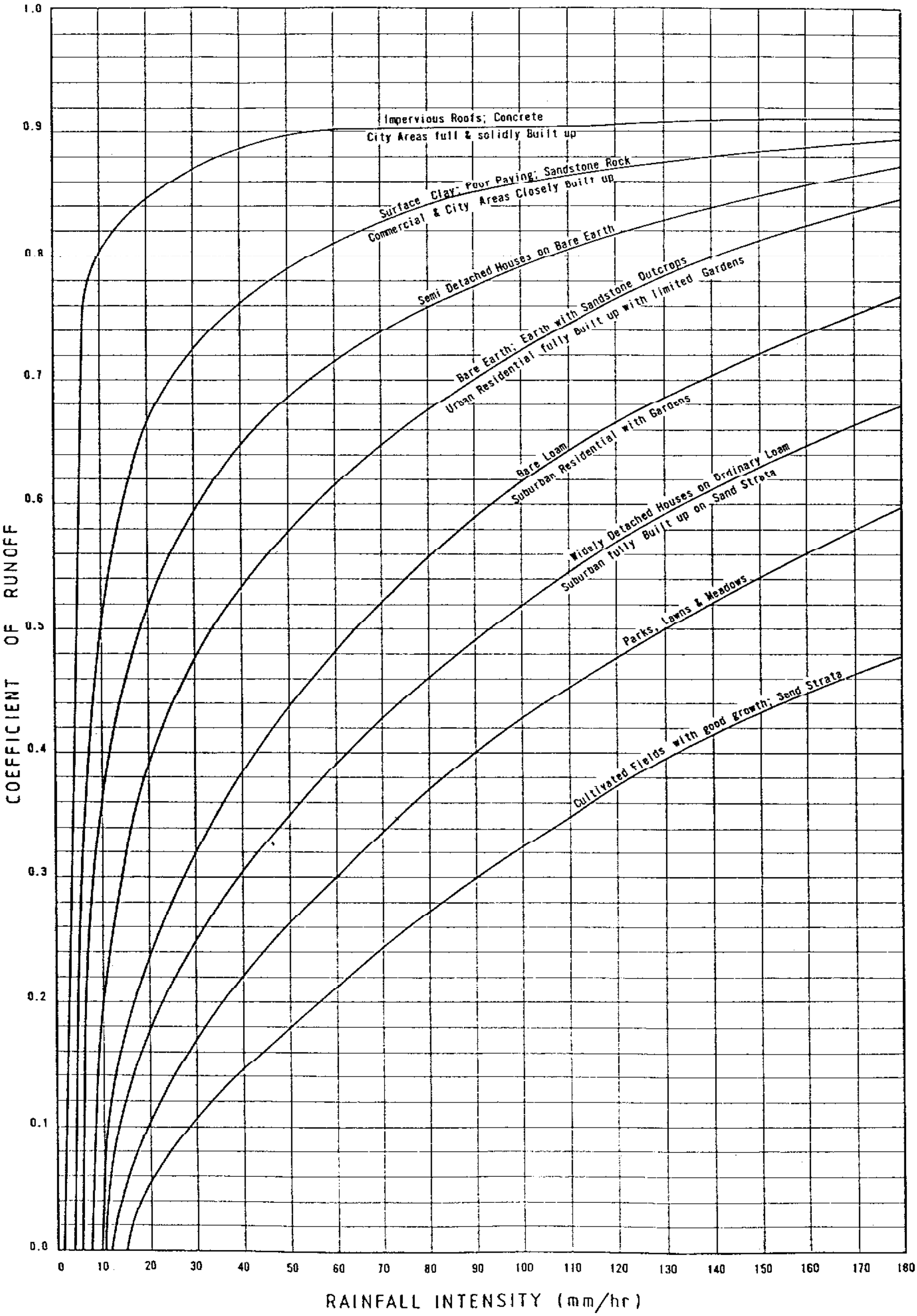
As the catchment areas gets larger the effect of channel storage on the attenuation of the flood wave becomes more pronounced. To allow for channel storage effect the peak discharge calculated by the basic Rational Method formula Q = CIA/360 should be multiplied by a storage coefficient (C_S) to modify the basic formula:

$$C_S = 2t_c/(2t_c + t_d) \qquad \text{(D.4)}$$

D.3 *Design hydrograph*

In the application of the modified rational formula in cases where a design hydrograph is required, the form of the hydrograph shown in figure D.4 should be used.

In figure D.3, the peak discharge Q_p is found from equation D.1. For detention


COEFFICIENT OF RUNOFF
RAINFALL INTENSITY (mm/hr)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Impervious Roofs; Concrete
City Areas full & solidly Built up
Surface Clay; Poor Paving; Sandstone Rock
Commercial & City Areas Closely Built up
Semi Detached Houses on Bare Earth
Bare Earth; Earth with Sandstone Outcrops
Urban Residential fully Built up with limited Gardens
Bare Loam
Suburban Residential with Gardens
Widely Detached Houses on Ordinary Loam
Suburban fully Built up on Sand Strata
Parks, Lawns & Meadows
Cultivated Fields with good growth; Send Strata

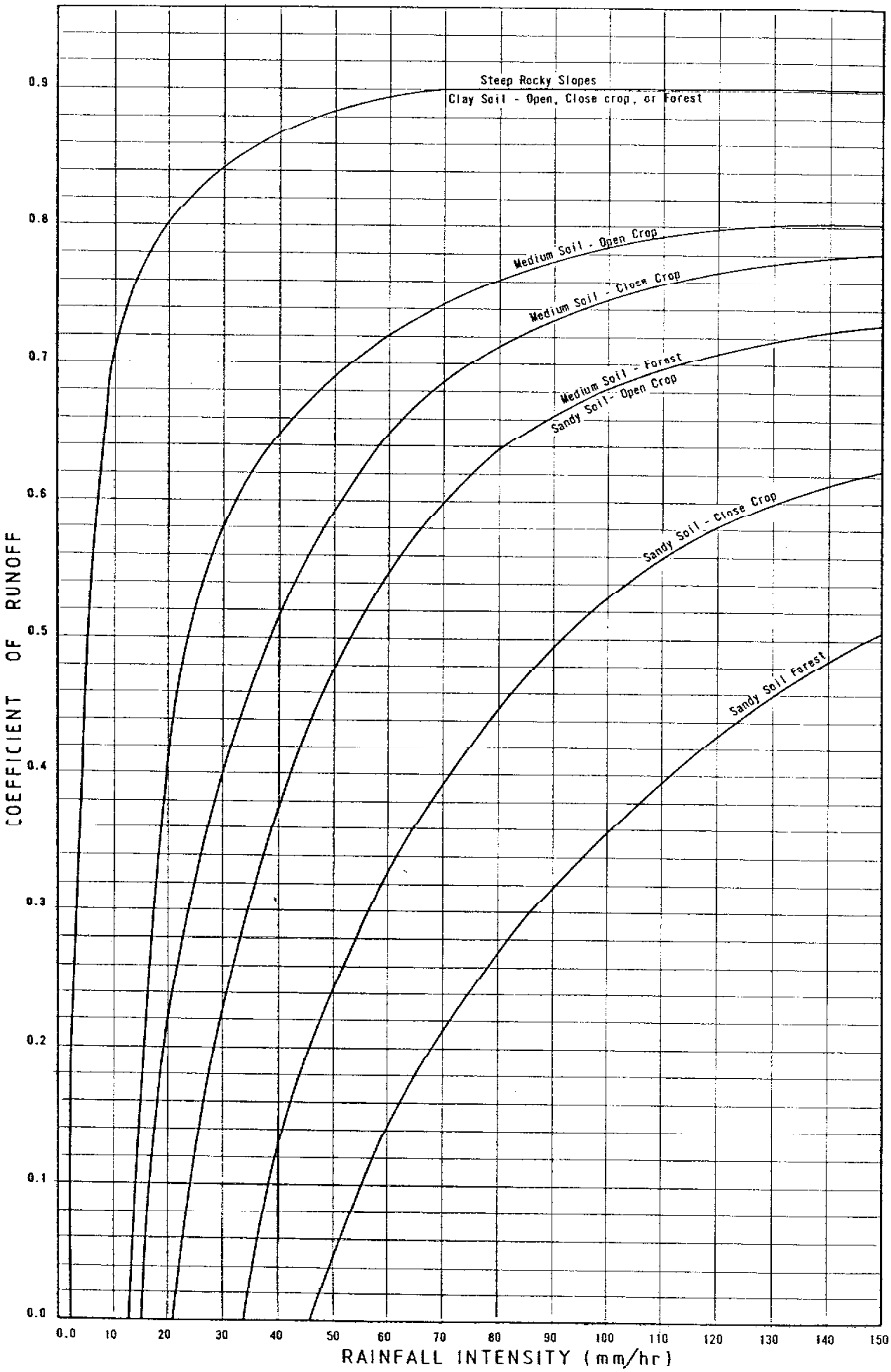


Figure D.3. Run-off coefficients for rural catchments

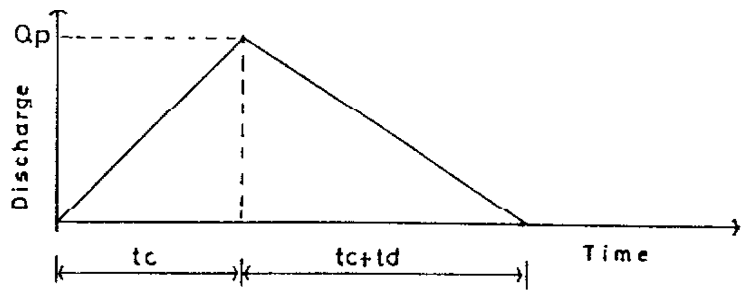
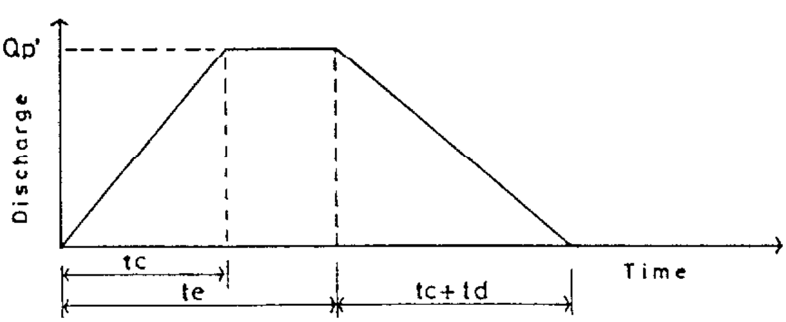


Figure D.4. Design hydrograph - rainfall duration equals time of concentration



the hydrograph shown in figure D.5 should be used. This situation generally occurs when the average outlet discharge of the pond is less than 50 per cent of the peak inflow.

In figure D.5 the peak discharge Q'_p is found by

$$Q'_p = F\,C\,C'_s\,I_e.A \qquad \text{(D.5)}$$

where

$$C_s' = 2t_e/(2t_e + t_d) \qquad \text{(D.6)}$$

t_e = the critical storm duration as determined by trial and error

I_e = the average rainfall density for the critical storm duration t_e and a return period T years.

D.4 *Partial areas effect*

The modified rational method described in section D.2 is based on the assumption that the peak discharge results from a storm of such duration that the whole of the catchment contributes to the runoff at the point being examined. At a point further down the principal drainage route the time of concentration increases and the intensity of rainfall as determined by the increasing time of concentration decreases. These effects can cause variations in the peak discharge which is calculated on the assumption that the whole area contributes. It is possible that an intense storm of duration less than the total time of concentration but having the same average frequency of recurrence, may produce a greater discharge because the higher intensity had a greater effect than the smaller contributing area. This situation is known as a partial area effect and should be checked for under the following situations:

(a) the junction of two main drains;
(b) the outlet of a large sub-area with a relatively short time of concentration;
(c) the outlet of a small area with a relatively long time of concentration.

A simplified method of determining the peak discharge with a partial area effect is as follows:

(a) Construct the normal hydrograph for the design point as set out in figure D.4 using the longest time of concentration and the total contributing area;
(b) Construct a hydrograph of the same shape as figure D.4 using the smaller time of concentration of the two drains in question and only using the area that would contribute to runoff in this shorter time;
(c) Check whether the new discharge is higher than that derived in (a) above;
(d) The area contributing can be roughly determined by going back the drain a length represented by the time (t_d + t_o) equal to the smaller time of

E. Channel design

E.1 *General*

Open channels can have advantages over piped systems in several ways - for example, lower cost, greater capacity, multiple use for recreational and aesthetic purposes, and potential for detention storage. There are also disadvantages which must be considered: for example, increased right of way needs and maintenance costs, as well as hazards to pedestrians and vehicular traffic. Careful planning and design for new works are needed to minimize the disadvantages and increase the benefits. The ideal channel is a natural one because velocities are usually low, resulting in longer times of concentration and, hence, lower downstream peaks. Channel storage is also available to reduce peak flows and maintenance costs are generally lower because of the natural stability of the channel. Lined channels should be chosen when right of way or velocity of flow considerations dictate the requirements, or increased capacity is required within a given right of way.

E.2 *Flow computation*

Use Manning's formula for uniform flow calculations:

$$Q = (A\,R^{2/3} s^{2})/n \qquad \text{(E.1)}$$

where Q = flow, m^3/sec
A = area of flow section m^2
R = hydraulic radius, m
s = slope of channel, m/m
n = Manning's roughness coefficient (given in table E.1)

Table E.1: Recommended Values for Manning's Coefficient of Roughness 'n'

Type of channel and description	n
Concrete lined	0.015
Stone pitching	0.025
Unlined/formed	0.035 - 0.045
Natural streams	0.040 - 0.050

E.3 *Lined channels*

Channel linings usually consist of concrete, stone pitching or a combination of the two. The decision on lining materials used principally relies on local custom and the local availability and cost of the materials. The side slopes will generally range from vertical to one to one and should be designed as retaining walls. The desirable minimum velocity is 0.75 - 1.0 metres per second for self-cleansing conditions and the maximum is 3.0 metres per second for reasons of safety.

E.4 *Vegetated channels*

Where there are no restrictions on right-of-way width and land slope is compatible, vegetated channels can normally be constructed at less cost. The invert of the channel should be lined for low flows designed with a capacity of 3-5 per cent of the design flow.

Erosion control measures will normally be necessary. Cut-off walls at regular intervals will help to maintain a stable grade and cross section. Design criteria are given in table E.2.

Table E.2. Design criteria for vegetated channels

	Major storm	Initial storm
Velocity	not more than 2 m/s	not less than 0.75 m/s
Depth	not more than 1.5 m	not less than 0.3 m
Side slopes	not steeper than 1 in 3	not steeper than 1 in 3
Freeboard	not less than 0.3 m	N/A
Manning's 'n'	0.035 - 0.045	0.035 - 0.045

E.5 *Natural Channels*

Natural channels in steep areas tend to have erodible banks and increased erosion can be expected with urbanization. Increased erosion may also occur in flatter sections as a result of increased urban discharge. Some modifications may be necessary to create more stable conditions and to ensure that the maximum velocity is kept below 2 metres per second wherever possible. Criteria and techniques which should be used in designing or checking the capacity of natural channels include the following:

(a) Channel and overbank capacity should be adequate for the major storm;
(b) Channel velocity shall be subcritical at any section;
(c) Water surface limits should be defined so that the flood plain can be zoned where appropriate, to prevent urban development.

E.6 *Unkerbed streets*

To ensure satisfactory drainage to adjacent open channels, formation and sealing should be taken to the end of main drains and shoulders should be graded to the edge of minor drains. If the road shoulder does not permit direct runoff to the drain, spaced inlets should be provided. Such inlets should be no wider than half a metre and be spaced at half the interval required for entry pits under kerbed gutter conditions.

E.7 *Design calculations*

The form in table E.3 could be adopted for general usage for systematically preparing the computations for the design of open channel systems in urban areas.

F. Drainage design for urban streets and pipelines

F.1 *General*

Design criteria for the collection and transport of runoff water on public streets is based on a reasonable frequency of interference to traffic when kerbs and gutters are constructed on each side of the street. That is, some portion of the road surface will be inundated once during the initial design storm return period. During this period, lesser storms may also cause some lesser degree of inundation. This is making use of the street as part of the urban drainage system but should not conflict with its primary function of traffic movement.

F.2 *Gutter capacity*

For streets with formed kerbs, the theoretical gutter capacity Q_g (m^3/s) can be calculated by using the modified Manning's formula for flow in a shallow triangular channel.

$$Q_g = 0.375^{z/n} s^{1/2} d^{8/3} \qquad \text{(F.1)}$$

where z = the reciprocal of the crown slope, m/m
n = Manning's coefficient of roughness
s = gutter slope, m/m
d = depth of flow in gutter, m

Typical values of n are:

Concrete	0.012
Hotmix	0.014
Flush seal	0.018
Stone pitchers	0.025

If the gutter is a lined or unlined drain or swale, an open channel equation such as Manning's formula (equation E.1) can be applied.

The gutter should be designed so that the width of flow on the road pavement does not exceed 2 m in width during the initial storm. Figure F.1 will assist in the design of gutters.

Table E.3. Stormwater design calculation sheet for channels

PAGE OF PAGES

LOCATION		SUB AREA TIME OF CONCENTRATION			SUB AREA RUNOFF COEFFICIENT			DRAIN DESIGN						DRAIN DETAILS						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
DRAIN SECTION	SUB AREA CONTRIBUTING	TIME OF OVERLAND FLOW	TIME OF DRAIN FLOW	SUB AREA TIME OF CONCENTRATION	SUB AREA	COEFFICIENT OF RUNOFF	EQUIVALENT (COL 6 x 7) IMPERVIOUS AREA	TOTAL EQUIVALENT IMPERVIOUS AREA	CRITICAL TIME OF CONCENTRATION (t_c)	TOTAL DRAIN TIME (t_d)	STORAGE COEFFICIENT (C_s)	RAINFALL INTENSITY (i)	DISCHARGE (COL 9x12x13x2.78 x10^{-3})	GRADE	SIZE OF CROSS SECTION	CAPACITY	VELOCITY	LENGTH	TIME OF FLOW IN SECTION	INVERT LEVEL
		Min	Min	Min	Ha		Ha	Ha	Min	Min		mm/hr	m^3/s	%		m^3/s	m/s	m	Min	

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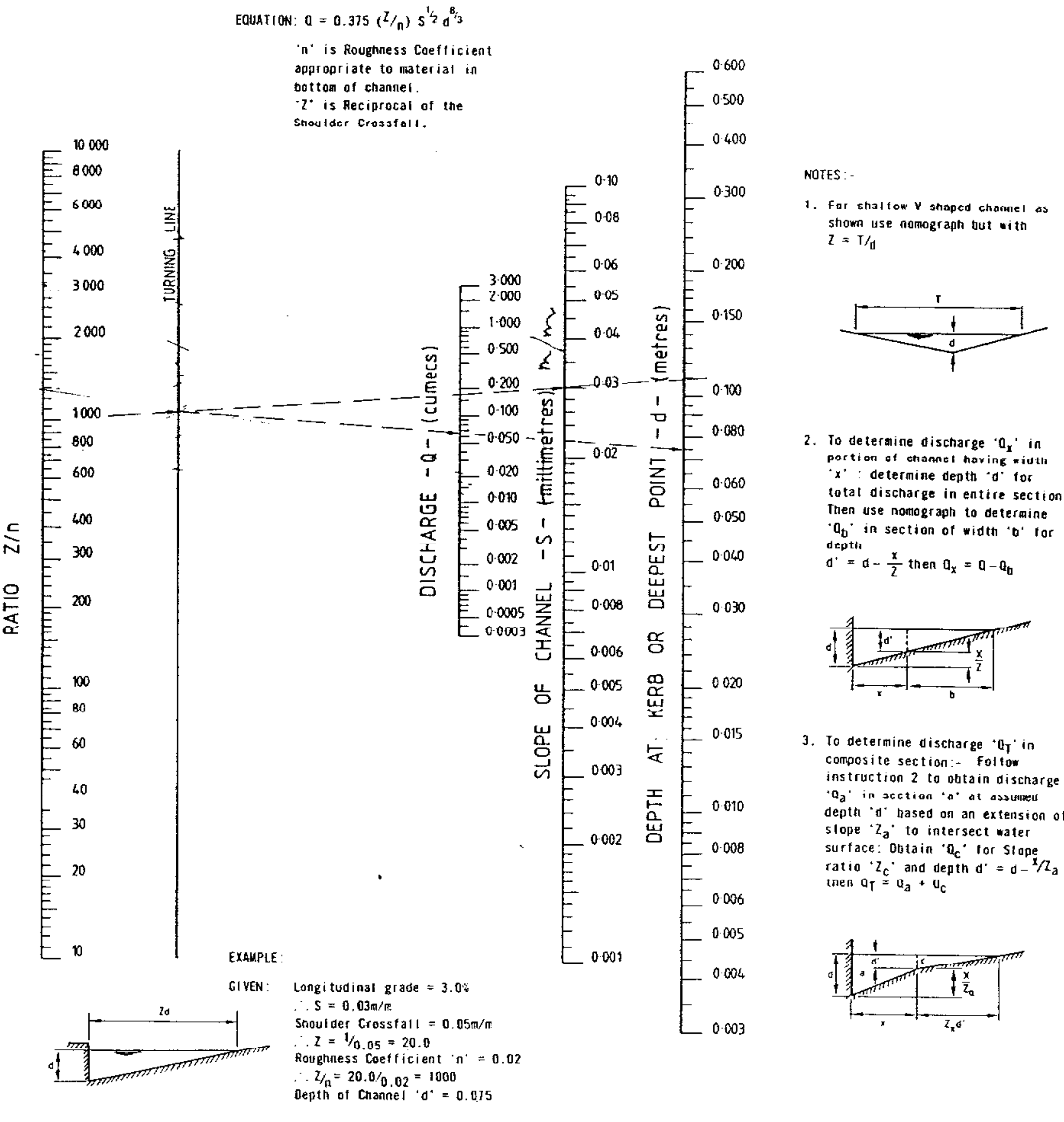


Figure F.1. Design chart for flow in triangular channels

F.3 *Drainage inlets*

A stormwater drainage inlet is an opening into a drainage system for the entrance of stormwater runoff. It is important that inlets be properly designed, constructed and maintained so that the drainage system operates at its full capacity. Sufficient openings shall be provided to limit the gutter flow width to 2 metres. There are various types of inlet but it is recommended that, where possible, the kerb opening inlet be used as it is the most dependable type. Figure F.2 illustrates typical details of one suitable type of kerb inlet.

(a) *Design*

Inlets may be installed either on a continuous grade or in sag points, i.e. a low point in the road grade. The inlets can be gratings or kerb opening inlets. A kerb opening inlet is an opening in a kerb through which the gutter flow passes to the drain. The gutter may be depressed or undepressed in the area of the grate or kerb opening. On continuous grades of less than 5 per cent slope, a depressed opening is recommended. The drawing in figure F.2 shows a depressed opening. While the gutter slope exceeds 5 per cent it is recommended that deflectors in the depressed gutter be used. For a sag condition the gutter should be the depressed type. For an underground drainage system, side entry pits should be used with precast concrete covers for ease of access for maintenance. Time of flow in the gutter can be estimated from Figure F.3.

For sag pits, the following relationships can be used:

(i) For a grating

$Q_i = 1.66\ Pd^{1.5}$ up to about 0.12 m of ponding ($d < 0.12$) (F.2)

or

$Q_i = 0.67\ A\ (2gd)^{0.5}$ over 0.43 m of ponding ($d > 0.43$) (F.3)

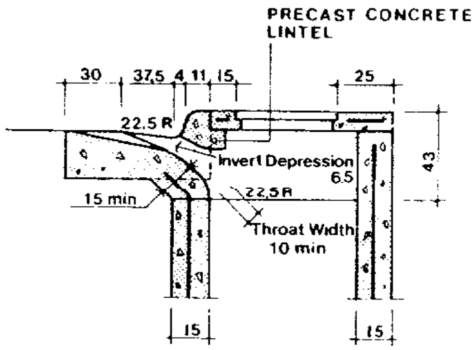
where Q_i is the inlet flowrate, m^3/s
- d is the average depth of ponding, m
- P is the perimeter length of the pit, excluding the section against the kerb, m (bars can be disregarded)
- A is the clear opening of the grate, m^2, (i.e., total area minus area of bars)
- g is acceleration due to gravity, 9.8 m/s^2

For depths between 0.12 and 0.43 m, the situation is indefinite, but generally the first equation is recommended.

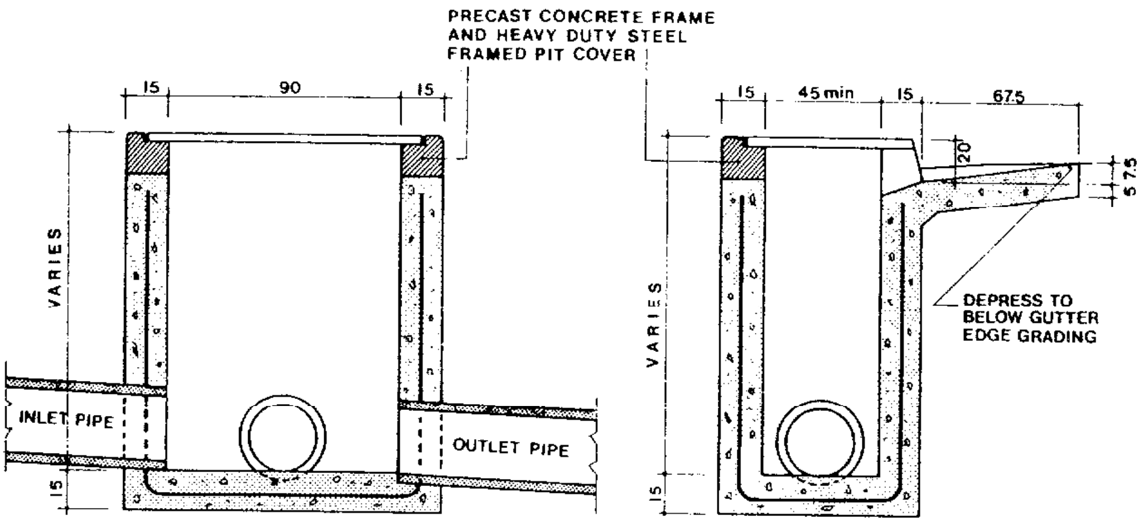
(ii) For an undepressed kerb inlet

For ponding up to about 1.4 times the height of the inlet, h ($d = 1.4h$)

$Q_i = 1.66\ L\ d^{1.5}$ (F.4)

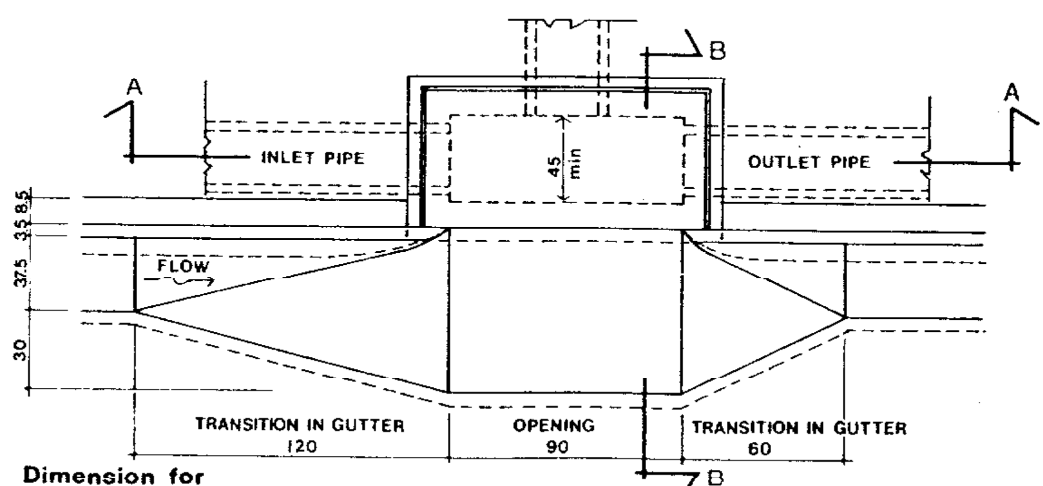


ALTERNATIVE PIT COVER



SECTION A-A WHERE NECESSARY PIT MAY BE DEEPER AS A SILT TRAP

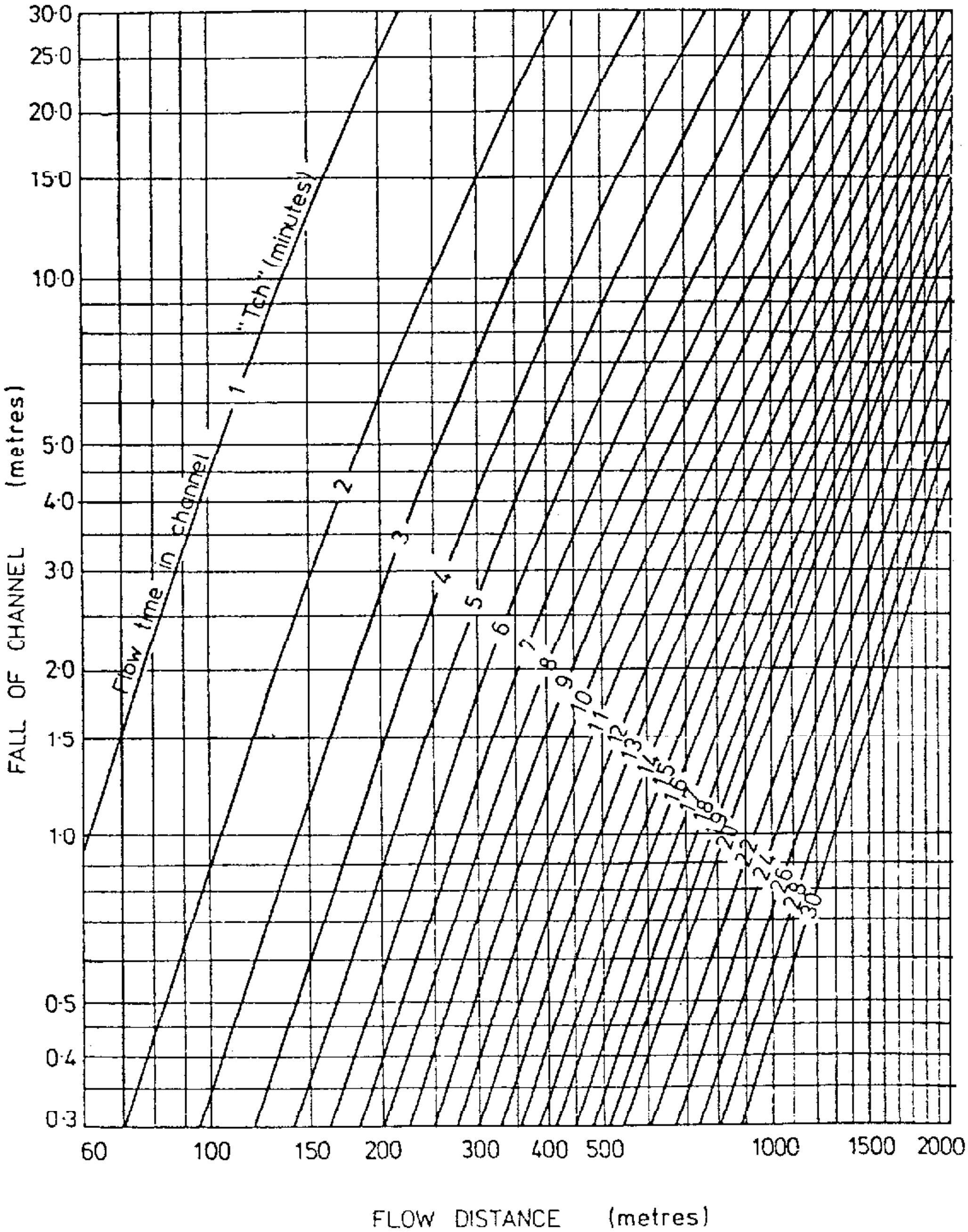
SECTION B-B



Dimension for
Vertical Kerb & Gutter

PLAN

Figure E.2 Typical inlet side entry for stormwater drain


Flow time in channel "Tch" (minutes)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
18
19
20
22
24
26
28
30
FALL OF CHANNEL (metres)
30·0
25·0
20·0
15·0
10·0
5·0
4·0
3·0
2·0
1·5
1·0
0·5
0·4
0·3
60
100
150
200
300
400
500
1000
1500
2000
FLOW DISTANCE (metres)

or for ponding greater than 1.4 h

$Q_i = 0.67\ A\ [2g(d - h/2)]^{1.5}$

where Q_i is the inlet flowrate, m^3/s
- d is the average depth of ponding, m
- L is the inlet width, m
- A is the clear area of the opening, m^2
- g is acceleration due to gravity, m^2/s

General relationships of this type are not available for pits on grade. Capacities of these can be changed significantly by small differences in dimensions and by features such as depressions and types of grate. Capacities are also influenced by characteristics of the adjacent roadway, such as cross-slope and roughness.

The capacity of depressed side entry pits is shown on figure F.4. Reduction factors should be applied to the theoretical capacity of inlets to compensate for effects which decrease capacity through debris plugging, pavement overlaying and variations from design assumptions. The allowed capacity shall be determined by applying the appropriate reduction from table F.1.

Table F.1. Reduction factors to apply to inlets

Condition	Inlet type	Percentage of theoretical capacity allowed
Sag	Kerb opening	80
Continuous grade	Kerb opening	80
Continuous grade	Deflector	75

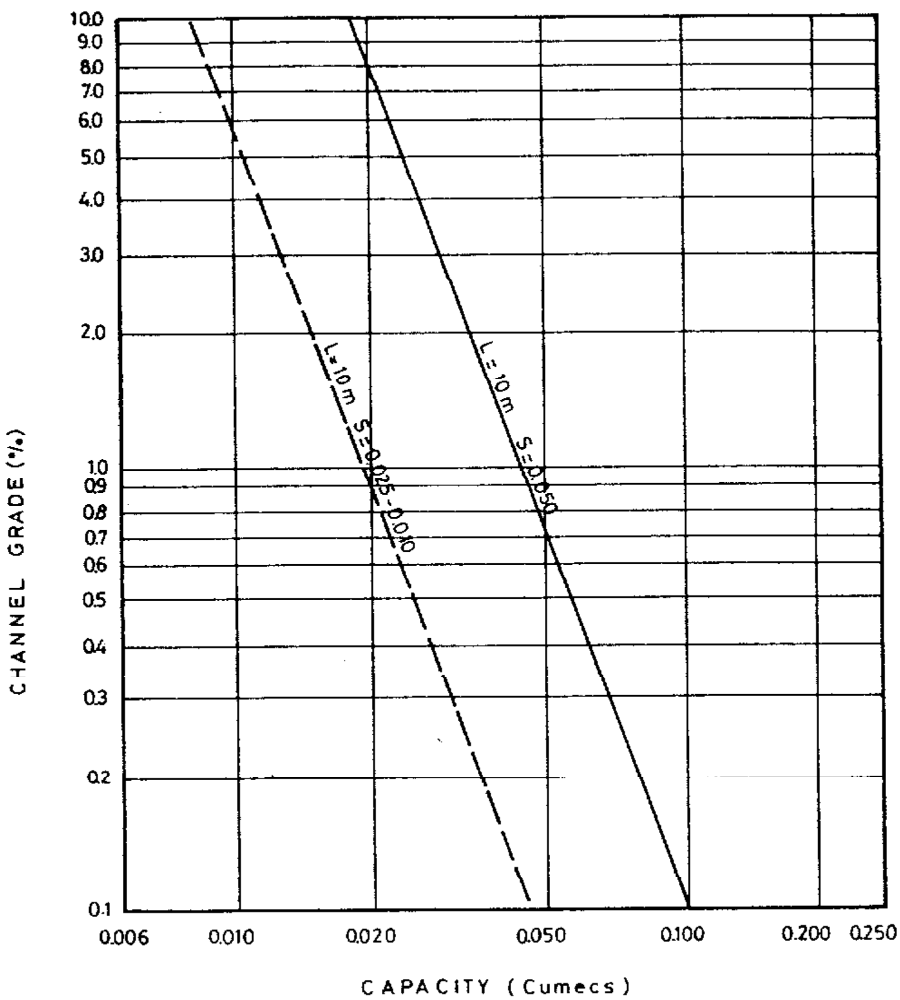
(b) *Spacing of inlets*

Figure F.4 shows the capacity of 1 m long depressed side entry pits for different longitudinal grades and shoulder crossfalls. In determining the required spacing of inlets, the flow from figure F.4 should be multiplied by the reduction factor in table F.1 to compare with the channel capacity determined from figure F.1.

F.4 *Pipe Flow*

For calculation of pipe size, the assumption is made that the pipes will flow full during the design flood. All methods of design require the estimation of friction losses using some formula. For full flows in circular pipes, the Darcy-Weisbach equation is more accurate:

$$h_L = (f\ L/D)\ (V^2/2g) \qquad (F.6)$$



NOTES
(1) Length of side entry pit opening "L" = 1.0
(2) Shoulder crossfall S = 0.05, 0.025, 0.010 m/m
(3) % Capture = 95%
(4) For other values of "L" or "Sc" use logarithmic interpolation
(5) S = 0.025 - 0.010 includes all crosfall within this range

Figure F.4. Design chart for capacity of side-entry inlets

where h_L = the head loss, m

f = a dimensionless friction factor

L = pipe length, m

D = pipe diameter, m

V = velocity of flow, m/s

g = acceleration due to gravity, m/s^2

The friction factor f is obtained from a suitable equation based on the Colebrook-White equation.

Pipe sizes can be determined from figure F.5 which is based on the Colebrook-White equations. These equations are considered to give the most satisfactory results and the equations for smooth turbulence and rough turbulence respectively are given below.

$$1/(f^{0.5}) = 2 \log (R/f) - 0.8 \qquad \text{(F.7)}$$

$$1/(f^{0.5}) = 2 \log (D/2k_s) + 1.74 \qquad \text{(F.8)}$$

where f = Darcy Weisbach friction factor

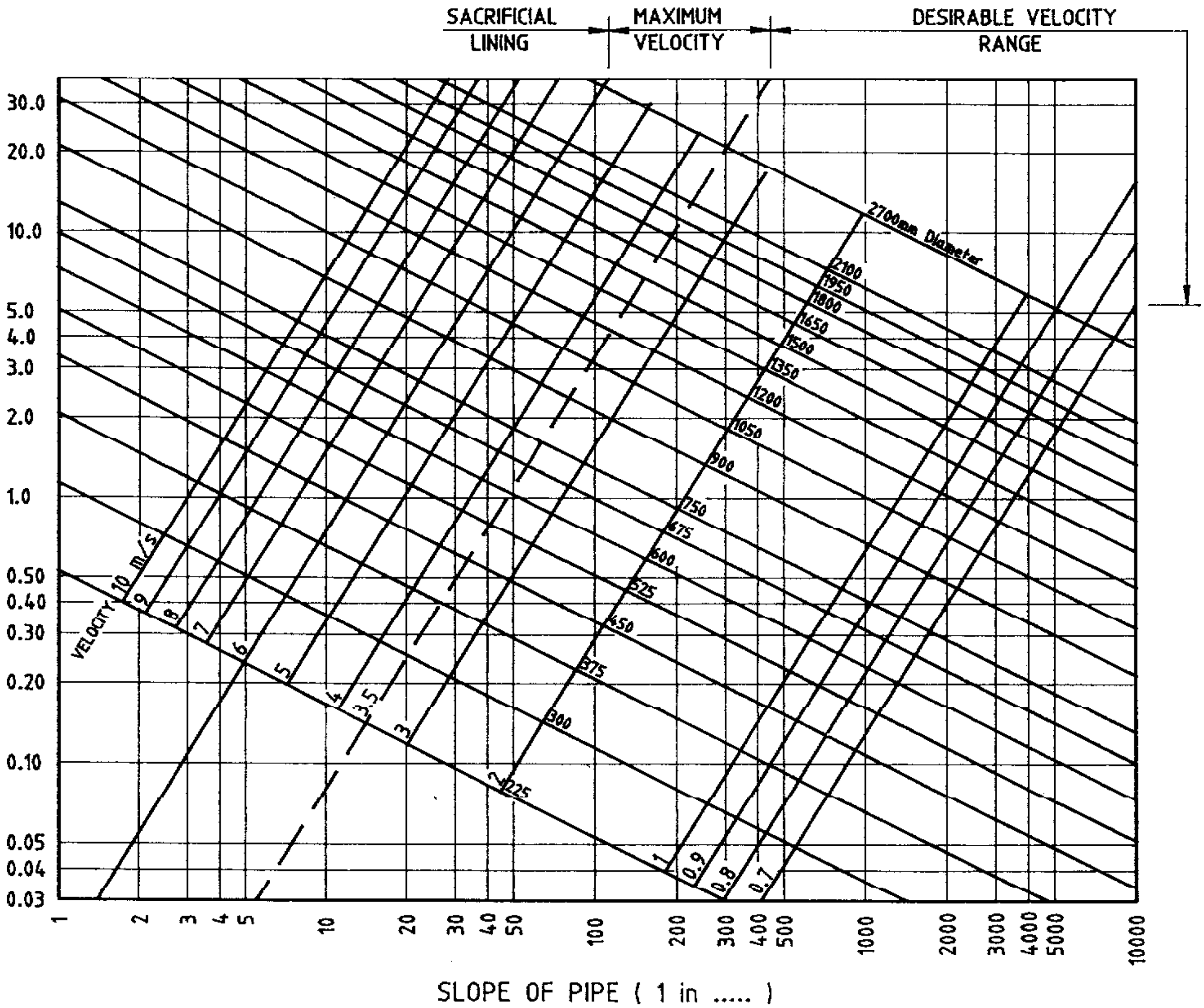
R = Reynolds number

D = pipe diameter, m

k_s = roughness factors

For the Colebrook-White equations, the values of the linear measure of roughness (k_s) can be found from table F.2.

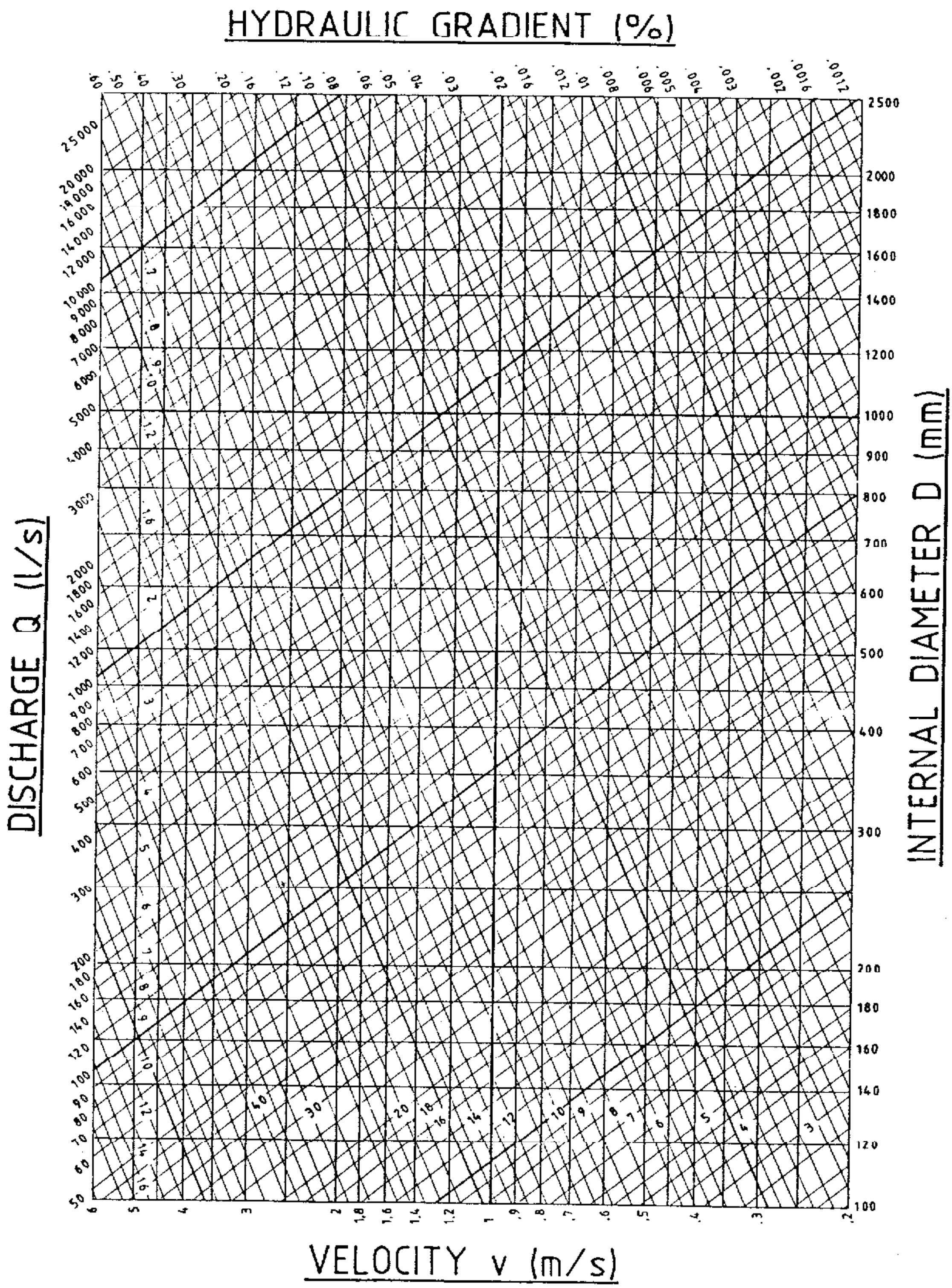
It is recommended that design wall roughness should reflect conditions well into the service life of the pipe, somewhere between the "good" and "poor" values given in table F.2. Thus for concrete pipes, a value of k_s = 0.3 mm is suitable. For analysis of existing pipes, k_s values appropriate to their condition should be used.



NOTE:- FOR CIRCULAR PIPES RUNNING FULL BUT NOT UNDER PRESSURE, THE SLOPE OF PIPE IS PARALLEL TO THE HYDRAULIC GRADIENT

(COLEBROOK - WHITE FORMULA)

Figure F.5(a) . Design chart for flow in circular pipes flowing full (k_s = 0.6 mm)



COLEBROOK-WHITE FORMULA, k = .010 mm

(Based on Colebrook-White formula for pipes flowing full with water at 20°C)

Figure F.5(b). Design chart for flow in circular pipes flowing full (k_s = 0.1 mm)

Table F.2. Recommended concrete roughness values (k_s) for Colebrook-White equations

Classification	k_s (mm) for condition Good	Normal	Poor
Concrete			
Class 4. Monolithic construction against oiled steel forms, with no surface irregularities, smooth-surfaced precast pipes with no shoulders or depressions at the joints.	0.06	0.15	0.60
Class 4a. Smooth-surfaced precast pipe-lines in units of 2 m or over, with spigot and socket joints, or ogee joints pointed internally.	-	0.15	0.3
Class 3. Monolithic construction against steel forms, wet-mix or spun precast pipes, or with cement or asphalt coating.	0.3	0.6	1.5
Class 2. Monolithic construction against rough forms, rough texture precast pipes or cement gun surface (for very coarse textures, take k_s equal to size of aggregate in evidence).	0.6	1.5	-
Class 1. Precast pipes with mortar squeeze at joints.	-	3	6
Smooth trowelled surfaces	0.3	0.6	1.5
Fibre-reinforced cement pipes	0.15	0.3	
Glass-reinforced plastic	0.003	0.010	0.015

F.5 *Pipe System Design*

The calculation process for a pipe network consists of the following basic steps:

(i) Layout of trial pipe network with approximate positions of inlets
(ii) Design and determine sub-catchment areas and time of flow (t_c) to each inlet (figure D.1, F.3 or F.5)
(iii) Estimate coefficient of runoff (C) from table F.2
(iv) Determine rainfall intensity for inlet design from IDF curves
(v) Calculate flow to site of inlet by conventional rational formula $Q = CIA/360$
(vi) Determine capacity of both gutter and inlet to accommodate this flow and adjust inlet location and type if necessary
(vii) Determine total catchment area, critical time of concentration, and estimate design flow for the point under consideration
(viii) Measure length and slope of pipe receiving this flow and obtain pipe size from figure F.5 or published tables
(ix) Obtain velocity of flow and time of flow to add to t_c for next calculation

Table F.3 could be used for the calculations required in the design of piped drainage

Table F.3. Stormwater design calculation sheet for pipelines

PAGE OF PAGES

LOCATION		SUB AREA TIME OF CONCENTRATION					SUB AREA RUNOFF COEFFICIENT			INLET DESIGN					DRAINAGE DESIGN					FLOW TIME	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	21
DRAIN SECTION	SUB-AREA CONTRIBUTING	TIME OF OVERLAND FLOW	LENGTH OF GUTTER FLOW	SLOPE OF GUTTER	TIME OF GUTTER FLOW	SUB-AREA TIME OF CONCENTRATION	AREA OF SUB-AREA	COEFFICIENT OF RUNOFF	EQUIVALENT IMPERVIOUS AREA (COL 8 x 9)	CRITICAL TIME OF CONCENTRATION	RAINFALL INTENSITY (I)	SUB-AREA DISCHARGE (COL $\frac{10 \times 12}{360}$)	INLET TYPE	AMOUNT BY-PASSED	TOTAL EQUIVALENT IMPERVIOUS AREA	DESIGN DISCHARGE (COL $\frac{10 \times 12}{360}$)	LENGTH OF SECTION	SLOPE OF SECTION	DRAIN DIMENSION	VELOCITY OF FLOW IN SECTION	TIME OF FLOW THROUGH SECTION (COL $\frac{18}{21 \times 60}$)
		Min	m	%	Min	Min	Ha		Ha	Min	mm/hr	m^3/s		m^3/s	Ha	m^3/s	m	%	mm	m/s	Min

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When determining pipe invert levels, losses in side entry pits and other junctions should be considered particularly in steeper areas.

G. Pumping capacities and storage requirements in polders

G.1 *Principles of drainage in a polder*

A polder is an area with ground levels which are so low in relation to the nearest river or the sea that free drainage is impossible. The area is then enclosed by three banks or dykes which prevent water from entering from the outside, and discharge of the rainfall on the area inside the levee banks is effected by pumping.

Because practically all the rain which falls on the area has to be pumped out again (with the exception of a small percentage which evaporates), the polder area should be limited in size.

The drainage system inside a polder consists of:

- Minor drainage system;
- The main collector drains situated in the lowest parts of the polder and heading towards the pumping station;
- A pumping station with storage.

If there is no storage, the pumping station would have to be able to pump out immediately whatever discharge comes down the main collector drain. The peak discharge, however, only occurs during a short period, and important reductions in cost of the installed pumping capacity can be obtained by providing a storage reservoir.

G.2 *Pumping capacity versus storage requirement*

A large capacity in the pumping station will make it unnecessary to have a large storage reservoir. A small pumping capacity will require a large reservoir from which the water can slowly be pumped out.

Somewhere between these two extremes lies the optimum capacity of the storage. This optimum is determined by economic considerations: for example, where the land required for a reservoir is scarce and costly, a large pumping capacity will be cheaper; where land is relatively cheap, a large reservoir and small pumps may be chosen.

Additional considerations which may influence the economic evaluation are those concerning the risk of inundations. On the one hand, if the pumps are too small the reservoir may not be empty before the next storm. However, if the reservoir is too small there will be no reserves should the pumps fail to work.

The usual method of establishing the optimum combination of pumping capacity and storage requirement is shown in figure G.1. In the figure the following mass curves or lines of accumulated volumes of water in mm on the total polder area are shown:

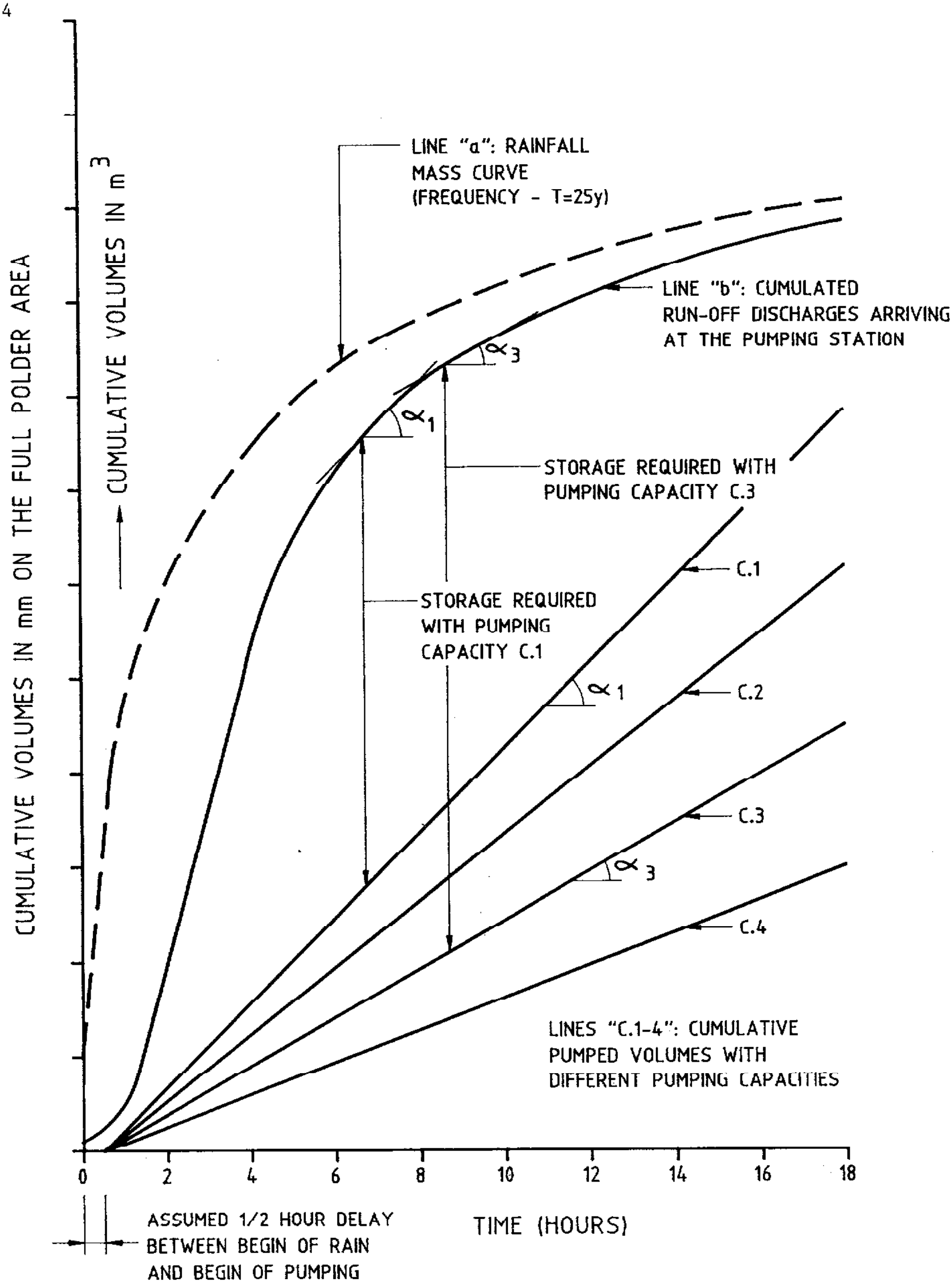

Figure G.1. Storage requirement and pumping capacity in a polder

(a) The mass curve of rainfall of the chosen average return interval (ARI) (for example the rainfall with an ARI of 20 years);

(b) The cumulated discharge arriving at the pumping station. This line is established by determining the run-off hydrographs of each sub-catchment area, using run-off coefficients appropriate for each case, and by combining all these hydrographs into a composite hydrograph for the whole polder. The shape of the polder area determines the time of concentration and the shift of line "b" in relation to line "a". The discharges arriving at the pumping station can be expressed as a water depth over the full polder area;

Lines C1, C2, C3 etc. are the lines of accumulated pumped volumes of water (again expressed as a water depth over the full polder area) obtained with different pumping capacities.

From the graphical presentation in figure G.1 the required storage capacity can be determined by drawing a tangent to the line "b" parallel to one of the "C" lines. This will indicate the storage capacity required in conjunction with the pumping capacity represented by that "C" line. This required storage capacity will have to be available in the storage reservoir between the lowest water level that can be obtained by pumping and the highest water level permissible in the reservoir in relation to the surrounding land levels.

The various pumping capacities and storage requirements can then be economically selected. Usually the economic pumping capacity will be somewhere between 10 and 20 l/s per ha.

The pumping station will have to be carefully designed to be able to discharge water straight from the incoming main drain, as well as from the reservoir. Also, the efficiency of the pumps should not differ too much between pumping at low or at high water levels in the reservoir. Archimedean screw-pumps are often most suitable for this purpose.

The reservoir should be excavated deep enough to prevent plant growth even at low water stages. In the dry season the water level maintained in the reservoir for this purpose can be higher than the low-water level which is needed in the wet season for the required storage capacity. Care should be taken to prevent debris from being thrown into the storage. Floating debris carried downstream in the main drain should be prevented as much as possible from being carried into the storage reservoir by the construction of suitable screens on the inlets to the reservoir.