Chapter 6

Stormwater management

6

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INTRODUCTION

The impact of development on the natural environment

Development is a process of growth and change, which implies improvement. Any development will therefore affect or impact on its environment in some way or other. We consider the building of roads, the erection of buildings and the general improvement of factors that cause inconvenience - like the drainage of stormwater - as development. However, this development may significantly change the hydraulic properties of an area. Typically, pervious layers are rendered less permeable or even impermeable. Depressions are raised to prevent ponding. Surfaces and conduits are constructed to drain runoff more efficiently. Natural vegetation is often removed, allowing reduced interception and transpiration. Limited vegetation cover exposes the soil to the impact of rain, which may lead to increased erosion. Natural meandering watercourses may be canalised to more effectively route flows through the development. Stormwater management is the science of limiting these negative impacts on the environment and enhancing the positive impacts, or catering for the hydraulic needs of a development while minimising the associated negative environmental impacts.

Drainage laws

Increasing development densities have influenced the servitude required to safely discharge runoff into the natural environment. This densification and modification of undeveloped land has also resulted in increased quantities and concentrations of flow with a concomitant increase in pollution.

Upstream landowners' responsibilities for discharging runoff onto downstream properties, and the concomitant responsibilities of downstream owners have a long history which is based largely on common law. This has been modified somewhat by legislation giving certain rights to central, regional and local authorities.

Three rules are generally applicable throughout the world today as far as the drainage of surface runoff is concerned. These concern:

- the "common enemy" concept;
- natural flow; and
- reasonable use.

Stormwater runoff is considered a *common enemy* and each property owner may fight it off or control it by retention, diversion, repulsion or altered transmission. The focus of the common enemy rule has two focal points:

- The need to make improvements to property, with the acknowledgement that some damage results from even minor improvements; and
- The principle of granting each landowner as much freedom as possible to deal with his land essentially as he sees fit.

The *natural flow (or civil law)* rule places a natural easement upon the lower land for the drainage of surface water along its natural course, and the natural flow of the water may not be obstructed by the owner of the lower property to the detriment of the interests of the owner of the higher property.

This rule has been modified to some extent in allowing, for example, surface runoff to be accelerated or otherwise altered into the natural stream. The landowner may, however, neither overtax the capacity of the watercourse nor divert into it runoff that would not naturally have drained into the watercourse (see *Barklie v Bridle* 1956 (2) SA 103 (S.R.)).

In efforts to promote drainage, many of these modifications to the natural-flow rule increase the burden on the lower land.

The *reasonable-use rule* provides that each property owner is permitted to make reasonable use of his land, even though by doing so he may alter the flow of the surface waters and cause harm to others. He incurs liability when his interference is unreasonably harmful (see *Redelinghuis v Bazzoni* 1975 AD 110(T)).

One can see that, in developing property, it is extremely difficult not to concentrate, increase or accelerate stormwater runoff onto downstream properties. Through the provincial ordinances, the authorities have been invested with the right to change the natural drainage of stormwater in the interests of the public as a whole. However with this right comes the responsibility to act with due care in keeping the effects of such deviations within acceptable limits. The general rule that "statutory authority when constructing a work is excused from liability for damage thereby caused to third persons" is subject to the proviso that the work must not be negligently executed or maintained (see *New Heriot Gold Mining v Union Government (Minister of Railways and Harbours*) 1916 AD 415, 421; *Johannesburg Municipality v Jolly* 1915 TPD 432; *Herbert Holbrow (Pty) Ltd v Cape Divisional Council* 1988 (1) SA 387(c)).

To ameliorate this development phenomenon, certain strategies and technologies are available. The goals of stormwater management should support the philosophy of lessening the impact of stormwater flow through and off developed areas. Stormwater should be considered a resource (see Figure 6.1).

Figure 6.1: San Antonio's famous main riverwalk loop. This tourist attraction can be isolated by its sophisticated flood attenuation and flood prevention facilities during major storm events. The project will enable a 100-year flood to be accommodated through the San Antonio River system

It is within the power of the local authority to construct works such as streets and drains which will have an effect on the flow (quantity, quality and velocity) of stormwater discharged on the downstream land.

Public bodies have been entrusted with statutory powers to enable them to carry out public duties. If it is impossible for them to carry out their duties without infringing upon the rights of others, it may be inferred that the legislators intended them to have the power to do so, in spite of the prejudicial effect on individuals. If, however, damage that could reasonably have been prevented is caused to individuals, the failure to take reasonably practicable preventive measures is negligence.

Case law offers opinions and provides principles on which to base the extent of liability of a local authority for damage caused by an increase in stormwater flow. In some cases the issue may be whether interference with private rights is justified where the exercise of statutory powers is alleged to have resulted in an injury to another.

Prohibition against pollution is addressed in Clause 19 of the National Water Act, Act 36 of 1998. This section deals with pollution prevention, and in particular the situation where pollution of a water resource occurs or might occur as a result of activities on land. The person who owns, controls, occupies or uses the land in question is responsible for taking measures to prevent pollution of water resources.

The dual drainage system

Developed areas are defined as any man-induced developments which have changed the environment. In this chapter, all developments in the continuum from rural to urban settings will be addressed.

Traditionally, runoff from frequent (minor) storms has been carried in the urban formal drainage systems. Typically this was achieved by draining runoff from properties into the streets and then via conduits to the natural watercourses. The system was intended to accommodate frequent storms and associated runoff. Today, the value of property is of such significance that engineers need to consider not only frequent storms but the more severe storms, which can cause major damage with sometimes catastrophic consequences (see Figure 6.2). The dual system incorporates a *minor system* for the frequent storm events and a *major system* for the less frequent but severe storm events. The major system may include conduits and natural or artificial channels, but would commonly also make use of the road system to convey runoff overland to suitable points of discharge. This is not very different from what has happened *de facto* except that formal cognisance is now given to the routing of runoff from all storms via the secondary use of roads and other facilities in the urban environment.

The use of the road system and open spaces (such as

Figure 6.2: Damage from major floods can be catastrophic

parks and sports fields) as drainage components of the major system, while imposing inconvenience to road users, is considered an acceptable land-use for these severe storm events.

Development changes the environment

High regard needs to be given to natural drainage patterns and systems. This is because development interferes with these systems. Stormwater management must therefore consider how development has interfered or will interfere with the natural systems. The design engineer, with the planning team, must then plan on how to cope with these changes, to lessen the impact of the altered runoff caused by this development.

It is recognised that development impacts negatively on the natural drainage systems in several ways:

- Permeability of the development area is decreased through increased population densities and fewer open spaces such as parks and gardens, or by the introduction of impervious areas such as surfaced streets, houses and amenities associated with the urban environment. This increases the runoff from the area during storm events, because of the reduced infiltration properties of the development area.

- The introduction of efficient stormwater drainage systems to deal with the *common enemy* implies that the runoff must be conveyed as efficiently as possible to the natural watercourses. The operative word *efficient* is here related to *cost-efficiency*. This has the effect of decreasing the time runoff takes to reach the natural watercourses. The result is a reduction of overland flow, meandering watercourses and the like, through a system which drains runoff to the watercourses as quickly as possible. The flood problem is therefore transferred downstream. Quicker responses in larger catchments make them more susceptible to the effects of high-intensity, shorter duration storm events.

- In more efficient drainage systems, peak flows occur more quickly. This effect has made developments more susceptible to shorter, more intense storm events which in the smaller catchments may lead to greater peak flows.

- The drainage systems are exposed to flows from more frequent, higher intensity storms because of the decreased times of concentration. It is recognised that short-duration storms have higher rain intensities than the longer rainfall events. This increases the pressure put by the frequent, high-intensity storms on the man-made drainage systems, which in turn put more pressure on the natural drainage systems.

- The quality of the runoff deteriorates. One only has to consider runoff from man-made environments which conveys pollutants such as fertilisers, discarded rubbish, spillages and discharges from vehicles, septic tank effluent as well as eroded soil.

The requirement for integrated planning

Against this background, the responsibility for sound planning to lessen these negative impacts rests with the whole design team, and not just with the drainage engineer. A holistic approach to planning needs to be taken, whereby land use is identified and a common commitment to its optimisation forms the background to the planning premises.

Where development projects are carried out with limited funds, the question of “minimum allowable standards” always comes to the fore. It is in these cases, especially, that the development equation becomes a question of balancing low capital cost at development stage against high maintenance costs for the rest of the time.

THE PURPOSE OF STORMWATER MANAGEMENT

Stormwater management is based on

- the need to protect the health, welfare and safety of the public, and to protect property from flood hazards by safely routing and discharging stormwater from developments;

- the quest to improve the quality of life of affected communities;

- the opportunity to conserve water and make it available to the public for beneficial uses;

- the responsibility to preserve the natural environment;

- the need to strive for a sustainable environment while pursuing economic development; and

- the desire to provide the optimum methods of controlling runoff in such a way that the main beneficiaries pay in accordance with their potential benefits.

While these goals may be reflected in other disciplines - and indeed may even be in apparent conflict with one another - specific objectives supporting these overall goals need to be identified for each specific project by the planning team.

PLANNING

Introduction

Planning is a fundamental function of the project team. It determines what the team wants to attain and how it should go about doing so. Some strategic issues need to be considered before any detailed design work can be entertained. This is strategic planning or "master planning".

Master planning

The whole purpose of planning is to facilitate the accomplishment of a project's objectives. Which objectives or goals drive the process really depends on the state of mind of those formulating them, but generally should spell out the why, where, what, when and how of the endeavour. Land use planning should be a consideration of what land resources are available and what they are suitable for, both in the short term and longer term.

Master planning should be concerned with the following principles:

Sustainable development

A key concept of master planning should aim at an enduring or sustainable development.

An initiative called *Caring for the earth, a strategy for sustainable living*, launched in partnership with the World Conservation Union, the United Nations Environment Programme and the World Wide Fund for Nature, stressed two fundamental requirements for sustainable agriculture, namely:

- securing a widespread and deeply held commitment to an ethic for sustainable living; and
- integrating conservation and development.

The World Health Organisation's *Global Strategy for Health and Environment* was a direct result of the United Nation's *Agenda 21* which was drawn up during the Earth Summit in June 1992 at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil. *Agenda 21* was an action plan to guide national and international activities to ensure that the natural resources of the world are managed in such a manner that sustainable development is achieved. The term "sustainable development" can be defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The idea that should guide all planning is that there is an interrelationship between the three concepts of health, the environment and development. Any change taking place in the one has a direct influence on the other two.

An essential element of rational land-use planning is land evaluation, which should be a systematic way of looking at the options available and of considering the environment in which these options are likely to operate, so that the results of different courses of action can be predicted. Physical planning therefore cannot be divorced from social and economic circumstances or from administrative and constitutional processes. More importantly, the protection of the environment against pollution decay is essential, to optimise the benefits of sustainable development.

Integration with other disciplines in the planning team

Development produces waste products. When people choose to live closer both to one another and to economic opportunities, there is inevitably an increase in the generation of waste products. The increased volume of wastes needs to be managed to lessen the impact on the environment. Solid waste technologies, the siting of cemeteries, water purification works, sewage works and industries are typical issues facing the planning team in the initial stage. All concern the stormwater specialist.

Layout planning and transport routes inevitably affect the natural drainage of stormwater. These constraints must be explored. Natural habitats will be affected and their importance must not be ignored.

Drainage of both sewage and stormwater is a natural constraint to development that may have to take priority over other services and amenities.

Policy impact assessment

All planning must start with certain premises. Many of these are dictated by outside influences and their impact on the planning at hand must be recognised and considered.

Policy guidelines from external sources may influence the objectives of any development. A policy impact assessment may be required to evaluate the importance of these policies and how they can affect or impact on the planned development. External influences may include policies from

- the World Health Organisation;
- the United Nations (UNCED);

- the South African Constitution;
- the Government's Reconstruction and Development Programme;
- white papers involving water law, water supply and sanitation - Department of Water Affairs & Forestry (DWAF); and
- integrated environmental management procedures - Department of Environmental Affairs & Tourism (DEAT).

While these issues may not all be obligatory, they do serve as a platform or frame of reference from a global and national perspective. They may influence the planning premises.

Strategic impact assessment

Certain constraints to planning and development have to be considered. These are mainly connected with the legal environment. A strategic impact assessment must involve consideration of the aims of the following legislation:

- National Water Act Water Act (Act 36 of 1998):
  To provide for the fundamental reform of the law relating to water resources and to provide for matters connected therewith.

  The legal responsibilities of the stormwater specialist influence the planning. The insertion of 20-year and 50-year flood lines on certain township plans is an example. What development takes place within these flood lines must be explored. The protection of sewage treatment works, cemeteries and solid waste sites from flooding must be considered.

- Conservation of Agricultural Resources Act (Act 43 of 1983):
  To provide for the control over the utilisation of the natural agricultural resources in the Republic in order to promote the conservation of the soil, the water resources and the vegetation and the combating of weeds and invader plants.

  Government Notice No. R1048 of Government Gazette No. 9238 of this Act indicated that:
  No land user shall ... cultivate any land on his farm unit within the flood area of a water course or within 10 metres horizontally outside the flood area of a water course.

  The "flood area" in relation to a water course is defined as *the area which, in the opinion of the executive officer, is flooded by the flood water of that water course during a 1-in-10 year flood.*

- Environment Conservation Act (Act 73 of 1989):
  To provide for effective protection and controlled utilisation of the environment.

- National Roads Act (Act 54 of 1971):
  To provide for the construction and control of national roads, including the disposal of stormwater on a national road.

- Minerals Act (Act 50 of 1991) and its Regulations:
  Specific issues relating to the Environmental Management Programme (EMP) are relevant.

- Minimum requirements for disposal of waste:
  Minimum requirements issued by the Department of Water Affairs & Forestry regarding the selection of sites, their development and management and eventual closure. Three specific references are:

  - *Minimum requirements for the disposal of waste by landfill.*
  - *Minimum requirements for the handling and disposal of hazardous waste.*
  - *Minimum requirements for monitoring at waste management facilities.*

- Health Act (Act 63 of 1977):
  To provide for measures for the promotion of health of the inhabitants of the Republic.

- Atmospheric Pollution Prevention Act (Act 45 of 1965):
  To provide for the prevention of pollution of the atmosphere.

  Specific measures are required for the purification of effluents discharged from appliances for preventing or reducing to a minimum the escape of any noxious or offensive gases escaping into the atmosphere, and for preventing the release of noxious or offensive constituents from such effluents into drains and drainage canals.

- Common law, case law and statutory law:
  Certain laws of parliament, provincial ordinances and government notices can alter existing rules and lay down the law, as it were. These statutory laws create legal duties upon specific persons or bodies and thus determine who is to be sued in delict when damage is caused (Committee of State Road Authorities 1994). Any person or body performing tasks in pursuance of statutory authority bestowed upon him or her to construct works such as streets and drains should heed the principles of the delict, to avoid legal liability for damage suffered by another party.

The basic starting point in South African law as regards the question of damage is the rule that harm rests where it falls, i.e. everyone must bear the damage he suffers, himself (Neethling et al 1990). However, there are grounds which can cause this burden of damage to shift to another, with the result that such other is obliged to bear the former's damage. This shifting (which forms the basis of the law known as law of obligations) of the burden can result from the causing of damage to a person by means of a delict (law of delict). Delict can be defined as the positive act or omission of a person, which in a wrongful and culpable (intentional or negligent) way causes harm to another. The main source of law upon which the South African law of delict has developed is case law.

Other requirements may include:

- Interim guidelines on safety in relation to floods. Safety evaluation of dams. South African Committee on Large Dams, September 1986. The new requirements are contained in Government Gazette Regulation Gazette No 3979, Vol 253, No 10366. Government Notice No R.1559.

- A guideline for groundwater protection for the community water supply and sanitation programme, 1995.

- South African Natural Heritage Programme.

- Conservation of wetlands (Department of Environmental Affairs & Tourism) and reports to the Ramsar Convention.

Stormwater management master drainage plan (MDP):

Master drainage planning should be contemplated on a catchment-wide basis, irrespective of urban and other man-made boundaries. The full environmental impact of the stormwater on that catchment must be investigated and is the responsibility of the controlling regional or local authority. The hydrological processes in the specific area need to be investigated and statistical data obtained. Hydraulic routing of the stormwater must be considered. In analysing stormwater drainage, consideration may need to be given to the use of open spaces like parks, sports fields, and transport circulation routes.

It is assumed that with development there is an increase in both the overall quantity and the peak flow rate of the runoff. Policies in the USA, for example, desire to restrict post-development peak factors to pre-development peak factors. This involves the retarding of stormwater on its route to the drainage streams. The important issue that the drainage specialist must address is the consideration of every storm event - from a severe, infrequent storm event (termed a major event) to the frequent, common storm events (termed minor events). Stormwater drainage technologies must be developed to deal with all these events. A typical formal drainage system avoids the nuisance which might result from frequent storms. This is termed the minor system. The major system will be supported by the minor system but will accommodate the unusually high runoff from infrequent hydrologic events.

Master planning is predominantly concerned with the major system. The minor system will be considered as a supporting one. Master planning may involve

- determination of the recurrence interval of the major flood event;

- determination of the recurrence interval for the minor flood events;

- provision of overall guidelines on runoff-detention requirements, pollution-abatement strategies, and the powers and responsibilities of developers and authorities within the catchment area;

- consideration of land use within flood plains and multi-use of stormwater facilities;

- guidelines on safety and maintenance;

- guidelines on environmental conservation; and

- reference to integrated environmental management (IEM) procedures and principles underpinning the Reconstruction and Development Programme.

While the values in Tables 6.1 and 6.2 are guidelines, the onus is on the drainage engineer to determine the risk associated with a certain recurrence interval. For areas where the risk of monetary loss, loss of revenue or loss of utilities is unacceptably high, a more stringent (or higher) recurrence interval and a higher level of service may need to be considered. On large structures such as bridges and major culverts for example, the Department of Transport has its specific analysis requirements (Committee of State Road Authorities 1994).

A 100-year recurrence interval flood line is required in terms of the National Water Act on residential development plans. Municipal authorities may, however, stipulate other flood lines. The concepts

Table 6.1: Design flood frequencies for major systems	
LAND USE	DESIGN FLOOD RECURRENCE INTERVAL
Residential	50 years
Institutional (e.g. schools)	50 years
General commercial and industrial	50 years
High value central business districts	50 - 100 years

Table 6.2: Design flood frequencies for minor systems	
LAND USE	DESIGN FLOOD RECURRENCE INTERVAL
Residential	1 - 5 years
Institutional (e.g. schools)	2 - 5 years
General commercial and industrial	5 years
High value central business districts	5 - 10 years

of best management practices (BMPs), good practice, or best available technology not entailing excessive cost (BATNEEC) may convince the planning team that more stringent recurrence intervals need to be considered, including planning for regional maximum floods (RMFs) or probable maximum floods (PMFs).

Detailed design

Stormwater drainage plan

Detailed planning refers to the planning of developments within a catchment. The design philosophies and critical concerns and issues will have been addressed in the master drainage plan. Stormwater drainage planning is the implementation of those policies and guidelines. It should strive to commit responsibilities to the design team and the authorities. Generic responsibilities include

- planning, feasibility studies and preliminary design;
- records of decisions and the development of an auditing system;
- detailed design;
- implementation or construction;
- the process of handing a scheme over to a responsible authority;
- operation and maintenance; and
- monitoring and reporting (elements of the auditing system).

Typically the controlling authority should be responsible for ensuring that detailed planning is compatible with the master drainage plan and that the objectives of stormwater management are attained. The design team needs to consider responsibilities throughout the design life of the project or development - the cradle-to-grave approach.

Responsibilities for runoff control

Stormwater management within an urban area is the responsibility of the local authority for that area, since the control of stormwater is considered a purely local matter.

Certain central and provincial government legislation, however, has encroached on the local authority's planning. Examples are

- the requirement to insert the 1-in-100 year flood lines on all township development plans (National Water Act 36 of 1998);
- prevention of water pollution (consumers) regulated by the departments of Water Affairs & Forestry, Environmental Affairs & Tourism, and Health;
- safety of dams (approved Professional Engineer);
- alteration of a public stream (Transvaal Road Ordinance 22 of 1957; Agricultural Holdings (Transvaal) Registration Act No 22 of 1919; Orange Free State Roads Ordinance 4 of 1968);
- auditing systems and records of decision (IEM); and

- Mines and Works Act.

Detaining and retaining stormwater

Runoff can be stored in constructed dams. However, to be effective, such dams usually demand much space. Successful detention of runoff may therefore have to rely on several technologies involving

- detention ponds (detention facilities) or roof-top detention;
- a preference for overland flow as opposed to hydraulically efficient engineering conduits;
- maintaining pervious surfaces and reducing impervious structures; and
- maintaining vegetation cover to increase interception and evapotranspiration.

MANAGING THE IMPACT OF DEVELOPMENT ON THE ENVIRONMENT

Rural development

The issues and concerns in rural environments may differ from those in the urban setting. Typical issues may include erosion, and soil salinisation. Transport routes may have gravel surfaces, and technologies used to drain runoff need to be carefully considered.

Layout planning

Many of the grid-type layouts inevitably concentrate stormwater in certain roadways. This is usually the case when planners design systems applicable to modern technological standards when they know that upgrading to these standards may take place only in the very distant future, if at all.

What is proposed is a move towards what agricultural engineers and conservationists have always practised - contour planning (e.g. contour ploughing, which is ploughing that follows the contours of land, perpendicular to its slope). This technology is particularly applicable to the more rural type of development (see the section on unsurfaced roads below for more detail).

An example of a tea estate demonstrates this type of layout well (see Figure 6.3). All access paths (which could be substituted by access roads in an urban environment) follow the contours. Other tracks are routed at right angles to the contours so that no extraneous runoff crosses or drains onto them. All stormwater can then be routed along the access paths to the natural channels or waterways.

Figure 6.3: Contour planning: An effective stormwater management tool

The advantage of contour technology is that all flow is routed overland in open channels. This minimises both the flow volumes (drainage occurs regularly) and velocities (open channel flow with flat gradients). This reduces erosion. Soakaways, permeable strata, vegetation interception, retention/detention facilities are some of the many tools at the drainage engineer's disposal. Overland flow in ditches or swales should be designed at the outset with the road layout planners, not afterwards. Where road crossings are required, causeways and drifts are easily constructed. This allows for the use of local labour and materials. Drop structures may also be included with silt traps, allowing maintenance workers to reclaim soil lost from the upstream area.

Preserving the natural environment

Natural resources

Before any layout planning should begin, detailed information regarding topography, geology, hydrology, and fauna and flora, needs to be obtained. Areas containing building materials (sands, aggregates, road materials, clays and the like) should not be sterilised by other land uses without consideration being given to their potential utilisation. Sandy areas are useful for recharging ground water. High-intensity development can be matched with soils of low permeability and vegetation of poor quality.

Alternative fuel sources may need to be developed. Otherwise uncontrolled denudation of the natural landscape may seriously damage the environment, leading to rapid degradation and soil erosion.

All life forms depend on water and, indirectly, on the soil. These two elements must therefore receive priority in any development planning.

All consequences of man's use of natural resources have to be analysed. In many informal settlements, for example, residents grow crops and keep animals, both for subsistence and informal selling. These agricultural practices must be recognised as part of the urban fabric. However, if agricultural practices are to be accepted, potential problems need to be addressed.

Assessing past failures

Poor farming practices have impacted negatively on the environment (Department of Agriculture 1995). Some of the consequences have been the following:

- Decreasing biodiversity. Natural habitats have been destroyed, leading to a decrease in the abundance and diversity of fauna and flora.

- Overgrazing. Overstocking and limited grazing rotation have resulted in denuded land and a threat of desertification. Selective grazing by animals on certain preferred plant species often leads to encroachment by unpalatable and undesirable plant species. Overgrazing is a particularly endemic problem (see Figure 6.4).

Figure 6.4: Overgrazing exposes the land to rain damage and can result in extensive erosion

- Pollution by fertilisers, pesticides, herbicides and fungicides. Cattle dips and feedlots are potential sources of pollution. Their proper design and management cannot be overemphasised (see Figure 6.5).

Figure 6.5: Runoff from feedlots contains high levels of pollutants

  Inorganic fertilisers are often environmentally costly. They can leach out of the soil and contaminate groundwater and streams. Other consequences of injudicious use of fertilisers can reflect in the build-up of toxicity, acidification and salinisation.

  Pesticides often kill non-targeted and usually beneficial organisms in the immediate application area. Non-biodegradable pesticides can accumulate in the soil and water, with hazardous consequences to animal and human life.

- Soil crusting. Incorrect tillage changes the structure of the soil compaction, resulting in poorer water infiltration: runoff increases and there is a greater risk of erosion.

- Dump sites also need protection (see Figure 6.6).

Figure 6.6: Dump sites must be protected against extraneous runoff

TECHNOLOGIES AVAILABLE TO THE ENGINEER

The hydrologic cycle

There are four basic aspects in the hydrologic cycle of interest to the hydrologist, namely:

- precipitation;
- evaporation and transpiration;
- surface runoff; and
- ground water.

Hydrology is used in stormwater management for the design and operation of hydraulic structures. These could include spillways, highway bridges and culverts, or urban drainage systems (Alexander 1990; Linsley et al 1975; Midgley 1972; Adamson 1981).

Flood routing

Many methods and techniques are available to aid the design engineer in calculating runoff hydrographs and associated flood peaks. The scope of this document does not allow for any detailed dealing with these techniques; reference only is made to them. There are many competent references for adequate coverage (Alexander 1990; Midgley 1972; Rooseboom et al 1981; Pansegrouw 1990).

There are also hydraulic simulations, methods and computer programs available that route stormwater runoff and predict hydrographs at nominated reaches in watercourses and drainage ways, e.g. *Hydrosim* (routing model using the kinematic flood-routing equation), and the *SCS method*.

Routing of storm water through drainage ways and rivers requires the computation of varied flow. Gradually varying flow is normally assumed. The computation to determine the variation in depth of flow with distance is available from many sources and is discussed later.

Flood-line determination

The determination of flood lines is usually based on the routing of stormwater through the water course (drainage way). The capacity of a natural channel (or any channel for that matter) is affected by the interaction of local features and the gradually varying flow profile. The routing problem has been addressed by Bakhmeteff (1932), Chow (1959), Henderson (1966) and French (1994). Their classifications of the flow profiles are well documented. Several computer programs are available to aid in the determination of water surface profiles.

Detention and retention facilities

A detention facility is designed to attenuate runoff, specifically the peak flows experienced in the reaches of a water course. These facilities may be planned on a multi-purpose basis as required by the controlling authority, and can achieve a number of stormwater objectives.

Many municipalities now require in their subdivision regulations that runoff from a development may not exceed pre-development runoff for a particular frequency design flood. This is normally accomplished by the construction of a detention basin or facility. The facility acts as a small flood-control reservoir, which can attenuate the peak of the runoff before it flows downstream.

The sizing and positioning of detention facilities needs to be done on a catchment basis, and should form part of the master drainage plan. The combined effect of discharges from various sub-catchments should be analysed to minimise possible adverse effects on the watercourse under consideration.

All dams need to be registered, classified and evaluated as *dams with a safety risk*, specifically any structure with a wall height greater than 5 meters. The evaluation process must involve an Approved Professional Engineer (APE).

To effectively determine the parameters of such a facility, flood routing the design inflow hydrographs through the storage in the basin with a predictable outflow needs to be done, so that downstream effects can be determined. Typical design data may include

- the relevant hydrographs for each of a range of design flood recurrence intervals or frequencies, taking cognisance of the ultimate possible post-development characteristics of the catchment;

- details of the storage and stage characteristics of the detention basin;
- details of the outlet structures with reference to the discharges from the structures at the various stages;
- structural and geotechnical details of the dam wall with regard to type of wall, materials, filters, founding details, spillway structure, erosion protection and freeboard;
- safety precautions related to floods and other hazards;
- possible recreational use of the facility; and
- maintenance issues, including sedimentation and maintenance of vegetation.

See also: American Society of Civil Engineers 1982; Brink 1979; Gerber et al 1980; Jennings et al 1978; Knight et al 1977; SA Institution of Civil Engineers, 1985.

Programs are available to do the flood routing of an inflow hydrograph through a detention facility to produce the downstream outflow hydrograph (HEC-1, Pond Pack). Many of these use the storage-indication working-curve method or Modified Puls method which is discussed in more detail in Appendix A to this chapter (Golding 1981).

Storage facilities may be purpose-built, designed primarily to attenuate runoff, and are usually in the form of wet (part retention, part detention) or dry (detention) facilities. Certain cities in America use underground tunnels and disused quarries, into which peak flows are routed. The effluent is then pumped from these facilities through purification systems before being discharged into the receiving rivers.

Supplementary facilities, whose primary function is not stormwater attenuation but which have been designed to function in an emergency as a stormwater-detention facility, can be designed in parking areas, sports fields and areas upstream of road embankments.

Outlets at stormwater-detention facilities

Culverts

Flow through culverts is dealt with in many text books. Nomographs are available, for example in US Department of Transportation (1985). Flow through culverts is also dealt with in Chow (1959) and French (1994). Most local authorities, provincial and national roads departments have their own design guidelines, to which the drainage designer should refer.

Flow types are categorised according to inlet control, barrel control or culvert, or outlet control. However, all culverts act to some extent as detention structures, because some stormwater upstream of the culvert accumulates before flowing through the culvert. An accurate assessment of the behaviour of a specific culvert configuration for detention facilities needs to be obtained over a range of flows and headwaters (see Figure 6.7).

Figure 6.7: Multiple-outlet structure of a detention pond

Proportional weirs

The proportional weir has one unique characteristic in that it has a linear head-discharge relationship. Details are provided in Appendix B of this chapter.

Improved inverted V-notch or chimney weir

The inverted V-notch (IVN) weir is a more practical, linear sharp-crested weir. Details are given in Appendix B of this chapter.

Spillway crests

Overflow spillway crests are widely used as outlets from detention facilities. Their design is outside the scope of this publication. Reese and Maynord (1987) provide an adequate reference.

Other control structures

Weirs are structures widely used in hydraulic engineering to control or measure flow. Typical weirs include the following:

- Broad-crested weirs
  - Rectangular
  - Triangular

- Sharp crested weirs
  Rectangular
  V-Notch
  Cipoletti weir
  Proportional or Sutro weir

- Parshall flume.

There are also other weirs. However, there are limitations to the applications of these types of weirs and contractions. French (1994) and Chow (1959) provide ample discussion on the subject. See also Keller (1989) and Francis (1969).

Bridge backwaters

Backwaters produced by bridge restrictions need to be analysed when flood lines are considered. For further reference see US Dept. of Transportation (1978), *Hydraulics of bridge waterways*, Hydraulic design series No 1.

Erosion protection

Energy dissipators

The dissipation of energy of water in canals or of water discharging from pipes must be considered when downstream erosion and scouring are possible. The drainage engineer is always faced with the problem of achieving this in an aesthetically pleasing way. Several technologies are available:

- Widening the drainage way and decreasing the depth of flow. This will have the effect of reducing the velocity of flow. Overland flow is a typical example.

- Increasing the roughness of the canal or drainage way. Although this will increase the total cross-sectional area of flow, it will decrease the velocity.

- Structures which include the following:
  Roughness elements
  USBR type II basin
  USBR type III basin
  USBR type IV basin
  SAF stilling basin
  Contra Costa energy dissipator
  Hook type energy dissipator
  Trapezoidal stilling basin
  Impact-type energy dissipator
  USFS metal impact energy dissipator
  Drop structures
  Corps of Engineers stilling well
  Riprap basins.

Reference to their selection and hydraulic design is given in US Department of Transportation (1983).

Examples of some energy dissipators are shown in Figures 6.8, 6.9 and 6.10.

Figure 6.8: Simple drop structures in a residential environment

Figure 6.9: Energy dissipator

Figure 6.10: Energy dissipator in a multiple land use setting

Structural elements

Structural elements that are typically used include:

- Geocells (e.g. Hyson-cells);
- Geotextiles (e.g. Bidim, MacMat, Sealmac);
- Geomembranes (HDPE linings and others);
- Riprap;
- Gabions (refer to SABS 1200);
- Reno mattresses (refer to SABS 1200);
- Linings (e.g. Armorflex); and
- Stone pitching (adequately covered in SABS 1200).

The reader is urged to approach the suppliers of these products for technical information.

Transitions

Kerb inlet transitions

Kerb inlets (lateral stormwater inlets) are widely used with kerbs and surfaced roads. Their performance has been discussed adequately by others. Forbes (1976), for example, proposed that on moderate to steep road gradients, the capacity could be substantially improved by incorporating an extended length of depressed gutter upstream of the inlet.

Culvert transitions

Culvert transitions are structures that attempt to converge wide, shallow subcritical flows into high-velocity critical flows which can be passed through deep, narrow throats that are more cheaply constructed as culverts or bridges. Sometimes termed *minimum energy* or *maximum discharge* designs, this concept allows large flows to be routed through smaller, more efficient and economical culverts or bridges without the usual backwater or headwater required to provide the energy necessary to pass the flow through a typical opening (Cottman and McKay 1990). Consideration must be given to the immediate downstream effects and energy dissipation.

Modification of the headwall and culvert opening details to conventional culverts and bridges can also reduce the energy loss at the entrance. This lends itself to a more efficient hydraulic design (US Dept. of Transportation 1985, *Hydraulic design of highway culverts*). However, a more efficient hydraulic design through the culvert structure generally leads to higher-energy waters at the outlet. Energy dissipators may have to be incorporated into the design.

Kerb inlets

The standards used by municipalities vary considerably. Generally, cognisance should be taken of the following:

- hydraulic performance;
- accessibility for cleaning purposes;
- ability of the top section of the culvert to bear heavy traffic;
- safety for all road users; and
- cost.

For further information, refer to Forbes (1976).

Side weirs

Side weirs are structures often used in irrigation techniques, sewer networks and flood protection. A special case of this is the kerb inlet (Hagner 1987; Burchard and Hromadka 1986).

Road drainage

Surfaced roads

The main function of urban roads is the carrying of vehicular, cycle and pedestrian traffic. However, they also have a stormwater management function. During minor storm events, the two functions should not be in conflict. During major storm events, the traffic function will be interrupted, the flood control function becomes more important and the roads will act as channels. Good road layout can substantially reduce stormwater-system and road-maintenance costs.

A well-planned road layout can significantly reduce the total stormwater-system costs. When integrated with a major system this may obviate the need for underground stormwater conduits. A key element is that the road layout should be designed to follow the natural contour of the land (Miles 1984). Coordinated planning with the road and drainage engineers is crucial at the pre-feasibility stage.

Stormwater runoff may affect the traffic-carrying capacity through:

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

Refer to Figures 6.11, 6.12, 6.13 and 6.14.

Figure 6.11: A lined open roadside channel

Figure 6.12: Incorrect vertical alignment has caused stormwater to bypass this kerb inlet. Kerb inlets in the intersecting road on the left have also not captured runoff from that road so that stormwater flows across this bus route, creating a hazard

Figure 6.13: This ponding is the result of encroachment of the grass verge onto the road. Grass-cutting maintenance operations should also include harvesting the grass, to prevent siltation and build-up of new grass growth

Figure 6.14: Flow across this intersection has resulted in siltation, which is inconvenient and hazardous to road users

<u>Sheet flow</u>

This flow is generated on a road surface and is usually least at the road crown, increasing towards the road edge. This can lead to hydroplaning when a vehicle travelling at speed has its tyres separated from the road surface by a thin film of water.

Sheet flow can also interfere with traffic when splashing impairs the vision of drivers.

<u>Channel flow</u>

Channel flow is generated from sheet flow and from overland flow from adjacent areas. As the flow proceeds it increases in volume, encroaching on the road surface until it reaches a kerb inlet or drain inlet. The result is reduced effective road width. Again, splashing produced by the tyres can lead to dangerous driving conditions.

It is important that emergency vehicles should still be able to use the road during major storms.

Figures 6.15 and 6.16 illustrate examples of channel flow.

Figure 6.15: Example of surface drainage in a residential setting

Figure 6.16: Open channel alongside an arterial road

Ponding

Ponding on roads may occur at low points, at changes in gradient, at sump inlets and road intersections. This can have a serious effect on traffic flow, particularly as it may reach depths greater than the kerb height or remain on the roadway for long periods. A particular hazard of ponding is that it is localised and traffic may enter a pond at high speed.

Flow across traffic lanes

Flow across traffic lanes may occur at intersections, when the capacity of the minor system is exceeded. As with ponding, localised cross-flows can create traffic hazards. Therefore, at road intersections, for example, traffic devices should be used to reduce traffic speed during downpours. In such cases allowing cross-flow may be preferable to maintaining the road gradient, which would have the effect of creating irregularities in the cross slope of the road.

Encroachment on roads by runoff

Major storm events

The encroachment by runoff from a major storm event onto primary roads should not exceed a depth of 150 mm at the crown of the road. This will allow access by emergency vehicles.

Minor storm events

The suggested maximum encroachment on roads by runoff from minor storms is given in Table 6.3.

Road gradients

Maximum road gradients

The maximum road gradient should be such that the velocity of runoff flowing in the road edge channels does not exceed 3 m/s at the limits indicated in Table 6.3. Where the velocity of flow exceeds this value, design measures should be incorporated to dissipate the energy.

Minimum road gradients

The minimum gradient for road edge channels should be not less than 0,4% (to reduce deposition of sediment).

Maximum road crown slope

The maximum slope from the crown of the road to the road edge channel is not governed by stormwater requirements.

Table 6.3: Suggested maximum encroachment of runoff on roads during minor storms

ROAD CLASSIFICATION	MAXIMUM ENCROACHMENT
Residential and lower-order roads	No kerb overtopping.* Flow may spread to crown of road.
Residential access collector	No kerb overtopping.* Flow spread must leave at least one traffic lane free of water.
Local distributor	No kerb overtopping.* Flow spread must leave at least one lane free in each direction.
Higher-order roads	No encroachment is allowed on any traffic lane.

* Where no kerb exists, encroachment should not extend over property boundaries.

Minimum road crown slope

The minimum slope from the road crown to the channel should be not less than 2% for a plain, surface or an average of 2% where the surface has a variable cross slope.

Unsurfaced roads

The drainage function of unsurfaced roads is dependent - and has a significant impact - on the planning of the road and access layout. If the roadway is to be used to channel and drain stormwater runoff, then the velocity of this runoff must be such that minimal erosion potential exists. This means that gravel roads, together with their side drains, need to have low gradients. Roads with steep gradients should, as far as possible, not be used as drainage ways, nor should any adjacent side drains without proper erosion protection. This protection can include drop structures, lined channels at critical sections, or regular drainage from the roadway into intersecting roads or drainage ways. Refer to Figures 6.17 and 6.18.

Figure 6.17: The contour-planning concept, to impede the drainage of runoff from the development

Figure 6.18 (a): Concentration of stormwater drainage in a roadway resulting in major inconvenience to road users

Figure 6.18 (b): Concentration of stormwater drainage in a roadway resulting in major inconvenience to road users

Runoff from earth or gravel roads will contain grit and its conveyance in pipes can eventually block or even damage the pipe network. Blockages are difficult to clear. In many instances maintenance is not done, rendering the network ineffectual. Use of pipelines in environments of high erosion potential is not recommended because of the high expense of maintenance and high risk of failure or non-performance.

An alternative to a network of pipes is an open-channel system on the roadsides for conveying minor storm runoff. This system may also convey dry weather flow in areas where there are high or perched water tables, and there is sullage from individual households or from communal water points. The positioning of communal water points must be carefully considered and soakaways or drainage from these points included in their design (see Chapter 9). Suitable erosion protection of the canal invert, including drop structures and silt traps, is important. See Figure 6.19

Figure 6.19: Roadside drains of the major system

The use of open roadside channels may necessitate a wider road reserve than that required to accommodate subsurface drains. This is particularly pertinent where open channels intersect with roadways or property access ways. The width of an open channel may increase progressively as the drain accepts more runoff. The road reserve may have to be widened or the channel deepened. The advantages of these alternative technologies must be compared. Open drains, like all systems, will require maintenance. However, this technology is not “out-of-sight, out-of-mind”. Siltation and other problems will immediately become apparent.

Where the whole roadway is used as a drainage way for the major system, erosion protection on the downstream road edge may need to be considered. The crossfall of the road should generally be against the natural ground slope so that the whole road width can act as a drainage way in the major system. To maximise the storage function of the roads as part of the drainage system in major storm events, the settlement layout should be planned so that the greatest length of road closely follows the ground contour (the contour-planning concept). Figure 6.20 shows an example of this planning concept of a rural village in highly erodible granitic soils. The erosion from this area was effectively eliminated.

Figure 6.20 (a): Layout planning in steep terrain

Figure 6.20 (b): Layout planning in steep terrain

Roof drainage

High-intensity short-duration storms are experienced in many parts of southern Africa. These violent storms are often accompanied by strong winds and hail, which may lead to damage and the flooding of buildings containing valuable assets.

It is considered prudent that designers of roof structures for large buildings take cognisance of the roof drainage system. The research done by Schwartz and Culligan (1976) suggested that the five-minute storm is likely to cause overtopping of gutters in buildings of conventional size. The approach to the design of roof lengths, gutter size, box receivers and downpipes is discussed in this reference.

In the United States of America certain authorities require that all runoff generated on certain properties be stored for slow discharge into the municipal drainage system. Ponding of rain on roofs is one retention technology. Others include using depressed areas on the property to store excess runoff. See Figures 6.21 and 6.22.

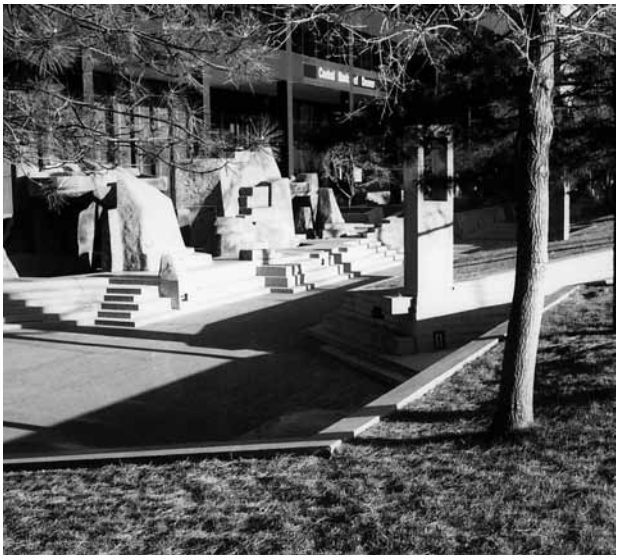

Figure 6.21: This office complex incorporated the entrance to the building in a detention facility. Under normal conditions, this area functions as a pleasant park with water features

Figure 6.22 (a): Depressed area to store excess runoff

Figure 6.22 (b): Runoff from this parking area is stored in the drainage ways using multiple-outlet drains

Upgrading issues

While greenfield development may encompass a more rigid planning procedure, upgrading projects should also be subjected to assessment of their possible environmental impact. In development, where greenfield development may be at the one end of the continuum and projects associated with mature developed areas at the other, the issues to be addressed in planning should be similar. A rigorous assessment of impacts - which may include operation and maintenance issues - should be considered. The classification of project proposals and their possible effects on certain areas and features are considered fully in the Guideline Document 1 of the IEM procedure (Department of Environment Affairs 1992b).

POLLUTION ABATEMENT

While the issue of quantity of stormwater runoff has been addressed in South Africa for some time, emphasis on the quality of runoff has lagged behind. While economic and social attention to development has been largely beneficial, the total cost of technology (that is, the opportunity costs of not considering the total waste stream produced by a technology) has not been considered in great depth in South Africa. This typically refers to issues, like health care, which concentrate on treating the symptoms instead of striving for a balance between prevention (reducing or eliminating the cause) and cure. The user, the man in the street, pays sooner or later, carrying both financial cost and forfeiting quality of life.

Sources of pollution

Air pollution

With the exception of pollution generated by motor transport, stationary fossil-fuel processes produce the bulk of air pollution in South Africa (Petrie et al 1992). Five activities in this category which generate air pollution are recognised:

- fuel combustion and gasification from stationary sources (particularly electrical power generation);
- fossil fuel burning in dense unserviced settlements;
- industrial and chemical processes (ferro-alloy industries, fertiliser production);
- solid waste disposal (incineration of industrial, residential and hospital wastes); and
- land surface disturbances (mining and construction activities, agricultural practices and veld fires).

Of particular concern is the acidic deposition by rain (acid rain) which may result in acidification of freshwater ecosystems, denudation of forested and agricultural areas, corrosion of metal surfaces and destruction of masonry structures.

While the Atmospheric Pollution Prevention Act provides for both administrative and judicial control measures, air pollution control is administered in practice by the chief officer of a local authority and the government mining engineer.

Point sources of water pollution

<u>Industrial</u>

Apart from the air pollution produced by industry, most industrial processes use water and produce effluent. Some of these processes include

- abattoirs;
- breweries;
- pharmaceuticals;
- fishing;
- tanning; and
- the fruit and vegetable industry.

The strategies for pollution abatement are focused on the reduction of water use at source and improved effluent purification technologies.

Runoff from industrial plant sites may contain toxic or hazardous pollutants. The installation of detention facilities can be one technology to store the effluent during periods of runoff and release it at a slower rate to a treatment process such as a wetland.

<u>Mining</u>

There are many pollutants emanating from mining operations, depending on the operations themselves. Probably the main concern to the drainage engineer is the so-called acid mine drainage and heavy metals.

The standard practice on South African mines varies considerably. The fundamental principles of keeping clean water and polluted water separate and preventing clean water from becoming contaminated are largely ignored by many mines (Pulles et al 1996).

Non-point sources of water pollution

Non-point sources of water pollution are difficult to locate. Some success has been obtained using infra-red aerial photography (Perchalski et al 1988). This technology can prove helpful in identifying non-point source problems that include

- oxygen depletion in dams; and
- runoff from city streets, farms, forests, mines, construction sites and atmospheric deposition.

<u>Agricultural pollution</u>

Poor farming practices have often impacted negatively on the environment. Some of the observed consequences have been

- decreasing bio-diversity;
- overgrazing through overstocking;
- pollution by fertilisers;
- pollution by pesticides, herbicides and fungicides;
- soil crusting; and
- irrigation with polluted water.

The scarcity of water has been identified as the single most limiting factor for economic growth in southern Africa. It is therefore essential that this scarce resource be utilised judiciously and sensibly for the benefit of all users, including the natural environment.

Certain standards of water quality are required for all users - from primary domestic use to water for irrigation, stock watering, recreation and the maintenance of aquatic habitats.

Water used for irrigation will always contain measurable quantities of dissolved salts. These include relatively small but important amounts of dissolved salts originating from the dissolving or weathering of rocks, soil, lime, gypsum and other salt sources as the water passes over or percolates through them. The suitability of water for irrigation will be determined by the amount and type of salts present. While the quality does not form part of the scope of this chapter, poor water quality may cause various soil - and therefore productivity - problems to develop, namely

- salinity;
- permeability;
- toxicity; and
- miscellaneous chemical problems (e.g. excess nitrogen in the water, pH).

Guidelines in terms of the sodium adsorption ratio (Ayers 1977) and the adjusted sodium adsorption ratio should be consulted to ensure that productivity is not limited by the water quality, and that users downstream are not disadvantaged by poor agricultural land use.

Urban pollution

Stormwater runoff from urban catchments has been found in many areas to be a major source of pollution to the water-receiving bodies. Practices such as effective rubbish collection, street cleaning, vegetation buffer strips and improved fertilizer practices ameliorate this pollution (see the section on street cleaning in Chapter 11: Solid waste management).

Soil erodibility

Examples of highly erodible soils in South Africa include the granitic soils found in Mpumalanga and the Highveld (Kyalami system). Although erosion is a natural phenomenon, interference by man with the natural environment can rapidly degrade the natural systems available to ameliorate this erosion. One of the major anthropological influences which occurs in many of the rural areas is the over-stocking of animals. See Figure 6.23.

Dispersive clays occur in any soil with high exchangeable sodium percentage (ESP) values. The testing procedures for the identification of dispersive clays are discussed by Elges (1985). Methods for constructing safe and economic structures with dispersive clays should be carefully considered.

Figure 6.23: Gully erosion by headwater upstream of a highway culvert inlet. Specific attention needs to be paid to structures founded in soils with high erosion potential

Grass-lined channels

Grassed waterways are generally a cost-effective way to convey stormwater (US Dept Agriculture 1987). The use of indigenous plants for stabilisation is recommended. The velocity of water flowing in the waterway should be limited in relation to the erodibility and slope of the waterway.

Fencing off the waterway in a rural environment is usually an effective way of controlling livestock so that the grass cover can be established. Once this cover has been established, livestock can be introduced onto the grassed waterway in a controlled manner. Figure 6.24 illustrates the concept.

Figure 6.24: An example of a grassed waterway