



KSVO • CUTA

Komitee van Stedelike
Vervoerowerhede

Committee of Urban
Transport Authorities

UTG 4

**GUIDELINES FOR
URBAN STORMWATER
MANAGEMENT**

1991



URBAN TRANSPORT GUIDELINES

UTG4

**GUIDELINES FOR
URBAN STORMWATER
MANAGEMENT**

1991

ISBN 1 874844 47 X

UTG4, 1-39, Pretoria, South Africa, 1991

Published in 1991 by the
Department of Transport
P O Box 415
0001 PRETORIA
South Africa

on behalf of
the Committee of Urban Transport Authorities

*Printed in the
Republic of South Africa
by Scientia Publishers, CSIR*

PREFACE

URBAN TRANSPORT GUIDELINES (UTG) is a series of documents written for practising transportation engineers which describes current recommended practice in selected aspects of urban transportation. They are based on South African experience and research and have the full support and approval of the Committee of Urban Transport Authorities.

To confirm their validity in practice, UTGs are circulated in draft form for a two-year period before receiving the final approval of CUTA. After final approval revised documents are issued as full UTGs. Suggestions for improvement may be sent at any time to:

The Secretary
Committee of Urban Transport Authorities
P O Box 415
0001 PRETORIA

UTG4 is now published as a final UTG, having been reviewed and approved by CUTA. It has not been found necessary to change the original text other than to add new information in a number of places. Five new sources have been added to the list of references.

SYNOPSIS

This document deals with stormwater management of run-off from proposed urban areas and to a limited extent from existing areas.

The aims set in this guideline document are, among others, the protection of life and property, the improvement of the quality of life of the community and the preservation of the environment.

Aspects covered in the document include the control of stormwater run-off, the prevention of erosion of natural watercourses and the protection of the ecosystems therein. Consideration is also given to the use of roads in stormwater run-off control. The control of pollution in run-off is also discussed.

SINOPSISIS

Hierdie dokument gaan in op die vloedwaterbeheer van afloop vanaf voorgestelde stedelike gebiede en, in 'n beperkte mate, vanaf bestaande gebiede.

Die oogmerke van hierdie riglyne het betrekking onder meer op die beskerming van lewe en eiendom, die verbetering van die lewensgehalte van die gemeenskap en die bewaring van die omgewing.

Aspekte wat in die dokument behandel word, sluit in die beheer van vloedwaterafloop, die voorkoming van erosie van natuurlike waterlope en die beskerming van die betrokke ekosisteme. Oorweging word ook geskenk aan die gebruik van paaie in vloedwaterafloopbeheer. Die beheer van besoedeling in afloop is ook bespreek.

KEYWORDS

Stormwater management, urban development, run-off, drainage, erosion, pollution, flood plain, flood control, recurrence interval, channel linings, flood safety

ACKNOWLEDGEMENTS

The Stormwater Working Group of the CUTA Technical Sub-Committee comprising:

A J Hay (Chairman)

R C Corin

A L Cross

A J Ritchie

is grateful to the many persons who provided information and guidance in the preparation of this document, in particular:

Mr L C Miles, previously of the CSIR, the City Engineers' Departments of the Municipalities of the cities of Johannesburg, Pretoria, Cape Town, Durban, Port Elizabeth and Bloemfontein; the University of the Witwatersrand Water System Research Programme, Department of Civil Engineering; the University of Pretoria's Department of Civil Engineering; the Division of Hydraulic and Water Engineering of the South African Institution of Civil Engineers; the National Building Research Institute, Ninham Shand Inc and Mr D E Simpson of the National Institute for Water Research.

CONTENTS

	Page
Preface	iii
Synopsis/Sinopsis	iv
Acknowledgement	v
1 Introduction	1
2 Stormwater Management – Goals, Objectives and Policies	3
3 Planning	5
3.1 Master planning	5
3.2 Detailed planning	11
4 Measures to control run-off	13
4.1 Storage facilities	13
4.2 Purpose-built storage facilities	14
4.3 Supplementary storage facilities	19
4.4 Subsurface disposal of run-off	20
4.5 Open channels	21
4.6 Removal of flow restrictions	22
4.7 Levees and flood walls	23
4.8 Flood-proofing of buildings	23
5 Roads to control run-off	25
5.1 The effect of stormwater run-off on the traffic-carrying capacity of roads	25
5.2 Road layout	27
5.3 Encroachment on roads by run-off	27
5.4 Encroachment on properties by run-off	28
5.5 Road gradients and crown slopes	28
5.6 Dished roads	29
5.7 Gravel roads	29
6 Quality of run-off	31
6.1 Methods to reduce pollution	31

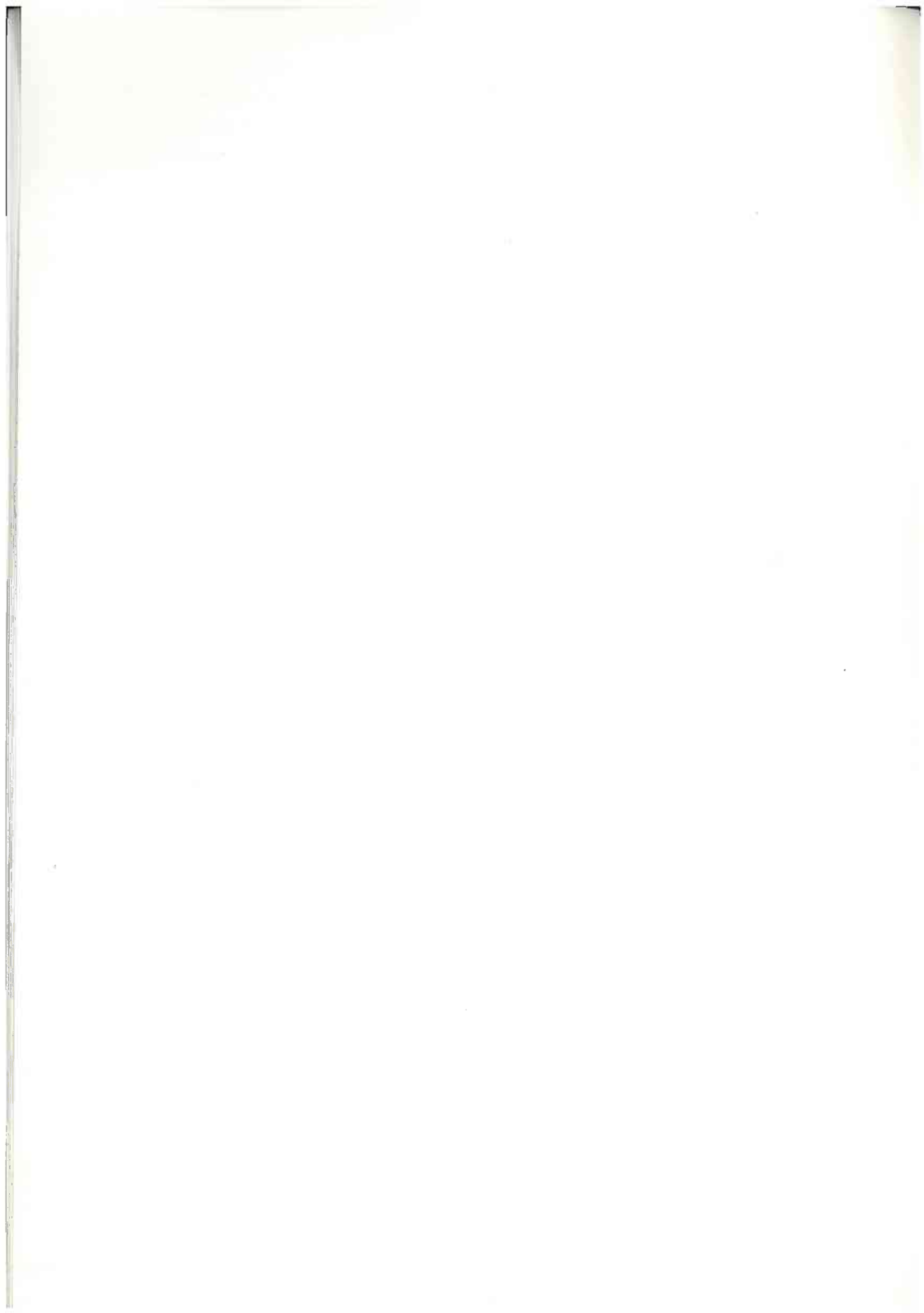
7	Safety	33
7.1	Flood warnings	33
7.2	Flood information and education	33
	References	34
	Bibliography	36
	Glossary	38

LIST OF FIGURES

1	Definition sketch for watercourse cross-sections	6
2	Definition sketch for road cross-sections	26

LIST OF TABLES

1	Design flood frequencies for major systems	8
2	Design flood frequencies for minor systems	12
3	Permissible encroachment of design floods on roads	28



1 INTRODUCTION

The process of urban development interferes with the natural discharge of stormwater. Run-off may be doubled and peak flows may be increased to many times the pre-development flow^{1,2}. The purpose of this document is to limit development in areas susceptible to flooding and to provide guidance on methods of attenuating flood peaks caused by urbanization and of controlling the quality of stormwater run-off.

It is common practice to provide a formal drainage system of pipes or channels to convey stormwater away from erven and streets and to discharge this water into natural watercourses. Such systems are traditionally designed to cope with storms of up to 10-year recurrence intervals. In the past, little or no thought was given to the discharge of run-off from severe storms that exceeded the capacity of the drainage system provided. Excess stormwater was left to find its own way overland via roads, road reserves or private property to the watercourses. This has often resulted in damage to roads and property by run-off from the more severe storms.

Comprehensive stormwater management should give due consideration to the orderly discharge of stormwater from storms of both low and high severity. For storms of low severity, which occur frequently, it is convenient to provide a pipe or channel system to avoid the frequent nuisance which might otherwise result from overland flow. This system has been termed the "minor system" and it corresponds to the pipe or channel systems which have traditionally been provided.

By considering the effects of the less frequent storms, a so-called "major system" can be identified as support to the conventional minor system. In the major system, consideration should be given to the downstream impacts of unusually high run-off.

The major system may include larger conduits and natural or artificial channels, but would frequently also make use of the road system to convey excess water to suitable points of discharge. This is not very different from what has previously happened *de facto*, except that formal recognition is now given to the logical and controlled routing of run-off via the roads or other facilities employed for this purpose.

Roads have traditionally played an important part in the urban drainage process. However, the conventional design of roads and drainage systems does not consider the control of floodwater beyond the capacity of roadside channels and pipe systems. One objective of major system design is to plan roads to cope with this excess water to avoid damage to properties and to the road itself.

Stormwater management should therefore be regarded as an extension of conventional drainage practice, recognizing the shortcomings of the practice and introducing the concept of control of run-off resulting from major storms.

Stormwater management has benefitted from the recent development of powerful computer programs which are available to most designers. These programs have facilitated the quantitative assessment of hydrological phenomena.

By identifying and dealing with problems before they occur, comprehensive stormwater management can lead to significant cost savings. Solutions to flooding are easier and cheaper when there is undeveloped land available than after development.

The concentration and deliberate routing of run-off can create problems, eg:

- (a) Road superelevations and vehicle entrances are weak links in a barrier that may otherwise have contained flow within the road reserve.
- (b) There is an apparent reluctance on the side of local authorities and educational bodies to accept the inundation of sports fields and parking areas, however infrequently.

However, these problems are not insurmountable.

The local-authority engineers who deal with stormwater in the country's largest cities as well as consulting engineers, seem to agree with the philosophy of minor and major systems. Some have already applied the concept not only to new developments, but also to help solve problems in existing townships.

There is therefore good reason to adopt the concept of minor and major systems, thus ensuring that risk to life and property is minimized over a wide range of storm frequencies.

In this document, this concept is used to formulate a stormwater management policy. The policy is interpreted in the form of planning guidelines. Sections on control measures and safety considerations are included to assist policy implementation at a more detailed level.

2 STORMWATER MANAGEMENT – GOALS, OBJECTIVES AND POLICIES

Stormwater management is described below in terms of a hierarchical framework of goals, objectives and policies. The chapters which follow provide guidance for the implementation of the policies in the planning and design stages.

The **goals** of stormwater management are:

- the protection of life and property from flood hazards;
- the improvement of the quality of life of the community, and
- the preservation of the natural environment.

The goals may be translated into a number of **objectives**, namely:

- to provide a stormwater drainage system for the convenience of the community and the protection of property from damage by the run-off from frequent storms;
- to prevent loss of life and reduce damage to property by the run-off from severe storms;
- to prevent land and watercourse erosion;
- to protect water resources from pollution;
- to preserve natural watercourses and their ecosystems, and
- to achieve the foregoing objectives at optimal total cost.

Based on these objectives, a number of statements can be made, constituting a **stormwater management policy**. These statements are:

- (a) The co-ordination of drainage planning should be initiated at the start of a planning operation for land uses (ie preparation of guideline plans).
- (b) Master drainage plans should be prepared, in collaboration with adjoining authorities for the existing and future development of the entire catchment.
- (c) Flood plains should be protected and preserved to perform their natural stormwater conveyance and storage functions and to support their ecosystems, but a balance must be achieved between the stormwater management goals and the overall goal of optimal land use.
- (d) Flood plains should be accessible to the public in the form of open space areas.
- (e) The stormwater drainage system should be designed to convey run-off in a controlled manner that will not adversely affect upstream, adjacent or downstream properties on watercourses.

- (f) Individual developments should have stormwater drainage systems that are integrated with the master drainage plan. Where master drainage plans are not available, attempts should be made to limit the post-development rates of discharge to pre-development values for a range of recurrence intervals.
- (g) Maximum use should be made of the flood control and drainage potential of roads by co-ordinating their layouts with other components of the drainage system.
- (h) All stormwater facilities that are not located in road reserves or public open spaces, should be located within servitudes or special reserves.
- (i) Pollutants should be removed at the source wherever feasible.
- (j) Watercourses should be inspected and maintained to control blockage, erosion and physical and chemical pollution.
- (k) Pre-development groundwater recharge rates should be maintained wherever feasible.

3 PLANNING

A stormwater management policy can be successfully implemented through adequate planning of stormwater drainage systems and the design, construction and maintenance of stormwater control measures where necessary. The degree to which the policy is implemented will depend, in the first instance, on specific legal requirements (eg the Water Act, Ordinances and By-Laws) and on more general responsibilities conferred by common law. In determining legal requirements, previous judgements indicate that, taking into account the financial resources of the controlling authority, a considerable margin of safety is expected. Where there is conflict between statutory requirements and these guidelines, the law must obviously take precedence.

The authorities responsible for stormwater management must recognize that run-off is a natural phenomenon generated by storms over catchment areas bounded by watersheds, and that the boundaries of towns and cities often do not coincide with watersheds. They may therefore have to control run-off from areas outside (upstream of) their jurisdiction or for the benefit of outside (downstream) areas. The problem is compounded by the growth of towns and cities to the point where they abut on each other, with the run-off from one urban area flowing directly into another. Consequently, where no regional authority exists, run-off should be managed in a spirit of co-operation between authorities. Adjoining authorities should be aware of each other's planning on a common watercourse and should avoid inconsistencies in planning and design. For example, the use of standardized precipitation data (eg intensity-duration-frequency curves) for the entire region should be considered.

The planning phase of stormwater management is conveniently undertaken in two stages. The first stage is the **master planning** of the main elements of the region's drainage system. The second stage is the **detailed planning** of the drainage systems for individual developments within the region's catchment areas, ensuring compatibility with the main elements.

3.1 MASTER PLANNING

The purpose of master planning is to optimize land use in a region whilst taking cognizance of the goals of stormwater management. Being a facet of land use control, master planning is the responsibility of the controlling regional or local authority. To be fully effective it should occur during the earliest phases of regional development. However, all existing urban areas lie in regions that are developed to a certain degree. The state of development of a region must therefore be recognized as a constraint in the planning process.

Master planning predominantly deals with the major system although it may be necessary to consider the main outfall of the minor system on some occasions. Master planning involves the following:

- qualitative identification of the major system;
- determination of the RI of major floods;
- identification of constraints;
- data collection;
- analysis of systems;
- determination of permissible land use in flood zones, and
- implementation of the preferred alternative.

3.1.1 Identification of major system by means of suitable plans (eg topographical, topo-cadastral)

The major system consists of all natural watercourses and major artificial conduits (including roads) in a catchment.

For the purposes of this document, the following definitions will apply:

- The flood plain is that area, regardless of geological origin, that borders watercourses or coastlines and that may be inundated by the major flood (see Glossary) or by the action of winds and tides, or by a combination of these.
- The flood plain fringe is that area that borders the flood plain and that may be inundated by the regional maximum flood (see Glossary).
- The flood zone is that area that may be inundated by the regional maximum flood. It contains the flood plain and the flood plain fringe.

These areas are shown in Figure 1.

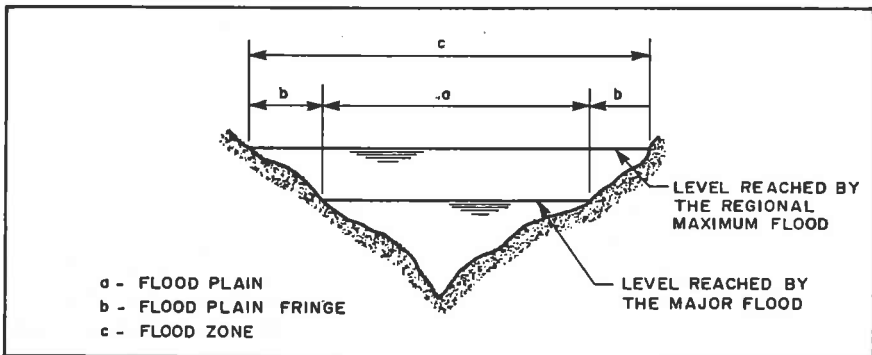


FIGURE 1

Definition sketch of watercourse cross-sections

3.1.2 Determination of the recurrence interval of the major flood

The width of the flood plain will be determined by the recurrence interval of the major flood. Hence, the selection of recurrence interval will affect permissible land uses along the watercourse. The goals of stormwater management imply the use of a long recurrence interval, to make flood plains as wide as possible.

The selection of recurrence interval for the major flood should be based primarily on an attempt to minimize the risk to human life in the flood area. Factors to consider include the density and type of development in the flood zone, the circumstances of occupation (eg daylight only, old-age homes, etc), the rate of increase of water level and period of warning, possible escape routes and the topography of the flood zone as it influences velocity and depth of flow³.

Of secondary importance in the selection of major flood recurrence interval is the cost-benefit relation between the cost of flood damage and the value of land. Here the factors to consider are:

- likelihood of structural damage by inundation;
- economic value of site, structure and contents, and
- possibility of sedimentation.

A similar approach is described by the New South Wales Government, Australia, in its Floodplain development manual⁴. The approach requires the selection of a Flood Hazard Category for planning purposes, based on the flood behaviour and associated risk for the particular topographical situation under consideration. This method requires a great deal of engineering input to arrive at an optimum solution but also ensures that development in floodplains is not unnecessarily restricted.

The approach is based on the fact that flooding and its effects vary both in time and place. Therefore to achieve a realistic approach to floodplain management it is necessary to divide the floodplain into categories descriptive of the impact that development may have on floodwater and the impact that floodwater may have on development.

In determining the flood hazard applicable to a particular area, the following factors are taken into consideration:

- depth and velocity of floodwaters;
- effective evacuation time; and
- evacuation difficulties, including isolation of some areas as floodwaters rise.

Two hazard categories are defined for the impact of floodwater on development – low hazard and high hazard.

Under low hazard conditions, people and their possessions could be evacuated by trucks, if necessary. Able-bodied adults would have little difficulty in wading and damage potential and the risk to life and limb would be low.

In high hazard areas, floodwater could cause structural damage to buildings. The potential danger to life and limb and social disruption and financial loss could be high.

Clearly each development should be treated individually. However, Table 1 provides guidance in the form of a range of recurrence intervals from which a first estimate can be selected.

TABLE 1
Design flood frequencies for major systems

Land use	Design flood occurrence interval (years)
Residential	20 – 100
Institutional (eg schools)	20 – 100
General commercial and industrial	50 – 100
High-value Central Business Districts	50 – 100

3.1.3 Identification of constraints

The character of the existing development and landownership may be a constraint in stormwater master planning. National legislation referring to specific developments and subordinate legislation (eg bylaws) may constrain desirable solutions. The degree of flexibility of proposed land uses and service routes (eg sewers, transmission lines, roads) should be determined.

Explicit financial constraints may also be evident.

3.1.4 Data collection

Some form of topographical, landownership and land use data will be available from the qualitative work already done. Further data is, however, required for the selected methods of analysis. In addition, data such as recorded stream flows, flood levels, problems caused by flooding and existing theoretical analyses should be sought and examined.

3.1.5 Analysis of a range of alternative systems of stormwater control

The flood zone, flood plain and flood plain fringe should be determined for the region under:

- current development, and
- ultimate development (taking account of the hydraulic effects of proposed development in the flood plain fringe) – the analysis should include no stormwater controls other than those already existing as well as a number of alternative proposed systems of control.

Hydrographs used to determine any specific situation (eg flood zone for current development) should be selected from two or more hydrographs resulting from different methods of analysis or values of design parameters. For consistency it may be desirable to use the same methods of analysis for the entire region.

Factors that should be considered in the formulation of alternative systems of stormwater control include:

- the benefits of changing land uses where possible;
- location and type of control;
- identification of areas in which the alternative is unable to resolve existing and anticipated stormwater problems;
- multi-use of control facilities;
- sources of pollution of run-off;
- specific areas of environmental concern, and
- safety and maintenance of controls.

Types of stormwater control are discussed in Chapter 4. Sufficient details of these control types should be given to permit identification of two or three alternatives for more detailed modelling. This would make possible a comparison of proposals and the final selection of a plan. The comparisons of the plans should consider capital costs such as those for construction, operation and maintenance and benefits such as reduced damages, other economic factors, multiple use, social and environmental factors as decided by the controlling authority. Multi-objective optimization techniques may facilitate the selection of the most suitable master plan⁵.

3.1.6 Determination of permissible land uses in the flood zone

There is currently no definitive national legislation dealing with development within floodlines. Although Section 169A of the Water Act (Act 54 of 1956) requires that floodlines be indicated on the relevant layout plans, it provides no guidance on the permissible types of development, if any, between the lines. The following approach is suggested where there is no subordinate legislation to cover development in the flood zone.

3.1.6.1 Permissible land use in flood plains

Restricting development in the flood plains is consistent with the objectives of protecting life and property against severe floods and of preserving the natural watercourse.

In new developments flood plains should be acquired by the controlling authority as a condition of approval for township development or subdivisions and in existing developments by purchase or dedication where deemed necessary for flood mitigation measures. These measures should include:

- (a) The preferred land use is public open space in the form of a continuous park strip along the length of the watercourse.
- (b) Private open space such as golf courses, nurseries, lawns and gardens, driveways and open space requirements for clustered buildings should be permitted.
- (c) Buildings should not be permitted.
- (d) Services, both underground (eg pipelines and cables) and overhead (eg transmission lines) should be permitted. Associated structures such as manholes and transmission line towers may require protection against erosion and flood ingress.
- (e) Roads of Class 4 and lower orders should be permitted⁶.
- (f) Alteration of original flow characteristics of the flood plain by changing the land surface profile (eg by excavating or filling in the flood plain), should not be permitted unless the controlling authority considers it unavoidable.

3.1.6.2 Land use in the flood plain fringe

Preference should be given to the benefits that the community may derive from the flood plain fringes remaining in their natural state before consideration is given to the construction of structures and facilities in the flood plain fringe.

However, in general, development in the flood plain fringe need only be subject to one restriction, namely that timeous evacuation of buildings be ensured by the provision of adequate escape routes.

It should be recognized that any construction within the flood plain fringe which constitutes an obstruction will increase the width of the flood zone.

3.1.7 Implementation of the selected scheme

Once a scheme has been selected, the final stormwater master plan should show the flood plain and flood plain fringe for:

- the current development, and
- the ultimate development with and without stormwater controls.

This would make it possible to implement the scheme in phases. As upstream development occurs, development within a certain distance of the downstream watercourses should be delayed until the necessary stormwater controls had been completed.

Stormwater management control facilities could be financed from a fund consisting of contributions by developers similar to the present financing of other services (eg sewerage).

3.2 DETAILED PLANNING

Detailed planning refers to planning of developments within a catchment. It requires consideration of both the minor and major systems. It includes the identification of responsible parties and the definition of their responsibilities. Detailed planning may be required for new developments in catchments that are highly developed or catchments with very little urban development. It may also be required to relieve drainage-related environmental problems (eg flooding, erosion, pollution) in existing developments. Although the state of development of the catchment can impose severe constraints on solutions, the goals and objectives of stormwater management should be met wherever possible.

The controlling regional or local authority should be responsible for ensuring that detailed planning is compatible with the master planning and that the objectives of stormwater management are attained. This may include specifying the maximum permissible rate of discharge of run-off from areas upstream of the development and the location of downstream stormwater outfalls.

The developer should be responsible for the design of the development's minor and major systems. This includes the control of actual and potential stormwater run-off from upstream areas, from the development itself and occasionally from areas outside the development's catchment.

The principles set out below should be used to prepare the detailed plan.

3.2.1 Effect on downstream areas

In order to limit the impact on downstream areas, developments should, if possible, include some form of stormwater control (see Chapter 4). The ideal would be to constrain the post-development peak discharge to the pre-development value, for a specified range of recurrence intervals, up to and including that of the major flood, although this is not always economically or practically feasible.

To assist evaluation of the downstream impact, the developer may be required to submit a report on the downstream outfall system(s). This should be for a distance specified by the controlling authority, noting the existing surrounding topography, soil types, embankments, vegetation, structures, abutting properties, etc which may be affected by stormwater. The report should include an assessment of the magnitude and significance of the impact of both the minor and major storms under both existing and ultimate conditions.

The downstream stormwater outfall may discharge into a natural watercourse or to a point of acceptance agreed upon by the downstream landowner and approved by the controlling authority.

If the discharge of stormwater from a development is concentrated on a downstream property where it was not concentrated before, a servitude for the conveyance of the stormwater should be acquired to cross that property and properties further downstream until it reaches a specified point of discharge.

Consideration should also be given to the avoidance of adverse impacts such as higher rates of flow, depositing of eroded material, etc during the construction of the upstream development.

3.2.2 Recurrence intervals for minor floods

The minor system is designed for relatively frequent events. The main problem caused by stormwater run-off under these conditions is likely to be inconvenience to pedestrian and vehicular traffic. The acceptable degree of inconvenience relates to the type of development and the vehicular traffic density. A guide to the selection of recurrence intervals using this approach is given in Table 2. The permissible degree of inconvenience to vehicular traffic is indicated by Table 3.

TABLE 2
Design flood frequencies for minor systems

Land use	Design flood recurrence interval (years)
Residential	1 – 5
Institutional (eg schools)	2 – 5
General commercial and industrial	5
High-value Central Business Districts	5 – 10

3.2.3 General

Within a development, due attention should be paid to roads as components of the major and minor systems. Weak links in the conduit formed by roads with kerbs should be guarded against, for instance T-junctions at the bottom of hills, vehicle entrances and intersections.

Particular attention should be given to the safety and maintenance of stormwater control facilities, which can themselves be hazardous.

Maintenance should encompass operational, aesthetic and health requirements.

The cost of constructing the various portions of the stormwater system may be apportioned between responsible parties in accordance with the stipulations laid down by the controlling authority.

4 MEASURES TO CONTROL RUN-OFF

Alternative measures for the control of run-off are discussed in this chapter and in Chapter 5. Storage facilities and subsurface disposal are required mainly for controlling the impact on areas downstream. Open channels, removal of flow restrictions, levees and flood walls, flood-proofing of buildings and use of roads as part of the major and minor systems are measures concerned mainly with protection of areas adjacent to watercourses. However, any measure may affect upstream, adjacent and downstream areas and adverse effects should be avoided. The effects of physical failure of a measure, or of exceedance of its design flood capacity, should also be examined. Such a failure may require the provision of escape routes or flood warning systems (see Chapter 7).

Overall land use control in the catchment area, as part of the planning process, is not discussed in this section but can, in itself, be the most effective means of run-off control.

Since schemes for the control of run-off will often be located in environmentally sensitive areas, they should be designed in consultation with environmental scientists when necessary.

4.1 STORAGE FACILITIES

Storage facilities attenuate the rate of run-off. They may be planned on a multi-purpose basis as required by the controlling authority and can achieve a number of stormwater management objectives.

Where the existing downstream stormwater system is clearly inadequate and its expansion or improvement is either financially prohibitive or otherwise undesirable, retarding of run-off should be mandatory.

The attenuating of the flows in a catchment brought about by the intended use of storage facilities should be taken into account in the design of these facilities. The combination of discharges from the various sub-catchments should be considered to minimize any adverse effects on the major stream and tributaries. The controlling authority should reserve the right to prohibit the retardation of run-off or to have changes made to the number, size and location of storage facilities, where the proposed retardation is not in the best interests of the community.

Storage facilities may be subject to the provisions of Section 9(C) of the Water Act (Dams with a Safety Risk), which should be consulted before commencing with design. Embankments used in the construction of storage facilities should be designed and constructed in accordance with accepted environmental practices and structural requirements by engineers with experience of earth dams. The stability of the structure and its spillway capacity should be related to the possible danger to life and damage to property downstream of the facility. Present and future downstream development should be considered when

making this assessment. Where there would be danger to human life, should the facility collapse, the design should be based on the guidelines on Safety in Relation to Floods⁷.

Storage facilities should not cause adverse backwater effects (see Section 4.6) or inundation that is unacceptable.

Economic evaluation should be made of the potential damage attributable to excess run-off or to malfunctions of the planned storage facilities and of the cost of providing alternative solutions or enlarged storage facilities.

Design calculations and other information for storage facilities should be provided with the site plan and should include the following:

- the relevant hydrographs (for highest peak flow rate and largest volume of flow) for each of a range of inflows such as the two-year, 10-year, 50-year and 100-year frequency post-development design floods;
- the outlet design calculations;
- the routed hydrographs for the above frequency storms;
- the embankment computations including seepage control, bank protection (piping, burrowing animals) and freeboard calculations;
- the effect of the facility on established flood plains;
- safety precautions deemed necessary, and
- the probable rate of sedimentation.

The developer, together with the controlling authority, should decide on the party responsible for the operation and maintenance of the storage facility. This may require that a maintenance agreement be executed as a condition of approval. Desilting is likely to form an important part of the overall maintenance.

Storage facilities may be:

- purpose-built – designed primarily to attenuate run-off, usually in the form of wet or dry retarding ponds, possibly underground if space is limited, or
- supplementary – primary function not of stormwater attenuation but which can be or have been adapted to attenuate stormwater as a secondary function. These include parking areas, sports fields and areas upstream of road embankments.

4.2 PURPOSE-BUILT STORAGE FACILITIES

The most common purpose-built storage facility is some form of pond. Ponds may be classified as on-site, on-stream, retarding, retention, dry or wet ponds or extended detention wetland systems⁸ (see Glossary). In most cases their selection and design will be dictated by economic considerations and the best use of available land.

Small ponds may be created artificially by constructing low earth dams across minor watercourses, or by excavating and grading the site where the pond is to

be located. Alternatively, natural or artificial depressions may be used in which run-off may accumulate and be retained for other uses or allowed to drain away. Groups of small ponds may be built where the presence of flood danger requires land-use restrictions that prevent the full-scale utilization of a storage site.

It may be economically possible to adopt existing ponds, borrow pits, or low-lying areas adjacent to watercourses to provide flood control storage.

4.2.1 Selection of storage sites

Selection of storage sites can be considered under the following:

- upgrading of drainage systems;
- storage in new developments;
- ponds in flat terrain;
- ponds in steep terrain, and
- position of storage in catchment.

4.2.1.1 Upgrading of storage system

The upgrading of drainage systems in existing developments and in developing areas often requires the provision of storage ponds. At this stage of development, suitable sites for ponds are generally very scarce. However, ponds can possibly be located along watercourses as off-stream ponds.

Off-stream ponds may be located clear of the major flood level (ie the flood plain) and may consist of an excavation in the flood plain fringe. The pond would be designed to accept only the stream flow during high flood stages and all lower flows will bypass the pond. Because of the low level of the pond relative to the stream, discharge from the pond by gravity may be difficult to achieve. A solution to avoid pumping is to pipe the discharge underground to a suitable downstream non-return outlet. However, the use of deep ponds emptied by pumping should not be discounted.

4.2.1.2 Storage in new developments

In new developments a certain percentage of the area is required to be dedicated for open spaces such as parks and green belts, and storage facilities may be located in these where practical.

To ensure that storage facilities are sited where they will be most effective with regard both to cost and operation, the drainage engineer and town-planner should co-ordinate their planning from the initial township layout planning stages.

4.2.1.3 Ponds in flat terrain

Problems may be experienced in the design of ponds emptied by gravity in flat terrain.

These ponds are usually of the excavated storage type. Often, the outlets have to be located at shallow depths to avoid deep excavation for the outlet pipelines or to facilitate discharge into downstream facilities. Consequently, the ponds are also shallow unless they are wet ponds that permanently contain a certain amount of water.

Because the ponds are shallow they have low capacities and to obtain sufficient storage capacity, the surface area of the ponds must be large. Providing sufficient land on which to site the ponds could be costly.

An alternative to emptying the ponds by gravity is pumping and a cost analysis should be made of the two methods.

4.2.1.4 Ponds in steep terrain

The provision of storage in steep terrain is made difficult by the depth necessary to obtain a reasonable volume of storage.

Ponds in such terrain tend to be a combination of excavated storage areas and embankments.

An alternative to on-site ponds may be the use of on-stream ponds in valleys where there are reaches with relatively low gradients. In evaluating the effectiveness of on-stream ponds, consideration must be given to the possibility of the capacity of the pond being exhausted by run-off from far upstream areas before effective storage of the intended local run-off has taken place.

4.2.1.5 The position of storage in catchment

The higher up in the catchment a storage facility is located, the longer will be the reach along which savings on drainage works can be made and along which flooding hazards can be reduced. On the other hand, the run-off is then controlled from a smaller percentage of the catchment. A balance must therefore be sought, through analysis, between these conflicting effects to optimize the effectiveness of the storage. Consideration must also be given to the protection of flood-prone and erosion-prone areas. To achieve this, storage may have to be located upstream of such areas.

Overseas experience has shown that regional storage is more satisfactory and more economical than storage on numerous individual sites. Its effectiveness improves when it is installed in the upper two thirds of the catchment area, serving areas in excess of 1 square km⁹.

4.2.2 Recommendations for the design of ponds

As noted earlier, the engineer should consider the consequences should the design flood be exceeded. He should take into account many factors, such as the type, size and depth of temporary storage, the construction of the pond^{10,11}, the height of the embankment above ground level, the topography of the catchment area and the type of land use, not only along the discharge route, but

also on the flood plain, both upstream and downstream of the facility, and the capacity of the downstream channel. He should consider the maximum allowable discharge from storage and the length of time that the water may be allowed to remain in the facility.

4.2.2.1 Geotechnical aspects

The geotechnical aspects of soils in which storage ponds are to be constructed should be investigated by competent and experienced engineers in this field, to avoid problems that may arise due to the nature of the soil. Information on soils may be found in other sources^{12,13,14,15,16}.

4.2.2.2 Inlet structures

The inlet to storage facilities may consist of pipes, culverts and weirs, as well as channels lined with natural or artificial material.

Inlet structures should be evaluated to ensure that they have sufficient capacity for the designated floods. To avoid backwater effects in the inlet structures, the incoming flows, unless pumped, should be discharged above the highest free surface level that the water in the pond will reach. Where backwater effects are acceptable or where it is necessary to discharge at levels below the free water surface level, the discharge openings should be above the anticipated build-up of sediment in the pond.

Grids may be necessary at the downstream ends of pipes and culverts to prevent children and large animals from entering. Such grids should be hinged at their upper ends so that they can swing open should they become obstructed by debris during a storm. The spaces between the bars should be about 150 mm¹⁷. Grids may also be required over the upstream ends of inlet structures. The design of these should be along the lines of those over outlet structures.

4.2.2.3 Outlet control devices

Outlet control structures may consist of a single pipe set at a height to maintain the correct level of water in a wet pond, or at the lowest level of the bottom of a dry pond. Alternatively, they may consist of a combination of orifices of various shapes and sizes, drop inlets, gratings, channels and narrow and broad-crested weirs. In order to reduce clogging, it is preferable to use a few large outlets rather than a cluster of small ones. The use of the reverse gradient pipe concept for outlets in the extended detention wetland system is a useful way of preventing clogging as well as containing debris and flotsam within the pond for easy removal after the flood has past.

Outlet control structures should be constructed of durable materials and installed in a structurally sound manner to discourage unauthorized misadjustment, such as removing, or drilling additional holes, in orifice plates. They should be self-operating and self-maintaining. Whenever possible, a facility should empty itself by gravity. Electrically operated pumping equipment may

become inoperative during storms when power supply is most likely to fail. Manually operated devices are subject to being maladjusted at inopportune times.

Consideration should be given to providing grids over outlets to prevent people from being drawn into them and to reduce the entry of debris which could clog the outlet. The total area of the openings in the grid should be selected so as to keep the rate of flow through the grid below 1 m/s so that the force holding anyone against the grid will not be excessive¹⁸. The grid bars should be inclined at an angle of about 30° to the horizontal so that debris will be washed up the grid and will thus not reduce the discharge rate. This will reduce the clogging that could increase the pressure on anyone washed against the grid. The spaces between the bars should be about 150 mm and the bars should not be of a mesh pattern which tends to clog and is difficult to clean. The bars should lie in the vertical plane and any lateral stiffening of the bars that may be required should be set back from them on distance pieces to clear the tines of cleaning rakes.

The discharge from storage facilities should preferably be by gravity. However, where pumping cannot be avoided, it is preferable that the run-off enters the facility by gravity and is drained by pumping.

The storage facility should be sited so that safe emergency discharge routes can be provided. These would come into operation without endangering life and property should the capacity of the facility be exceeded or should the facility not operate as planned.

The top of an embankment may be designed to act as a spillway to carry the overflow away safely in the event of the capacity of a facility being exceeded.

4.2.2.4 Dry ponds

Drains should be provided in dry ponds to convey dry-weather flows that would otherwise wet the bottoms of the ponds, kill grass, cause its irregular growth or become a nuisance. These may be open channels or underground conduits. The latter usually require less frequent maintenance than open channels if constructed at suitable gradients. The drains may also be designed to convey the minor flood through the ponds to avoid the frequent wetting of the bottoms of the ponds and the accumulation of pollutants in the ponds.

The bottoms of dry ponds should be constructed with sufficient slope to drain properly and remove all run-off between storms from the storage area. The bottom should also be firm enough to support maintenance vehicles.

The depth of a water table below the grassed surface of a pond should be such that the growth of the grass is not affected¹⁷. This will vary with the type of grass, but a depth of 1 m would be adequate in most cases.

Subsurface drains could be considered as a possible solution to some of the problems of dry ponds.

4.2.2.5 General

Areas of a pond subject to erosion by water flowing at high velocities, such as at inlet and outlet control devices, should be adequately protected (eg by riprap, concrete aprons, etc).

The sides of ponds that are to be grassed should be sloped to facilitate mowing and maintenance and such slopes should not be steeper than 1:3 (vertical : horizontal). A slope of 1:6 should be adequate to permit mowing by tractor-driven mowers.

Where the growth of aquatic plants is not desirable in retention ponds, the minimum depth of the permanent water to inhibit their growth should be 1,2 m after allowance has been made for siltation¹⁸.

4.2.3 Recreational use of ponds

4.2.3.1 Dry ponds

The geometric shape and depth of the pond may have to be adjusted to allow for the location and correct orientation of sports fields and for space to accommodate spectator seating and circulation.

4.2.3.2 Wet ponds

Activities that may have to be catered for in wet ponds include fishing, power-boating, sailing, wind-surfing, rowing and swimming.

4.2.4 Maintenance of ponds

Storage ponds will require some form of ongoing maintenance to preserve their effective performance. The nature and severity of problems encountered with a storage pond will depend on its type, function and location, as well as on the conditions pertaining at the site. Many potential problems can be avoided by proper design and construction procedures. Some of the problems that are commonly experienced with storage facilities have been listed elsewhere¹⁸.

Weed growth control and the mowing of grass are necessary for aesthetic reasons and for mosquito control requirements. Where aesthetic requirements are not a governing factor, the mowing of grass may, to a large extent, be neglected.

4.3 SUPPLEMENTARY STORAGE FACILITIES

Some of the preceding discussion relating to storage ponds applies equally to supplementary facilities. However, the following additional considerations apply to specific facilities.

4.3.1 Parking areas

Parking areas may be designed to retard the rate of run-off. The area should be shaped to allow access to and from parked vehicles with the least inconvenience to users. The maximum depth of water retained should not

exceed 200 mm for passenger car parks and 300 mm for truck parks. Slopes used in the formation of the surface should be a minimum of 1 % and a maximum of 4 %.

Discharge from ponding areas should be through controlled outlets that enable the area to drain within about 30 minutes of a rainfall event.

Pervious material may be used, where practical, as an alternative to conventional parking area paving, depending on geotechnical aspects and if approved by the controlling authority.

Parking areas may also be used to channel run-off to seepage pits or grassed areas for infiltration.

4.3.2 Areas upstream of road embankments

Where roads cross watercourses, the embankment may be designed as a dam so that it creates a temporary storage facility. Normal flows would pass unimpeded through appropriately sized culverts in the embankment but high flows would be retarded. Where the embankment may be overtopped, the road must act as a spillway. The embankment should be designed by engineers with experience of earth dams. They must make provision for overall bank stability, scour protection and any failure of the embankment.

4.3.3 Sports fields

The deliberate routing of stormwater through sports fields is a new concept that may require considerable attention to detail before it is permitted by the landowner.

4.4 SUBSURFACE DISPOSAL OF RUN-OFF

In pervious soil, the subsurface disposal of run-off often offers a short-term alternative to surface control. This may take the form of dry wells or trenches¹⁸. Other examples are roof run-off discharged directly onto lawns or indirectly via a storage tank¹⁹. Parking areas can use porous asphalt pavements (an opengraded asphalt-concrete mixture with a high proportion of larger aggregate) although maintenance will be required to prevent the pores from clogging with sediment²⁰. Concrete grid pavements can also be used for parking areas, with grid openings filled with lawn or porous material²¹.

Geotechnical investigations should be undertaken to determine properties such as the permeability of the soil and the depth of the water table. The investigation should also identify potential problems such as heave, collapse, sinkhole formation or ground-water pollution.

A disadvantage of this method of run-off disposal is that in time sediment may seal the soil interface and reduce the rate of infiltration.

4.5 OPEN CHANNELS

Open channels may be either natural or artificial. Ideal channels are those that have been created naturally and have reached some degree of stability. Where artificial channels are created, they should correspond to natural drainage patterns.

Open channels may form part of both minor and major systems. They have significant advantages, which include low construction cost, large discharge and storage capacities, reduction in the quantity of run-off as a result of infiltration in grassed ponds and benefits in the recreational, aesthetic and sociological fields. Disadvantages are the space they occupy, the degree of maintenance they require and their possible use for illegal dumping.

When planning channels, careful attention should be given to their stability^{22,23}. The designer should not only consider hydrological data, such as rainfall and run-off, but if possible, should also consider a long-term study of existing watercourses in the area. This should relate to the history of stream stability, high flood levels, bed deposits, dry weather flows and the effects thereon of any part of an urban development.

4.5.1 Channel linings

Channel linings are used to achieve a number of stormwater management objectives. They prevent watercourse erosion, thereby protecting property from damage by run-off and possibly even reducing damage to property by the run-off from rare storms.

Materials used for lining channels include grass, concrete, boulders set in concrete, gunite, riprap, gabions and mats made of various materials.

Lining a channel with a material that is smoother than the existing natural material will result in increased flow velocities and discharge rates. This reduces the problems downstream and may conflict with the objectives of stormwater management. It is therefore not a desirable solution to a stormwater control problem. When there is no other feasible solution, sloping the channel banks will reduce the flow velocity to a certain extent. In spite of the above reservations, it may be desirable to use a smooth lining for the portion of the channel that conveys normal dry-weather flow in an attempt to reduce siltation and to facilitate the clearing away of debris.

Original channel cross-sections may be changed when lining a natural channel. In areas which are accessible to the public, cross-sections with continuous vertical sides in excess of 1 m should be avoided unless precautions are taken to prevent public access to the channel. Where steep-sloping smooth linings are used it may also be desirable to prevent public access. Rough linings have the advantage of causing turbulence which discourages children from entering the channel. Compromise between space and aesthetic requirements may result in a stepped or trapezoidal cross-section.

Although grass may eventually become established over gabion linings and some types of mat, it may be desirable to use grass itself as a channel lining where space permits. A disadvantage of grass linings is that they are particularly vulnerable to erosion during the early stages of the establishment of the grass cover and during long dry spells when the grass dies. The long-term equilibrium of a grassed channel will depend not only on the maximum velocity when flowing full, but also on the long-term average annual peak flow. For stability, the channel should be designed to be self-cleaning at the "mean flood" flow.

The use of suitable indigenous trees to limit erosion by the binding action of their roots should also be considered.

To ensure that the velocity of flow in a channel remains low, it should be shallow and have sides which slope at not more than about 1:4²⁴. A channel that is too narrow is subjected to excessive bed erosion and one that is too wide, to random deposits, which make the bed unstable. The bed can be stabilized to some extent by sloping it from the sides to the centre at a gradient of 1-2 % and lining the lowest part to form a smooth sub-channel to carry dry-weather flow. The sub-channel will protect the bed from scour along the route of the base flow where grass would not grow because of continual inundation. It also prevents the formation of pools that may either be enriched by garden fertiliser, causing rank growth, or polluted by street wash-off. The channel can also be used as a marker to indicate the correct level of the bed should it be covered by deposits which have to be cleared away.

4.5.2 Drop structures

Where the gradient of a channel would be too steep to keep flow velocities within acceptable limits, the level of the bottom of the channel may be stepped by means of one or more drop structures to give a suitable gradient.

A shallow basin or apron should be constructed below the drop structure to dissipate the energy of the falling water. The sides of the structure should be taken up to the top of the channel free-board, should have the same shape as the channel and be well anchored into the sides of the channel. To prevent water from standing in the basin below the drops, the basin should be drained by a sub-channel. In channels lined with durable materials such as concrete or stone, the drop structure should be constructed as part of the channel lining. In channels with less durable linings, the drop structure should be constructed in a durable material such as concrete or stone.

The design of the drop structures should be based on methods given in other documents^{25,26,27}.

4.6 REMOVAL OF FLOW RESTRICTIONS

Existing bridges and culverts may have capacities less than the channel design flow. Although this may be desirable because of reducing flows downstream, the resulting inundation upstream may be unacceptable. Depending on the

severity of the problem and the effect on downstream areas, it may be necessary to remove or upgrade the structure.

Flow restrictions may also result from the accumulation of silt and debris in and around these structures, making inspections and maintenance necessary.

4.7 LEVEES AND FLOOD WALLS

Levees and flood walls act as barriers between the stream and the area to be protected. They confine the flood water to those parts of the flood plain where little damage will be caused in the conveying of the flood water. They are also used to prevent flooding due to waves or tides.

Levees are usually earth embankments and flood walls are usually constructed of concrete and therefore take up less space than levees.

Levees and flood walls have certain disadvantages such as:

- reducing the storage capacity of floodplains and increasing the velocity of flow;
- overtopping by floods greater than the floods for which they are designed, which may even cause failure of the structure;
- difficulties in ensuring a safe and sound structure at sites where there are poor foundation soils and poor materials for the construction of levees;
- accumulation of water on the low land behind the structure which will have to be drained or pumped away, and
- requiring regular maintenance of levees to ensure their safe working condition. Because of the long periods between storms proper maintenance may be neglected and the levees may fall into a state of disrepair.

Generally, it is preferable to build up areas to be protected by filling to the required level of safety rather than to use levees and flood walls²⁸. However, building up by placing material in the flood plain should be discouraged unless unavoidable.

4.8 FLOOD-PROOFING OF BUILDINGS

Flood-proofing of buildings consists of design adjustments to the structure primarily to reduce flood damages. It is applicable mainly to substantial structures such as commercial and industrial buildings.

Commonly used methods are:

- elevation of buildings to above flood levels;
- provision of walls to resist hydraulic pressures;
- waterproofing of walls to prevent seepage;
- installation of pumps to control seepage;
- control valves on sanitary and storm sewers;

- protection of power points;
- sealing of manhole covers;
- measures to reduce uplift on the building by underground water, and
- underpinning of building foundations that are subject to subsidence under flood action.

Other than the elevation of buildings, flood-proofing is often difficult to achieve and maintain and it requires particular attention to the protection of engineering services.

Further information on flood-proofing of buildings may be found in other documents²⁴.

5 ROADS TO CONTROL RUN-OFF

The primary function of a road is to carry traffic. Stormwater is regarded as a nuisance to be disposed of as quickly as possible. Out of this concept arose the reticulation network that forms the minor system.

However, the concept must be extended when considering the effects of severe storms. Roads may become rivers and due regard should be taken of the safety of upstream, adjacent and downstream areas. The layout and geometric design of roads must take cognizance of their function as part of the major system.

During frequent storms the traffic and drainage functions are not usually in conflict; however, beyond a certain frequency, conflict will undoubtedly arise. Stormwater management should attempt to resolve the conflict through compromise, with safety as the overriding objective. Regarding the road as part of the major system is not an attempt to transfer the risk to the traffic but an attempt to control a situation that has always existed.

5.1 THE EFFECTS OF STORMWATER RUN-OFF ON THE TRAFFIC-CARRYING CAPACITY OF ROADS

Stormwater run-off may affect the traffic-carrying capacity of roads in the following ways:

- sheet flow across the road surface;
- channel flow along the road;
- ponding of run-off on road surfaces, and
- flow across traffic lanes.

5.1.1 Sheet flow on roads

Sheet flow generated on a road surface is normally least at the crown (see Figure 2) and increases towards the edge of the road. It can lead to hydroplaning and may interfere with traffic because of the splash that impairs the vision of drivers. Sheet flow usually occurs when stormwater has to flow a long distance to reach a roadside channel and may result from incorrect or inadequate road crown slopes.

5.1.2 Channel flow

The flow of water in roadside channels increases in volume as it proceeds along the channel and encroaches on the road until it reaches an outlet.

The allowable depth and width to which a road should become inundated will depend on the class of road and suggested values are given in Table 3.

5.1.3 Ponding

Ponding on roads occurs at low points, changes of gradient, sump inlets, road intersections and blocked kerb inlets.

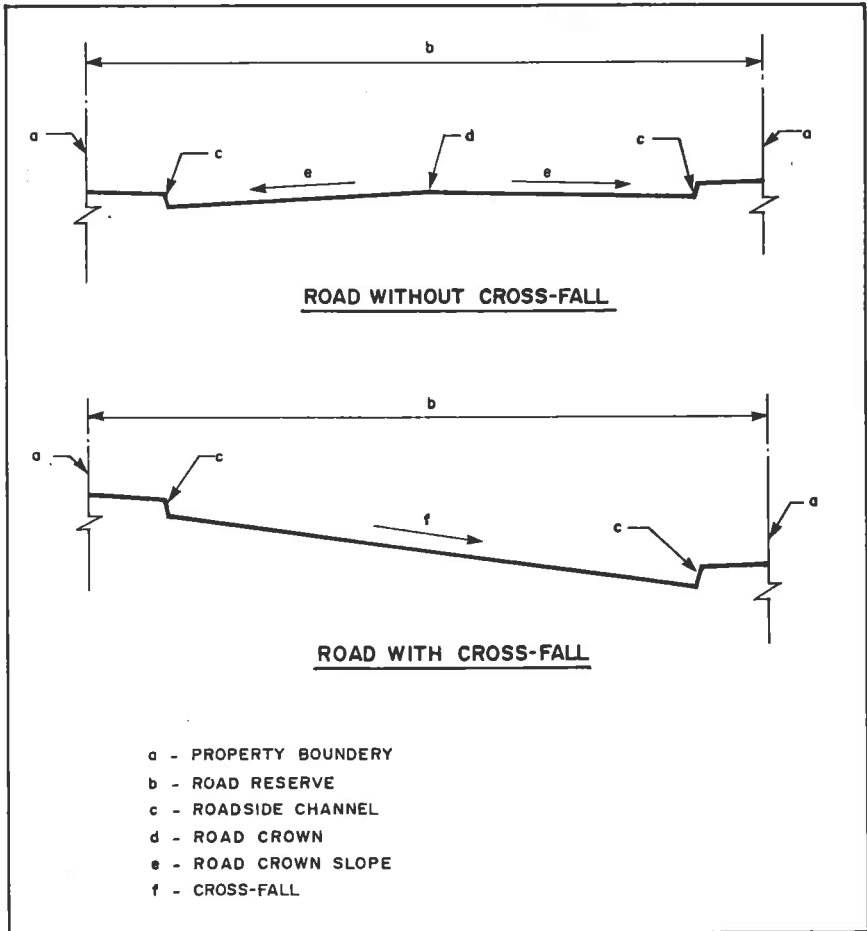


FIGURE 2
Definition sketch for road cross-sections

5.1.4 Flow across traffic lanes

Flow across traffic lanes may result from the super-elevation of the road surface on curves, at intersections or when the capacity of the upper roadside channel on roads with cross-falls is exceeded.

Localized cross-flows, as with ponding, create traffic hazards. In roads where the traffic is of low volume and travels at low speed, cross-flow does not create a serious problem.

It can have a serious effect on traffic flow particularly as it may reach depths greater than the kerb and remain on the roadway for long periods.

A particular hazard of ponding is that it is localized and traffic may accidentally enter a pond at high speed.

At road intersections where cross-flow is concentrated, consideration should be given to a local underground stormwater system or suitable adjustment of the cross-sections of the intersecting roads.

5.2 ROAD LAYOUT

A well-planned road layout can reduce the total stormwater management and drainage-related road maintenance costs significantly and when efficiently integrated with a major system, may obviate or substantially reduce the need for underground drainage conduits.

The greatest stormwater management benefit will be derived from the road layout when consideration is given to stormwater management requirements in the preliminary stages of township layout planning. As the planning progresses there should be co-ordination of the town planning, stormwater management and related disciplines so that the best alternatives can be identified.

Roads have a substantial stormwater storage capacity when aligned at low gradients. Roads should be aligned so that they can safely discharge stormwater directly into watercourses or storage areas such as parks, greenbelts and channels.

Road layouts should be designed to avoid T-junctions on the downgrade where water in the road would flow across the intersections endangering traffic and the downstream properties.

5.3 ENCROACHMENT ON ROADS BY RUN-OFF

5.3.1 Major flood

The encroachment of run-off from the major flood at the crown of the road on Class 4 (local distributors) and higher-order roads should not exceed a depth of 150 mm to allow the operation of emergency vehicles such as ambulances²⁴. The depth of flow in lower-order roads will depend on the level of adjacent properties.

5.3.2 Minor flood

Suggested values of permissible encroachment on roads by the design floods in Table 2 are given in Table 3²⁴.

Where roads (usually of Class 4 and higher orders) pass through areas of different land use, consideration should be given to designing the entire route to the most onerous recurrence interval (from Table 2) of any land use that occurs along it.

TABLE 3*Permissible encroachment of design floods on roads*

Road classification	Maximum encroachment
Residential and lower-order roads (Classes 5b to 5f)	No kerb overtopping* Depth of flow not to exceed 10 mm at crown
Residential access collectors (Class 5a)	No kerb overtopping* Flow spread must leave at least 20 % of total road width free of water
Local distributors (Class 4)	No kerb overtopping* Flow spread must leave at least 40 % of total road width free of water
Higher-order roads	No encroachment is allowed on any traffic lane

*Where no kerbing exists encroachment shall not extend over property boundaries.

5.3.3 Kerb inlet capacities

To remove the water from the road once the maximum design encroachment for the various design floods has been reached, well placed and correctly sized and spaced kerb inlets are required²⁹. The hydraulic performance of kerb inlets, particularly under supercritical flow conditions which occur when the longitudinal road gradient exceeds about 2,5%, requires careful consideration.

5.4 ENCROACHMENT ON PROPERTIES BY RUN-OFF

The level of the major flood on roads should not encroach on adjacent properties by exceeding the level of the back of the road reserve verge. For flat areas and areas lying lower than the road level where encroachment by run-off cannot reasonably be avoided and for paved areas, such as parking areas, special precautions should be taken to protect buildings from flooding. These may include the zoning of such areas to require buildings to have ground floor levels above the design flood level or buildings to be flood-proofed. In some cases, it may also be necessary to control the positions and levels of driveways giving access to properties on the lower sides of the roads.

5.5 ROAD GRADIENTS AND CROWN SLOPES

5.5.1 Major flood

The **maximum** gradient of a road with regard to stormwater drainage is dependent upon the velocity and depth of flow of the major flood that will not damage the road surface and drainage system or be a danger to the public.

5.5.2 Minor storms

5.5.2.1 Roadside channels

The **minimum** gradient of roadside channels, to minimize sedimentation should be not less than 0,4 % (1:250).

The **maximum** gradient of roadside channels should be such that flow velocities do not exceed 3 m/s at the deepest part of the channel. Where this velocity will be exceeded, special measures should be introduced in the design for the dissipation of energy.

5.5.2.2 Road crown slopes

The **minimum** slope from the crown of a road to the side channel should not be less than 3 % (1:33).

The **maximum** slope from the crown of a road to the side channel is not governed by stormwater management requirements.

The minimum gradient and minimum crown slope should never be used together.

5.6 DISHED ROADS

Dished roads are shaped to perform a drainage function. As this function conflicts with traffic-carrying functions, dished roads should be used only in sanitary lanes or where traffic is slow-moving, of low density and the dished part of a road does not exceed 150 m in length.

The following points should be taken into account when considering the use of dished roads:

- the difficulty of locating stormwater inlets that are not a hazard to pedestrians and cyclists;
- the hazard created by splash;
- the nuisance created by continuous flows such as seepage, and
- the failure of the road surfacing that would encourage water penetration into the road structure and thus accelerate the deterioration of the road.

5.7 GRAVEL ROADS

Gravel roads are often a feature of the low-cost residential townships common in a number of urban areas. In general, due to their susceptibility to erosion, gravel roads have little potential for stormwater control. Where road gradients are flat and some form of kerbing is present to contain flow within the road, it may be possible to use gravel roads to route and store run-off from major storms.

The choice of surface level for gravel roads will be influenced both by drainage considerations and by longer-term planning. Gravel roads may be constructed

above the level of the surrounding ground to protect the road surface from stormwater ingress and facilitate road drainage. If, however, it is intended to improve the road surface by paving at a later stage, it may (depending on topography and economics) be desirable to construct the road at or below the level of the surrounding ground.

Use of an underground pipe network for stormwater drainage, common in the case of surfaced roads, is an unsuitable solution for gravel roads. Apart from problems with inspection and high maintenance costs caused by siltation, capital costs may not be appropriate to the standard of other services in the development.

In this environment open channels have the advantage of ease of inspection and of provision of a drain for communal taps and ground water. However, road intersections may give rise to problems with road cross-sections but precedence must be given to the stormwater flow and the road cross-sections designed accordingly. On steep gradients and erodible soils the channel may require a durable invert.

6 QUALITY OF RUN-OFF

The quality of the "first flush" in urban run-off is often comparable to the quality of raw domestic sewage. Compared with unpolluted river water, concentrations of pollutants in run-off may be an order of magnitude higher and because of the greater rainfall run-off yield from urban, compared with rural catchments, the export coefficients of pollutants (kg/ha/annum) are even higher.

Pollution control is therefore an important facet of a stormwater management policy.

The sources of pollutants in urban areas fall into three main categories:

- atmospheric fall-out, both wet and dry, including dust particles, aerosols and gases;
- erosion of catchment materials for example from buildings, pavements and other pervious areas, and
- transported materials from vehicles, spills and littering.

The quality of run-off can vary greatly during a storm. Often, concentrations of pollutants are much higher during the first stages of run-off due to initial wash-off of accumulated material from impervious surfaces. The "first flush" phenomenon can be used advantageously in planning treatment of run-off to minimize environmental impact. Other factors that determine quality are the length of the antecedent dry period that causes pollutant build-up, and rainfall intensity which has the power to dislodge and transport particles from impervious surfaces and also to erode pervious areas. The mean quality of run-off can also vary widely for the above reasons.

When pollutants from urban run-off are discharged into receiving waters, they may affect water quality in different ways. An important immediate effect may be dissolved oxygen depletion which is harmful to aquatic life. Longer-term effects are nutrient enrichment which may lead to eutrophication with problems such as periodic blooms of nuisance algae, de-oxygenation, fish kills and filter clogging at water treatment works. Little is known of the long-term toxicity to organisms from heavy metals, hydrocarbons and pesticides.

Chemically inert pollutants include litter and the products of erosion. Apart from their aesthetic effects on the flood plain they may have an adverse effect on the operation of hydraulic structures.

6.1 METHODS TO REDUCE POLLUTION

The following methods can be considered for pollution reduction:

- (a) Street cleaning can be an effective method of removing litter and sand-sized particles. Overall pollutant removal by street sweepers is, however,

not very efficient with an upper limit of 30% removal being reported for well-run programmes and a more typical removal of 10-30 %³⁰.

- (b) Sub-surface disposal of stormwater into the ground close to the point of rainfall is an effective method of reduction of flows and consequently surface water pollution. (See Section 4.4.)
- (c) Storage ponds can control pollution as well as flooding by causing biological transformations and the settlement of solids^{31,32,33}. (See Section 4.1.)
- (d) Wetlands, marsh areas and reed beds are capable of absorbing pollutants within certain limits. They are also of value in attenuating floods and have the added advantage of producing a unique ecosystem.
- (e) In-system devices such as swirl regulator/concentrators and diversion boxes can be used for solids separation and diversion of "first flush" run-off for further treatment^{34,35}.
- (f) Gross pollutant traps consisting of silt traps and refuse racks can be constructed at strategic positions in the drainage system to remove pollutants³⁶.

7 SAFETY

Consistent with the objective "to prevent loss of life", stormwater management should aim to eliminate flood hazards. It must be recognized, however, that this will not always be possible; the aim then becomes the reduction of risk. This may be achieved by:

- flood warnings;
- flood information and education;
- preventing the public from approaching hazardous situations, and
- making the onset of hazards as gradual as possible.

7.1 FLOOD WARNINGS

Effective flood forecasting and warning of impending flooding enable the community to prepare for a possible flood and so to reduce danger to life and property.

Flood warning is usually only possible in large catchments with long response times but it may not be possible to forecast flood levels.

A flood warning should not be a general warning, as such has little impact on the community. To be effective the warning should not be ambiguous, but should clearly state what is expected to happen at specific places at specific times²⁸. Action groups should be set up to co-ordinate and direct disaster plans for the area.

7.2 FLOOD INFORMATION AND EDUCATION

Information and educational programmes should be planned to inform officials, planners and decision-makers of the technical aspects of stormwater management and to educate the public in general.

Technical information should include hydrological and hydraulic aspects of floods of various magnitudes, flood-prone areas, impacts of land use on run-off and flood-mitigating measures.

Public awareness programmes should be undertaken to make the public aware of flood hazards, the impact on their property and measures they may take to mitigate flooding.

Methods to disseminate information may include news media, films, pamphlets, warning signs and marks showing flood levels on suitable sites such as on bridges.

REFERENCES

This list is referred to by superscript numbers in the text.

- 1 CANADIAN DEPARTMENT OF ENVIRONMENT AND ONTARIO MINISTRY OF ENVIRONMENT. *Manual of practice on urban drainage*. Draft No 3, Urban Drainage Subcommittee, Canadian Environmental Protection Service, Ottawa, 1980.
- 2 DAVIS, D W. *Storm drainage and urban region flood control planning*. Technical Paper No 40, US Army Corps of Engineers, Hydraulic Engineering Centre, California, October 1974.
- 3 SA DEPARTMENT OF WATER AFFAIRS, FORESTRY AND ENVIRONMENTAL CONSERVATION. *Guidelines for development within areas susceptible to flooding*. 1981.
- 4 NEW SOUTH WALES GOVERNMENT. *Floodplain development manual*, Sydney, December 1986.
- 5 HAIMES, Y Y *et al.* *Multi-objective optimization in water resource system*. Amsterdam, Elsevier Scientific Publications, 1975.
- 6 SA DEPARTMENT OF COMMUNITY DEVELOPMENT. *Guidelines for the provision of engineering services in residential townships*. Pretoria, 1983, pp B5-B8.
- 7 SA NATIONAL COMMITTEE ON LARGE DAMS (SANCOLD). *Safety evaluation of scheduled dams: interim guidelines on safety in relation to floods*. September 1986. Report No 1.
- 8 SCHUELER, T R and HELFRICH, M. *Design of extended detention wet pond systems*, Washington DC, Department of Environmental Programs, Metropolitan Washington Council of Governments, 1988.
- 9 DENVER REGIONAL COUNCIL OF GOVERNMENTS. *Urban storm drainage criteria manual*, Vol 1, Sixth printing, Denver, Colorado, September 1978.
- 10 BADENHORST, D B. *Gronddamme*. Symposium on the planning, design and construction of small dams, Pretoria, 1982.
- 11 BLIGHT, G E. *Seepage from clay-lined ponds*. R/BOU 186, National Building Research Institute, Pretoria, CSIR, 1966.
- 12 BRINK, A B A. *Engineering Geology of southern Africa*. 4 vols, Pretoria, Building Publications, 1979.
- 13 GERBER, F A *et al.* 'n *Identifikasietode vir die identifisering van dispersiewe grond*. Technical Report TR.104, SA Department of Water Affairs, Forestry and Environmental Conservation, July 1980.
- 14 JENNINGS, J E *et al.* Application of Geotechnics to the solution of engineering problems – essential preliminary steps to relate the structure to the soil which provides its support. *Proceedings of the Institution of Civil Engineers*, Part I, Vol 64, November 1978, pp 571-589.
- 15 KNIGHT, K *et al.* *Stability of shale slopes in the Natal Coastal Belt*. 5th Southcoast Asian Conference on Soil Engineering, Bangkok, Thailand, 2-4 July 1977.
- 16 SA INSTITUTION OF CIVIL ENGINEERS. Problem soils in South Africa: State-of-the-art symposium. *The Civil Engineer in South Africa*, Vol 27, No 7, July 1985.

- 17 HALL, M J *et al.* *Guide to the design of storage ponds for flood control in partly urbanised catchment areas.* Technical Note 100. Construction Industry Research and Information Association, London, 1980.
- 18 AMERICAN PUBLIC WORKS ASSOCIATION. *Urban Stormwater Management.* Special Report No 49, 1981.
- 19 THEIL, P E. *Introduction of stormwater management for urban drainage systems.* Urban stormwater management seminar, National Building Research Institute, CSIR, 1981.
- 20 FIELD, R *et al.* *Status of porous pavement research.* Water Research Vol 16, 1982.
- 21 DAY, G E *et al.* *Run-off and pollution abatement characteristics of concrete grid pavements.* Bulletin 135, Virginia Water Resources Research Centre, 1981.
- 22 KOVACS, Z P. *Scour and protection measures at drainage works.* Pretoria, Van Niekerk, Kleyn and Edwards, 1974.
- 23 VAN HEERDEN, W M. M³/S in kanale en pype. *Agricultural Engineering in South Africa.* Vol 4, No 1, 1970.
- 24 WRIGHT-McLAUGHLIN ENGINEERS. *Urban Storm Drain Criteria Manual.* 2 Vols, Denver Regional Council of Governments, Colorado, 1969.
- 25 CHOW, V T (Ed), *Open-channel Hydraulics.* New York, McGraw-Hill, 1959.
- 26 HENDERSON, F M. *Open Channel Flow.* New York, Macmillan, 1966, pp 191-202; 422.
- 27 SEARCY, J K. *Reported design of roadside drainage channels.* Hydraulic Design Series No 4, (Reprint) US Department of Transportation, Federal Highway Administration, Washington, December 1973.
- 28 VICTORIA WATER RESOURCES COUNCIL. *Flood plain management in Victoria.*
- 29 NATIONAL TRANSPORT COMMISSION. *Manual on road drainage,* Second edition, Pretoria, 1983.
- 30 SARTOR, J D *et al.* Street sweeping as a water pollution control measure; Lessons learned over the past ten years. *The Science of the Total Environment,* Vol 33, 1984, pp 171-183.
- 31 COLSTON, N V. *Characterization and treatment of urban land run-off.* PB 240987, US National Technical Information Service, Washington, 1974.
- 32 SIMPSON, D E. Unpublished data. CSIR, 1985.
- 33 WHIPPLE (Jr) *et al.* Settleability of urban run-off pollution. *WPCF Journal,* Vol 53, No 12, 1981.
- 34 FIELD, R. *Urban Run-off: Pollution Sources, Control and Treatment.* Water Resources Bulletin, Vol 21, No 2, 1985.
- 35 NEWMAN, D F *et al.* *The diversion box: A proven technology for pollution abatement.* Public Works, October 1982, pp 54-55.
- 36 PHILIPS, B C and GOYEN, A C. *Guidelines for improving urban stormwater quality using water quality control structures,* Seminar on urban runoff water quality, Sydney, July 1987.
- 37 KOVACS, Z P. *Maximum flood peak discharges in South Africa – an empirical approach.* Technical Report TR.105, SA Department of Water Affairs, Forestry and Environmental Conservation, October 1980.

BIBLIOGRAPHY

The selected bibliography which follows is additional to the references used in the text and provides further reading in this field.

- 1 ALEXANDER, W J R. *Depth-area-duration-frequency properties of storm precipitation in South Africa*. Technical Report TR.103, Revised edition, S A Department of Water Affairs, Forestry and Environmental Conservation, May 1980.
- 2 ALEXANDER, W J R. *Flood frequency estimation methods*. Technical Report TR.109, Revised edition, S A Department of Water Affairs, Forestry and Environmental Conservation, May 1980.
- 3 CARTER, C A *et al*. *Stormwater Master Planning*. Municipal Engineer Vol 16, No 1, January/February 1985, pp 30-32.
- 4 CHAPMAN, G A. *Toxic materials in the aquatic environment*. PB 297837, U S National Technical Information Service, Washington, 1978.
- 5 CHOW, V T (Ed). *Handbook of Applied Hydrology*. New York, McGraw-Hill, 1964.
- 6 FIELD, R *et al*. *Urban Run-off Pollution Control Technology Overview*. PB 264452, U S National Technical Information Service, Washington.
- 7 GREEN, I R A. *WITWAT Stormwater Drainage Program - Version 2*. Report No 2/1984, Water Systems Research Program, University of the Witwatersrand. May 1984.
- 8 HICKOK, E A. *Urban run-off treatment methods, Vol 1 - Non-structural wetland treatment*. PB 278172, U S National Technical Information Service, Washington, 1977.
- 9 MEIN, R G. *Urban Hydrology 5266*. Monash University Report of Civil Engineering – unpublished notes, Melbourne, 1983.
- 10 MIDGLEY, D C *et al*. *Design flood determination in South Africa*. Report No 1/72, Amended edition, Hydrological Research Unit, University of the Witwatersrand, 1979.
- 11 MILES, L C. Stormwater drainage in urban areas. *Municipal Engineer*, Vol 10, No 2, March/April 1979, pp 27-35.
- 12 MILES, L C. *Stormwater management*. R/BOU 831, National Building Research Institute, Pretoria, CSIR, 1980.
- 13 PITT, R *et al*. *San Francisco Bay area national urban run-off project*. PB 83-163093, U S National Technical Information Service, Washington, 1981.
- 14 ROBEY, D L. *Effects of urbanisation on annual peak flow frequency analysis*. Urban Hydrology Seminar, Davis, California.

- 15 ROOSEBOOM, A *et al.* *NTC Road Drainage Manual*. National Transport Commission, Pretoria, 1981.
- 16 S A INSTITUTION OF CIVIL ENGINEERS. *Legal implications of urban stormwater drainage symposium*. Johannesburg, 29 August 1984.
- 17 SCHEAFFER, J R *et al.* *Urban Storm Drainage Management*. New York, Marcel Dekker Inc, 1982.
- 18 STEPHENSON, D. *Stormwater Hydrology and Drainage*. Amsterdam, Elsevier Scientific Publishing Company, 1981.
- 19 SIMPSON, D E *et al.* *Quality and quantity of stormwater run-off from a commercial land use catchment in Natal, South Africa*. *Water Science and Technology*, Vol 14, 1982, pp 323-338.
- 20 WATSON, M D. *Application of ILLUDAS to stormwater drainage design in South Africa*. Report No 1/81, Hydrological Research Unit, University of the Witwatersrand, 1981.
- 21 WATSON, M D *et al.* Current stormwater drainage practice in South Africa. *The Civil Engineer in South Africa*, Vol 24, No 6, June 1982.
- 22 WIGINTON, P J *et al.* Accumulation of selected trace metals in soils of urban run-off retention basins. *Water Resources Bulletin*, Vol 19, 1983, pp 709-718.
- 23 WHITING, E R *et al.* *Invertebrates and urban run-off in a small northern stream, Edmonton, Alberta, Canada*. *Hydrological*, Vol 102, 1983, pp 73-80.

GLOSSARY

(Reference should be made to Figures 1 and 2 as definition sketches for flood plains and roads respectively.)

DESIGN STORM – a hypothetical storm of a specified recurrence interval for which the amount of run-off is computed for the sizing of stormwater drainage facilities.

DRAINAGE AREA – that part of a catchment above a specified point that contributes to the run-off at that point.

DRAINAGE SYSTEM – See stormwater drainage system.

DRY POND – a retarding pond that remains dry during dry-weather flow conditions.

DRY-WEATHER FLOW – the flow in a watercourse, primarily made up of ground water that seeps from the ground, but it may result also from melting snow or regulated release of water.

EXTENDED DETENTION WETLAND SYSTEM – consists of three complementary storage components: (i) a permanent wet pond, (ii) an extended detention storage volume and (iii) a stormwater management storage volume.

GROUND-WATER RUN-OFF – that part of the infiltrating water that percolates downward until it becomes ground water. Eventually after an indirect passage, it enters a stream that intersects its path and becomes dry-weather flow or base flow.

MAJOR DRAINAGE SYSTEM OR MAJOR SYSTEM – a stormwater drainage system to contain the major flood.

MAJOR FLOOD – the design flood used to determine the major system.

MINOR DRAINAGE SYSTEM OR MINOR SYSTEM – a stormwater drainage system to contain the minor flood.

MINOR FLOOD – the design flood used to determine the minor system.

OFF-STREAM POND – a retarding pond, sometimes known as a balancing pond. This is usually a depressed area located alongside the main channel and into which water flows during peak flood periods. The stored water returns to the main channel as the floodwater subsides.

ON-SITE POND – a retarding pond located on the same land development where the run-off is generated.

ON-STREAM POND – a retarding pond located on a watercourse and through which normal dry-weather flow passes.

OUTFALL – See stormwater outfall.

REGIONAL MAXIMUM FLOOD – the flood calculated by means of the Francou-Rodier formula³⁷.

RETARDING POND – a pond in which run-off is retarded for controlled release during or immediately after a storm.

RETENTION POND – a pond in which run-off is retained for future use, such as the recharging of ground water.

RUN-OFF – that part of the precipitation that falls on a drainage area and is discharged from the area. It appears in several forms depending upon the source of its flow, which may be surface, subsurface or ground-water flow.

STORMWATER DRAINAGE SYSTEM – all the facilities used for the collection, conveyance, storage, treatment, use and disposal of run-off from a drainage area to a specified point.

STORMWATER OUTFALL – the point at which run-off discharges from a conduit.

SUB-SURFACE RUN-OFF – the flow derived from water infiltrating into the soil and flowing laterally in the upper soil strata. It reaches the receiving streams or bodies of water fairly soon after a rainfall event without joining the main body of ground water.

SURFACE RUN-OFF – that part of the run-off that travels over the ground surface and in channels to reach the receiving streams or bodies of water.

WATERCOURSE – any land upon which storm run-off or flood water may concentrate and flow either regularly or infrequently. Watercourses may be created naturally or may be man-made, the flow may be either on the land surface or underground.

WET POND – a retarding pond which, apart from evaporation and infiltration, retains a fixed amount of water even under dry weather conditions. The storage capacity of such a pond is the additional volume of water that can be contained above the permanent water level.