1 INTRODUCTION

In order to design a stormwater drainage system for a road or road network, the designer must understand hydrology. Hydrology is the study of rainfall, its properties and laws and its distribution over the earth's surface. The stormwater characteristics which concern the designer are the intensity, duration, frequency, and behaviour of stormwater over the total catchment area affecting the road, also the movement of the water on the road surface, and how to contain, control and remove this water.

Hydrology is not an exact science and hydraulic calculations are based on historical, statistical, and empirical methods. There are many methods of calculating discharge. These notes will focus on the Rational Method which has wide application. Much of the work is empiric in nature and normally, charts tables and nomographs, based on a large database of observations, are available to perform the calculations for a particular method.

Once the stormwater runoff has been calculated, the drainage system may be designed to accommodate it. Drainage systems are costly, and affordability dictates that the elements of a drainage system cannot be designed so large as to cope with any volume of stormwater that might possibly reach it. The principle adopted is to design for the largest flow volumes that may be expected to occur with a certain frequency or recurrence interval, knowing that the capacity will be exceeded from time to time. Measures must then be available to manage the excess flow. This might mean simply accepting that a certain amount of consequent damage will occur “once in *x* years”, and must be tolerated. Where there is large runoff and a risk of great damage if the design capacity is exceeded, it may be necessary to select a longer recurrence interval and produce a more conservative design. Risk and damage costs should be weighed up against the extra cost of increased system capacity.

2 TERMINOLOGY

The terms used in stormwater design are normally self-explanatory and familiar. Others that appear more formidable, for example "isohyets", are simple in concept, an isohyet being the line on a regional map joining points of equal mean annual rainfall. A contour line of mean rainfall, if you will.

The following terms, listed with explanations, are commonly used:

Rainfall intensity:		The precipitation, normally measured in mm/h
Rainfall distribution	:	Varies with time and place
Duration	:	The duration of the design storm, taken as equal to the time of concentration
Time of concentration	:	The time taken for stormwater to travel from the head of the catchment area to any given point downstream, normally measured in minutes
Catchment area	:	An area of land which, due to the contours, gathers all the water that will drain to a specified point downstream
Recurrence interval	:	The period (in years) at which a certain rainfall intensity is calculated to recur
Design storm	:	The peak rainfall intensity that is likely to occur in the recurrence period chosen for design purposes
Mean annual rainfall	:	The average yearly rainfall at a point, as measured over a period of years
Run-off	:	The quantity of stormwater discharging from an area in a given time, measured in litres/second (l/s) or in cubic metres per minute or second - the last being referred to as a cumec
Run-off coefficient	:	The proportion of precipitation that will flow off a catchment area depending on the permeability, roughness and surface nature of the area
Sub-surface run-off	:	That part of rainfall infiltrating into the soils and flowing in upper strata to resurface without joining the mains body of underground water.
Groundwater run-off	:	water Infiltrating into underground water storage which partially reappears as spring water. This is also referred to as dry weather flow
Sheet flow	:	Unconfined flow over a surface
Stream flow	:	Discharge confined to flow in a limited path or watercourse
Flood plain	:	The area of land adjacent to a watercourse which will be inundated by stream flow under flood conditions
Capacity	:	The quantity of stormwater that can be carried in a gutter, channel, pipe inlet, culvert, bridge or water course. It depends on the gradient, cross-sectional shape and area and the roughness or retardance factor
Roughness (or retardance)		Normally designated as the 'n' value a surface or of the lining of the carrier
Average slope	:	Also known as the hydraulic gradient. The average slope from the head of the catchment area to the point of design in a system and is calculated as height difference divided by total

flow length

Freeboard : The height difference between the water surface and the top of the containing structure

Overtopping : When stormwater flows over the top of a containing structure due to excess quantity

Ponding : Occurs at low points on a road or surrounds, or where stream flow is interrupted - it can have serious consequences if ponding occurs on a road surface and remains for a period

Detention or retention ponds Basins to interrupt watercourse flow for the purpose of flood control and for storage.

Interception : The percentage of stream flow that is removed/extracted by an inlet

Flooded width : The width on a road surface inundated by water overflowing the stormwater channel.

3 DISCHARGE "Q"

The discharge from a catchment area is a function of

- ❑ storm recurrence interval
- ❑ area of catchment
- ❑ intensity of rainfall
- ❑ time of concentration/storm duration
- ❑ run-off coefficient

These are discussed in the following sections

3.1 Recurrence interval

Storms of low intensity occur frequently, while very intense storms are less frequent. When the consequences of under-design would be severe, it is appropriate to design for a storm with a longer recurrence interval, and thus of greater intensity. For the purpose of designing a stormwater discharge system for roads, it is first necessary to know what storm flood the system must cater for. This would stem from a policy decision a decision to be made by the authorities, based on factors such as the class of the road and the need to prevent loss of life and significant damage to property resulting from the run-off from rare storms.

Thus a recurrence interval or frequency must be stipulated for the design storm to be accommodated by the various parts of the stormwater system. This applies equally to the provision of flood protection measures for a major storm, and to the design of the carrying capacity for minor storms and associated minor elements such as kerbs and channels. The recommendation for the former is to design for a storm with a 100 year recurrence interval, although the analysis of cost implications may result in a shorter interval in certain areas. Table M5.1 below gives the recommended values for various standards of urban development.

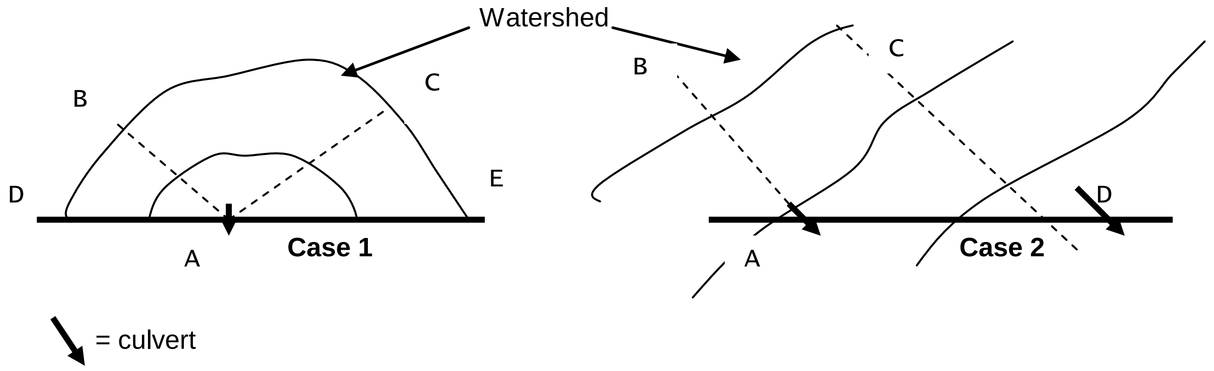
It is of interest to note that, although the recurrence interval for a ten year storm means that one storm of that intensity should occur on average in a ten year period, statistically that storm might perhaps occur tomorrow but there is only a 40 % probability that one or more such ten year storms will occur in the next ten year period.

In all cases, the consequences of the more occasional flood with a longer return interval must be considered, and the result may sometimes lead to the use of a greater return interval for the design storm.

Table M5.1: DESIGN RECURRENCE INTERVALS	
Land use	Recurrence interval for design for minor storm
Residential	2 years
Institutional and public buildings (eg schools, old-age homes, post offices)	5 years
Commercial and industrial	5 years
High value central business	5 to 10 years

3.2 Area of catchment (A)

The area of catchment of rainfall flowing to any particular collection point for design consideration is the total area in the relevant watershed that lies upstream of that point and will drain to it, without the diversion of any water along some other drainage path. It is measured on a contour map from the line of the watershed (the highest ridge) to lines plotted at right angles to the contours from the design point, or where applicable, to some barrier that may intercept water flowing outside that area and force it to the design point concerned (typically the road embankment).



The contour map is also used to measure the catchment slope (from the elevation difference) and the longest flow length.

For case 2, the catchment area for the culvert at D would be the area ABCD.

For case 1, the catchment area for the culvert at A would be the area ABC as defined above plus the wedges ADB and ACE which must also contribute to the runoff at A unless there are other culverts between A and D or A and E.

3.3 Intensity (I)

The most variable factor in a storm is the intensity of rainfall. The intensity of precipitation is not uniform over time nor across a geographic area. The total volume of water falling on a catchment area depends not simply on the maximum intensity of rainfall at any point but also the variation of intensity over the whole area and the variation of intensity during the time period under consideration, which is taken to be the same as the time of concentration, T_c. These variations tend to recur in particular locations and are related to the local climatic conditions, the topography, and the mean average annual rainfall. As a result, statistical data bases for the area are of value.

Empirical formulae and diagrams for the determination of average rainfall intensity have been developed. These are typically based on average annual rainfall, storm duration, return period and climatic area, and may also have an adjustment factor for the size of catchment. Locally, reports by the University of the Witwatersrand Hydrological Research Unit and the Department of Water Affairs, Forestry and Environmental Conservation. are available to assist in calculating precipitation.

The best results are obtained where accurate measurements have been recorded over long periods and intensity/duration and run-off charts prepared on an historical basis.

3.4 Time of concentration (T_c)

The design storm is chosen as the storm which has the shortest duration (and thus greatest intensity) that will extend long enough to cover the period required for the water from the furthest point in the catchment (time-wise) to reach the outlet point/design point. It therefore has a duration equal to the time of concentration of the catchment area.

The run-off and time of concentration for overland flow is directly related not only to the average slope but also to the nature of the terrain (surface characteristics), which is quantified as a run-off co-efficient for which several tables have been prepared.

3.5 Run-off coefficient (F)

The total run-off is related to several factors including the roughness and permeability of the catchment area. Tables of run-off factors are shown in the Department of Community Development "*Guidelines for the planning and design of human settlements*". Other typical values for rural areas appear below, overleaf. In determining the value of the co-efficient to be used, careful judgment must be applied and both the present and the future land use should be considered. New development and the associated paving of large areas of grassland, for instance, can have a dramatic effect on the runoff volume.

3.6 Total run-off (Discharge) (Q)

There are numerous methods of computing the total discharge at a point in the catchment area.

For urban areas, the Rational Method is most commonly used. The method becomes less accurate for large areas and, for catchments over about 1 300 ha, one of the other methods should be used independently or as a check on the Rational Method results.

The Rational formula is based on the factors discussed above and is expressed as

$Q = AFI/ 360$

where Q = maximum rate of run-off (m^3/s), A = catchment area (ha)

F = run-off coefficient I = maximum intensity of rainfall (mm/h)

Runoff Coefficients, Rural Areas				
Factor	Component	Mean Annual Rainfall		
		< 600	600 - 900	> 900
Cs Average Slope	Flat < 4%	0,01	0,03	0,05
	Moderate 4-11%	0,06	0,08	0,11
	Steep 11-35%	0,12	0,16	0,2
	Very Steep >35%	0,22	0,26	0,3
Cp Permeability	Very Permeable	0,03	0.04	0,05
	Permeable	0,06	0,08	0,1
	Semi Permeable	0,12	0,16	0,2
	Impermeable	0,21	0,26	0,3
Cv Cover	Forest, Bush	0,03	0,04	0,05
	Cultivated	0,07	0,11	0,15
	Grassland	0,17	0,21	0,25
	Bare Rock	0,26	0,28	0,3

4 URBAN STORMWATER MANAGEMENT

Stormwater management is the collection, conveyance, storage and disposal of stormwater runoff to prevent flood damage and reduction of water quality. Sometimes permanent or temporary storage facilities, subsurface disposal, attenuation and diversion measures are used to manage the quantity and rate of runoff.

Within a new township, stormwater control must be a major consideration when planning the layout. Stormwater management, flood control, the capital cost of installation and maintenance are all dependent on the basic township layout.

The development of an area inherently results in an increase in the area of impermeable surfaces (roofs, paved streets etc.) and causes changes in the runoff pattern due to the reshaping of the land surface and drainage paths. The construction of efficient water carriers such as paved roads and underground drainage systems has a dramatic effect on the rate of runoff, increasing the rate of runoff and reducing the time of concentration. Flood peaks become shorter and hence more severe. These effects can be alleviated by proper planning of the township layout in conjunction with an efficient system of stormwater control.

The concentration of population and vehicles also results in land pollution. This affects the quality and the soiled nature of the stormwater runoff within the built-up area to a varying degree, being worst after prolonged dry periods followed by low intensity rainfall and runoff. It has been said that stormwater in the first storm after a dry spell is fouler than anything ever found in a foul water sewer.

4.1 Objectives

The planning of a stormwater drainage system must be based on principles which will lead to the achievement of the following objectives:

(I) preventing loss of life and significant damage to property resulting from the runoff from rare storms.

(ii) providing a stormwater system which prevents frequent minor storms from causing inconvenience to the community and protects property from flood damage by frequent storms.

(iii) finding solutions to the problems of increased runoff caused by urban development and providing the most economical control facilities compatible with the environment.

(iv) reducing the pollution of the immediate runoff and of the bodies receiving it.

4.2 Design considerations

The basic requirements that stormwater drainage systems should provide protection from major and minor storm runoff are in a sense conflicting. For major storms the rate of runoff should be retarded to reduce flood peaks, while for minor storms the runoff is best handled by rapid removal. The solution is to consider the system as having two separate and allied parts. In fact, these conflicting requirements generally refer to different parts of the overall system, and these parts may be treated differently, so the conflict is more apparent than real. The minor-storm rapid-removal technique generally applies to the ;local area close to where the rain has fallen. The method of dealing with major storms (slowing it , detention) generally applies to parts of the system further downstream where a number of local drainage conduits have already converged.

An assessment should be made of the damage likely to be caused by the failure of a given drainage system. If the damage is out of proportion to the additional costs involved in adopting the next higher return interval, then this should be done.

4.2.1 Major storm drainage systems

The major system is designed to attenuate runoff and consists of artificial and natural open channels, roadways, storage facilities and flood plains.

The layout of road patterns should be co-ordinated with the runoff requirements of the drainage system so that the time of concentration can be increased, thereby minimizing flood hazards. Rates of runoff can possibly be achieved that do not differ significantly from the pre-development levels. In the event of an infrequent major storm, the roadway itself will act as the water carrier. Under these circumstances traffic expects the roadway to be water covered and travels accordingly. The total capacity must be such that no private property will be flooded under the most severe storm conditions. Overflow points must be provided to remove the excess runoff safely, possibly to specially provided temporary storage facilities called dry attenuation areas. These areas will be flooded only for short periods during a major storm and may include areas that normally have other functions such as parks, paying fields, golf courses and parking areas. During major storms these areas do not serve their dry-weather functions, so there is little conflict between the separate functions. Other areas available for temporary storage are natural and artificial ponds and dams, open areas, and green belts. Longer-term storage may be provided by wet storage areas which include larger dams, pans, lakes, reservoirs and open watercourses with their related flood plains. Maintenance following storms is a factor requiring correct management.

4.2.2 Minor storm drainage systems

The function of the minor system can best be fulfilled by the rapid removal of the runoff from the area where it falls, most importantly the local street surface. Thus, a system of effective water carriers, to cater for the minor storm of the frequency chosen for the design, must be designed and constructed to convey the runoff in a controlled manner to natural or artificial watercourses or ponds.

During minor storms, roads also serve to carry stormwater runoff. During minor storms the traffic function will be interrupted, and the drainage function becomes more important. Good planning of road layouts can substantially help in the provision of adequate drainage at minimum cost.

A well-planned road layout when efficiently integrated with a major drainage system may reduce the need for underground drainage.

The greatest benefit will be derived from the road layout when consideration is given to drainage requirements in the preliminary stages of planning the township layout. When efficiently integrated with a major system, it may obviate or substantially reduce the need for underground drainage conduits.

Roads have a substantial stormwater storage capacity potential when located at flat gradients. Stormwater from roads should discharge into watercourses or storage areas such as parks, greenbelts and slow-flowing channels.

4.2.3 Intersections

Steep gradients on roads can results in excessive flow-past at intersections and care should be taken in the design to avoid hazardous situations developing, particularly at Tee intersections.

4.2.4 Low Points

Low points on a road between intersections can sometimes not be avoided. Special care is needed to ensure that excessive ponding does not cause either danger or damage.

5 COMPONENTS OF AN URBAN DRAINAGE SYSTEM

5.1 Channel flow

Stormwater run-off may be intercepted by means of channels, dykes or watercourses before it reaches a road and thus disposed of in a separate system. Stormwater that falls on the road or reaches the road from adjacent areas will be carried initially by the road, contained by the kerb and flowing in the channel and on the road surface. There are various standard kerb profiles which would typically be overtopped by a depth of flow exceeding about 150 mm. The permissible flooding on the road is controlled by the overriding objective of safety and varies with the class of the road. The flooded width can be calculated from an accepted method to determine the capacity of an open channel, such as Manning's Formula.

The minimum crossfall on a bituminised surface is 2 %, and the minimum longitudinal channel gradient is 0,5 %. The maximum longitudinal gradient should not result in water flowing at a velocity exceeding 3 m/s. Special measures may be necessary to dissipate energy and reduce velocity.

When an infrequent major storm occurs, traffic will be disrupted regardless of the road and stormwater design. Motorists will expect to find fairly deep sheets of water and areas of ponding on the road surface. Under these circumstances, the stormwater and flood protection system should be ensure a water depth not exceeding 150 mm on a width of the travelled way on major roads, so as to allow for the passage of emergency vehicles. Some flooding of properties on the lower side of the road may be unavoidable and zoning laws must cover the flood-proofing of some buildings. Access driveways are vulnerable points.

The permissible encroachment on roads by <u>minor</u> floods is:

Purely residential roads	-	no kerb overtopping; flow width to crown of road
Lower-order mixed usage	-	no kerb overtopping; at least one lane must remain free of water
Higher-order mixed usage	-	at least one lane in each direction must remain free of water
Vehicle-only routes	-	no encroachment on any lane

Dished roads or inverted crown roads are used only where slow, low density traffic is present and for lengths not exceeding 150 m. In essence, these apply more to pedestrian-only streets. Single cross-fall roads have reduced stormwater carrying capacity, due to the channel being on one side only.

5.2 Kerb and Grid inlets

At or upstream of the point at which the roadway flow is calculated to reach the capacity of the channel, a kerb inlet should be located to intercept and dispose of the stormwater. It is recommended that side opening kerb inlets should be used for all carriageways. Grid type inlets should be used only for draining areas where ponding occurs off roads, in medians, open areas or parking areas. Grid inlets are subject to blockage and require regular maintenance. The size provided should exceed the theoretical capacity required for free discharge under weir or orifice conditions.

The capacity of side opening kerb inlets can be calculated by methods outlined in various technical papers such as those by H Forbes and Z Zwamborn. Normally, inlets are designed for 80 % interception (20 % flow past). The minimum inlet opening normally used should be not less than 1,5 m.

In addition to kerb inlet locations dictated by flow and capacity considerations, inlets must be located at intersections and where necessary to prevent cross flows on carriageways and ponding.

5.3 Stormwater pipes

From the inlets, stormwater is carried in underground pipes. The design of pipes (normally concrete) and the bedding and laying thereof is a specialist study and is specified in detail by most authorities. The carrying capacity of the pipes is determined from Manning's uniform flow formula or Scobey's formula. Charts are published in various reference books and are also available from pipe manufacturers.

Regardless of capacity, the minimum size of pipes in public streets should be 300 mm diameter and many authorities specify a minimum of 450 mm diameter.

5.4 Culverts, canals and bridge openings

The capacity of all built-up sections shall be calculated by the Manning formula for channel flow or obtained from the charts based on this formula. The design of bridge openings is a specialist are beyond the scope of these notes.

5.5 Joints

Normally, ogee butt joints without seals are used for stormwater pipes. In dolomitic areas or sandy or active soils and in areas of unstable sloping ground, all joints must be made water tight.

5.5 Manholes and junction boxes

Manholes or junction boxes are located where stormwater drains join each other, and at sharp bends. At manholes, the soffit (overt) of the smaller drain should not be lower than that of the larger drain. The floors should be benched for the lower half of the pipe diameter to reduce turbulence.

5.6 Natural watercourses

The pipe and/or culvert system finally discharge into a natural watercourse or pond. The entry point should be protected against erosion. The capacity of the watercourse shall be checked to ensure that damage causing flooding will not result under storm flow conditions.

6 RURAL DRAINAGE

The geometric designer is required to produce a road on which the road user is safe at all times and "all times" includes during wet weather. Reference to all-weather roads implies that the convenience of access will be unaffected by weather conditions. Furthermore, a constructed road represents a substantial financial investment and it is necessary to safeguard that investment. Economy demands that it be protected against stormwater damage. It is however possible to meet these three objectives of safety, convenience and economy with regard to the road, but still wreak havoc on the surrounding environment. This can happen easily principally by virtue of the fact that rural roads tend to be barriers to stormwater flow; their stormwater management tends to create a concentration of water which can very easily result in downstream erosion, causing damage to farmlands and other property. As propounded by the Riekert Commission, roads and transport facilities should create minimum side effects, and this is also applicable to stormwater management.

One function not normally required of rural roads is to serve as a conduit for the drainage of the surrounding topography as is normally done with streets in the urban environment. Rural roads are not kerbed, and rainfall is removed from their surface as quickly as possible by having suitable surface slopes.

6.1 The safety of the road user

A road surface has a lower coefficient of friction when wet. Very few drivers are unaware of this phenomenon but remain undeterred. Speeds reduce marginally, if at all when it is wet, and headways do not increase. Special provision thus has to be made to protect the driver from the results of his own folly.

If the surface, instead of being merely wet, is overlain by a sheet of water, tyre treads fill with water faster than it can be drained away. A thin film of water bridges the gap between adjacent treads and the contact between tyre and road surface is broken. The vehicle is then aquaplaning and is totally out of control. This circumstance can arise from water standing on the road to a depth of just a few millimetres – it has been stated as eight to ten millimetres but may be less and aquaplaning is a threat when speeds reach 70 km/h or more.

Water flowing across the road can transport mud or silt onto the road surface. In this case, the possibility of skidding out of control extends beyond the duration of the storm that caused the flow in the first instance.

6.2 Road user convenience

Road user convenience is a feature of the all-weather road and requires that, regardless of weather conditions, the road will be passable at all times. Economic considerations preclude providing a drainage system that can cope with the worst storm of all time, but a return period of twenty years - or fifty years in the case of a major structure - for bridges and typically ten years for culverts should be within the capabilities of the system.

6.3 Protection of the road against erosion and seepage.

Water penetrating the design layers of the road pavement causes a loss of structural strength in these layers and can lead to premature deformation of the pavement.

Gravel surfaces on gradients lose their fine material and may be converted into boulder beds.

If water is allowed to flow down a fill slope, gully formation occurs, and these gullies can ultimately erode back across the shoulder and into the paved surface. Water flowing down cut slopes also leads to gully formation and the highly energised stream of water flowing down a gully can easily damage the shoulder in addition to transporting silt onto the road surface.

A longitudinal flow of water adjacent to the toe of a fill can progressively undercut the fill. It is extremely difficult to inhibit the failure mechanism that ensues. The toe of fill having become vertical is prone to develop slip circles which cause cracking either in the shoulder or in the paved surface which in turn allows the penetration of water. This water lubricates the shear plane of the slip circle enhancing the probability of failure of the fill.

The interface between in situ and imported material in the road formation is a discontinuity which can readily be attacked by seepage. On steep side slopes, a combination of inadequate benching and inadequate drainage can result in the entire road sliding to the valley below.

7 METHODOLOGIES OF RURAL DRAINAGE

Two fundamentally different approaches to rural drainage require consideration. The difference between them stems from the relative weighting attached to the various objectives listed previously, with convenience being a key element. Basically, a distinction is drawn between the provision of drainage in First World and Third World situations. The First World scenario may be seen as one where the traffic is of such volume that it justifies relatively high expenditure on drainage to sustain more-or-less uninterrupted traffic flow.

Convenience is a major feature of the First World environment, hence the importance attached to all-weather roads. Costs incurred in achieving convenience are seemingly not critical. The Third World or developing area on the other hand has a host of infrastructural demands competing for inadequate funding and convenience has to be sacrificed in terms of economic expediency. In both cases, protection of the investment made is important but the difference in value of objectives makes it possible to adopt differing techniques of stormwater management.

The First World situation requires drainage systems which do not allow stormwater to reach the road surface and which rapidly remove any water which falls onto the surface. These systems can broadly be referred to as upstream protection of the road. Third World drainage systems, on the other hand, allow stormwater to reach the road but then seek to minimise the resulting damage by means of downstream protection.

Upstream protection (“first world”) requires a system of cut-offs and drains which concentrate water at points where it can be taken across the reserve under the road. It follows that sufficient height of fill has to be provided to allow for culvert construction at frequent intervals. As a general rule of thumb, pipe culverts may be provided at 100 to 200 metre intervals in the absence of defined water courses and a height of fill of roughly one metre is required to accommodate these culverts. First World rural roads thus tend to have a vertical alignment running roughly one metre above ground level. Stormwater is concentrated into a series of smooth concrete pipes crossing the road. It can achieve substantial flow speeds in the pipes and it is necessary to disperse these flows in and perhaps beyond the road reserve if erosion is to be avoided.

Downstream protection (“third world”) is successful simply because it does not require stormwater to be concentrated upstream of the road. Overland flows tend to be dispersed and slow moving because of the friction offered by vegetation. This water is allowed to flow over the road by keeping the vertical alignment of the road surface as close as possible to natural ground level. The downstream “shoulder breakpoint” or edge of the road prism would be at or only slightly above natural ground level and, where it is above ground level, stone pitching protects the fill slope.

Watercourses are crossed by means of paved low-level causeways, which may be provided with sufficient piping to accommodate perennial flows. Not surprisingly, maintenance gangers often find that these pipes get blocked by the local inhabitants. The result is that the causeway becomes the weir of a shallow dam, which is useful for the supply of drinking water and laundry facilities to the community, without inhibiting the movement of traffic across the water course.

Storms upstream of the causeway cause the road to be impassable, but only for the relatively few hours required for the flood to subside. This is apparently not perceived as a matter of any particular consequence by the community.

8 DRAINAGE OF THE RURAL ROAD RESERVE

Drainage of the road reserve involves removal of water from the road surface into longitudinal drains and then its further removal to areas where it can safely be discharged downstream of the reserve. The rural approach to the drainage of water falling in the immediate area of and close to a road or street is in principle almost the diametrical opposite of urban drainage where water is drained towards the reserve rather than away from it.

Drainage of the road surface is achieved by provision of a camber, with the road surface dropping from a central crownline towards either side at a rate typically of 2 to 3 % or else a single crossfall to one side. In addition, road authorities sometimes specify a minimum gradient of 0,5 % along the road to assist in removal of stormwater. In practice, this is required only when the pavement is bounded by kerbs and channels and the problem can also be resolved by providing a separate channel grading.

Rural drainage is invariably achieved by means of open channels, mainly because of the ease of maintenance that they suggest. For these channels to be effective they must neither silt nor scour. Fine sands are no longer transported when water velocities are lower than 0,5 m/s, so that this represents a limit below which silting is likely. Unpaved drains should, in consequence, have gradients which are not flatter than 1:200. If drains are paved, the lower coefficient of friction makes it possible to achieve self-cleansing velocities at gradients of 1:300 and less. Practical experience indicates, however, that it is difficult to construct paved drains to the tolerances demanded by gradients flatter than this and local imperfections may cause silting of an otherwise adequate drain.

Natural top soil tends to scour when velocities exceed about 0,9 m/s. Clays and gravels scour at velocities in the range of 1,2 m/s to 1,5 m/s. Shales, depending on their hardness, can accommodate velocities of 1,8 to 2,4 m/s and rock is able to resist scour at velocities as high as 4,5 m/s. Study of the in-situ material and comparison with anticipated channel velocities is required in order to formulate a decision on paving as a means of overcoming scour. As a rough guide, an unpaved channel should not be steeper than 1:50.

As an alternative to paving a channel where the in-situ material may scour, it is possible to reduce velocities by constructing weirs across the unpaved drain. The drain will then become a series of stilling basins at consecutively lower levels. A major advantage of this technique is that the drain establishes its own invert level and is thus maintenance free.

Drainage structures close to the line of travel represent a hazard to road users. The designer must ensure that they are less of a hazard than the stormwater they are required to control, and this can be achieved by locating them as remotely as possible from the roadway and selecting a design of structure which will minimise the consequences of striking or traversing them.

8.1 Longitudinal drainage

Some typical components of rural drainage systems are illustrated in Figure M5.1.

8.1.1 Side drains

In cuts, water flows from the paved surface across the shoulder to a side drain.

The side drain is bounded on one side by a slope of 1:4, which provides some prospect of recovery to a vehicle that has left the shoulder. To get the side drain as far as possible from the road, it is located against the cut face.

Very often, a crest curve is in cut. The possibility arises that a longitudinal drain at a constant height below the gradeline will have an inadequate slope at the top of the curve. As an illustration, a curve with a K-value of 100 will have a gradient of less than 1:200 for a distance of 50 metres on either side of the crest. It will therefore be necessary to provide a forced channel grading over this section of the cut, by making the cross-fall less than 1:4 at the flattest point and gradually steepening it back to 1:4 over a length of say 50 metres. The drain capacity will be reduced just at the crest where the capacity needed is least.

In the past, it was the practice to give the side drain a minimum depth of 500 mm to ensure that the design layers did not get wet. More recently, concern for the safety of the road user has dictated that 500 mm now be considered a maximum depth, it having been established that fears for the integrity of the design layers were unfounded. What it amounts to is simply that water does not stay in the channel long enough to be able soak all the way through to the design layers under the roadway. The separate channel grading often applied to the top of the crest curve thus commences at the height of the shoulder breakpoint, ie zero depth, and is constructed at a constant fall of not less than 1:200 to a point where two conditions are satisfied, namely that:

- ❑ a depth sufficient to accommodate the anticipated quantity of water has been achieved,
- ❑ the “unforced” vertical alignment reflects a gradient of 0,5 % or more.

The minimum width of drain is taken as 900 mm purely because a lesser width is inconvenient to clear by hand. If the drain extends over a considerable distance without there being any possibility of discharging the accumulated water, a greater width of drain has to be provided by widening the cut rather than steepening the slope between the drain and the shoulder breakpoint. If widening is not practical, the capacity of the drain can be improved by means of paving which will increase flow velocity.

The side drain can be extended past the end of the cutting along the toe of the fill, until it can emerge at ground level. It is usually located close to the reserve boundary fence to avoid damage to the toe itself.

8.1.2 Edge drains on embankments

Water flowing across a shoulder and down the fill slope can lead to erosion. Guardrail posts tend to serve as points of concentration of water so that, as a general rule, edge drains are needed where there are guardrails, or where the fill material is erodible. Edge drains are raised rather than depressed because the latter may result in vehicle's wheels snagging under the guardrail.

8.1.3 Chutes

The need to provide edge drains in the first instance automatically requires that chutes be provided to transport stormwater down the fill slope at intervals. Chutes can be anything from a half-round pipe to a major structure and water speeds are very high. Stilling basins are required at their outlets if downstream erosion is to be avoided. Attention has to be paid to the chute inlet to ensure that water is properly deflected out of the edge drain. Without this deflection, the lowest chute in the series may be flooded with consequential severe damage to the fill.

8.1.4 Median drains

A median drain carries the water falling on the median, and on horizontal curves, prevents water from the outside carriageway flowing across the inner carriageway. Because of the space available, these drains are seldom paved and are invariably grassed with a shallow V-profile the bottom of which is gently rounded. Median drains typically discharge via grid inlets into a simple underground system, usually comprising a series of short pipes under a carriageway, discharging into a toe drain, or at ground level outside the road prism. On occasion the median inlets may have to discharge into a longitudinal pipe also in the median. This can occur for example in a long cutting where lateral discharge is not possible.

8.1.5 Catchwater drain

The catchwater drain is intended to protect cut slopes from overland flow which runs into the road reserve from one side. It is a raised berm and relies on grassing of the natural topsoil to restrict water speeds. Transverse weirs can also be used if necessary. These drains find application even if the cut is excavated in material which is unlikely to scour because they also have the effect of reducing the quantity of water that has to be removed by the side drain at the bottom of the cut face.

8.2 Transverse drainage

The sole object in providing a rural road with stormwater drainage is to get water away from the road as quickly as possible. The sole purpose of longitudinal drainage is thus only to transport water to a point where transverse drainage can take place.

Transverse drainage of the road surface is by means of the camber or crossfall, as discussed. Transverse drainage of the road reserve is typically achieved in conjunction with the drainage of the “external” catchment area. Culverts are located and sized to accommodate watercourses crossing the road reserve. Their sizing must allow for the drainage of the external catchment plus the upstream side of the reserve.

Drainage of the sides of the reserve area can be managed by the placing of mitre banks at regular intervals to protect a toe drain. These banks deflect water from the toe drain and may be stone pitched to accommodate the change of direction forced on the flow of water, since this change of direction can ultimately cause the mitre banks to be breached. Mitre banks are provided at regular intervals to disperse the water as evenly as possible onto adjacent farm lands and, to reduce water speed, they can also be ngled towards nearly parallel with the natural contours.

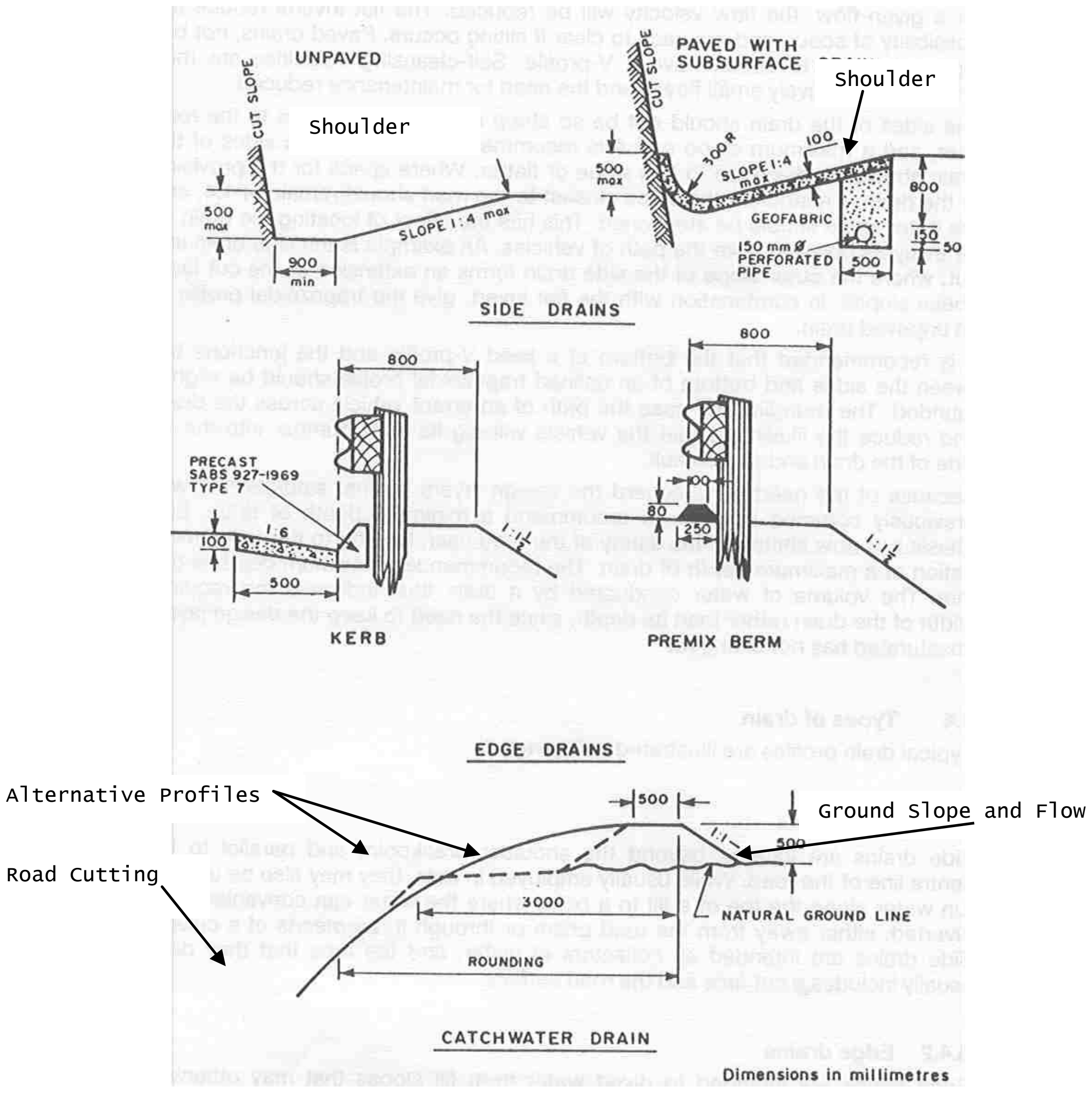


Figure M5.1: Typical rural drainage components