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CHAPTER 11 STORMWATER DRAINAGE

11.1 INTRODUCTION

11.1.1 General

Stormwater drainage is the science of draining that part of rainfall which appears on the surface and disposing it to an acceptable disposal site, e.g. Stream, Lake or Ocean through an outfall. With increasing urbanisation it becomes increasingly important but is far too often neglected or relegated to an afterthought in the development of urban infrastructure.

This science is important because unattended high flood levels can cause property damage, loss of life and other problems to the health of a society e.g. contaminating the ground with sewage from flooded septic tanks and pit latrines.

In the past, attention to this problem has been severely limited, especially in unplanned peri-urban areas with the consequence that in the rainy seasons, poorer residents having access to it, use ponded, polluted surface water even when potable water is available at kiosks and the overflow from pit latrines in particular, draining into such depressions, is a principle cause of disease outbreaks such as cholera.

Whilst an adequate network of properly constructed and maintained drains can help alleviate this problem, there remain the problems of flood flow peaks and pollution.

Alleviating flood flow peaks is most easily done by use of natural flood plains and wetlands and many towns and Cities in Tanzania originally contained such natural features. Regrettably over the years many of these have been reclaimed and built upon with the result that urban run-off increasingly causes flooding and destruction of property as well as occasional loss of life.

Another increasing problem is the pollution load being conveyed by stormwater drainage systems out into rivers, lakes and the ocean and again this is a problem rarely addressed until now.

New sections have therefore been added to this Chapter to introduce the subject, (Section 11.2); and to discuss flow storage and control structures to alleviate flooding and pollution control measures to try and reduce the downstream flood peak and pollution problem (Section 11.7). Otherwise only minor revisions have been made to the previous edition.

11.1.2 Definitions

The following definitions are applicable to this Chapter:

(i) **Catchment Area (A)**

This is the area to be considered for drainage.

(ii) **Rainfall Intensity; (i)**

This is the rate at which rainfall occurs expressed in depths units per unit time. It is the ratio of the total amount of rain to the length of the period in which the rain falls.

(iii) **Run- off coefficient (c)**

The ratio of the maximum rate of runoff, to the uniform rate of rainfall with a duration equal or exceeding the time of concentration which produced this rate of runoff.

(iv) **Storm Flow; (Q)**

This is the portion of the total precipitation from a given area that appears in natural or artificial surface streams.

(v) **Time of concentration; (tc)**

This is the total time spent by a droplet reaching the ground surface from the remotest point in the catchment to travel all the way down the channel.

(vi) **Return Period, (Tr)**

This is the average time interval in years between the occurrence of a flood of a specified magnitude and an equal or larger flood.

11.2 IMPACTS OF URBANISATION ON STORMWATER RUNOFF

Development in general but urban development in particular changes not only the physical, but also the chemical and biological conditions of waterways and downstream water resources.

When land is developed, the hydrological cycle is disrupted and altered. Clearing removes the vegetation that intercepts and slows runoff allowing the return of rainfall to the air through evaporation and transpiration. Grading flattens hilly terrain and fills in natural depressions that slow and provide temporary storage for rainfall, scraping off and removing the topsoil and layers of humus and compacting the remaining subsoil. Rainfall that once percolated into the ground now runs off the surface. The addition of buildings, roadways, parking lots and other surfaces that are impervious to rainfall further reduces infiltration and increases runoff.

Depending on the magnitude of change to the land surface, the total runoff volume can increase dramatically. These changes both increase the total volume of runoff, and accelerate the rate at which runoff flows across the land. This effect is further exacerbated by drainage systems such as gutters, storm drains and lined channels that are designed to quickly carry runoff away from the development to rivers and streams.

Development of impervious surfaces also reduces the amount of water that infiltrates into the soil and groundwater, thus reducing the amount of water that can recharge aquifers and feed streamflow during periods of dry weather.

Finally, development and urbanization affect not only the quantity of stormwater runoff, but also its quality. Development increases both the concentration and types of pollutants carried by runoff. As it runs off rooftops and gardens, roads, parking lots and industrial sites, stormwater picks up and transports a variety of contaminants and pollutants to downstream waterbodies.

The cumulative impact of development and urbanisation, and the resultant changes to both stormwater quantity and quality in the entire land area that drains to a stream, river, lake or estuary determines the conditions of the waterbody. Urban development in particular within a watershed has a number of direct impacts on downstream waters and waterways, including:

- Changes to stream flow
- Changes to stream geometry
- Degradation of aquatic habitat
- Water quality impacts

11.2.1 Changes to Stream Flow

Urban development alters the hydrology of watersheds and streams by disrupting the natural water cycle resulting in:

- Increased Runoff Volumes – Land surface changes can dramatically increase the total volume of runoff flowing in and from a developed watershed.
- Increased Peak Runoff Discharges – Increased peak discharges for a developed watershed can be two to five times higher than those for an undisturbed watershed.
- Greater Runoff Velocities – Impervious surfaces and compacted soils, as well as improvements to the drainage system such as storm drains, culverts and ditches, increase the speed at which rainfall runs off land surfaces within a watershed.
- Timing – As runoff velocities increase, it takes less time for water to run off the land and reach a stream or other waterbody.
- Increased Frequency of Bankfull and Near Bankfull Events – Increased runoff volumes and peak flows increases the frequency and duration of smaller bankfull and near bankfull events which are the primary channel forming events.
- Increased Flooding – Increased runoff volumes and peaks increase the frequency, duration and severity of out-of-bank flooding.
- Lower Dry Weather Flows (Baseflow) – Reduced infiltration of stormwater runoff causes streams to have less baseflow during dry weather periods and reduces the amount of rainfall recharging groundwater aquifers.

A diagrammatic representation of what occurs is shown in Figure 11.1 below:

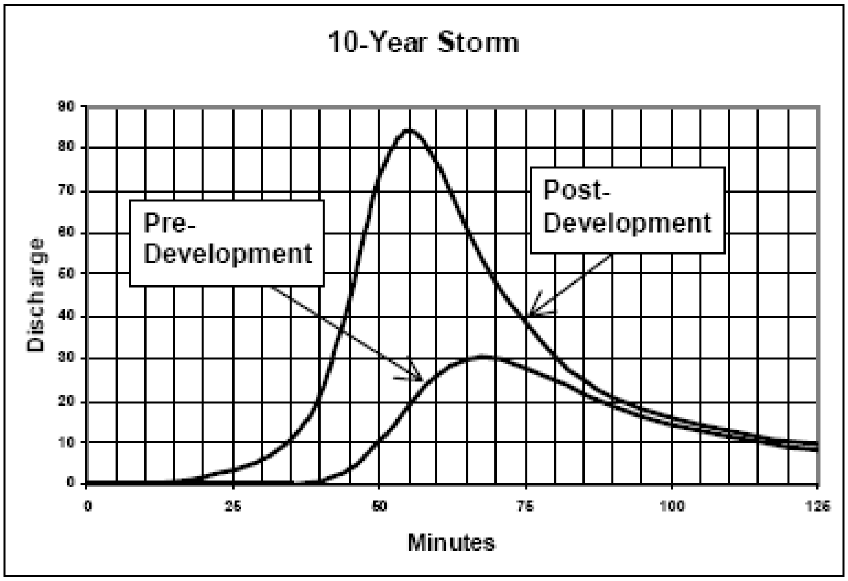


FIGURE 11.1: TYPICAL HYDROGRAPH UNDER PRE- AND POST DEVELOPMENT CONDITIONS

11.2.2 Changes to Stream Geometry

The changes in the rates and amounts of runoff from developed watersheds directly affect the morphology, or physical shape and character, of Georgia's streams and rivers. Some of the impacts due to urban development include:

- Stream Widening and Bank Erosion – Stream channels widen to accommodate and convey the increased runoff and higher stream flows from developed areas. More frequent small and moderate runoff events undercut and scour the lower parts of the streambank, causing the steeper banks to slump and collapse during larger storms. Higher flow velocities further increase streambank erosion rates. A stream can widen many times its original size due to post-development runoff.
- Stream Downcutting – Another way that streams accommodate higher flows is by downcutting their streambed. This causes instability in the stream profile, or elevation along a stream's flow path, which increases velocity and triggers further channel erosion both upstream and downstream.
- Loss of Riparian Tree Canopy – As streambanks are gradually undercut and slump into the channel, the trees that had protected the banks are exposed at the roots. This leaves them more likely to be uprooted during major storms, further weakening bank structure.
- Changes in the Channel Bed Due to Sedimentation – Due to channel erosion and other sources upstream, sediments are deposited in the stream as sandbars and other features, covering the channel bed, or substrate, with shifting deposits of mud, silt and sand.
- Increase in the Floodplain Elevation – To accommodate the higher peak flow rate, a stream's floodplain elevation typically increases following development in a watershed due to higher peak flows. This problem is compounded by building and filling in floodplain areas, which cause flood heights to rise even further. Property and structures that had not previously been subject to flooding may now be at risk.

These effects are illustrated in the following schematic.

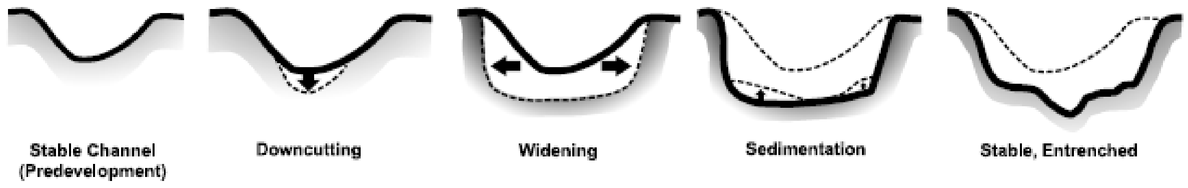


FIGURE 11.2: CHANGES TO A STREAM'S PHYSICAL CHARACTER DUE TO WATERSHED DEVELOPMENT

11.2.3 Impacts to Aquatic Habitat

Along with changes in stream hydrology and morphology, the habitat value of streams diminishes due to development in a watershed. Impacts on habitat include:

- Degradation of Habitat Structure – Higher and faster flows due to development can scour channels and wash away entire biological communities. Streambank erosion and the loss of riparian vegetation reduces habitat for many fish species and other aquatic life, while sediment deposits can smother bottom-dwelling organisms and aquatic habitat.

- Loss of Pool-Riffle Structure – Streams draining undeveloped watersheds often contain pools of deeper, more slowly flowing water that alternate with “riffles” or shoals of shallower, faster flowing water. These pools and riffles provide valuable habitat for fish and aquatic insects. As a result of the increased flows and sediment loads from urban watersheds, the pools and riffles disappear and are replaced with more uniform, and often shallower, streambeds that provide less varied aquatic habitat.
- Reduced Baseflows -- Reduced baseflows due to increased impervious cover in a watershed and the loss of rainfall infiltration into the soil and water table adversely affect in-stream habitats, especially during periods of drought.
- Increased Stream Temperature – Runoff from warm impervious areas, storage in impoundments, loss of riparian vegetation and shallow channels can all cause an increase in temperature in urban streams. Increased temperatures can reduce dissolved oxygen levels and disrupt the food chain. Certain aquatic species can only survive within a narrow temperature range. Thermal problems are especially critical for streams flowing from highland which straddle the borderline between coldwater and warmwater stream conditions.
- Decline in Abundance and Biodiversity – When there is a reduction in various habitats and habitat quality, both the number and the variety, or diversity, of organisms (wetland plants, fish, macroinvertebrates, etc.) are also reduced. Sensitive fish species and other life forms disappear and are replaced by those organisms that are better adapted to the poorer conditions. The diversity and composition of the benthic, or streambed, community can be used to evaluate the quality of urban streams. Aquatic insects also are a useful environmental indicator as they form the base of the stream foodchain.

Fish and other aquatic organisms are impacted not only by the habitat changes brought on by increased stormwater runoff quantity, but are often also adversely affected by water quality changes due to development and resultant land use activities in a watershed.

11.2.4 Water Quality Impacts

Non-point source pollution, which is the primary cause of polluted stormwater runoff and water quality impairment, comes from many diffuse or scattered sources, many of which are the result of human activities within a watershed. Development concentrates and increases the amount of these non-point source pollutants. As stormwater runoff moves across the land surface, it picks up and carries away both natural and human-made pollutants, depositing them into streams, rivers, lakes, wetlands, coastal waters and marshes, as well as in to underground aquifers. Other than increased sediment load from de-forestation and river bank cultivation, non-point source pollution is the leading source of water quality degradation. Water quality degradation in urbanizing watersheds starts when development begins.

Erosion from construction sites and other disturbed areas contribute large amounts of sediment to streams. As construction and development proceed, impervious surfaces replace the natural land cover and pollutants from human activities begin to accumulate on these surfaces. During storm events, these pollutants are then washed off into the streams. Stormwater also causes discharges from sewer overflows and leaching from septic tanks and pit latrines. There are a number of other causes of non-point source pollution in urban areas that are not specifically related to wet weather events including leaking sewers, sanitary sewage spills, and illicit discharge of commercial/industrial wastewater and wash waters to storm drains. Due to the magnitude of the problem, it is important to understand the nature and sources of urban stormwater pollution. Table 11.1 summarizes the major stormwater pollutants and their effects. Some of the most frequently occurring pollution impacts and their sources for urban streams are:

- Reduced Oxygen in Streams – The decomposition process of organic matter uses up dissolved oxygen (DO) in the water, which is essential to fish and other aquatic life. As organic matter is washed off by stormwater, dissolved oxygen levels in receiving waters can be rapidly depleted. If the DO deficit is severe enough, fish kills may occur and stream life can weaken and die. In addition, oxygen depletion can affect the release of toxic chemicals and nutrients from sediments deposited in a waterway.

  All forms of organic matter in urban stormwater runoff contribute to the problem. In addition, there are a number of non-stormwater discharges of organic matter to surface waters such as sanitary sewer leakage and septic tank and pit latrine leaching. Another major problem in Tanzanian towns is the ubiquitous plastic bag, often filled with household waste all too many of which end up in watercourses, polluting the environment both chemically and visually.

TABLE 11.1: SUMMARY OF URBAN WATER POLLUTANTS

Constituents	Effects
Sediments—Suspended Solids, Dissolved Solids, Turbidity	Stream turbidity Habitat changes Recreation/aesthetic loss Contaminant transport Filling of lakes and reservoirs
Nutrients—Nitrate, Nitrite, Ammonia, Organic Nitrogen, Phosphate, Total Phosphorus	Algae blooms Eutrophication Ammonia and nitrate toxicity Recreation/aesthetic loss
Microbes—Total and Fecal Coliforms, Fecal Streptococci Viruses, E.Coli, Enterocci	Ear/Intestinal infections Shellfish bed closure Recreation/aesthetic loss
Organic Matter—Vegetation, Sewage, Other Oxygen Demanding Materials	Dissolved oxygen depletion Odors Fish kills
Toxic Pollutants—Heavy Metals (cadmium, copper, lead, zinc), Organics, Hydrocarbons, Pesticides/Herbicides	Human & aquatic toxicity Bioaccumulation in the food chain
Thermal Pollution	Dissolved oxygen depletion Habitat changes
Trash and debris	Recreation/aesthetic loss

- Nutrient Enrichment – Runoff from urban watersheds contains increased nutrients such as nitrogen and phosphorus compounds. Increased nutrient levels are a problem as they promote weed and algae growth in lakes, streams and estuaries. Algae blooms block sunlight from reaching underwater grasses and deplete oxygen in bottom waters. In addition, nitrification of ammonia by micro-organisms can consume dissolved oxygen, while nitrates can contaminate groundwater supplies. Sources of nutrients in the urban environment include wash-off of fertilizers and vegetative litter, animal wastes, sewer overflows and leaks, septic tank and pit latrine seepage, detergents, and the dry and wet fallout of materials in the atmosphere.

- Microbial Contamination – The level of bacteria, viruses and other microbes found in urban stormwater runoff often exceeds public health standards for water contact recreation such as swimming and wading. Microbes can also contaminate shellfish beds, preventing their harvesting and consumption, as well as increasing the cost of treating drinking water. The main sources of these contaminants are sewer overflows, septic tanks, and pit latrines, and urban wildlife such as rats, crows, and pigeons.
- Hydrocarbons – Fats, oils, and greases contain a wide array of hydrocarbon compounds, some of which have shown to be carcinogenic, tumorigenic and mutagenic in certain species of fish. In addition, in large quantities, oil can impact drinking water supplies and affect recreational use of waters. Oils and other hydrocarbons are washed off roads and parking lots, primarily due to engine leakage from vehicles. Other sources include the improper disposal of motor oil in storm drains and streams, spills at fueling stations and the lack of or poorly maintained restaurant grease traps.
- Toxic Materials – Besides fats, oils and greases, urban stormwater runoff can contain a wide variety of other toxicants and compounds including heavy metals such as lead, zinc, copper, and cadmium, and organic pollutants such as pesticides, PCBs, and phenols. These contaminants are of concern because they are toxic to aquatic organisms and can bio-accumulate in the food chain. In addition, they also impair drinking water sources and human health. Many of these toxicants accumulate in the sediments of streams and lakes.

  Sources of these contaminants include industrial and commercial sites, urban surfaces such as rooftops and painted areas, vehicles and other machinery, improperly disposed household chemicals, landfills, hazardous waste sites and atmospheric deposition.
- Sedimentation – Eroded soils are a common component of urban stormwater and are a pollutant in themselves. Excessive sediment can be detrimental to aquatic life by interfering with photosynthesis, respiration, growth and reproduction. Sediment particles transport other pollutants that are attached to their surfaces including nutrients, trace metals and hydrocarbons. High turbidity due to sediment increases the cost of treating drinking water and reduces the value of surface waters for industrial and recreational use. Sediment also fills ditches and small streams and clogs storm sewers and culverts, causing flooding and property damage. Sedimentation can reduce the capacity of reservoirs and lakes, and silt estuaries. Erosion from construction sites, exposed soils, street runoff, and streambank erosion are the primary sources of sediment in urban runoff.
- Higher Water Temperatures – As runoff flows over impervious surfaces such as tarma and concrete, it increases in temperature before reaching a stream or pond. Water temperatures are also increased due to shallow ponds and impoundments along a watercourse as well as fewer trees along streams to shade the water. Since warm water can hold less dissolved oxygen than cold water, this ‘thermal pollution’ further reduces oxygen levels in depleted

urban streams. Temperature changes can severely disrupt those aquatic species which survive within a narrow temperature range.

- Solid waste and Debris – Considerable quantities of solid waste and other debris are washed through storm drain systems and into streams, lakes and estuaries. The primary impact is the creation of an aesthetic 'eyesore' in waterways and a reduction in recreational value. n smaller streams, debris can cause blockage of the channel, which can result in localized flooding and erosion.

11.2.5 Addressing Stormwater Impacts

The focus of any stormwater drainage system design is more than just designing drains, channels and culverts to convey the stormwater away from human habitation etc. It is how to effectively deal with the impacts of urban stormwater runoff through effective and comprehensive stormwater management. This involves both the prevention and mitigation of stormwater runoff quantity and quality impacts through a variety of methods and mechanisms.

Stormwater management is a topic well beyond the scope of this Design manual which can only deal with basic design principles and highlight the need for a comprehensive management policy for Local Authorities. Responsible development can however assist and some of these aspects are discussed in later Sections suggesting ways in which system design can assist in the implementation of stormwater management and help address the impacts of new development and redevelopment, and both prevent and mitigate problems associated with stormwater runoff.

Overall however this can only be accomplished by:

- Developing land in a way that minimizes its impact on a watershed, and reduces both the amount of runoff and pollutants generated;
- Using the most current and effective erosion and sedimentation control practices during the construction phase of development;
- Controlling stormwater runoff peaks, volumes and velocities to prevent both downstream flooding and streambank channel erosion;
- Where financially possible, treating post-construction stormwater runoff before it is discharged to a waterway;
- Implementing pollution prevention practices to prevent stormwater from becoming contaminated in the first place; and
- Using various techniques to maintain groundwater recharge.

11.2.6 Urban Flooding Risks

There will always be risks of loss of life due to urban flooding.

However, it is possible to cite conditions under which rain storms may cause heavy flooding and risk to life and experience elsewhere in East Africa has made a basic level of prediction practicable even down to determining the potentially most dangerous week or weeks of the year. These are based on analysis of rainfall patterns, on ground conditions, antecedent rainfall and timing of the rain storm. In general, several days of antecedent rain that has saturated the ground and an afternoon - evening storm which peaks during the late evening have been associated with the greatest loss of life. Town and City Authorities should be made aware of this and should such conditions occur, warnings broadcast over the radio can be very effective in putting citizens on their guard during such situations.

Motorists also need to be made aware of the dangers of rain falling after long dry spells when rubber from tyres will make surfaced roads very slippery, whilst even shallow sheet flow of water across a road can carry lighter vehicles off the road altogether. Timely newspaper articles, television and radio broadcasts can also assist here.

11.3 URBAN AND SITE PLANNING

It is beyond the scope of this Design Manual to address the issues of Urban Planning and Site Layout Detailing. Suffice to say that what Urban Planning is done is rarely adhered to and the concept of Site layout detailing to minimise off-site stormwater quantity and quality problems is all too rarely considered by architects and builders.

The result is the engineer charged with designing stormwater systems is left with the mess to sort out and results in costly infrastructure and continuing environmental degradation. The principles that need to be addressed are however quite clear and include:

The basis needs to be a set of minimum stormwater standards to guide urban planners and architects and builders.

The goal of a set of minimum stormwater management standards for areas of new development and significant redevelopment is to reduce the impact of post-construction stormwater runoff on the watershed. Assuming some basic urban planning has been undertaken and is being adhered to, at site level this can best be achieved by:

(1) maximizing the use of site design and non-structural methods to reduce the generation of runoff and pollutants;
(2) managing and treating stormwater runoff though the use of structural stormwater controls; and
(3) implementing pollution prevention practices to limit potential stormwater contaminants.

However, once minimum standards are introduced, the following development activities are suggested to be exempted from the minimum stormwater management standards:

- Developments that do not disturb more than 500 square metres of land;
- Individual single family residential plots. (Where single family plots are part of a subdivision or phased development project, then at the project level there should not be an exemption from the minimum standards); and
- Additions or modifications to existing single-family structures.

It is recommended that Municipal and Town Planners should be encouraged to set a number of minimum standards that are then to be applied in their area of jurisdiction. Taking into account local conditions and the extent of land, wetland and downstream watershed degradation that has already occurred, as relevant to a particular situation these should be required to address or provide:

(1) Better Site Design Practices for Stormwater Management
(2) Stormwater Runoff Quality Proposals
(3) Stream Channel Protection Measures

(4) Overbank Flood Protection
(5) Extreme Flood Protection
(6) Downstream Hydrologic Analysis
(7) Groundwater Recharge Possibilities
(8) Construction Erosion and Sedimentation Control
(9) Stormwater Management System Operation and Maintenance
(10) Pollution Prevention
(11) Stormwater Management Site Plan to address the above ten requirements

11.4 DESIGN CRITERIA

Once faced with an actual situation, however poor, the designer of a stormwater drainage system must first determine the quantity of water to be accommodated.

Drainage works are usually designed to dispose of the flow from a storm having a specified return period, Tr which is found by applying the following expression to the historic database:

$$Tr = (N+1) / M) \tag{11.1}$$

Where, N = Number of times of flood occurrence, and
M = Number of years between flood occurrence

11.4.1 Determination of Quantity of Stormwater

Due to the random nature of the occurrence of rain storms, the engineer does not know at the design stage, what the maximum flow through his/her storm drainage system will be over its expected life time. Likely flows must be estimated on the basis of the analysis of past rainfall data.

A widely used statistical description of heavy rainfalls is that of intensity – duration - frequency curves (I-D-F curves) as illustrated in Figure 11.3. Such curves are developed by processing the data describing the time variation of the rain intensity for a large number of storms observed at a recording station over a number of years.

Once again however, caution is advised as the presently predicted effects of global warming will be to increase storm intensity, even if total annual rainfall remains largely unchanged or only likely to show minor plus/minus variations from the recent historic past. However, unless or until climate change prediction models become more precise, the only recourse open to the designer is to draw the Clients attention to this and/or suggest a slightly more rigorous return period than has been used in the past.

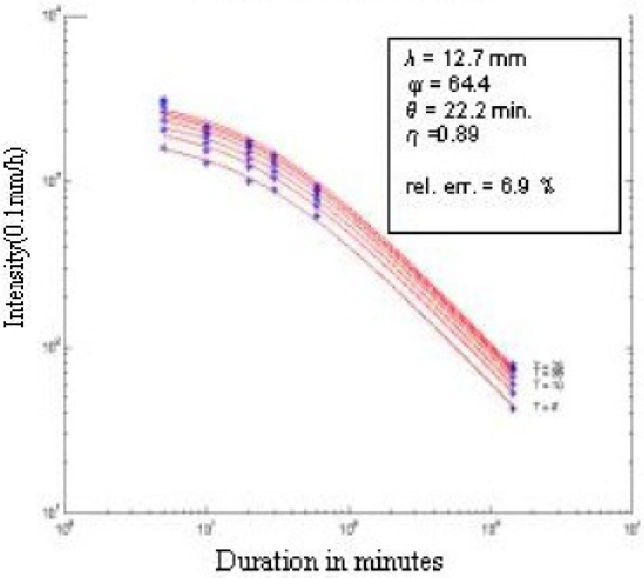


FIGURE 11.3: TYPICAL INTENSITY-DURATION-FREQUENCY CURVES

If there is enough data available, the design storm can otherwise be selected on the basis of I-D-F-curves, i.e. select the heaviest storms that the storm drainage system is designed to allow for without any flooding.

11.4.2 Rainfall - Intensity - Duration – Frequency Relationships

The rate at which rain falls over an area and its duration are of importance for several reasons. A duration equal to the time of concentration, or the time required for the water to run from the furthest part of the catchment basin to the point in question, is critical since the shorter the duration of a rain storm the greater may be its average intensity. The greater intensity to be expected for the critical duration therefore will produce the greatest runoff.

For drainage districts and storm sewers it is rarely economical to design for the greatest rainfall and therefore it is usual to consider that such structures may be overtopped at intervals of 2,5, 25 & even 50 years or other periods depending up on the cost of the structure and the damage that will result in overtopping.

If sufficient local data are available, frequencies can be computed by the designer using the formula in equation 11.1.

When designing the drainage system on the basis of extremely rare and heavy rainstorms (long return period), the cost of drainage structures will be very high and the costs due to flooding and damage over a period of years will on the other hand, usually be low. Low construction costs but higher costs due to frequent flooding will result from using design storms with a short return period, Ideally, the selection of a return period for storms should reflect an economic balance between the cost of drainage structures and the cost of possible damage due to flooding. The difficulty in such instances is to estimate the likelihood as to loss of life that such designs may cause.

Tests on urban catchments have shown that for the determination of peak runoff discharges, the Rational Method gives sufficiently accurate results for catchments of up to about 50 ha. Due to assumptions regarding homogeneity of rainfall and equilibrium conditions at the time of peak flow, the rational method should not be used on areas larger than this without subdividing the overall watershed into sub-basins including the effect of routing through any drainage channels, whilst for areas more than 50 ha the UK TRRL (Transport and Road Research Laboratory) method should be used, but preferably the former as it was specifically developed for eastern Africa unless a more recent Rainfall – Intensity - Duration analysis is unavailable.

(a) The Rational Method

If rainfalls were applied at a constant rate to an impervious surface, the runoff from the surface will eventually reach a rate equal to the rate of rainfall. The time required to reach this equilibrium is the time of concentration, tc, and for small impervious areas it can be assumed that if rain persists at a uniform rate for a period at least as long as tc, the peak of runoff will equal the rate of rainfall. This is the basis of the Rational formula originally developed in imperial units.

$$Q = k \times C \times i \times A \qquad 11.2$$

Where, Q = runoff discharge (m³/s)

k = conversion factor = 0.00278

C = dimensionless runoff coefficient

i = rain intensity (mm/h)
A = catchment area (ha)

The rain runoff discharge (Q) is that portion of the total precipitation from a given area, that appears in natural or artificial surface streams, whilst the catchment area (A) is the surface area (watershed) which contributes its drained waters to a specific site.

The rainfall intensity (i) is the maximum or peak flow of a runoff depends on the intensity and duration of rainfall. The intensities are derived with the analysis of rainfall charts (I-D-F-curves) corresponding to the selected return period, Tr.

Runoff coefficient (C) – is the ratio of the maximum rate of run – off to the uniform rate of rainfall with a duration equalling or exceeding the time of concentration which produce this rate of runoff, values for which are given in the following Table.

TABLE 11.2: COEFFICIENTS OF RUN OFF FOR USE IN THE RATIONAL METHOD

AREA DESCRIPTION	COEFFICIENT C
Business	
CBD	0.70-0.95
Neighbourhood	0.50-0.70
Residential	
Single-Family	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Residential (suburban)	0.25-0.40
Apartment	0.50-0.70
Industrial	
Light	0.50-0.80
Heavy	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.35
Railroad yard	0.20-0.35
Unimproved	0.10-0.30

CHARACTER OF SURFACE	RUNOFF COEFFICIENT C
Pavement	
Asphaltic and concrete	0.70-0.95
Brick	0.70-0.85
Roofs	0.75-0.95
Lawns, sandy soil	
Flat, 2 percent	0.05-0.10
Average, 2-7 percent	0.10-0.15
Steep, 7 percent	0.15-0.20
Lawns, heavy soil	
Flat, 2 percent	0.13-0.17
Average, 2-7 percent	0.18-0.22
Steep, 7 percent	0.25-0.35

(b) TRRL Method

The TRRL Method was developed specifically for Tanzania, Kenya and Uganda using rainfall data for a selected number of stations and resulting in a number of Tables and Graphs that are referred to in its application.

See TRRL Report 623 'The Prediction of Storm Rainfall in East Africa', 1974, and TRRL Report 706 'The East African Flood Model', 1976. Copies of the Reports can be downloaded from the DfID web site after free registration at: <www.transport-links.org/>.

The Intensity – Duration relationship applicable for durations between 15 minutes and 24 hours takes the form:

$$I = a / (T + b)^n \qquad 11.3$$

Where,

I = intensity (mm/hr)

T = return period (yr)

and 'a', 'b' and 'n' are constants.

Based upon the work by TRRL an acceptable value for 'b' for Tanzania was found to be $^1/_3$.

Data derived for the other two constants for some rainfall stations in Tanzania are shown in Table 11.3, below:

TABLE 11.3: INTENSITY – DURATION RELATIONSHIPS IN TANZANIA FOR SOME MAJOR CENTRES IN TANZANIA

STATION	2 - YEAR		5 - YEAR		10 - YEAR	
	a	n	a	n	a	n
Dar es Salaam	57.83	0.91	68.83	0.86	77.41	0.84
Dodoma	55.35	0.95	71.28	0.91	82.43	0.88
Kigoma	58.51	0.97	74.79	0.88	83.89	0.86
Mbeya	42.20	0.97	55.62	0.97	64.16	0.98
Tabora	55.20	1.00	70.84	1.02	82.52	1.03
Zanzibar	59.83	0.81	76.06	0.72	86.29	0.69

Because a constant value for 'n' could not be applied to the whole of East Africa, the area was split up into four zones, namely:

(a) Coastal strip
(b) Arid
(c) Central Highlands
(d) Inland (all other zones)

For specific application of the TRRL Method, refer to the maps and charts in the two publications mentioned above.

(c) SCS Method

The US Soil Conservation Service (SCS) [now USDA Natural Resources Conservation Service] hydrologic method requires basic data similar to that of the Rational Method, namely: drainage area, a runoff factor, time of concentration, and rainfall. The SCS approach, however, is more sophisticated in that it also considers the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that decreases during the course of a storm. Details of the original 1962 methodology can be found in the SCS 'National Engineering Handbook, Section 4, Hydrology', and the latest updated version, (2004), entitled 'Part 630 Hydrology Chapter 10 Estimation of Direct Runoff from Storm Rainfall'; both obtainable from <www.info.usd.gov/CED/>.

If the SCS method is to be used, it is advisable to first check the results against those for a nearby gauged catchment to ensure the accuracy level is acceptable. However, some designers prefer to use both TRRL and SCS methods and compare results before deciding on which is the more applicable in any particular circumstance.

11.4.3 Factors Affecting Run - off

Factors that effect Run-off include rainfall, solar-radiation, geology of the area, shape and character of the drainage area, soil characteristics and soil cover.

a) Rainfall

The total precipitation should be learned and its character i.e. the proportion of rain and snow. The distribution is important since rains occurring during the growing season for vegetation may contribute little to run-off. The intensity, duration, extent and usual path of storms will have an effect upon the amount of precipitation and flood flows.

b) Solar radiation

Solar radiation and its variations on the watershed will affect evaporation. Low radiation causes low temperature, whilst the amount and type of vegetal cover affects infiltration and the loss of water by transpiration.

c) Topography

The topography of the drainage area, its degree of roughness and slope affects the time of concentration of the direct runoff and there by cause high or low run off rates. Evaporation is not very important during floods because they generally occur in a time scale so short that, the amount of evaporation is small; peak rates of runoff are greater when concentration times are short because all the runoff is delivered in a short period.

d) Geology of the area

The perviousness or imperviousness of the sub terrain formations is important. If pervious, the slopes of the strata and their extent and points of discharge require study. The condition of the channel of the stream, whether it is pervious or there is an extensive under flow, will greatly affect the surface flow.

e) Shape and character of the drainage area

This will affect concentration and runoff. Shapes providing quickest concentration will tend to produce greatest, peak flow. The relation to mountains, the ocean, large lakes and wooded areas may also have important effects.

f) Infiltration

The entrance of rainwater into the ground is known as infiltration. The amount of infiltration depends up on a number of conditions on the watershed, the more important of which are discussed below:

g) Rainfall characteristic

A small rainfall may all be absorbed and produce no run off. Heavy rains compact the soil surface by impact of the raindrops and reduce entrance. This is especially noted on bare soils even where cultivated. The increased porosity resulting from plowing or cultivating is soon lost by compaction. Storms of low intensity are likely to have high infiltration rates.

h) Soil characteristics

The smaller pore sizes in the surface soil, the smaller will be infiltration. Small soil particles, as in clay, mean small pores, while sand or gravel is at the other extreme. Mixtures of large and small particles tend to pack and reduce pore size. Fine soils cement together into clusters and thus increase their permeability.

i) Soil cover

The type of surface cover is important in several ways. It protects the soil from compaction by rain and also provides detention on the surface and thereby increases infiltration opportunity, the degree of action depending on the density of the cover.

11.4.4 Design of Storm Drains

The design of storm drains conforms to the principles of flow in open channels. The main problem is the selection of economic pipe or channel sizes and slopes capable of carrying the expected flow.

For a source of possible design software, see Chapter 9, section 9.4.2.1.

The main rules governing selections of pipe and channel size and slope are:

- The pipe is assumed to flow full under conditions of steady, uniform flow;
- The minimum pipe diameter should preferably be 250 or 300 mm (although 200mm can also be used in some circumstances);
- The minimum velocity flowing full should be at least 0.8 m/s;
- Pipe sizes should never decrease in the downstream direction to avoid possibilities of clogging smaller pipes with debris entering the drain;
- Pipe slope should conform to the ground slope as far as possible for minimum excavation (in some cases it may be possible to use a smaller pipe by exceeding the ground slope). If this makes the use of smaller pipe possible for some distance down-slope, it may be economical despite increased excavation; and
- Pipe grades are described in terms of the elevation of the invert, or inside bottom of the pipe. Where pipes of different size join, the tops of the pipes are placed to the same elevation and the invert of the larger pipe is correspondingly lower then that of the smaller pipe. This does not apply to tributary drains, which may enter the main sewer through a drop manhole.

11.5 DRAINAGE SYSTEMS COMPONENTS

Stormwater drainage systems are mainly open channels and closed conduits (pipes) with a free-water surface. Stormwater from the surfaces is conveyed through the drainage systems to the discharge point by gravitation. The slopes of the drainage system should be planned to follow the natural topography in order to minimize excavation and installation costs.

Systems carrying stormwater can be divided into two categories: separate stormwater systems carrying only stormwater and combined systems carrying both sanitary sewerage and stormwater. The latter should however be avoided as both sewerage costs and sewage treatment costs escalate significantly as a result.

In addition, open channels are in effective means of conveying storm water but when included in combined systems, such open channel may cause odour nuisance and health risks and therefore closed conduits are imperative in such situations.

Storm drainage systems consist of inlet boxes for collecting the runoff, conduits (open or closed) for conveying it and manholes for inspection. Drainage channels in streets should be lined with concrete bricks, inter-locking pre-cast slabs, or reinforced hollow blocks, to ease maintenance and to resist earth and vehicular loads.

11.5.1 Uniform Flow in Open Channels

a) Open channels

The open channel may take the form of a canal, flume, tunnel or partial filled pipe. Open channels are characterized by a free water surface.

b) Hydraulics of open channels

Open channel flows may be classified either by time criterion or space criterion.

i) Time criterion

There are two categories:

1. Steady flow
2. Unsteady flow

In steady flow the water depth at any section does not differ or change with time during the period of interest whereas in unsteady flow the water depth changes with time.

ii) Space criterion

Flow in an open channel is said to be uniform if the discharge and water depth remain the same in every section throughout the channel.

In uniform flow, water depth, water area, discharge and the velocity distribution at all sections throughout the entire channel reach must remain unchanged.

The energy gradeline, the water surface line, the channel bottom line must be parallel to each other, see Figure 11.4

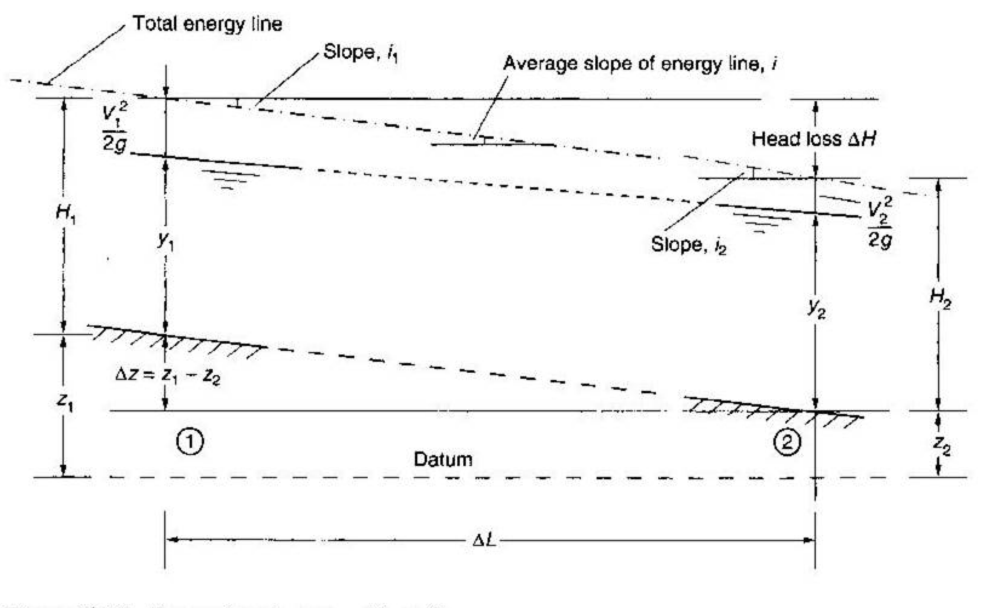


FIGURE 11.4: CHANNEL PROFILE AND ENERGY LOSS

Considering the energy equation between section 1 and 2

$$z_1 + y_1 + V_1^2/2g = z_2 + y_2 + V_2^2/2g + \Delta H \qquad 11.4$$

Where,

z = elevation of channel bottom above an Arbitrary datum (m)

y = depth of flow (m)

V = average velocity in (m/s)

ΔH = headloss between section 1 and 2 (m)

g = acceleration due to gravity (m/s^2)

In uniform flow: $y_1 = y_{2,}$ and $V_1 = V_{2,}$ hence: $z_1 - z_2 = h_L = S_L$

Where,

S = is the slope of the energy grade line

L = is the distance between points 1 and 2.

The rate of flow in open channel can be derived by using the Manning equation:

$$V = C \times (1/n) \times R^{2/3} \times S^{1/2} \qquad 11.5$$

Where,

C = a constant (1.0 in metric units and 1.486 in imperial units)

V = average velocity of flow (m/s)

R = hydraulic radius = ratio of wetted section area to wetted perimeter

n = roughness coefficient of the channel.

S = energy gradient, the headloss per length (m/m) of flow path.

It should be noted that this equation is not dimensionally balanced but has dimensions of length to the power of one-sixth.

In simplifying the calculation involved and facilitating solutions of open channel problems, nomographs are often used, see Appendix 11.1. Alternatively, these days, there are on-line calculators freely available for use, for example that at AJDesign: <www.ajdesigner.com/index.htm>.

Note: The Manning equation is applicable where the channel bed slope is less than 0.1.

Table 11.3 illustrate values of the roughness coefficient of 'n' against channel materials.

TABLE 11.4: ROUGHNESS COEFFICIENT 'n' FOR DIFFERENT CHANNEL MATERIALS

CHANNEL MATERIAL	'n'
Plastic, glass, drawn tubing	0.009
Neat cement, smooth metal	0.010
Planed timber, asbestos pipe	0.011
Wrought iron, welded steel, canvas	0.012
Ordinary concrete, asphalted cast iron	0.013
Unplaned timber, vitrified clay	0.014
Cast iron pipe	0.015
Rubble masonry	0.017
Riveted steel, brick	0.016
Smooth earth	0.018
Corrugated metal pipe	0.022
Firm gravel	0.023
Natural channel in good condition	0.025
Natural channel with stones and weeds	0.035
Very poor natural channel	0.060

11.5.2 Drainage Structures

Drainage structures include weirs, flumes, gutters, inlets, open-channel sections, and culverts.

a) Weirs

For weir formulas to give accurate values of discharge the upstream face of the weir must be vertical and at right angles to the channel, whilst the crest of the weir must be horizontal. In addition atmospheric pressure should be maintained under the nape and the approach channel should be straight and unobstructed. The head 'h' should be measured far enough upstream from the weir to avoid the effects of curvature of the water surface near the weir.

The standard formula for discharge over a suppressed rectangular weir is:

$$Q = C_W' \, 2/3 \times 29 \times L \, (h+V_0^2 / 2g)^{3/2} - V_0^2 / 2g)^{3/2}] \qquad 11.5$$

Where,

C_W' = coefficient characteristic of flow condition over the weir.

L = length of the weir crest in (m)
h = head on the crest (m)
V_0 = velocity of flow in the channel just upstream from the weir

Unsuppressed rectangular and V-notch weirs will prove more accurate for flow measurement, especially for small flows than suppressed rectangular weirs.

The discharge over an unsuppressed rectangular weir or V-notch is given by:

$$Q = C_W'' \times (8 / 15) \times 2g \times h^{5/2} \tan \Theta/2 \qquad 11.6$$

$$= 4.28 \times C_W'' \times h^{5/2} \times \tan \Theta/2$$

Where,

Θ = vertex angle of the notch
CW" = a is a coefficient ≈ 0.50, varying slightly with head and notch angle.

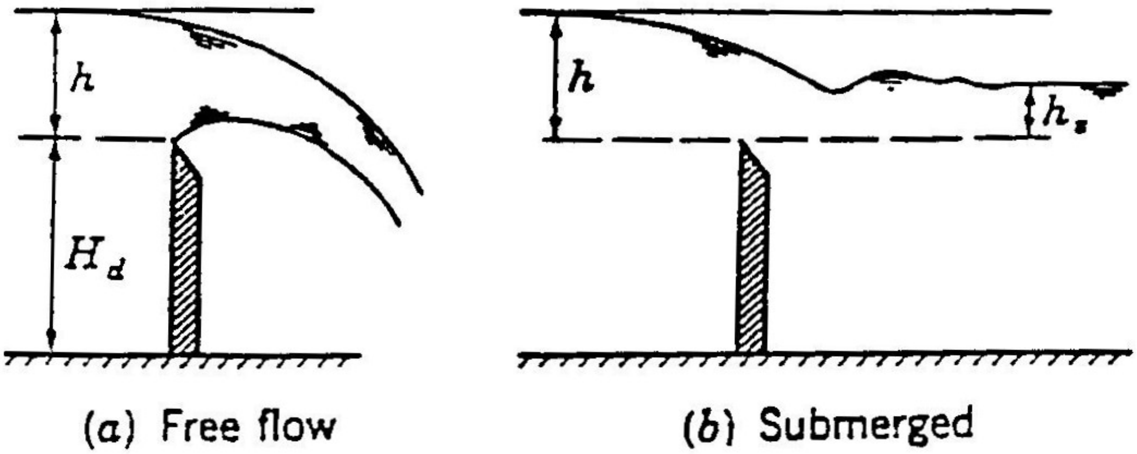


FIGURE 11.5: WEIR FLOW IN OPEN CHANNELS

b) Flumes

These are devices for measuring the flow of water. If water contains suspended sediment some will be deposited in the pool above a weir, resulting in a gradual change in the weir coefficient. Moreover the use of a weir results in a relatively large headloss. Both these difficulties are at least partially overcome by use of venturi – type flume. One of the most common of the venturi flumes is the parshall flume.

Flow through a parshall flume usually occurs in a free – flow condition with critical depth at the crest and a hydraulic jump in the exit section. The discharge equation for parshall flumes with widths from 30 cm through 2.4 m under free flow condition is $Q=4 \times B \times h_a{}^{1.522B}$

For best results a parshall flume should be installed in a straight section of channel where flow conditions are relatively uniform. Refer to Figure 11.6 for details of a parshall flume.

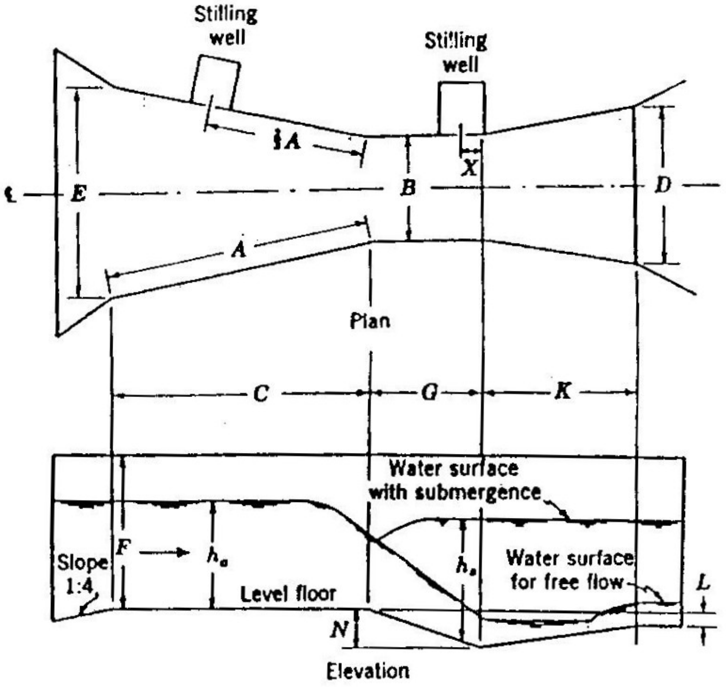


FIGURE 11.6: A PARSHALL FLUME

c) Gutters

The discharge capacity of gutters depends on their shape slope and roughness. Manning’s equation can be used for calculating the flow in gutters; the roughness coefficient 'n' must be modified somewhat to account for the effect of lateral inflow from the street. Moreover, with the wide, shallow flow and the varying transverse depth common in gutters, the flow pattern is not symmetrical and the boundary shear stresses have an irregular distribution. For well finished gutters, 'n' has a value of about 0.016 when used in the Manning equation. Unpaved gutters or gutters with broken pavement will have much higher values of n. Gutters are generally constructed with a transverse slope of 1:20 and 15 cm curb height, the width of flow in a gutter will be 3 m when there is no freeboard.

d) Inlets

Gutter flow is intercepted and directed to buried sewers by drop inlets. Two types of inlets are available (i) Grated inlets, (ii) A curb – opening inlet. See Figure 11.7.

Grated inlets are openings in the gutter bottom protected by grates. A curb – opening inlet is an opening in the face of the curb which operates much like a small side channel spillway.

The location of street inlets is determined largely by the judgment of the designer.

A maximum width of gutter flow of about 4.5 m has been suggested as a suitable criterion for important highways.

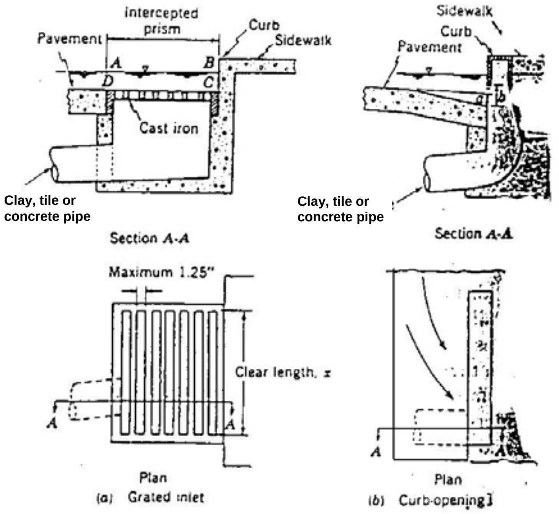
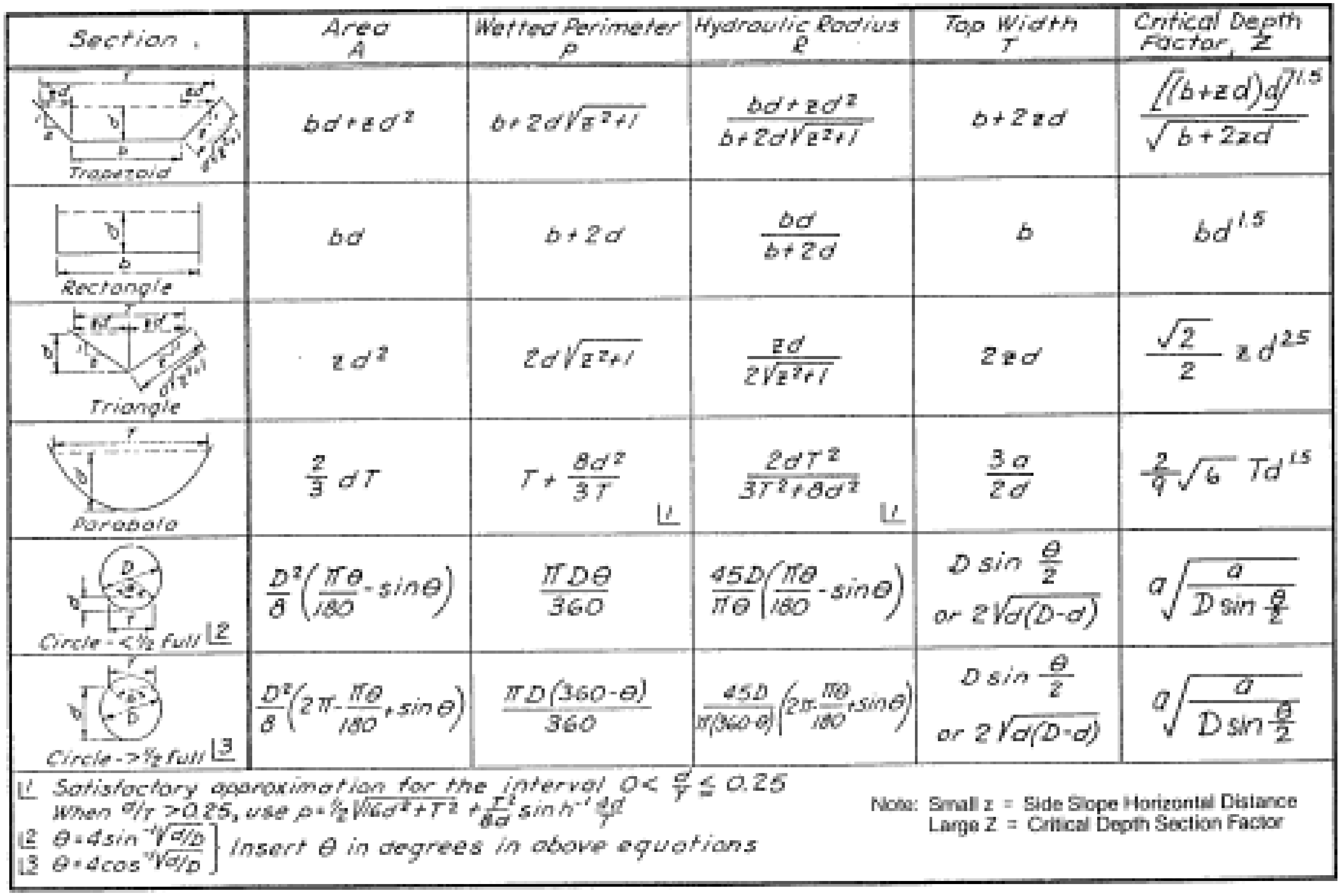


FIGURE 11.7: SOME TYPICAL STORM DRAIN INLETS

e) Open channel sections

Geometric information on areas, wetted perimeters and hydraulic radius is presented in the following Figure for various Hydraulic shapes:



Section	Area A	Wetted Perimeter P	Hydraulic Radius R	Top Width T	Critical Depth Factor, Z
Trapezoid	$bd+zd^2$	$b+2d\sqrt{z^2+1}$	$\frac{bd+zd^2}{b+2d\sqrt{z^2+1}}$	$b+2zd$	$\frac{[(b+zd)d]^{1.5}}{\sqrt{b+2zd}}$
Rectangle	bd	$b+2d$	$\frac{bd}{b+2d}$	b	$bd^{1.5}$
Triangle	zd^2	$2d\sqrt{z^2+1}$	$\frac{zd}{2\sqrt{z^2+1}}$	$2zd$	$\frac{\sqrt{2}}{2}zd^{2.5}$
Parabola	$\frac{2}{3}dT$	$T+\frac{8d^2}{3T}$ [1]	$\frac{2dT^2}{3T^2+8d^2}$ [1]	$\frac{3a}{2d}$	$\frac{2}{9}\sqrt{6}\,Td^{1.5}$
Circle - <½ full [2]	$\frac{D^2}{8}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$\frac{\pi D\theta}{360}$	$\frac{45D}{\pi\theta}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$	$a\sqrt{\frac{a}{D\sin\frac{\theta}{2}}}$
Circle - >½ full [3]	$\frac{D^2}{8}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$\frac{\pi D(360-\theta)}{360}$	$\frac{45D}{\pi(360-\theta)}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$	$a\sqrt{\frac{a}{D\sin\frac{\theta}{2}}}$

[1] Satisfactory approximation for the interval $0 < \frac{d}{T} \leq 0.25$
When $d/T > 0.25$, use $p = \frac{1}{2}\sqrt{16d^2+T^2}+\frac{T^2}{8d}\sinh^{-1}\frac{4d}{T}$

[2] $\theta = 4\sin^{-1}\sqrt{d/D}$
[3] $\theta = 4\cos^{-1}\sqrt{d/D}$
Insert θ in degrees in above equations

Note: Small z = Side Slope Horizontal Distance
Large Z = Critical Depth Section Factor

FIGURE 11.8: OPEN CHANNEL GEOMETRIC RELATIONSHIPS FOR VARIOUS CROSS-SECTIONS

11.6 RAINFALL DATA

Rainfall data is desirable because storm run – off is a result of a rainfall, and the determination of the quantity of run-off depends largely on the rainfall characteristics.

Rainfall data enables determination of the return period, e.g. a certain drought length, flooding magnitude, etc. Direct measurements of these processes are usually not available and it is therefore necessary to use rainfall as an indicator and a predictor of these phenomena. Several problems may however appear because the available rainfall records are usually not long enough and the return period of the rainfall is not the same as that of the resulting runoff.

For Tanzania the analysis of maximum one hour rainfall intensity and maximum daily rainfall intensity obtained from the Data Services Division of the Tanzanian Meteorological Agency (TMA) are taken as guiding in the determination of the rainfall intensity for the storm water drainage design.

The Network Section of the Division currently runs a synoptic network comprising 25 stations operating on a 24-hour, 15-hour, 12-hour and 9-hour basis depending on the staffing situation. The Agency also operates 13 agro-meteorological and one marine station.

The station network is relatively small compared to the large size of the country. There are about 2,000 rainfall stations but only about 600 are operating regularly. The operation of these stations depends on volunteer observers. TMA has 154 Climatological stations throughout the country. The map opposite shows the synoptic observation network manned wholly by TMA.

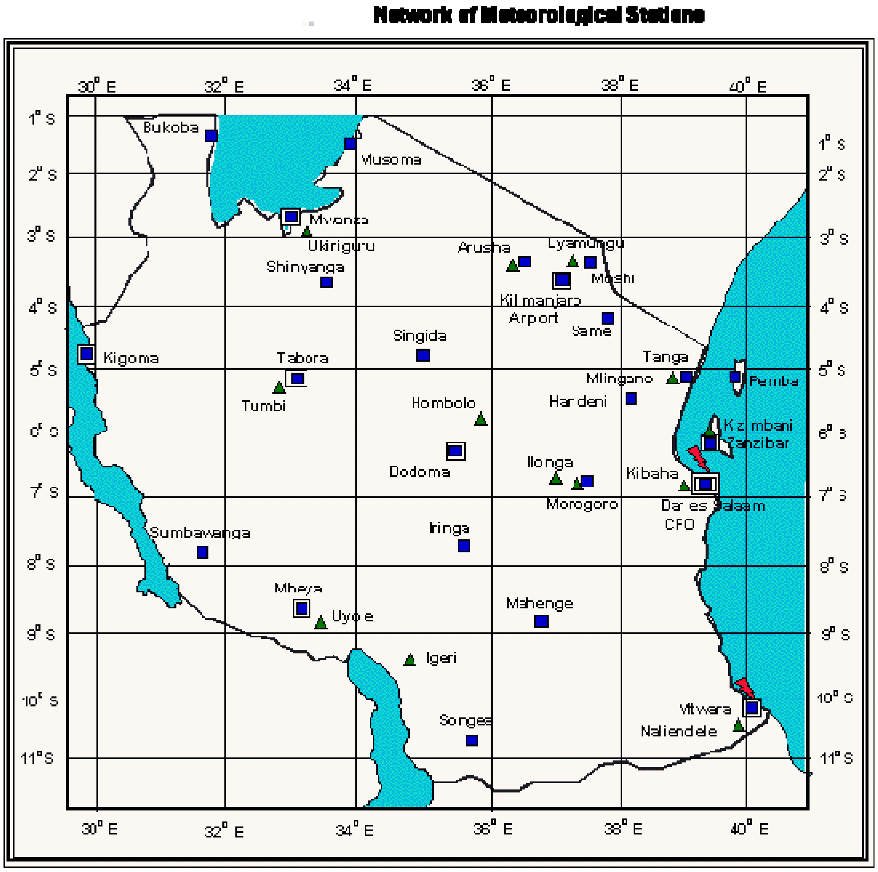


FIGURE 11.9: THE OBSERVATION NETWORK MANNED BY THE TANZANIA METEOROLOGICAL AGENCY

11.7 FLOOD PEAK ALLEVIATION AND POLLUTION CONTROL

11.7.1 Flood Peaks

An increase in flood peaks is an inevitable consequence of urbanisation as illustrated in Figure 1. Whilst this cannot be avoided, there are a number of ways such peaks can be alleviated and wherever practicable is very desirable in stormwater drainage systems.

Where they exist, the best way of doing this is in natural wetlands. Unfortunately, although they occur in a number of urban environments, they have been encroached upon over the years, both by formal reclamation and development and by informal settlements. In the latter case in particular, the inhabitants of the encroached are at risk from flooding. In both cases, the effect is to increase peak flow and flood risk downstream.

All remaining wetlands in urban areas in particular need protection from further encroachment expect under very special circumstances, and instead they should be treated as the natural lungs and recreational zones of the town.

11.7.2 Pollution Load

Water quality and pollution load is now a major problem in stormwater drainage in towns and cities across Tanzania. The problem is fourfold namely:

- Pollutants released by industrial and commercial enterprises into the stormwater system such as fats, oils and greases, they should be addressed on site;
- Sanitary waste that either gets into stormwater drains during the rainy season as a result of high groundwater table or is deliberately released by householders from septic tanks and the like;
- Disposal of solid, generally household waste into drains and watercourses, sometimes but not always as a result of an inadequate rubbish collection system, and
- Plastic waste such as plastic bags and bottles carelessly discarded by the original user after use.

Where a high groundwater table occurs during the rainy season, the use of convention dug pit-latrines should be discouraged and alternative sanitation structures encouraged, such as the eco-san toilet. Areas reliant on septic tanks should be routinely patrolled and householders who discharge their septic tank waste prosecuted.

Hygienic disposal of solid waste requires both education of the population and the provision of sufficient facilities such as communal collecting containers and an effective solid waste collecting system, including the licensing of private collecting companies.

Plastic waste is a pernicious problem that requires either a collecting and re-cycling system or in the case of plastic shopping bags in particular, their banning from use.

Whilst natural wetlands are by far the best way of attenuating flood peaks they preferably should not be taken into account when deciding of pollution control measures, even though they are capable of providing for much of this. Sole reliance on natural wetlands for this purpose will only lead to their eventual degradation.

11.7.3 Structures Stormwater Controls

Structural stormwater controls are engineered facilities intended to treat stormwater runoff and/or mitigate the effects of increased stormwater runoff peak rate, volume, and velocity due to urbanization.

Because, with the possible exception of Total Suspended Solids and Faecal Coliform it is usually the base flow of stormwater drainage that is the most polluted, consideration should be given to separating base load from and excess run-off by use of a flow regulation to off-line structural stormwater control by either diverting the water quality volume or other specific maximum flow rate to an off-line structural stormwater control, or bypassing flows in excess of the design flow rate.

An example of a culverted interceptor isolation - diversion structure is shown in Figure 11.10.

Because of the long dry spells experienced in most parts of the country with the rain concentrated into just a few months in one or two rainy seasons, using natural vegetation such as grass to line stormwater channels has somewhat limited applicability. However, where soils are porous and such natural vegetation can be maintained or will quickly regenerate at the start of a rainy season, it is a solution worth considering. Routine maintenance is also important if they are to be effective.

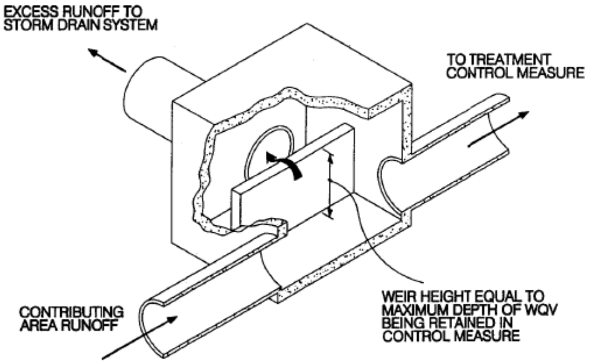


FIGURE 11.10: AN INTERCEPTOR ISOLATION - DIVERSION STRUCTURE

A guide to the general effectiveness in reducing the pollution load of stormwater in different structures is give in Table 11.8 below

TABLE 11.8: DESIGN POLLUTANT REMOVAL FOR STRUCTURAL STORMWATER CONTROLS

STRUCTURAL CONTROL	TOTAL SUSPENDED SOLIDS	TOTAL PHOSP-HOROUS	TOTAL NITROGEN	FAECAL COLI-FORM	METALS
Stormwater Ponds	80	50	30	70	50
Stormwater Wetlands	80	40	30	70	50
Sand Filters	80	50	25	40	50
Filter Strips	50	20	20	-	40
Grass channels	50	25	20	-	30
Organic Filters	80	60	40	50	75
Submerged Gravel Wetland	80	50	20	70	50
Gravity (oil-grit) Separator	40	5	5	-	-
Porous Concrete	-	50	65	-	60
Modular Porous Paver Systems	-	80	80	-	90
Alum Treatment	90	80	60	90	75

The various Structures mentioned in the above Table are briefly summarised below. Some are primarily for pollution reduction and others primarily for flood peak attenuation whilst others have a dual purpose.

a) Stormwater Wetlands: Stormwater wetlands are constructed wetland systems used for stormwater management. Stormwater wetlands consist of a combination of shallow marsh areas, open water and semi-wet areas above the permanent water surface. There are several variations including: Shallow Wetlands; Extended Detention Shallow Wetlands; Pond/ Wetland Systems; and Pocket Wetlands.

b) Stormwater Ponds: Stormwater ponds are constructed stormwater retention basins that have a permanent pool (or micropool) of water. Runoff from each rain event is detained and treated in the pool. There are several variations including: Wet Pond; Wet Extended Detention Pond; Micropool Extended Detention Pond; and Multiple Pond Systems.

c) Sand Filters: Sand filters are multi-chamber structures designed to treat stormwater runoff through filtration, using a sand bed as its primary filter media. Filtered runoff may be returned to the conveyance system, or allowed to partially exfiltrate into the soil. Limited applicability.

d) Filter Strips: Filter strips are uniformly graded and densely vegetated sections of land, engineered and designed to treat runoff from and remove pollutants from small areas through vegetative filtering and infiltration. They should be between 25 m (impervious souls) to 50 m (pervious soils) long and with slopes of between 2% and 6%, and be designed for sheet flow of from 1 – 2 cm deep. As far as practicable, pedestrian access should be restricted. Any signs of short-circuiting should be attended to promptly.

e) Grassed Channels: Vegetated open channels designed to filter stormwater runoff and meet velocity targets for the water quality design storm and the 2-year storm event. Applicable for areas up to 2 ha and where velocities are non-erosive and do not exceed 0.3 m/s. Residence time should not be less than 5 min. They should have broader bottoms and denser vegetation than other channels with a parabolic or trapezoidal cross section. They can incorporate small check-dams to improve retention time.

f) Organic Filter: A design variant of the surface sand filter for small areas or industrial/institutional premises using organic materials in the filter media. Not considered applicable in public areas as has high maintenance requirements. Suitable for low-permeability soils with a high water table.

g) Submerged Gravel Wetlands: One or more cells filled with crushed rock designed to support wetland plants. Stormwater flows subsurface through the root zone of the constructed wetland where pollutant removal takes place. Suitable for industrial/commercial premises where space is restricted and has moderate to high maintenance requirements. Designed to allow stormwater to flow subsurface through the root zone of the constructed wetland. The outlet from each cell is set at an elevation to keep the rock or gravel submerged. Wetland plants are rooted in the media, where they can directly take up pollutants. In addition, algae and microbes thrive on the surface area of the rocks.

In particular, the anaerobic conditions on the bottom of the filter can foster the de-nitrification process. More commonly used as part of a wastewater treatment, can be designed to treat stormwater. Mimicking the pollutant removal ability of nature, this structural control relies on the pollutant-stripping ability of plants and soils to remove pollutants from runoff. Dissolved pollutants are not effectively removed and requires frequent maintenance. Performance dependent on design and frequency of inspection and cleanout of unit. See also Chapter 10, section 10.8.2.3.

h) Gravity (Oil-Grit) Separator: Hydrodynamic separation device designed to remove settleable solids, oil and grease, debris and floatable matter from stormwater runoff through gravitational settling and trapping of pollutants. Suitable for garages, workshops restaurants and abattoirs, it should be made a requirement for the granting of planning permission in all such instances. See also Chapter 9, section 9.9.3.

i) Porous Concrete: Porous concrete is the term for a mixture of coarse aggregate, portland cement and water that allows for rapid infiltration of water and overlays a stone aggregate reservoir. This reservoir provides temporary storage as runoff infiltrates into underlying permeable soils and/or out through an under-drain system. Provides limited retention capacity. Not recommended.

j) Modular Porous Paver Systems: A pavement surface composed of structural units with void areas that are filled with pervious materials such as sand or grass turf. Also known by the trade name ‘grasscrete’. Porous pavers are installed over a gravel base course that provides limited storage as runoff infiltrates through the porous paver system into underlying permeable soils.

There are many different types of modular porous pavers available from different manufacturers, including both pre-cast and mould in-place concrete blocks, concrete grids, interlocking bricks, and plastic mats with hollow rings or hexagonal cells. Suitable for low traffic areas, or for residential or overflow parking applications, but has high maintenance requirements.

k) Alum Treatment System: Chemical treatment of stormwater runoff entering a wet pond by injecting liquid alum into storm sewer lines on a flow-weighted basis during rain events. Not recommended.

APPENDIX 11, NOMOGRAPH FOR SOLVING MANNING's EQUATION

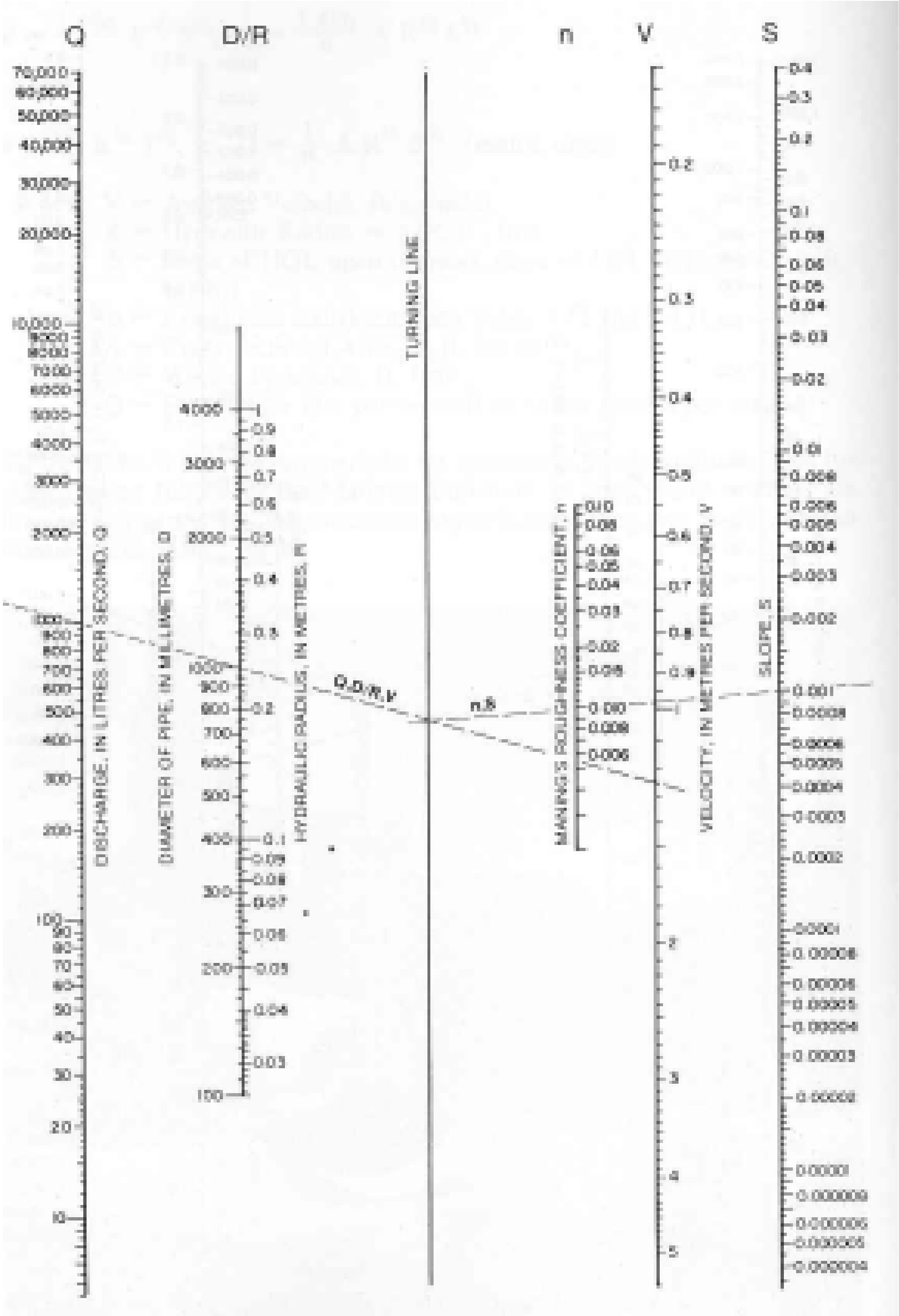


FIGURE: NOMOGRAPH FOR SOLVING MANNING EQUATION

REFERENCE BOOKS TO ALL CHAPTERS

In addition to numerous articles freely available on the Internet, and several National and International Standards consulted in producing this 3rd Edition, the following documents were referred to in compiling this and earlier editions of the Design Manual.

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