O&M MANUAL OF STORM WATER DRAINAGE SYSTEM

ENERGY MANAGEMENT AND OPERATION & MAINTENANCE OF 16 SELECTED MCs SERVICES INFRASTRUCTURE ASSETS PROJECT

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PITCO (PRIVATE) LIMITED

Contents

List of Figures

List of Tables

1. INTRODUCTION TO STORM WATER DRAINAGE SYSTEM

Storm water drainage systems are integral to urban planning and environmental management, designed to safely manage the flow of rainwater and melted snow from areas that can't absorb it, such as roads, rooftops, and pavements. Their importance becomes evident when one realizes that as urban spaces expand, the ground's natural ability to absorb water decreases. More roads, buildings, and other impermeable structures rise, preventing water from seeping into the ground, which can result in an increased volume and speed of runoff.

An efficient storm water drainage system plays multiple roles in our urban environment. Firstly, it prevents flooding. By channeling rainwater away swiftly, these systems shield roads, buildings, and other infrastructural elements from being submerged. Flooding is more than an inconvenience; it can lead to significant economic and health impacts.

Beyond flooding, these drainage systems are guardians of our water quality. As rainwater rushes across urban surfaces, it can collect various pollutants from roads, industries, and other urban sources. If this untreated water, then flows directly into our rivers, lakes, and oceans, it can lead to serious environmental degradation. Properly designed drainage systems have features or associated facilities that treat this water, filtering out harmful substances before they reach natural water bodies.

1.1. Overview of Storm Water Management

Storm water management is a comprehensive approach to addressing the challenges and complexities associated with rainfall, runoff, and the subsequent flow of water in urban and suburban areas. At its core, the practice seeks to balance the needs of human populations with the requirements of the natural environment, aiming to mitigate the negative impacts of urbanization on water quality and quantity.

As urban areas expand, vast stretches of land become covered by impervious surfaces, such as asphalt roads, concrete pavements, and rooftops. These surfaces prevent rainwater from being absorbed into the ground, leading to an increased volume of runoff. This runoff, if not managed correctly, can cause a range of problems. For instance, the swift flow of water can result in flooding, eroding soil, damaging property, and even endangering lives.

When a catchment is developed, the proportion of land covered by impervious surfaces (roads, parking areas, compacted soils, roofs, driveways and pavements) is increased and this can reduce the area available for stormwater infiltration. Where stormwater has been traditionally managed through open drains and piped drainage, up to 80% of the rainfall volume can become direct runoff. However, new approaches in stormwater management aim to prevent pollution at the source, maximise infiltration to reduce stormwater runoff, recharge groundwater and minimise change to the natural water balance. The removal of catchment vegetation cover contributes to increased runoff, as there is reduced transpiration rates and less removal of water from the soil by plants. Therefore, retaining native vegetation is an important feature of stormwater management.

In traditionally drained built environments, there is a reduction in natural water catchment storage when floodplains and natural wetlands are in-filled for development. At the same time, paved surfaces are smoother than natural surfaces, so water can travel faster across the surface and will reach the receiving waters more quickly. In traditional stormwater management systems, peak flow rates can increase by a factor of up to ten. In these conditions, waterways have to hold larger and often sudden or rapidly peaking runoff flows.

The effects of catchment urbanisation, using a traditional drainage approach on stormwater runoff characteristics, can be summarised as follows:

- increased peak discharges, runoff volume and velocity
- decreased response time
- increased frequency and severity of flooding, and
- change in characteristics of urban waterways from ephemeral to perennial systems (Wong et al, 2000).
- Figure 1 shows the components of the water cycle or hydrological cycle.
- The increase in imperviousness results in greater runoff, and that receiving surface water volumes are likely to be greater.

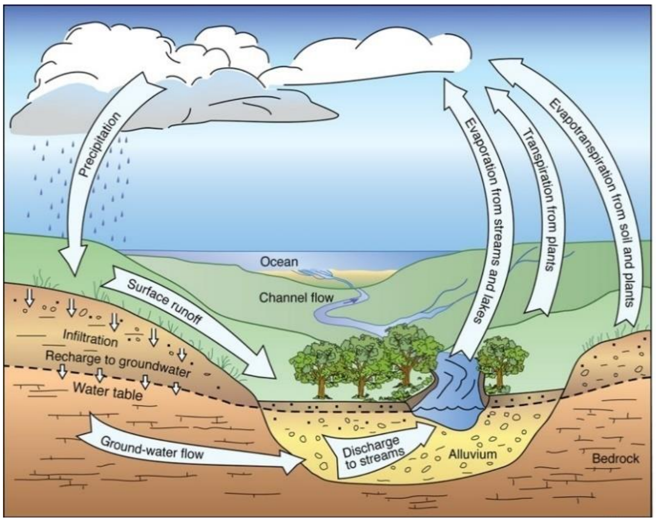

Figure 1: The Hydrologic Cycle

Majority of urban areas, be it large metropolis or small municipal town, severely lack effective storm water drainage facilities. Unplanned development coupled with encroachment of existing natural drainage corridors, waterways etc. exacerbates the problem of urban drainage. In the quest for extreme development, important environmental benefits from natural functionaries like waterways/water bodies are often ignored, overlooked, and compromised.

Figure 2: Ponding on roads after rain

This aspect, along with recent trends in climate change is also causing the rise in incidences of acute waterlogging, urban flooding, and related adverse economic and health impacts. Storm flows, if not regulated or routed to its convergence of safe disposal, may cause unprecedented degradation of urban infrastructure causing severe damage to life and property, depending on the degree of severity of storm event.

In recent years, frequency of urban flooding has increased, and the issue is getting more pronounced day-by-day due to its enormous socio-environmental hazards leading to traffic snarls and disruption in urban life.

To protect the urban areas against flooding in a phased manner, consistent with availability of resources, storm water drainage systems need to be planned and implemented in structured manner considering various aspects of design, operation & maintenance and economics.

1.2. Basic Methods being adopted in current project

These measures are being adopted in this drainage project.

- Construction of new drains with planning horizon of 2032 and 2050.
- To utilize drains, sewers and road/drain in an integrated manner
- To make the best use of the capacity of drains and sewers in particular
- To consider where and how rainwater flowing on the road surface is taken into the drains.
- To design and construct more effective drainage facilities
- Construction of gully gratings to connect ponding points to sewers and drains.
- Construction of gully gratings at critical points and linking these points through piped drains or open channels with main drains.
- Construction of inlet facilities and drains/drainage pipes connected to drains or disposal stations utilizing hydrograph estimated.
- Study of inflow volume to Disposal Stations in wet weather to determine appropriate capacity of them
- To estimate actual inflow volume to Drainage stations in wet weather
- To determine appropriate and necessary capacity of Drainage stations
- To study the necessity to enlarge the capacity of a Drainage station.

Figure 3: Gully grating in rain

1.3. Urban Drainage system in Punjab

Urban storm water drainage systems have got priority in Pakistan only after drinking water supply and sewerage projects in the majority of the cases. Due to fast pace of urbanization and migration of people from rural areas to urban areas in quest of livelihood and better education, there has been immense pressure on urban infrastructure, worsening the problem of urban drainage systems in Punjab. Some of the important factors responsible for present status of poor urban drainage system in cities are as under:

1. The natural drainage systems in most of the cities are in jeopardy, and the problem of flooding is worsening with time due to non-availability of properly engineered storm water drainage infrastructures. The problems are exacerbated due to encroachment and rampant dumping of garbage & solid waste in the drains on one hand and absence of preventive maintenance on the other.
2. The existing storm water collection network in the cities is mainly designed to serve as a combined system for sewage as well as storm water runoff. Augmentation and rehabilitation, including separation of storm water from sewage in such facilities, invite highest level of challenges for municipal engineers and financial resources.

   Many important cities in the country receive high average annual rainfall during monsoon. High intensity rainfall in the cities is responsible for frequent flooding.

Figure 4: Monsoon Flooding in urban areas

MCs are responsible for Planning, designing and construction of water supply, sewerage and drainage facilities for:

- New works
- Rehabilitation and augmentation of the existing system
- Operation and maintenance of water supply, sewerage and drainage system
- Billing and collection of rates, fees and charges for the services provided to consumers

Most of the cities in Punjab are situated on flat topography which does not allow disposal of sewage and storm water from the city through gravity flow. For this purpose, a number of pumping stations are located in the urban drainage network for eventual disposal of the wastewater and storm water. With in the cities, wastewater is drained through a network of lateral, branch and trunk sewers into different disposal stations and then pumped out for ultimate disposal into canals or rivers through open or closed drains.

Figure 5: A view of storm water drain regulating structure and Pumping Station

1.4. Importance of Operation and Maintenance (O&M)

Storm water drainage systems play a critical role in the urban ecosystem, safeguarding communities from the potential dangers of uncontrolled water flow and ensuring the preservation of environmental quality. To ensure their effectiveness and longevity, consistent operation and maintenance (O&M) are paramount. The importance of O&M for storm water drainage systems can be explored in-depth through its implications for urban safety, environmental health, and economic stability.

1.4.1. Urban Safety and Public Health

At the heart of any storm water drainage system is the goal to protect communities from flooding. Properly functioning systems prevent the inundation of roads, homes, and vital infrastructure. When these systems are not regularly inspected and maintained, blockages can lead to unexpected overflows during heavy rainfalls, posing a risk to public safety. Waterlogged areas can also become breeding grounds for mosquitoes and other disease vectors, potentially leading to public health concerns. Regular O&M practices ensure the system functions as intended, protecting communities from such threats.

1.4.2. Environmental Health

Storm water, as it flows over urban surfaces, picks up a variety of pollutants, from motor oil on roads to fertilizers and pesticides from gardens. A well-maintained drainage system can help in either directing this water to treatment facilities or slowing its flow to allow natural filtration processes to occur. Without consistent maintenance, these systems can become compromised, leading to direct discharge of polluted water into natural water bodies. This not only degrades the quality of lakes, rivers, and coastal waters but can also harm aquatic life and ecosystems dependent on these water sources.

1.4.3. Economic Stability

The economic implications of an ill-maintained storm water drainage system are vast. Flooding can damage property, infrastructure, and even disrupt businesses. Roads covered in water or damaged by erosion can hinder transportation, impacting commerce and daily life. Moreover, a city or community known for its flooding issues might deter potential investors or developers. Regular O&M activities, in contrast, can preempt these challenges, ensuring that urban areas remain economically vibrant and are perceived as stable environments for business and development.

1.4.4. Sustainability and Future Preparedness

As climate change brings forth unpredictable weather patterns and potentially heavier rainfall events, the importance of a functional storm water drainage system cannot be overstated. Routine O&M practices ensure that these systems are always prepared for the next big storm, mitigating risks associated with changing climatic conditions. Moreover, through maintenance, there's an opportunity to integrate newer, sustainable technologies or practices that might enhance the system's efficiency and eco-friendliness.

In conclusion, the operation and maintenance of storm water drainage systems are not mere routine tasks but essential components in safeguarding urban communities. They stand at the intersection of public safety, environmental conservation, economic resilience, and future preparedness, underpinning the very essence of sustainable urban living.

2. COMPONENTS OF STORM WATER DRAINAGE SYSTEM

2.1. Drainage options

The drainage problems of an individual neighborhood are part ofa hierarchy of problems related to the drainage network of the wholecity and corresponding with the hierarchy of drains which compose it. These drains range from the major canals or large sewers which collect water from large areas of the city down to the small ditches ordrainpipes that run along the roadside or serve individual proper- ties.

At the most basic position in the hierarchy is the receiving water body into which the system discharges. This may be the sea, a lake ora river. The water level in the receiving water body fixes the minimum level of the drainage channels, because the pumping of storm- water is not feasible for any but the wealthiest communities. Even if it were possible to afford pumps large enough to handle the amounts of water involved, they would not be practical because of the many difficulties of maintenance and the extent of the damage that would result from malfunction or breakdown of the pumps. The water level in the receiving water body comes very close to ground level in many flat low-income areas, which means the drains cannot be made very deep.

2.1.1. Primary drainage system

Primary drainage system, composed of main drains, is sometimes called interceptor drains. These serve large areas of a city or the city as a whole, and often follow the line of natural drainage channels such as rivers or streams.

Figure 6: Primary drain

2.1.2. Secondary drainage system

Finally, there is the secondary drainage system, a network of small drains within each neighborhood. These are sometimes known as micro-drainage or laterals, and each serves a small catchment area, ranging from a single property to several blocks of houses.

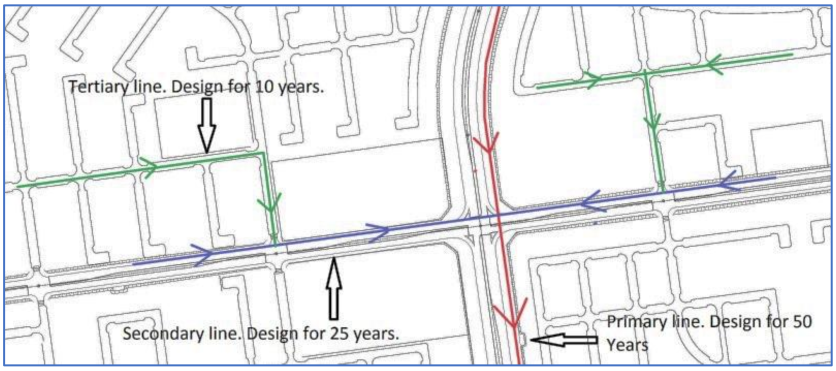

Figure 7: Primary and secondary sewers

Here's an overview of various stormwater drainage solutions used internationally:

2.1.3. Swales and Grassed Channels

Swales and grassed channels are simple yet effective components of a stormwater drainage system. They are designed as shallow, wide, and vegetated channels that direct water away from critical areas. Besides guiding stormwater, the grass and other plants lining a swale help to filter out sediments and pollutants from the water.

Figure 8: Grassed channels

These channels are an important aspect of sustainable stormwater management, as they promote infiltration, thereby recharging local aquifers. Their gentle slopes and vegetated surfaces slow down water flow, reducing the risk of erosion and flash flooding.

2.1.4. Permeable Pavements

Permeable pavements are an innovative approach to managing stormwater in urban areas with limited green space. Unlike traditional pavement, which is designed to be impervious and can contribute to stormwater runoff, permeable pavements allow water to pass through, thereby reducing runoff volume and peak flow rates. This system can include porous asphalt, pervious concrete, or interlocking pavers. They are especially useful in parking lots and driveways, turning these typically impervious areas into components of the stormwater management system.

2.1.5. Dry Wells and Infiltration Trenches

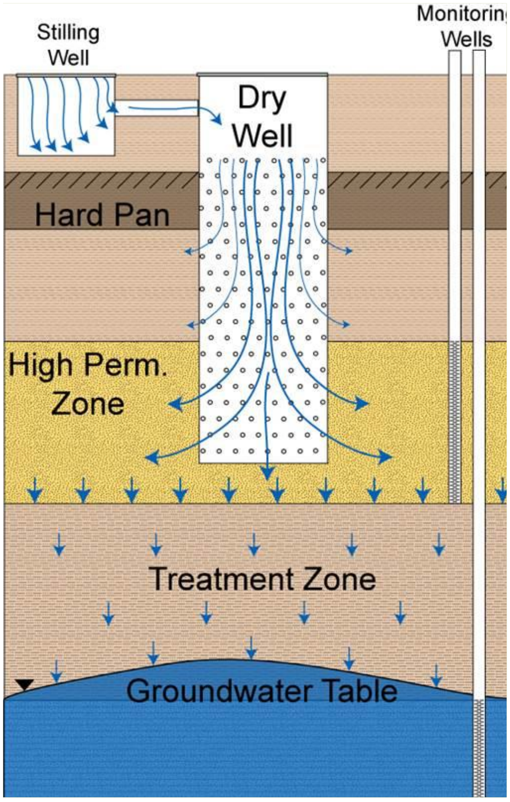

Figure 9: Dry well and infiltration trench

Dry wells and infiltration trenches are subsurface structures that promote the infiltration of stormwater into the ground. Dry wells are often cylindrical and may be filled with gravel or lined with a permeable material. Infiltration trenches are similar but are constructed as elongated pits. These components are designed to temporarily store stormwater, allowing it to slowly infiltrate into the surrounding soil. This not only reduces surface water runoff but also aids in recharging groundwater supplies and filtering pollutants.

2.1.6. Retention and Detention Basins

Retention basins, or wet ponds, are stormwater management facilities that provide both water quality treatment and peak discharge control. They are designed to have a permanent pool of water and often look like natural ponds. Detention basins, on the other hand, are designed to detain stormwater temporarily and are dry between storm events. Both types of basins are engineered to slowly release stormwater at controlled rates, which can reduce downstream flooding and erosion.

2.1.7. Storm Sewers

Storm sewers, or storm drains, are a network of pipes or channels that carry stormwater away from urban areas to prevent flooding. They are particularly vital in densely populated regions where large volumes of stormwater must be quickly and efficiently moved to avoid property damage and safety hazards. Regular inspection and cleaning are necessary to keep these systems functioning optimally and prevent blockages and overflows.

2.1.8. Stormwater Wetlands

Stormwater wetlands are engineered systems that use natural processes to treat polluted stormwater. They are designed to have a permanent or semi-permanent pool of water and are planted with native wetland plants. These wetlands are effective at removing pollutants through sedimentation and biological uptake. They also provide valuable urban green space and habitat for wildlife.

2.1.9. Cisterns and Rain Barrels

Cisterns and rain barrels are stormwater controls that capture and store rainwater for later use, typically for irrigation. This reduces the amount of stormwater that must be managed during and after rain events and can lead to significant water savings. They are generally connected to the downspouts of building gutters.

Figure 10: Cistern and rain barrel system

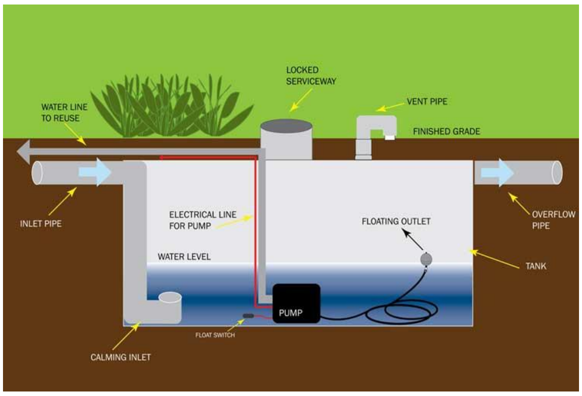

Figure 11: Cistern and rain barrel systems

2.1.10. Outfall Structures

Outfall structures are critical components at the point where storm sewers discharge into natural water bodies, such as rivers or lakes. They are engineered to dissipate the energy of the outgoing water, reducing the speed and erosive potential of stormwater as it exits the storm sewer system. These structures might include a series of steps, a stilling basin, or riprap (loose stone) to slow down the water and protect the receiving water body from excessive sediment disruption or bank erosion.

Each drainage option has its own set of advantages, considerations, and suitability based on the specific environmental, urban, and climatic context. Often, a combination of several methods provides the most effective and holistic approach to stormwater management in urban areas.

2.2. Storm open and closed Drains

In Punjab, the management of stormwater, particularly in urban areas, relies heavily on a combination of open and closed drainage systems. Each has its unique design and functionality, responding to varying environmental, urban, and economic contexts.

Drainage systems can be different for stormwater and sewers, but sometimes both these inputs drain into the same underground drainage system. The advantage of having separate drainage systems is that stormwater runoff is not so dangerous that it has to be treated. This can be drained directly into water bodies. Water containing sewage and industrial wastes, on the other hand, can be extremely toxic. Therefore, they have to undergo at least a primary treatment before they can be let into water bodies.

2.2.1. Open drain

Open drains, often referred to as channels or ditches, are surface structures that carry water in plain view. These surface conduits can range from small roadside trenches to expansive channels that course through the heart of urban areas. Their most defining characteristic is their visibility, which can make identifying blockages or maintenance needs relatively straightforward.

While typically less costly to construct than their closed counterparts, open drains can pose safety risks. Without proper barriers, they may become hazards, especially in areas with high pedestrian traffic. Additionally, open channels can consume considerable land, making them less ideal in densely populated urban areas where space is at a premium. However, a notable benefit of open drains is the allowance for natural processes. Water in these channels can undergo evaporation, and if vegetation lines the drains, there's an opportunity for some filtration and pollutant removal.

In flat low-lying areas subject to flooding, a major problem often results from the relatively high level of the receiving water body. Because of the limited slope to which drains can be laid when water flows along them it is quite slow and inefficient. Together with the difficulty of digging deep drainage channels especially where the groundwater level is high, results in drains having to be proportionally wider in order to have sufficient water passage. There is also a risk of puddle building in which pests such as mosquitoes can breed. Building a drainage channel with sloping sides and a narrow bottom helps to maintain a steady flow speed whatever the water level in the channel. A refinement of this principle is to build a channel with a composite section

2.2.1.1. Transportation of wastewater in open drains

It could be a temporary solution to transport wastewater (greywater or even blackwater) in open drainage systems. Open drains are not a satisfactory technology for transporting sewage, even when the solids have been removed by some form of septic /interceptor tank (even sullage is likely to carry faecal contamination from laundry wastes, hand and body washing etc., albeit the concentrations being lower this should be considered). There are two reasons why open drains are unsatisfactory for sewage transport (CORCORAN et al. 2010):

- People can easily come into contact with the wastewater, with its potentially high pathogen content.
- Since it is almost impossible to keep stormwater out of drains, any flooding will be floodwater merged with diluted sewage (WORLDBANK 2011). Very often open drains/channels are misused for depositing litter, excreta and household sewer lines are sometimes illegally connected to open drainage systems.

Figure 12: Transportation of wastewater in open drain

2.2.1.2. Road Side Open Storm Drains

An open storm drain is a type of drain that typically runs parallel to a road or a property's edge. It is a long, uncovered drainage channel that carries stormwater into the local sewer system for treatment and management. Open storm drains can effectively collect stormwater, but they have a few disadvantages.

First, open storm drains aren't cheap; they can be expensive to set up and maintain. They also aren't very attractive, making them a wrong choice for anyone concerned with appearances, and they can smell bad. Safety is another consideration–if you choose to go with an open storm drain, you need to have it surrounded by a fence to prevent people or animals from falling into the channel.

Figure 13: Open storm drain

2.2.2. Closed Drain

Closed drains operate out of sight, conveying water through enclosed conduits. Often termed as storm sewers or culverts, these systems are frequently found beneath city streets, diverting water quickly and efficiently away from urban centres.

Figure 14: Closed drains

They are particularly suitable for areas where space is constrained, as they don't interfere with surface activities or land use. Given their concealed nature, closed drains reduce the risk of stormwater picking up additional contaminants from surface pollutants. Yet, this same characteristic also poses challenges. Maintenance and inspection of closed drains can be a more intricate affair. Specialized equipment may be needed to identify blockages, and the processes for cleaning and repair can be both challenging and costly. Furthermore, closed drains do not facilitate the natural water treatment processes that open drains potentially offer.

2.2.3. French Drains

These systems consist of a small drain grate or catch basin near the foundation of the home or building. The grate directs the water into a connected pipe in the ground, which guides the water to the street or a retention basin.

It is a real option for a stormwater drain in backyard areas, mainly because you can cover the pipe with decorative gravel or grass. Many brands also give you options for grate covers with decorative designs to help tie everything together seamlessly.

Figure 15: French drain

2.2.4. Trench Drains

One of the most traditional forms of storm water drain design is the trench drain. A trench drain consists of a long, wide drain channel covered by a grate cover. The trench drain from Landscape Drains features a durable stainless-steel body that can handle large amounts of water runoff. Landscape Drains offers decorative grates, which allow you to customize the system's appearance to fit your landscape design better.

Figure 16: Trench drain

The system is also compatible with a catch basin and strainer basket, which allow you to catch objects and larger debris that makes it past the grates.

2.3. Factors effecting storm water flows

Surface runoff is precipitation that runs off the landscape

Figure 17: Surface runoff

2.3.1. Meteorological factors affecting runoff

- Rainfall intensity
- Rainfall amount
- Rainfall duration
- Distribution of rainfall over the drainage basins
- Direction of storm movement
- Precipitation that occurred earlier and resulting in soil moisture
- Other meteorological and climatic conditions that affect evapotranspiration, such as temperature, wind, relative humidity, and season

2.3.2. Physical characteristics affecting runoff

- Land use
- Vegetation
- Soil type
- Drainage area
- Basin shape
- Elevation
- Topography, especially the slope of the land
- Drainage network patterns
- Ponds, lakesreservoirs, sinks, etc. in the basin, which prevent or delay runoff from continuing downstream

2.3.3. Curves/bends in drains

Curves and bends are sometimes unavoidable in drain alignments. The complexity in the design arises due to increase in friction losses along the curve that causes serious local erosion due to spiral flow motion induced by the centrifugal force which is very pronounced and irregular in the bend.

Therefore, in order to reduce the super elevation of the water surface that occurs due to the difference in elevation of water surface between inside and outside wall of the bend at the same section and maintain the freeboard, a minimum radius of curvature of 3 times the width of the drain should be provided in the horizontal curve. Benching should be provided at the bend to minimize the sedimentation at the inner side of the bend.

2.3.4. Junction Sump for storm water drain intersection

A sump of sufficient size shall be provided where drains converge or intersect. The minimum internal width of the sump shall not be less than 2 times the width of the drain leading away from the sump. Drains shall enter the sump at angles less than a right angle and at different levels wherever possible. The invert level of the downstream drain shall be lower than the invert level of the sump so that no stagnant water will collect in the sump.

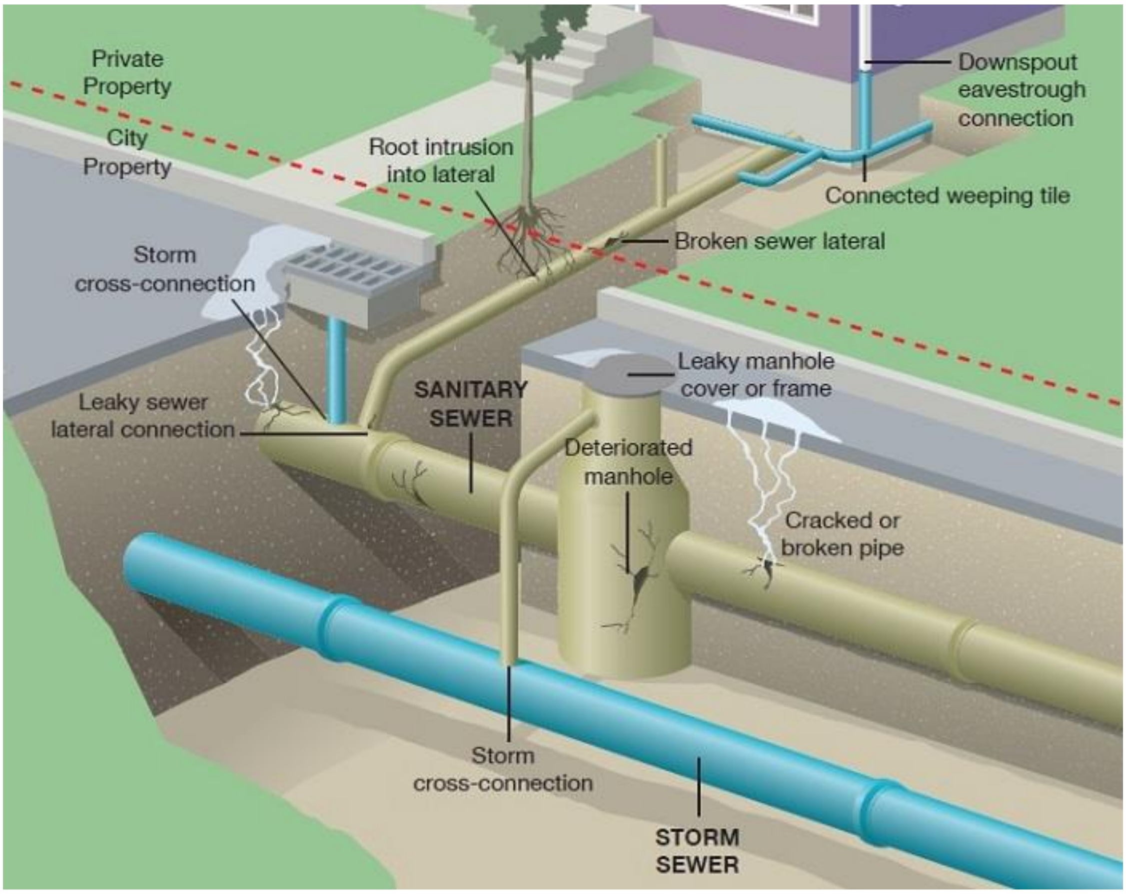

Figure 18: Storm cross connection in to sanitary sewer

2.3.5. Hydraulically Efficient Channel Section

The conveyance of a channel section of a given area increases with a decrease in its perimeter. Hence a channel section having the minimum perimeter for a given area of flow provides the maximum value of the conveyance. With the slope, roughness coefficient and area of flow fixed, a minimum perimeter section will represent the hydraulically efficient section as it conveys the maximum discharge. This channel section is also called the best section.

2.4. Storm Water Detention and Retention Systems

Peak runoff reduction can be achieved through the implementation of on-site ABC Waters design features and structural detention and retention features, such as:

- - Detention tanks
- - Retention ponds/Sedimentation basins
- - Large perimeter drains
- - Wetlands
- - Planter boxes
- - Bioretention swales

- \- Porous pavements
- \- Bioretention basins or rain gardens, etc.

Features such as bioretention basins, and gravel trenches may be designed to hold stormwater runoff in porous subsoil voids or at the surface by allowing for temporary surface ponding. These features may be incorporated with the architectural design of the developments to create aesthetically pleasing and functional storage systems.

Figure 19: Rain Garden

Figure 20: Retention Pond

Reduction in peak runoff of a site can be achieved by using one or a combination of detention/retention measures, depending on the availability of space, intended functions of the stormwater management system, and costs. These detention systems may be used in conjunction with rainwater harvesting and reuse systems. However, to ensure the detention volume is available for the next storm event, the storage volume for the rainwater harvesting and reuse system would have to be catered for separately from the detention volume.

2.4.1. Infiltration Basins

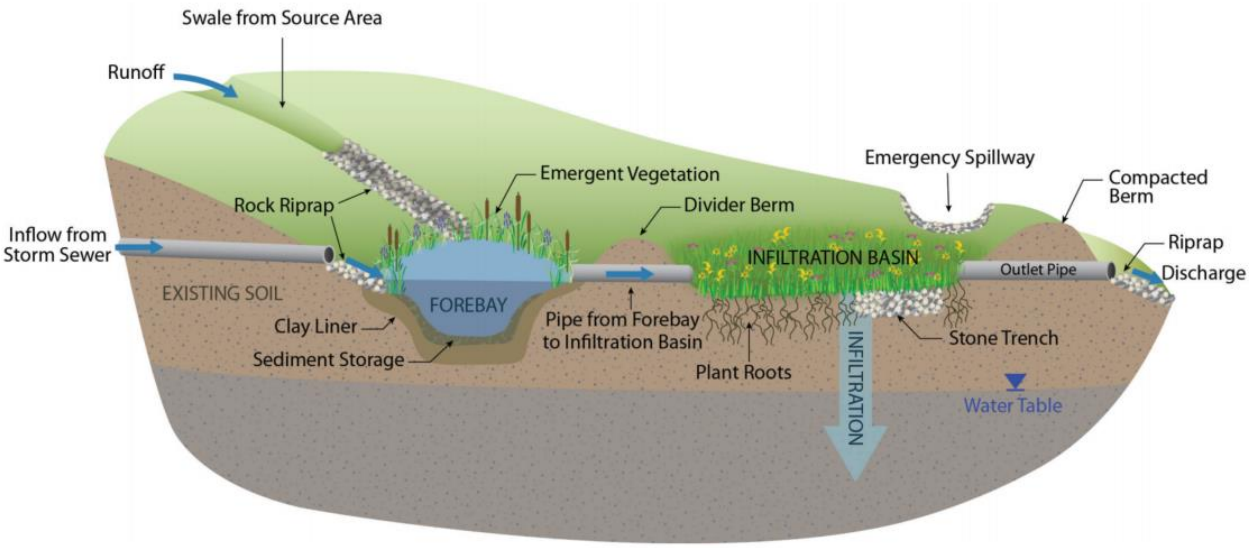

Figure 21: Infiltration Basin

Infiltration basins are designed to capture a storm water runoff volume, hold this volume and infiltrate it into the ground over a period of days. Infiltration basins are almost always placed off-line, and are designed to only intercept a certain volume of runoff. Any excess volume will be bypassed. The basin may or may not be lined with plants. Vegetated infiltration systems help to prevent migration of pollutants and the roots of the vegetation can increase the permeability of the soils, thereby increasing the efficiency of the basin. Infiltration basins are typically not designed to retain a permanent pool volume. Their main purpose is to simply transform a surface water flow into a ground water flow and to remove pollutants through mechanisms such as filtration, adsorption and biological conversion as the water percolates through the underlying soil. Infiltration basins should be designed to drain within 72 hours in order to prevent mosquito breeding and potential odor problems due to standing water and to ensure that the basin is ready to receive runoff from the next storm (US EPA, 1993a). In addition to removing pollutants, infiltration basins are useful to help restore or maintain pre-development hydrology in a watershed. Infiltration can increase the water table, increase baseflow and reduce the frequency of bank full flooding events.

2.4.2. Porous Pavement Systems

Porous pavement is an infiltration system where storm water runoff is infiltrated into the ground through a permeable layer of pavement or another stabilized permeable surface. These systems can include porous asphalt, porous concrete, modular perforated concrete block, cobble pavers with porous joints or gaps or reinforced/stabilized turf (Urbonas and Strecker, 1996). Permeable pavement can be used in parking lots, roads and other paved areas and can greatly reduce the amount of runoff and associated pollutants leaving the area. Porous pavement systems are suitable for a limited number of applications. Typically, porous pavement can only be used in areas that are not exposed to high volumes of traffic or heavy equipment. They are particularly useful for driveways and streets and in residential areas, and in parking areas in commercial areas. Porous pavement is not effective in areas that receive runoff with high amounts of sediment due to the tendency of the pores to clog. Porous pavements require maintenance including periodic vacuuming or jet-washing to remove sediment from the pores. Paved areas should be clearly marked to indicate that a porous pavement system is in use and to prevent frequent use by equipment, to prevent excess traffic volume, to limit the use of de-icing chemicals and sand, and to prevent resurfacing with non-porous pavement.

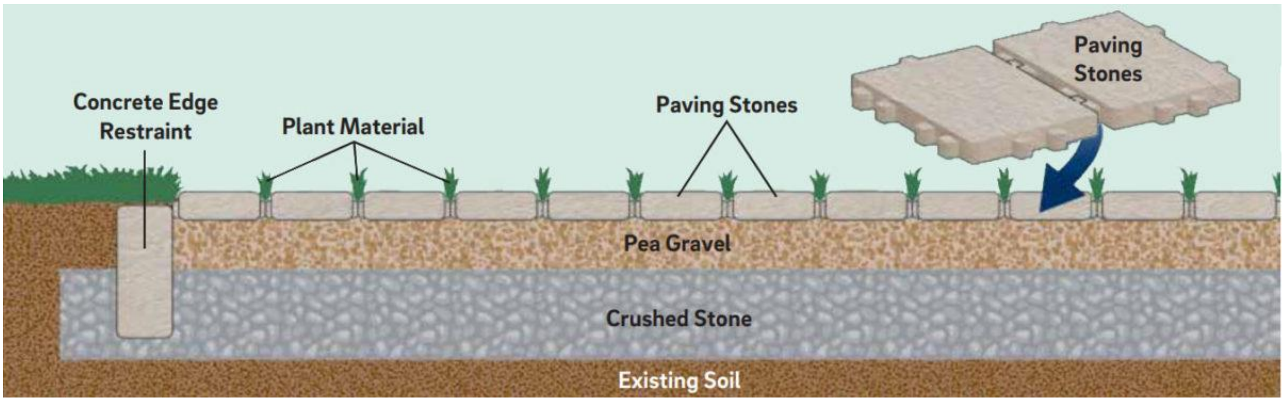

Figure 22: Porous pavement system

2.4.3. Infiltration Trenches and Wells

An infiltration trench or well is a gravel-filled trench or well designed to infiltrate storm water into the ground. A volume of storm water runoff is diverted into the trench or well where it infiltrates into the surrounding soil. Typically, infiltration trenches and wells can only capture a small amount of runoff and therefore may be designed to capture the first flush of a runoff event. For this reason, they are frequently used in combination with another BMP such as a detention basin to control peak hydraulic flows.

Infiltration trenches and wells can be used to remove suspended solids, particulates, bacteria, organics and soluble metals and nutrients through the mechanisms of filtration, absorption and microbial decomposition. They are also useful to provide groundwater recharge and to increase base flow levels in nearby streams. As with all infiltration practices, the possibility for groundwater contamination exists and must be considered where groundwater is a source of drinking water. Pictures of infiltration trenches are shown below.

Figure 23: Infiltration Trench Type 1

Figure 24: Infiltration Trench Type 2

2.4.4. Detention Systems

Detention systems are BMPs that are designed to intercept a volume of storm water runoff and temporarily impound the water for gradual release to the receiving stream or storm sewer system. Detention systems are designed to completely empty out between runoff events, and therefore provide mainly water quantity control as opposed to water quality control. Detention basins can provide limited settling of particulate matter, but a large portion of this material can be re-suspended by subsequent runoff events. Detention facilities should be considered mainly as practices used to reduce the peak discharge of storm water to receiving streams to limit downstream flooding and to provide some degree of channel protection. There are several types of detention facilities used to manage storm water runoff, including detention basins and underground vaults, pipes and tanks.

Figure 25: Detention Basin

Detention basins are designed to intercept a volume of storm water, temporarily impound the water and release it shortly after the storm event. The main purpose of a detention basin is quantity control by reducing the peak flow rate of storm water discharges. They are designed to not retain a permanent pool volume between runoff events. and most basins are designed to empty in a time period of less than 24 hours. The treatment efficiency of detention basins is usually limited to removal of suspended solids and associated contaminants due to gravity settling. The efficiency can be increased by incorporating a forebay or pre-settling chamber for the accumulation of coarse sediment, facilitating periodic cleaning in order to prevent washout by subsequent runoff events. Detention basins can limit downstream scour and loss of aquatic habitat by reducing the peak flow rate and energy of storm water discharges to the receiving stream, but their removal of pollutant of potential water quality concern can be limited.

2.4.5. Underground Vaults, Pipes and Tanks

Underground detention facilities, such as vaults, pipes and tanks, are designed to provide temporary storage of storm water runoff. Significant water quality improvements should not be expected in underground detention facilities. They should mainly be used for providing storage to limit downstream effects due to high peak flow rates. Like detention basins, underground detention systems are designed to empty out between runoff events so that storage capacity is available for subsequent runoff events. In addition, studies are being conducted to evaluate the usefulness of in-system detention (storing runoff temporarily in the storm drainage system through the use of valves, gates, orifices, etc.). This is a potential alternative for retrofitting existing storm drains in the upper portions of the drainage system to delay the peak discharge rate and provide a limited amount of additional temporary storage volume. However, a careful analysis of the storm drainage system is necessary in order to prevent flooding in the upper reaches of the drainage area.

Figure 26: Underground Vaults Tanks

2.4.6. Retention Systems

Retention systems include wet ponds and other retention systems such as underground pipes or tanks. Retention systems are designed to capture a volume of runoff and retain that volume until it is displaced in part or in total by the next runoff event. Retention systems can provide both water quantity and quality control. The volume available for storage, termed the water quality volume, is provided above the permanent pool level of the system. The main pollutant removal mechanisms in retention systems is sedimentation. By retaining a permanent pool of water, retention systems can benefit from the added biological and biochemical pollutant removal mechanisms provided by aquatic plants and microorganisms, mimicking a natural pond or lake ecosystem. Also, sediments that accumulate in the pond are less likely to be re-suspended and washed out due to the presence of a permanent pool of water. In addition to sedimentation, other pollutant removal mechanisms in retention systems include filtration of suspended solids by vegetation, infiltration, biological uptake of nutrients by aquatic plants and algae, volatilization of organic compounds, uptake of metals by plant tissue, and biological conversion of organic compounds.

2.4.6.1. Retention Ponds

Retention ponds (also known as wet ponds) are designed to intercept a volume of storm water runoff and to provide storage and treatment of this runoff volume. Water in the pond above the permanent pool level is displaced in part or completely by the runoff volume from subsequent runoff events. Retention ponds, when properly designed and maintained, can be extremely effective BMPs, providing both water quality improvements and quantity control, as well as providing aesthetic value and aquatic and terrestrial habitat for a variety of plants and animals.

Pollutant removal in retention ponds can occur through a number of mechanisms. The main mechanism is the removal of suspended solids and associated pollutants through gravity settling. Aquatic plants and microorganisms can also provide uptake of nutrients and degradation of organic contaminants. Retention basins that incorporate an aquatic bench around the perimeter of the basin that is lined with aquatic vegetation can have an added pollutant removal efficiency. This littoral zone can aid in pollutant removal efficiency by incorporating mechanisms found in wetland systems. These mechanisms include removal of sediment by filtration by aquatic plants's removal of metals and nutrients through biological uptake by aquatic vegetation and degradation of organic contaminants. If the bottom of the pond is not lined, then infiltration can occur aiding in the maintenance of local groundwater supplies. A diagram of a typical wet pond is shown below.

Figure 27: Retention Pond

2.4.7. Constructed Wetland Systems

Constructed wetland systems incorporate the natural functions of wetlands to aid in pollutant removal from storm water. Constructed wetlands can also provide for quantity control of storm water by providing a significant volume of ponded water above the permanent pool elevation. Constructed wetland systems have limits to their application. A water balance must be performed to determine the availability of water to sustain the aquatic vegetation between runoff events and during dry periods. In addition, a sediment forebay or some other pretreatment provision should be incorporated into the wetland system design to allow for the removal of coarse sediments that can degrade the performance of the system. Also, construction sediment should be prevented from entering constructed wetlands, as the resulting sediment loading can severely degrade the performance of the system. Constructed wetlands are particularly appropriate where groundwater levels are close to the surface because groundwater can supply the water necessary to sustain the wetland system.

Storm water runoff should not be intentionally routed to natural wetlands without pretreatment due to the potentially damaging effects runoff can have on natural wetland systems. In addition, natural wetlands that receive storm water runoff should be evaluated to determine if the runoff is causing degradation of the wetland, and if so, measures should be taken to protect the wetland from further degradation and to repair any damage that has been done. In addition, local permitting authorities should be consulted prior to designing and maintaining constructed wetland systems in order to determine if any local regulations apply to their use or maintenance.

2.4.7.1. Wetland Basins and Wetland Channels

Wetland basins and channels are any of a number of systems that incorporate mechanisms of natural wetland systems for water quality improvement and quantity control. A wetland channel is designed to develop dense wetland vegetation and to convey runoff very slowly (Urbonas and Strecker, 1996). Generally, this rate is less that 2 feet-per-second at the 2-year peak flow. Wetland basins may be designed with or without an open water (permanent pool) component.

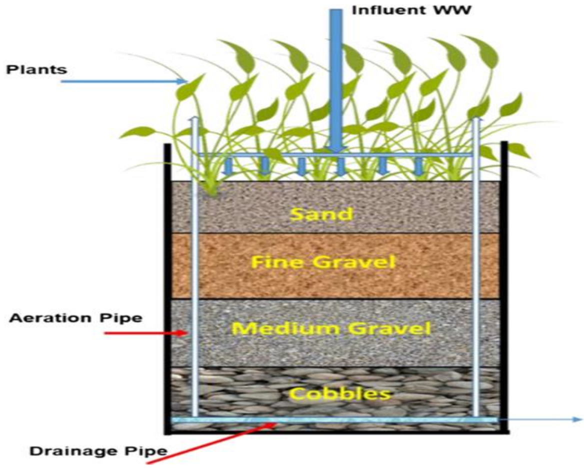

Figure 28: Constructed wet land basin

Figure 29: A view of Wetland Basin

Wetland basins with open water are similar to retention ponds, except that a significant portion (usually 50 percent or more) of the permanent pool volume is covered by emergent wetland vegetation. Wetland basins without open water are inundated with water during runoff events, but do not maintain a significant permanent pool. Wetland basins of this type, also known as a wetland meadow, support a variety of wetland plants adapted to saturated soil conditions and tolerant of periodic inundation by runoff.

Pollutant removal in wetlands can occur through a number of mechanisms including sedimentation, filtration, volatilization, adsorption, absorption, microbial decomposition and plant uptake. In addition, wetlands can provide for significant water storage during runoff events, thus supplying water quantity control as well. A diagram of a typical storm water wetland system is included below.

2.4.8. Biofiltration/Bioretention Systems

Bioretention systems are designed to mimic the functions of a natural forest ecosystem for treating storm water runoff. Bioretention systems are a variation of a surface sand filter, where the sand filtration media is replaced with a planted soil bed. Storm water flows into the bioretention area, ponds on the surface, and gradually infiltrates into the soil bed. Pollutants are removed by a number of processes including adsorption, filtration, volatilization, ion exchange and decomposition (Prince George's County, MD, 1993). Treated water is allowed to infiltrate into the surrounding soil, or is collected by an under-drain system and discharged to the storm sewer system or directly to receiving waters. When water is allowed to infiltrate into the surrounding soil, bioretention systems can be an excellent source of groundwater recharge. A diagram of a typical bioretention area is shown below.

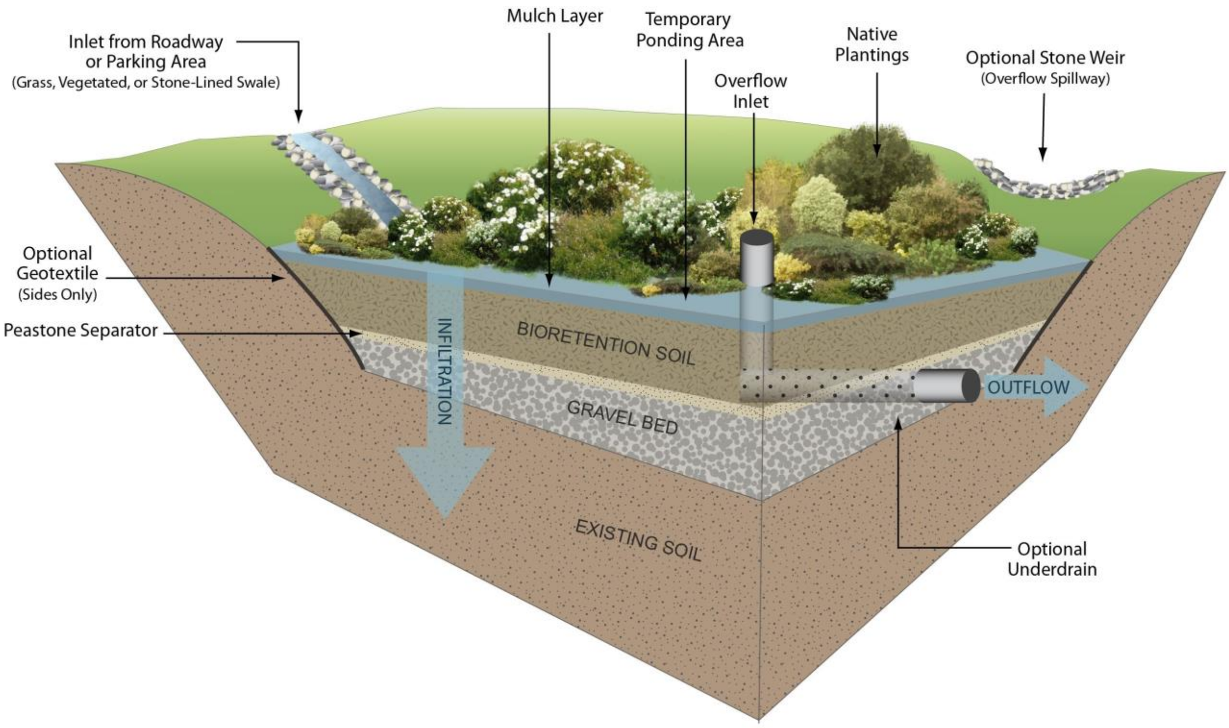

Figure 30: Bioretention system

2.4.9. Vegetated Swales

Figure 31: Vegetated Swales

Vegetated swales are broad, shallow channels with a dense stand of vegetation covering the side slopes and channel bottom. Vegetated swales are designed to slowly convey storm water runoff, and in the process trap pollutants, promote infiltration and reduce flow velocities.
Vegetated swales can be either wet or dry. Dry swales are used in areas where standing water is not desired, such as in residential areas. Wet swales can be used where standing water does not create a nuisance problem and where the groundwater level is close enough to the surface to maintain the permanent pool in inter-event periods. Wet swales provide the added benefit of being able to include a range of wetland vegetation to aid in pollutant removal.

2.5. Outlet Structures

Storm drain outlets are used to conduct storm water away from developed lots, buildings, housing developments, etc. and usually discharge into the nearest stream.

- Storm drainage channels should be of a size capable of accommodating peak storm events.
- Storm drainage outlet structures should not be constructed directly on-stream banks, but should be constructed some distance back and a channel excavated from the outlet structure to the stream.

2.5.1. Implementation Procedures

Storm drain outlet structures should be constructed after excavating a channel to the stream; this channel should be constructed so that it is generally oriented parallel to the direction of flow of the receiving stream. This channel should be lined with clean stones to reduce the velocity of water exiting the outlet structure before the water enters the stream in order to avoid streambed and stream bank erosion. The channel should be fully stabilized prior to the entry of storm water into it to prevent erosion and consequent downstream siltation.

Figure 32: Storm drain outlet channel 1

Figure 33: Storm drain outlet channel 2

Once storm drain outlets have been properly constructed and stabilized regular maintenance is usually not required.

2.5.2. Sluice gates

Figure 34: Sluice gates

Drainage sluice gates are built at the end of drainage channels to discharge floodwater in the controlled area into rivers or lakes to prevent waterlogging. Sluice drains; when the control area has the task of water storage and irrigation, the sluice gate can be closed to store water when the water level of the outer river is low. In addition to the functions of blocking tides and draining waterlogging, the drainage gates built in the tidal section can also draw the river water (freshwater) supported by the high tide during the water demand period of the control area for irrigation. During the low tide, the ship was opened to facilitate shipping.

The characteristic of the drainage sluice gate is that it not only needs to hold the water in both directions but also can pass the water in both directions.

2.6. Erosion and Sediment

Introduction: The three cornerstones of the 'erosion and sediment control industry' are *drainage control*, *erosion control*, and *sediment control*. The functions of construction phase drainage, erosion, and sediment controls are presented below.

- Drainage control measures aim to prevent or reduce soil erosion caused by concentrated flows (including the management of rill and gully erosion), and to appropriately manage the movement of 'clean' and 'dirty' water through the site.
- Erosion control measures aim to prevent or reduce soil erosion caused by raindrop impact and sheet flow (i.e. the control of splash and sheet erosion).
- Sediment control measures aim to trap and retain sediment displaced by up-slope erosion processes.

It is noted that on most work sites, best practice sediment control measures cannot, on their own, provide adequate protection of downstream environments. Therefore, appropriate drainage and erosion control measures must also be applied, at all times, especially on clayey soils. Desirable environmental protection is only achieved when all three control measures are working in a coordinated manner during each stage of the construction process.

One of the most notable features of the erosion and sediment control profession is that there is almost always an exception to every rule and guideline. The fact that a control measure is observed to work well on one site does not mean that it will work well on all sites. Similarly, the fact that a control measure has repeatedly failed within one region does not mean that the technique will not be useful within another region.

Even though erosion and sediment control practices sit at the cutting edge of common sense, their application to a given site must represent an appropriate balance between theory, past experience, and common sense. Also, no rule or recommendation should be allowed to overrule the application of unique, site-specific solutions, where such solutions can be demonstrated to satisfy the environmental objectives and the specified performance standards. Here are some examples of erosion:

2.6.1. Impacts of soil erosion and sediment runoff

- Dust generated on construction sites can cause significant problems to neighboring properties.

- Sediment deposition within stormwater drainage pipes and culverts can:
- cause property flooding
- increase flooding and safety risks on roadways
- increase maintenance costs for stormwater asset owners such as local governments
- increase the risk of mosquito problems

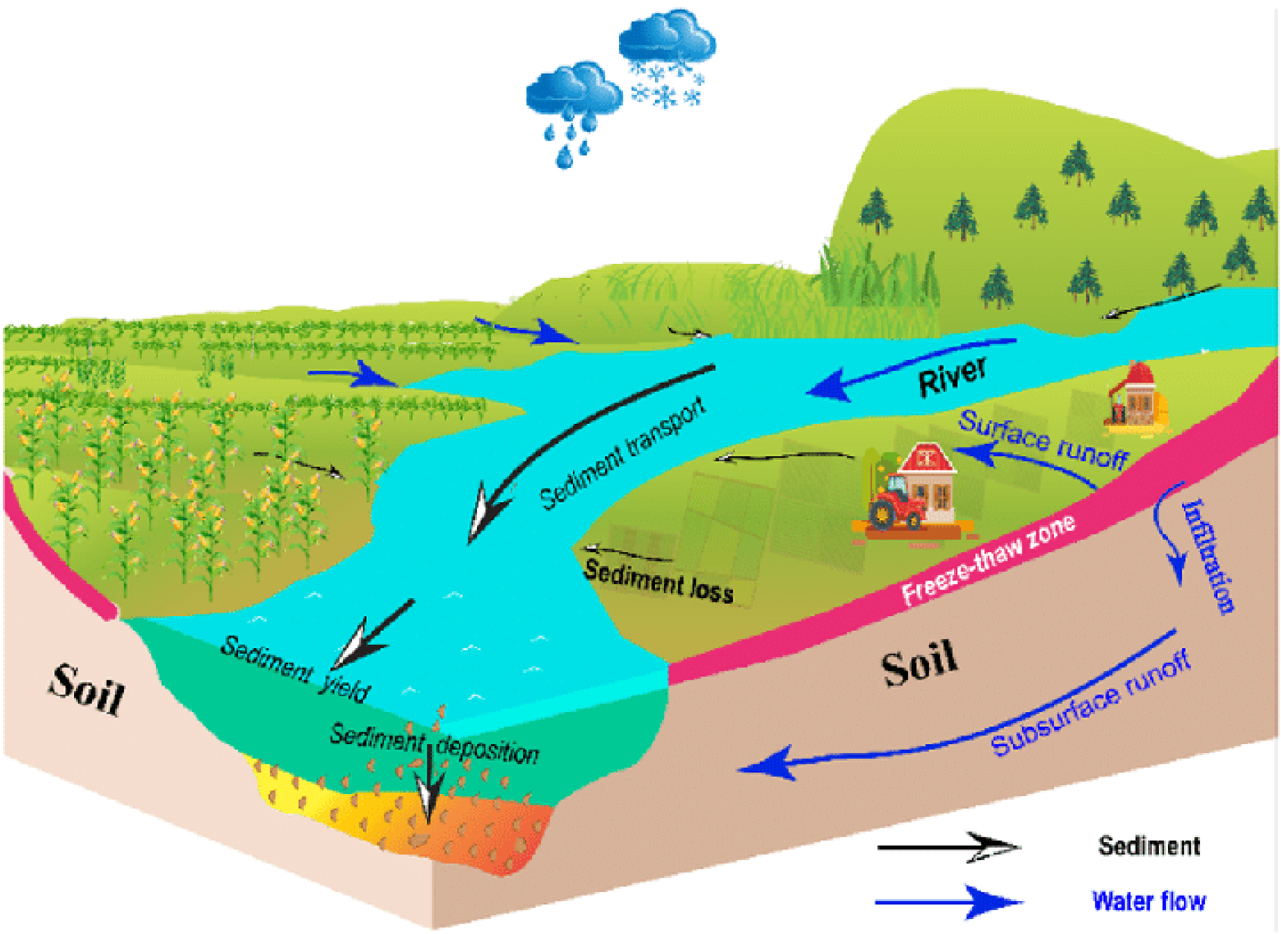

Figure 35: Impact of soil erosion

Figure 36: Blockage of stormwater pipes & culverts due to dust

2.6.2. Sedimentation within waterways

- The deposition of coarse sediment in minor waterways, such as creeks, can:
- increase the risk of property flooding
- cause bank erosion and channel instabilities
- cause the loss of essential aquatic habitats
- increase the weed infestation of creeks
- increase maintenance costs for stormwater asset owners such as local governments

Figure 37: Sedimentation within waterways

2.6.3. Suspended fine sediments in water ways

- The release of fine sediments and turbid water into minor waterways can:
- adversely affect the health and bio- diversity of aquatic life within permanent pools
- adversely affect fish numbers and fish breading
- increase the concentration of nutrients and metals within permanent waters
- reduce light penetration into pools
- increase the frequency, cost and damage of de-silting operations

2.6.4. Sedimentation of rivers and estuaries

- The release of sediments and turbid water into rivers and estuaries can:
- adversely affect the health and bio- diversity of aquatic life within these water bodies
- adversely affects fish numbers and fish breading
- increase the concentration of nutrients and metals within these waters
- reduce light penetration into the water
- increase the risk the cost of water treatment works associated with both farm dam and town water supplies

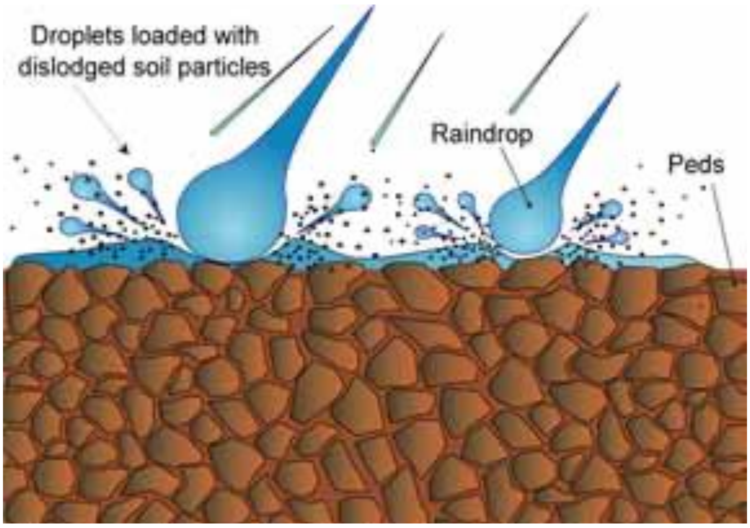

Figure 38:Raindrop impact erosion

- Raindrops can exert significant force upon impact with the ground.
- The resulting soil erosion is often difficult to detect and consequently is often ignored.
- Raindrop impact erosion is a major cause of the release of fine, clay-sized particles resulting in highly turbid (brown) runoff.
- It would not be unseasonable for raindrop impact erosion to cause the release of 1 to 2 cm of soil during the construction phase.


Figure 39: Erosion of a depressive soil

- Soil chemistry can have a significant influence over the severity and extent of soil erosion.
- If a soil is 'dispersive' then it is likely to be highly unstable when wet, resulting in severe, deep riling (or 'fluting' shown left), tunnel erosion and/or gully erosion.

3. OPERATION OF STORM WATER DRAINAGE SYSTEM

3.1. Storm Event Monitoring and Response

Storm Event Monitoring is the process of collecting real-time data before, during, and after a storm event. This involves the use of sensors, gauges, and other meteorological tools to track rainfall intensity, duration, and other parameters. Advanced systems may even integrate weather forecasts and satellite imagery.

A well-implemented monitoring system provides timely alerts to municipalities and emergency response teams, allowing them to proactively handle potential flooding situations. By understanding the current conditions and predicting the immediate effects of a storm, resources can be allocated efficiently, ensuring safety and minimizing damage.

Figure 40: Storm control Room

3.1.1. Stormwater monitoring

Monitoring refers to the monitoring of stormwater discharges from a defined point in the stormwater system during defined storm events. All stormwater monitoring sites may be manholes within the storm collection system or the storm open drains culverts.

The purpose of the monitoring is:

- To estimate the volume of infiltration/inflow entering various sewer segments/ sewer sheds in the city’s Wastewater Collection and Transmission System;
- To provide flow data required for the assessment of the capacity of various sewer segments;
- To measure or predict the effectiveness of related rehabilitation in meeting Level of Service performance targets;
- To provide modeling input data for system flow calibration and projections;
- To support the prioritization of sanitary sewers for more advanced inspections and analysis so that cost effective rehabilitation results in I/I reduction and restored capacity; and

- To measure flow coming from and going to inter-governmental users or providers for billing purposes.

A System-Wide Flow and Rainfall Monitoring Program is integral to the development and maintenance of the Wastewater System Hydraulic Model relative to making capacity decisions or confirming the capacity status of portions of the conveyance system. The Program serves an important role in building the hydraulic model components and calibrating the results.

3.1.1.1. Storm water Flow Monitoring

Depending on the specific Program's needs, there are two types of flow meters used - permanent and temporary. Permanent meters provide system information over a longer period and produce long-term monitoring data that will provide historical trending. Permanent meters can use alternating current (AC) or direct current (DC) power (a combination of batteries and solar panels). Temporary meters or short-term flow monitoring sites provide data as a "snap-shot" in time. Temporary meters use DC power provided by batteries. The network of flow and rainfall meters includes:

- Permanent flow meters that will monitor via an automatic wireless system in real time every 15 minutes. Area-velocity flow monitors are primarily used.
- Rain gauges are located within the city where the data obtained is shared with the public. Rain gauges are installed at all important points where ponding occurs.
  Data from flow meters and rain gauges are collected via remote wireless technology and can be viewed online.
- The rain gauges sites with wireless equipment will transfer the rainfall data to the remote data server.
  The City Governments can contract for the installation and continued maintenance of flow monitors and rain gauges. The contract may include the following activities, staff, and equipment:
- **Installation or Removals:** Equipment generally consists of flow meters, digital Doppler velocity sensors, wireless data acquisition modems, battery, solar power option, rain gauges, and software.

Figure 41: Doppler flow meter installed on a drain

- **Maintenance:** Maintenance of hardware at each location is to be conducted once a month and consists of equipment cleaning / check-ups to provide proper flow meter and rain gauge functioning and accurate data recording.
- **Calibration:** Flow meter and rain gauge will be calibrated as needed during each visit. Appendix.

- During the visit, a diagnostic test will be performed and necessary actions will be taken such as sensor cleaning and calibration until the equipment malfunction is corrected.

3.1.1.2. Criteria for Establishing the Location of Equipment

a) Flow Monitors

The number of flow monitors and their locations are based on several criteria. The first criterion is the facilitation of sewer sheds or drainage areas isolation to determine the dry- and wet- weather flow in a specific isolated area. The sewer map is the basis used for determining the flow paths and points for isolation. The second criterion is even distribution. When the meters are evenly distributed in the sewer sheds and drainage areas, the data are more reliable and more useful for modeling and other program needs. GIS maps are used to help determine the distribution of the meters. The third criterion is the relative significance of the flow control points. The concerned Agency focuses on such points as major lift stations, the wastewater treatment plants, and the inter-jurisdictional connections.

Listed below are the flow isolation and control points for meter locations:

- Most sewer shed discharge points, except for sewer sheds with small service areas or insignificant flows
- Isolation points upstream of the sewer shed for the purposes of determination
- Wastewater Treatment Plants
- Major Lift Stations
- Connection points with other local jurisdictions
- Historical repeated significant Sanitary Sewer Overflow locations

Additional flow monitoring data are also obtained from the run time data and drawdown tests at lift stations.

The following criteria are used in selecting flow meter types:

- Pipe size
- Flow ranges
- Hydraulic conditions
- Telemetry method
- Operating principle
- Accuracy
- Duration
- Data management
- Cost

b) Rain Gauges

Rain gauges measure rainfall intensity and durations throughout a specific monitoring period. Rainfall data is synchronized with flow monitoring data to determine the rain density volume and peaking factor.

Rain gauges are the most common device for measuring rainfall. A standard non-recording gauge collects rain falling on a standard area (in the UK, a 127mm diameter funnel with the rim placed 300mm above ground level) over a known period of time. The volume of the stored rainfall is measured manually and, if necessary, converted to rainfall intensity (depth/time) by dividing by the collection area. Collection periods range from 6 hours to one month, but one day is typical. Since urban drainage systems can respond in less than 6 hours, the data from non- recording gauges is of limited value in this application.

Figure 42: Standard Rain Gauge

Figure 43: Tipping Bucket rain gauge

Recording gauges are able to provide a continuous record of rainfall. The tipping-bucket rain gauge collects rainfall over short periods of time in a balanced reservoir consisting of two miniature compartments. Rainwater enters the first compartment until the weight of the water makes it tilt. Water begins to enter the second compartment while the first empties. Thus, the gauge produces a series of tips with a changing frequency depending on the rainfall intensity. The number of tips per unit time is therefore related to the rainfall intensity. A record is made either of the number of tips in a set time interval or the time of each tip. Typically, this is recorded electronically and stored in the memory of a data logger on site or transmitted over telephone lines to a central station. The data can be downloaded to a computer at convenient time intervals for processing. The range of rainfall depth resolution is 0.1 to 0.5 mm/tip.

The meteorological Department has installed rain gauges on the limited points only therefore often the true picture of the rainfall in the city is not depicted in their report. It is therefore, suggested that MCs may procure rain gauges to install at all important points of the city to measure exact rainfall on a particular date.

c) Computer Based Data Management System

A server is designated specifically for flow monitoring data storage. The flow and rainfall monitoring data team maintains the data internally with the assistance of the Information Technology Department. Data can also be accessed through the server internally.

In addition to storing and organizing the data, the flow and rainfall monitoring software will also be used to:

- Communicate with the flow monitoring sites and maintain data continuously uploaded to server
- Allow remote viewing of live data from internet browsers internally and externally and share data with multiple users
- Share data with GIS and modeling software packages, for the sewer system hydraulic modeling
- Generate and print graphs for data
- Perform flow analysis to determine the rain inflow volume and rate
- Generate and print monthly reports and flow study reports

3.1.1.3. Program Operations Quality Assurance and Quality Control

a) Rainfall Data Analysis: Rainfall data will be used for the analysis to classify the storm events and determine the storm frequency, duration, volume, and peak intensity for all selected rain gauge sites.

b) Flow Analysis: The combination of flow and rainfall monitoring data is used to estimate the peak flows associated with selected storm events. Flow and rainfall data are used for Hydraulic Model calibration and flow analysis to determine rain density entering the system. The data is also used to assess capacity availability in the sewer system and prioritize upgrades and rehabilitation needs to provide additional capacity, as needed as well as capacity evaluations for various sewer sections.

3.2. Problems of Flat Areas:

In flat low-lying areas subject to flooding, a major problem often results from the relatively high level of the receiving water body. This limits the slope to which drains can be laid, so that water flows along them quite slowly. Together with the difficulty of digging deep drainage channels where the groundwater level is high, this means that drains have to be relatively wide in order to have sufficient capacity.

Sometimes there is no alternative to using landfill to raise the levelof the ground in all or part of the neighborhood. Landfill limited to the streets will cause increased flooding of people's plots and houses,so that adequate quantities should be provided, sufficiently close to people's houses for them to cart it away and spread it on their premises. They should be helped to judge how to place it by marks painted in advance on each house showing the level to which the ground should be raised by the landfill.

The idea of people placing rubble and soil inside their houses to raise the floor level may seem strange to some, but there are low- income urban areas whose residents have been glad of up to 50 cm of landfill placed in this way. Their houses will eventually need modification or rebuilding as a result, but the impact of landfill can so transform an area that residents often wish to build a new house more appropriate for the improved surroundings, once they are convinced that it will be safe from flood damage. The water level in the receiving water body often fluctuates, owing to tidal effects or the flow of water into it from other catchment areas. These variations in level can be analyzed in terms of their return period when a decision is made as to the depth of landfill required.

Alternatively, tidal variations in level can be turned to advantage by installing a sluice gate at the outlet from the drainage system which is opened at low tide and closed when the level rises. The need for landfill can also be avoided by building a large embankmentor dike along the bank of a river liable to flood, or right around the residential area creating a "polder".

Figure 44: The polder system

Of course, some installation such as a sluice gate is needed to allow a way out for waterdrained from the area. However, no such arrangement should be considered without very thorough study by an engineer and a guarantee of reliable operation and maintenance. A dike that overflows or a sluice gate that fails to function could do enormous damage.

Another difficulty in the drainage of flat areas is the deposition of sediment in the drains, owing to the slow speed of flow of the water. Where possible, drainage systems should be designed to produce a minimum "self-cleansing" speed of flow, at least when the drains are running full, so that water will carry the sediment along with it. In a drainage channel with a rectangular cross-section, the water will flow slowly in a thin layer on the bottom after light or moderate rain.Moreover, any irregularities in the flat bottom will create puddles in which mosquitos can breed. Building a drainage channel with sloping sides and a narrow bottom helps to maintain a steady flow speedwhatever the water level in the channel. A refinement of this principle is to build a channel with a composite section.

Figure 45: Deposit of sediment

Figure 46: channel with sloping side

The central channel with a narrow bottom is to carry the flow in dry weather and moderate rain, while the outer channel is for the occasional heavy flood flow. The outer channel floor should prefer- ably slope gently down to the central channel or “cuneate”.

A self-cleansing speed of flow also requires a minimum slope, which is greater for small drains than for large ones. Roughly speaking, a channel 10—15 cm wide will need a minimum slope of about 1% to achieve a self-cleansing speed of flow. A channel twice the size needs roughly half the slope. Such minimum slopes are not always achievable, though, as there may not be a sufficient drop in level from the street to the receiving water body. However well the system is designed, some sediment is bound to be deposited, so that regular cleaning is essential to keep the drains working.

3.3. Stormwater Capacity Assessment of Existing Open Drains

Assessing the capacity of open drains involves understanding how much water these systems can handle before they overflow. This requires an examination of the physical dimensions of the drain, its current state (e.g., any blockages or damage), and the volume of water it typically receives.

Computer simulations can also play a role, modeling various rainfall scenarios to predict how the drain would respond. An efficient capacity assessment will highlight vulnerabilities in the system and guide upgrades or modifications to accommodate larger volumes of water, especially in light of changing climate patterns.

3.3.1. General

Complete reach-wise discharge capacity data of existing drains are not available normally in MC records. Some discharge capacity values may be available but the accuracy is not considered of high reliability. These constricted sections may have been cropped up due to human activities over the time span. As such it is understood that the discharge capacity of a main drain may not be in increasing trend but there may be certain bottleneck locations which may cause reduction in discharge capacity in the reach.

3.3.2. Effect of Sewage Inflow

With increase in population the inflow of sewage through the sewage lift stations in the drainage system has definitely increased tremendously which has become the cause of flooding during monsoon storms. The sewage inflow has not only decreased the capacity of drain due to sediment accumulation but has also deteriorated the flow condition and created environmental hazard along the drain stretches.

3.3.3. Field Data Collection

With the objective of ascertaining the discharge capacities of main drains on the basis of existing field data the requisite survey of drains must be carried out. The cross sections at various locations are measured including drain depth from bank to bed and flow depth in the main drains. The field data thus obtained for working out the discharge capacities may be used as below:

Name of drain: -----------

Table 1: Working out the discharge capacities

Parameter	measuring unit	Values
Section/Type		
Location		
Top	width(ft)	
Bottom	width(ft)	
Flow depth	Ft	
Full Flow	depth ft	
Slope	S(ft/ft)	
Flow area	ft^2	
Wetted perimeter	P(ft)	
R(hydraulic radius)	A/P(ft)	
Manning's coefficient (C)		
Velocity	V (ft/s)	
Discharge (Q)	Cusec	

The flow may be calculated by Manning's formula for open channels **Q-AV**
Where:

Q = discharge, cfs V = velocity, ft/s A = flow area, ft^2

When actual channel or stream velocity measurements are not available, the velocity can be calculated using the Manning's equation shown in Equation

V = 1.486(R^2/3) (S^1/2)/n

Where:
V = mean velocity of flow in feet per second
R = hydraulic radius in feet
S = slope of the energy gradient or, for assumed uniform flow, the slope of the channel in feet (vertical) per foot (horizontal)
n = Manning's roughness coefficient or friction factor of the channel lining

3.4. Estimation of Runoff

The essential requirement for designing of Storm Water Drainage system is the proper estimation of storm runoff to downstream drains or the point of disposal. It has a bearing on optimizing the cost of infrastructure as well as its performance. The parameters like rainfall intensity, imperviousness factor, runoff coefficient, recurrence period, climate change, and identification/zoning of drainage catchment play an important role. In this section various methods of estimation of storm runoff like Rational Method, Time Area Method, Unit Hydrograph Method, and Rainfall-Runoff Simulation method are explained.

3.4.1. Basic concepts

Rainfall is normally measured in millimeters; 1 mm of rainfall on a flat area of land, with no infiltration into

the ground, evaporation into the air, or runoff to drainage, would flood the area to a depth of 1 mm. Rainfall intensity is a measure of the rate at which rain is falling, and is usually expressed in mm/hour.
The intensity of rainfall varies during each storm, reaching a peak value much greater than the average for the whole storm. Very high rates of rainfall can come in bursts lasting a few minutes, but not long enough to cause flooding or serious erosion. An important question therefore is the period of time over which rainfall is to be calculated. For a duration of a few minutes, very high intensities would be reached; a drain designed on this basis would be unnecessarily large and expensive.

Fig. A2.1. Rainfall intensity–duration graph for Cebu, Philippines

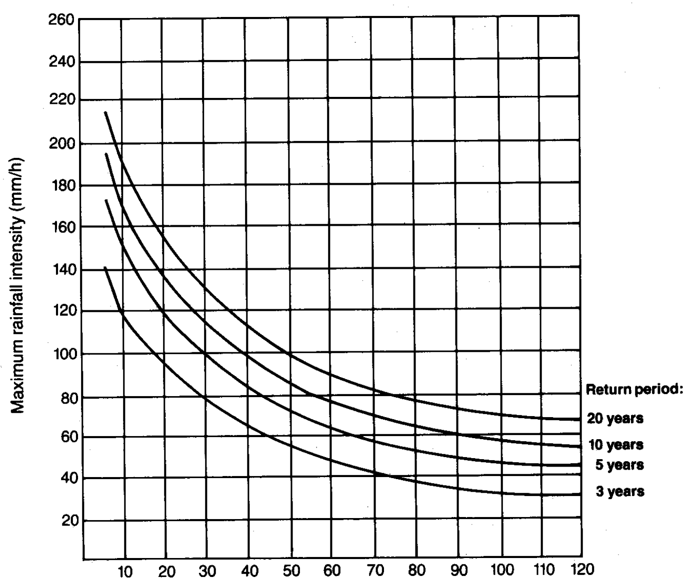

Figure 47: Rainfall intensity—duration graph for Cebu, Philippines

However, if the rainfall intensity is taken as the average for the entire duration of the storm, this would give too low a figure, and drains designed using it would be overloaded for much of the time. The way in which rainfall intensity is related to duration and return period is illustrated by Fig. below, which is based on records for the city of Cebu, Philippines. (Note: the curves in Fig. below cannot be used in other cities, because rainfall conditions vary greatly in different parts of the world.)
The correct duration to use in designing a drain is the "concentration time" of the catchment area which it serves. That is, the amount of time required for water falling on the most far-flung point in the catchment area to run over the ground, into the drainage system, and downstream to the drain that is to be designed. Smaller catchment areas have shorter concentration times. Water flows faster down relatively steep slopes, so that concentration times are also shorter in hilly areas.

However, very short bursts of rainfall lasting less than 15 minutesare unlikely to do serious damage. Thus, a reasonable rule of thumb for small catchment areas (less than 5 ha) is to use a concentration time of 15 minutes. Where average land slopes are greater than 0.5%, this time can be used for areas up to 20 ha. In flatter areas, slightly longer concentration times can be used for areas over 4 ha. A reasonable approximation would be to add one minute for each extra hectare up to 20 ha. For larger catchment areas, it is advisable to consult an engineer.

Runoff from a catchment is that fraction of precipitation which generates surface flow. It thus represents the output from the catchment corresponding to precipitation in a given unit of time. For given precipitation, initial losses due to the interception, evapo- transpiration, infiltration and detention storage requirements have to be first satisfied before the commencement of runoff. After these losses are met, the excess rainfall moves over the surface termed as storm runoff.

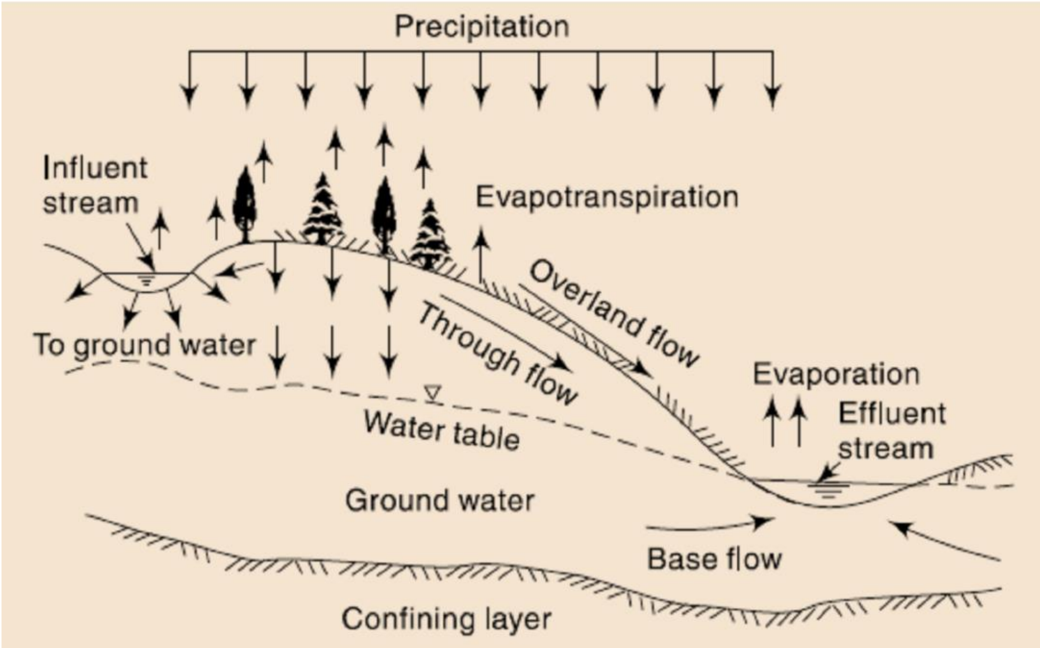

Figure 48: Different routes of runoff

3.4.2. Methods of Runoff Estimation

The following methods are generally used for runoff estimation for the design of urban storm water drainage systems.

a) Rational Method
b) Time Area Method
c) Unit Hydrograph Method
d) Rainfall-Runoff process simulation

The above methods and their use in the design of storm water networks are given below.

a) Rational Method

The rational method was developed during the second half of the 19th century for estimating design discharge from an urban catchment. Majority of urban storm drainage systems are designed based on the Rational Method, in as much as 90% cases across the globe, in spite of having several limitations.

Steps of computation for Rational Method

The procedure for the estimation of storm runoff by the rational method is mentioned in the following steps:

Step 1: Obtain historical rainfall data of 30 years or more for the given project area Step 2: Select a return period as required (5 or 2 years depending upon size of the city).
Step 3: Prepare the IDF curve for the above return period.
Step 4: Demarcate the catchment
Step 5: Determine the time of concentration (tc)
Step 6: Determine rainfall intensity against the time of concentration from IDF curve Step 7: Determine runoff coefficient (C)
Step 8: Calculate peak flow by Rational formula

Storm water drains are designed, taking into account the peak flow. The peak flow is defined as the flow when the entire catchment is contributing to its outlet. This will occur when the given intensity of rainfall begins instantaneously and continues until the time of concentration.

b) Partial Area Effect

In general, the appropriate time of concentration (tc) for calculation of the flow at any point is the longest time of travel to that point. However, in some situations, the maximum flow may occur when only part of the upstream catchment is contributing. Thus, the product of runoff coefficient, lesser catchment area and higher rainfall intensity which is resulting from a lower tc may produce a greater peak discharge than that if the whole upstream catchment is considered. This is known as the 'partial area effect'.

This can occur in 2 cases as described below:

i. The first case occurs when a highly impervious section exists at the most downstream area of a watershed and the total upstream area flows through the lower impervious area. When this occurs, two separate calculations should be made. First, calculate the runoff from the total drainage area with its weighted C value and the intensity associated with the longest time of concentration. Second, calculate the runoff using only the smaller impervious area. The typical procedure would be followed using the C value for the small impervious area and the intensity associated with the shorter time of concentration. Compare the results of these two calculations and use the largest value of discharge for design.
ii. The second case occurs when a smaller, impervious area is tributary to the larger primary watershed of less impervious area. When this occurs, two sets of calculations should also be made. First, calculate the runoff from the total drainage area with its weighted C value and the intensity associated with the longest time of concentration. Second, calculate the runoff to consider how much discharge from the larger primary area is contributing at the same time as the peak from the smaller, impervious tributary area. When the small area is discharging, some discharge from the larger primary area is also contributing to the total discharge. In this calculation, use the intensity associated with the time of concentration from the smaller impervious area. The portion of the larger primary area to be considered is determined by this equation:
iii. $A_C = A^{t_{c1}} / t_{c2}$
iv. Where,
v. Ac : Smaller impervious tributary area to the larger drainage area
vi. A : Larger drainage area
tc1 : Time of concentration of the tributary area
tc2 : Time of concentration of larger drainage area

c) Unit Hydrograph Method

The unit hydrograph method is an outcome of investigation into the geometric properties of the surface runoff portion of the hydrograph in its relation to an effective rain that has fallen during a unit time. The unit hydrograph is, therefore, defined as the hydrograph of direct runoff resulting from a unit depth (1 cm) of rainfall excess occurring uniformly over the catchment and at a uniform rate for a specified duration (D hours). A typical 30 min unit hydrograph is shown below.

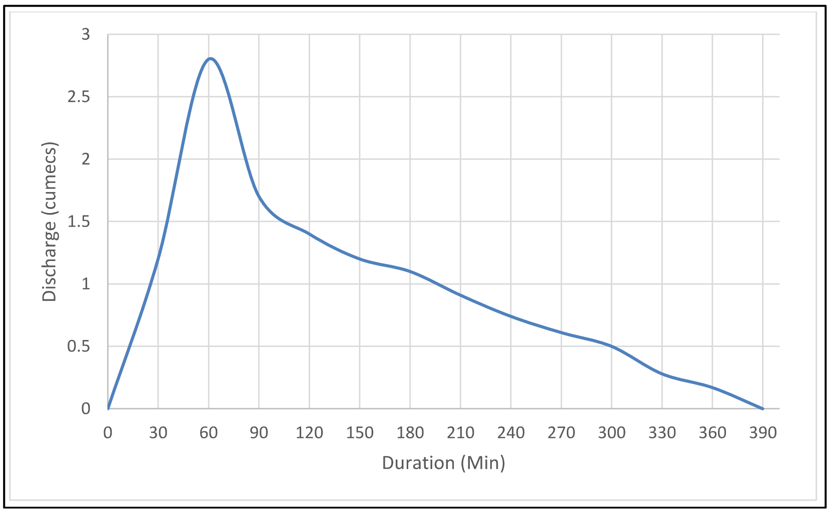

Figure 49: Unit hydrograph

d) Procedure for estimation of runoff

If properly understood and applied, the 'rational method' can produce satisfactory results for sizing storm drains, street inlets, and small on-site detention catchments. The formula for calculating peak flow is given as below:

Q_p= 10CIA

Where,

Q_p : Peak flow at the point of design, m^3/hr

C : Runoff coefficient, dimensionless

I : Average rainfall intensity should be taken for the duration of rainfall equal to the time of concentration, mm/hr

A : Catchment area, hectares

This formula is dimensionally consistent to other measurement systems.

Although this method is widely used in storm water drainage design, the estimation of runoff involves the following assumptions:

a) The maximum size of a catchment should be between 8 to 10 sq km
b) Larger catchments can be sub-divided into smaller sub-catchments
c) The peak flow occurs when the entire catchment is contributing to the flow
d) The rainfall intensity is uniform over the entire catchment
e) The rainfall intensity is uniform over a time duration equal to the time of concentration
f) The frequency of the computed peak flow is the same as that of the rainfall intensity corresponding to the return period of the 'design storm.'
g) The coefficient of runoff is the same for all storms of all recurrence probabilities

The design return period of a storm is an average period of time after which it reoccurs, for a given rainfall magnitude or more corresponding to a particular duration of time. This is integral part of IDF curve developed, based on analysis of past rainfall data, for designing of storm water drainage systems. Depending on importance of the drainage area, socio-economic conditions of the city and other constraints such as funding for infrastructure and availability of space for construction of drains, the design return period of storm should be judiciously adopted in estimation of storm runoff. In view of the above, the recommended design return period of storms is given in Table 3-2 for estimation of storm runoff.

Table 2: Recommended Design Return Period for various types of urban catchments

S.NO	Urban catchment	Return period	
		Big cities*	Small cities**
1	Central Business and commercial	Once in 5 years	Once in 2 years
2	Industrial	Once in 5 years	Once in 2 years
3	Urban Residential	Once in 5 years	Once in 2 years
4	Airports and other critical infrastructure	Once in 100 years	Once in 50 years

*Big Cities are cities having population 1 Lakh and above
**Small cities are cities having population less than 1 lakh

N $t_o = \frac{0.218\,(1.1-C)L^{0.5}}{S^{0.333}}$

4.4.1.6.2 Time of flow (t_f)

$t_f = L_{drain} / V$

The velocity of flow in m/s is computed from the Manning's equation

$$V = \frac{1}{n}R^{0.67}S^{0.5}$$

Where,
V : Velocity of Flow, m/sec
t_f : Time of travel, minutes
n : Manning's roughness coefficient R : Hydraulic radius, m
S : Longitudinal slope
Note: It may not be always feasible to design / retrofit the storm water drains for the recommended return period in all the cities. In cases where redesigning / retrofitting is not feasible as per recommended return period due to city profile / site constraints, efforts should be made to adopt recommended return period by adopting 'Best Management Practices, (BMP) like in-situ rainwater harvesting methods within premises / plots, along the storm water channels / conduits and storm retention/ detention structures to accommodate the excess runoff. However, the preferred return period shall be as per those recommended in the Table above.

Runoff Coefficient

The coefficient of runoff (C), is a function of the nature of surface and assumed to be the same for all storms of all recurrence probabilities. Recommended values of C on various surface types of the catchments are given in Table 3-3. While choosing the values for C, the ultimate development of the catchment as per the master plan should be taken into consideration.

Table 3: Runoff co-efficient of various surfaces

Sr No	Type of Area	Runoff Coefficient
1	Commercial Area	0.70 - 0.95
2	Industrial Area	0.60 - 0.90
3	Institutional Area	0.70 - 0.95
4	Residential Area • High Density • Low Density	 0.60 - 0.75 0.40 - 0.60
5	Recreational Area	0.10 - 0.25

6	Pavement • Asphaltic Pavement • Concrete Pavement • Brick Pavement	 0.70 - 0.95 0.80 - 0.95 0.70 – 0.85
7	Roof Catchment • Tiles • Corrugated Metal Sheets • Concrete	 0.8 – 0.9 0.7 – 0.9 0.7 – 0.90

Whereas the use of the runoff coefficient implies there is a constant ratio of rainfall to runoff, the actual ratio will vary over the course of a storm due to the condition of the area and the variability of the rainfall pattern. A common practice is to use average coefficients for various types of areas and assumed that the coefficients will be constant throughout the duration of the storm.

Weighted average runoff coefficient of catchment area containing different character of surfaces for a flow concentrating at a point may be estimated as follows:

Weighted average of 'C' values of different type of urban surfaces should be calculated by the following formula

$$C = \frac{C_1A_1+C_2A_2+C_3A_3+\ldots\ldots\ldots}{A_1+A_2+A_3\ldots\ldots\ldots}$$

Where,
C1, C2, C3 .... are runoff coefficients of urban surfaces
A1, A2, A3................. are areas of respective urban surfaces
Time of Concentration in storm drainage system (tc)
The rainfall intensity (I) in the rational formula is the average rainfall intensity over a given duration equal to the time of concentration for the drainage area.
The time of concentration (t_c) is defined as flow travel time taken from the hydraulically most remote point in the contributory catchment to the point under consideration. The time of concentration for drain sizing is the time required for water to travel from the most hydraulically distant point in the total contributing catchment to the design point. Typically, this time consists of two components:

i. Time for the surface flow to reach the first inlet, i.e., t_0
ii. Time to flow through the storm drainage system to the point of consideration i.e. t_f .

$t_c = t_0 + t_f$
The inlet time is dependent on the distance of a farthest point in the drainage catchment to the inlet manhole as said above, as well as, on the shape, characteristics and topography of the catchment. It generally varies from 5 to 30 minutes in urban areas. In hilly areas the inlet time may be as low as 3 minutes, where steep slopes are encountered. However, the following formula is widely used to determine inlet time to reasonable accuracy.

Time of surface flow (t0)

The formula to compute the time of surface flow has been developed by the Corps of Engineers, USA from airfield drainage data. The method was originally intended for use on airfield drainage problems but has now been used frequently for surface flow in urban catchments.

The formula to calculate time of surface flow (t_0) is given as follows:

$$t_o = \frac{0.994\ (1.1 - C) L^{0.5}}{S^{0.333}}$$

Where,

t_o : Time of surface flow (Minutes)

C : Rational Method runoff coefficient L : Length of surface flow (m)

S : Surface Slope, in percentage (%)

Note: If slope (S) is expressed as a ratio, then the formula to be applied is

e) US-SCS Curve Number Method

The storm rainfall of 2-year frequency and characteristics of the catchment areas are used to develop the runoff hydrographs by US-SCS Curve Number method based on synthetic unit hydrograph for the catchment area. This method requires the following information about the catchment area.

- Maximum 24-hour rainfall for the design return period.
- Length of nullah/stream measured along the longest path travelled by storm water from head to the site
- Catchment area
- Time of Concentration (Tc)
- Time to Peak (Tp)
- Curve Number (CN) based on the land use in the drainage area and hydrological soil groups (Curve numbers for various catchment conditions are described in text books of Hydrology). The US-SCS Curve Number method is based on the relationships as given below.
  $I_a = 0.2S$
  S = (1000/CN) – 10
  $Q = (P-0.2S)^2 / (P + 0.8S)$
  Where
  Q = Runoff (Inch)
  P = Rainfall (Inch)
  S= Potential maximum retention after runoff begins Ia = Initial abstraction

Initial abstraction (Ia) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Ia is highly variable but generally is correlated with soil and cover parameters. Through studies of many small agricultural watersheds, Ia is approximated by the following empirical equation: **Ia = 02.S**

Potential maximum retention (S) is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by:

S = (1000/CN) – 10

The major factors that determine CN are the hydrologic soil group (HSG), cover type, treatment, hydrologic condition, and antecedent runoff condition (ARC). Another factor considered is whether impervious areas outlet directly to the drainage system (connected) or whether the flow spreads over pervious areas before entering the drainage system (unconnected).

Hydrologic soil groups

Infiltration rates of soils vary widely and are affected by subsurface permeability as well as surface intake rates. Soils are classified into four HSG's (A, B, C, and D) according to their minimum infiltration rate, which is obtained for bare soil after prolonged wetting. Most urban areas are only partially covered by impervious surfaces: the soil remains an important factor in runoff estimates. Urbanization has a greater effect on runoff in watersheds with soils having high infiltration rates (sands and gravels) than in watersheds predominantly of silts and clays, which generally have low infiltration rates.

Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission **(greater than 0.30 in/hr).** Soil Texture: Sand, loamy sand, or sandy loam

Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (**0.15-0.30 in/hr).** Soil Texture: Silt loam or loam

Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission **(0.05-0.15 in/hr).** Soil Texture: Sandy clay loam

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high-water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr). Soil Texture: Clay loam, silty clay loam, sandy clay, silty clay, or clay.

4. CHANNEL DESIGN AND CONSTRUCTION

At its core, stormwater channel design revolves around effectively and safely conveying stormwater runoff from urbanized areas to appropriate outlets, preventing flooding, and minimizing erosion. These channels, whether natural or man-made, are developed to accommodate the varying volumes and speeds of stormwater, ensuring that the water flows in a controlled manner.

Beyond mere conveyance, modern stormwater channel design often incorporates elements to improve water quality, enhance local biodiversity, and ensure aesthetically pleasing urban landscapes.

4.1. The design of Road side drains

The ideal design will strike a balance between functionality, sustainability, and cost-effectiveness.

The cheapest drains of all are unlined channels, which can be cut along the roadside with a road grader.

- The sides of an unlined drain should not slope by more than 1 in 2 to ensure that they will be stable.
- If the slope along the drain is greater than about 1%, the drain may be damaged by scouring, and some lining will usually be required to protect the channel bottom from the fast-flowing water.
- For slopes of 1—5%, partial lining is likely to be sufficient and will cost less than complete lining. In a partially lined drain, special protection is needed at the most vulnerable points, such as culverts, drain junctions, sharp bends, and steep sections.

Another cheap measure, especially suitable for the upper part of a partially lined channel, is to lay turf or sow grass, whose roots will help to hold the soil in place. The most satisfactory grasses are those that spread sideways and cover the surface of the soil. Their rapid growth can be encouraged with fertilizer, by laying topsoil, and by building temporary check walls to cause silt to be deposited.

For relatively gentle slopes, the lining does not have to be of solid concrete or masonry. Compacted gravel or stone will be sufficient. Drains with vertical sides always need a lining to support the sides. As this type of channel is used only when space is in short supply and when the drains have to pass close to houses, the lining must be strong enough to protect adjacent house foundations.

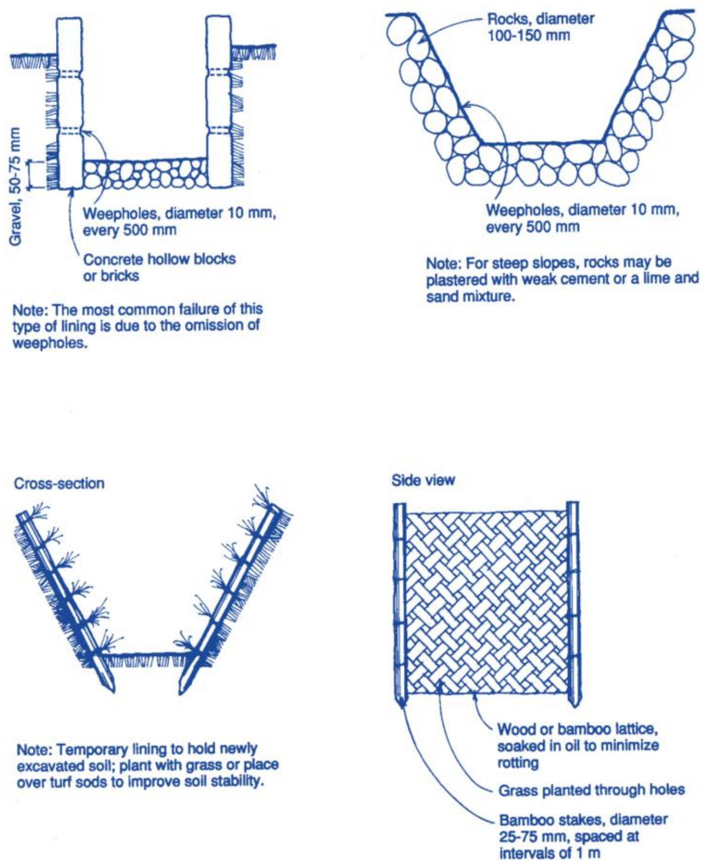

Figure 50: Drains in narrow streets

Lined drainage channels often fail because the lining does not allow water to enter from the ground at either side. Either this causes water pressure to build up and overturn the linings, or the water runs alongside the drain, cutting a parallel channel. The solution is to provide weepholes, about 10 mm in diameter, in the lining at the sides. This can be done with short lengths of pipe running horizontally through the masonry and embedded in the mortar, spaced at intervals of not more than 1 m.
In very narrow streets where heavy vehicles do not pass and space is at a premium, the road itself may be designed to function as a drain. This is possible only if the slope is less than 5% and if the road has a surface such as compacted gravel or stone to protect it from erosion. Alternatively, drainage channels may be provided with removable covers, which should have holes or notches in them to enable water to enter and make it easier to remove them to clean the drain beneath. The latter approach can also be used on very steep sections, with a series of prefabricated channel elements laid as a stepped drain beneath a pedestrian stair- way.

The smallest channels, less than 300 mm deep, do not need weepholes, and can conveniently be lined with brick or with precast concrete elements. Elements should weigh less than 50 kg, so that they can be carried and laid in place by two persons without machinery. Precast channels should preferably be laid on a bed of compacted sand, 50 mm thick. A single channel size can be adapted for larger flows by laying it deeper and building up the sides with masonry.
Prefabricated elements have the advantage over masonry or in-situ concrete linings in that they can be laid relatively quickly. Masonry drains take a long time to build, and concrete poured in place requires several days to set. Meanwhile, local traffic is disrupted, and the fresh masonry or concrete can be ruined by a sudden downpour of rain. If the drains are built in the dry season to avoid an unexpected rainstorm, there may be a shortage of water to cure the concrete in place. In a covered workshop, elements are protected from the sun and rain, water for curing can be made available, and quality control is easier and better than in conventional construction work.

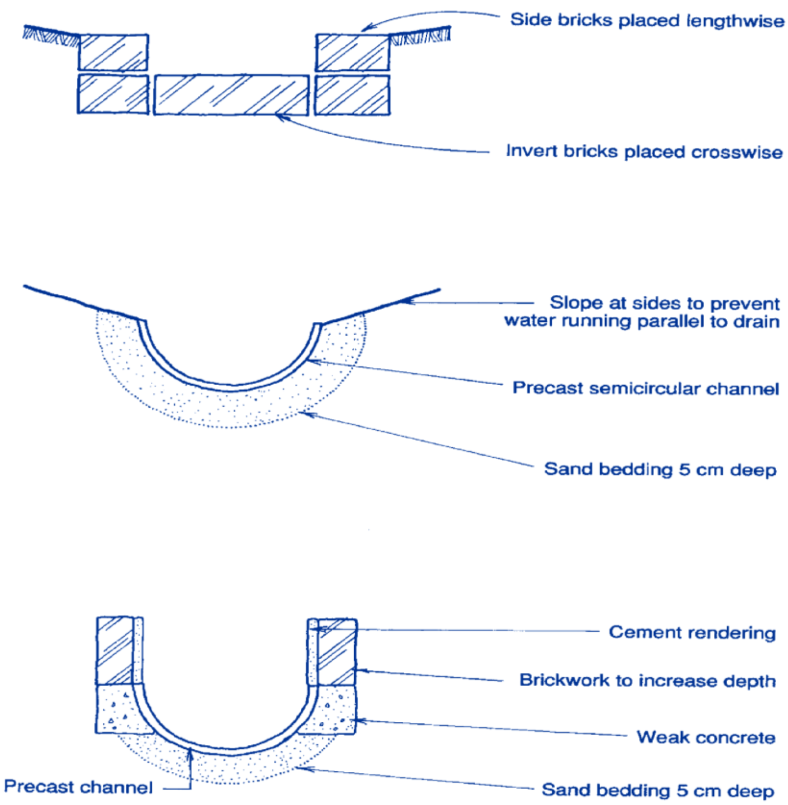

Figure 51: Cross-section of three types of small open drains

4.2. Types of construction of Storm Water Drains

Drains are generally either of masonry or RCC construction. The general construction description of masonry and RCC drains are given as follows:

4.2.1. RCC drains

Figure 52: RCC drain

Tertiary drains are usually constructed in rectangular section either of masonry or reinforced cement concrete. Where it is proposed to construct precast RCC drain, the same should not be less than 50mm thick and should be reinforced with 3 longitudinal bars of 6mm diameter and 2 crossbars of same size in 0.6 m length and mound should be removed after 48 hours then they shall be kept well-watered for a fortnight and after this watering shall be discontinued and the drain should be left to cure for another fortnight before laying. The ground should be kept to the exact shape and slope at which drains are to be laid and the trench will be watered and rammed.

4.2.2. Brick Drains

Figure 53: Brick drain

The brickwork shall be in cement mortar 1:3 and plastered smooth with cement plaster of 1:2, 20 mm thick. A change in the alignment of the brick drain shall be on a suitable curve conforming to the surface alignment of the road.

Rectangular Section: In congested urban areas, small or medium drains are constructed in a rectangular section covered with suitable RCC slabs to protect against dumping of solid waste from the local residents. Rectangular drains are normally constructed in hilly regions due to space crunch.

Trapezoidal section: Primary and secondary drains that normally carry a considerable quantity of storm flows are constructed in trapezoidal section. Especially outfall channels that sometimes carry entire storm flows from the catchment are designed in larger sections that often resemble irrigation channels. In such cases it is preferable to economize the cost by constructing earthen channels with cement concrete lining.

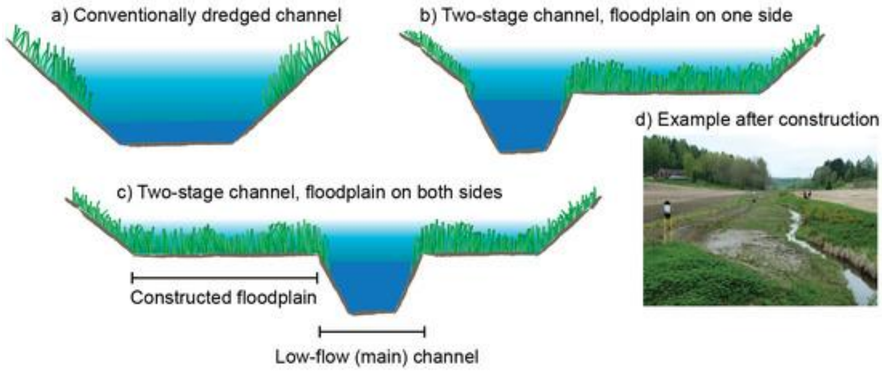

Figure 54: trapezoidal shaped channel

Typical cross-sections of (**a**) conventionally dredged trapezoidal-shaped channel and (**b**,**c**) two-stage channel, with (**d**) the two-stage channel after construction. The dark blue refers to the water level at the mean discharge and light blue to the water level at high discharges.

4.3. Engineered main Channels

The storm drainage system should be designed in an environmentally responsible manner to minimize disruption of the natural environment of the city natural streams/waterways. Engineered waterways/channels are preferred means of meeting the objective by providing a drainage system that more closely resembles natural streams/waterways. These channels are components of the major drainage system designed to collect and convey flows from minor drainage system. The following sections discuss the design guidelines for engineered channels as well as modified natural channels.

Figure 55: Concrete Channel

Figure 56: Natural Channel

Table 4: Design Guidelines for Engineered Channels

Sr No.	Item	Value

1	Design Flows	25 years Return Period (as per the past historical data)
2	Flow Regime	Froude number < 0.8
3	Design velocity with grassed lining- With other lining such as- • Riprap • Concrete	1.2 m/sec maximum • 1.8 m/sec • 3.0 m/sec
4	Maximum Longitudinal Slope	0.4 % for natural lining 0.2 % for concrete lining
5	For steep slope	Drop structure may be provided
6	For curvature into the channel	Centerline of curvature should have minimum radius, 2× top width, but not less than 30 m

Note: Natural channels should be preserved as far as possible, and engineering of channels should be minimized.

4.3.1. Curvature and Super Elevation

Superelevation should be provided on outside bend of channel as per the following equation:

$$\Delta y = \frac{V^2 T}{2gr_c}$$

Where,

Δy : Difference in water surface elevation inside vs outside of the curve.

v : Mean velocity

T : Top width of channel section

g : Acceleration due to gravity

r_c : Radius of curvature

4.3.2. Uniform gravity flow

Manning's Equation for uniform gravity flow:

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

Manning's Equation for uniform flow in terms of discharge:

$Q = (1/n) \times (A^{5/3}/P^{2/3}) \times S^{1/2}$

For circular section: $Q = (0.3118/n) \times D^{8/3} \times S^{1/2}$

Where,

V : Velocity of flow in m/sec

R : Hydraulic radius (Flow area (A)/Wetted perimeter (P)) in m.

S : Slope of Hydraulic Gradient

n : Manning's coefficient of roughness for Channels / conduits

P : Wetted perimeter in m

A : Area of cross section of water area in m^2

Q : Discharge in m^3/sec

D : Diameter of pipe in m

Owing to its simplicity and acceptable degree of accuracy in a variety of practical application, Manning's formula is valid for turbulent flow which is the most widely used uniform flow formula for designing storm water pipe conduits and channels. Due to its long practical use, values of n for a very wide range of surfaces are available as given in the Table below:

While choosing the storm water pipe diameters, minimum required diameter is computed and the next larger commercially available pipe diameter is selected. In circular conduits, maximum velocity occurs at 0.81 depth and maximum discharge occurs at 0.95 depth.

Table 5: Coefficient of roughness for channel flow for use in manning's formula

Type of Material	Condition	Manning's n
Salt-glazed stoneware	a) Good	0.012
Pipe	b) Fair	0.015
Cement concrete pipes	a) Good	0.013
(With collar joints)	b) Fair	0.015
Spun concrete pipes (RCC & PSC) with S / S Joints (Design value)		0.011
Masonry	Neat Cement Plaster	0.018
	Sand and Cement Plaster	0.015
	Concrete, steel troweled	0.014
	Concrete, wood troweled	0.015
	Brick in good condition	0.015
	Brick in rough condition	0.017
	Masonry in bad condition	0.02
Stonework	Smooth, dressed ashlar	0.015
	Rubble set in cement	0.017
	Fine, well-packed gravel	0.02
Earth	Regular surface in good condition	0.02
	In ordinary condition	0.025
	With stones and weeds	0.03
	In poor condition	0.035
	Partially obstructed with debris or weeds	0.05

4.3.3. Design velocities to be ensured in gravity storm conduits/channels

Table 6: Design velocities for gravity flow

Sr. No	Criteria	Value
1	Maximum Velocity	0.6 m/s
2	Minimum Velocity	3 m/s

For larger drains, the freeboard shall be higher up to 90 cm depending upon the discharge. For storm conduits, freeboard is not defined as they are supposed to run full.

4.3.4. Freeboard

Table 7: Freeboard of engineered channels should be provided as given in table

Sr.No	Discharge m3/s	Freeboard.mm
1	Below 3	450
2	3 and above but below 30	600
3	30 and above but below 300	900
4	300 and above but below 3000	1200
5	3000 and above	1500

4.3.5. Channel Linings

Channel linings should be provided wherever the bed and banks are not in stabilized condition and likely to be eroded in high floods in the natural channel. Different types of channel linings are as follows:

a). Rigid Lining: under rigid lining criteria following type of linings are considered:

- Concrete
- Precast concrete slab
- Stonemasonry
- Cellular reinforced concrete paving with infill soil.

b). Flexible lining: under flexible lining criteria following type of linings are considered:

- Rip-rap
- Gravels
- Gabion or random Rubble

Each type of lining should be scrutinized for its applicability, how it meets other community needs, its long-term integrity, maintenance needs, etc. As lining is costly component of a lined channel. Therefore, such shape of channel should be adopted, which has less surface area and more hydraulic capacity. Though semi-circular section provides maximum hydraulic capacity with minimum surface area per unit length, but cost and ease of construction provides preference of trapezoidal section, which is somewhat pragmatic approximation of semi-circular shape. Hence, trapezoidal section is adopted for storm water drains/ channels.

4.4. Kerb and Gutter

A pavement gutter is defined as a section of pavement adjacent to the roadway which conveys water during a storm runoff event. It may include a portion or all of a travel lane. Gutter sections usually have a triangular shape with the kerb forming the near-vertical leg of the triangle. Conventional gutters may have a straight cross slope or a composite cross slope where the gutter slope varies from the pavement cross slope.

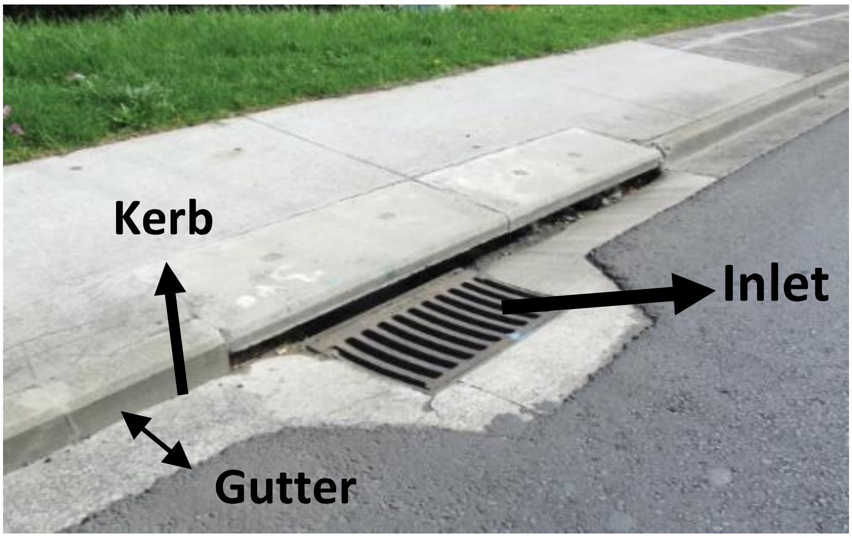

Figure 57: Kerb and gutter

4.4.1. Design of Gutters

Gutter Flow calculations are necessary to establish the spread of water on the shoulder, parking lane, or pavement section. Streets with uniform cross slopes like that shown in Figure above are found in urban areas. Since the gutter flow is assumed to be uniform for design purposes, Manning's equation is appropriate with a slight modification to account for the effects of a small hydraulic depth (A/T). However, for main roads and highways minimum gutter width should not be less than 0. 6 m.

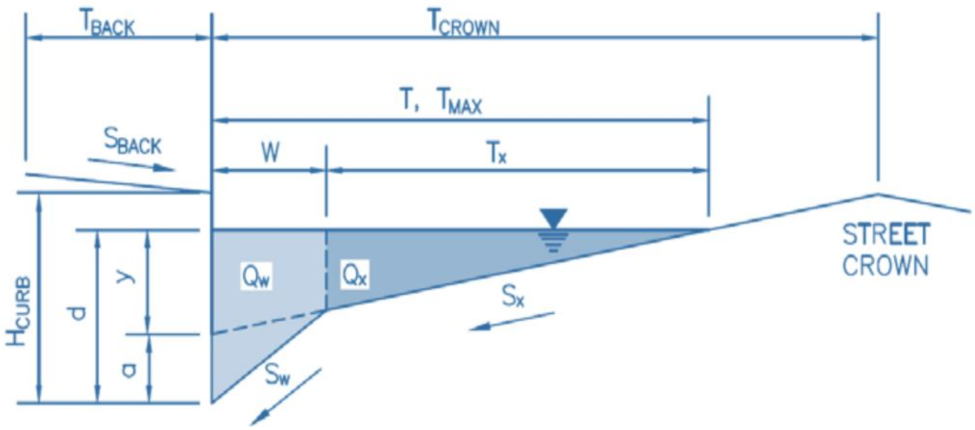

Figure 58: triangular cross-section

For a triangular cross-section as shown above, Manning's equation for gutter flow is written as:

$$Q = K_c S_x^{5/3} S_L^{1/2} T^{8/3}$$

Where,
Kc : Empirical constant equal to 0.376
n : Manning's roughness coefficient for gutter flow
Q : Flow rate (m^3/s)
T: Width of flow (spread), m
Sx: : Cross slope, m/m

SL: : Longitudinal slope, m/m

Equation neglects the resistance of the kerb face since this resistance is negligible.

The flow depth (m) can be found using: Y = TSx

And,

The cross-sectional flow area, A = S_xT^2

Table 8: Manning's n for gutter flow

Surface Type	N
Concrete	0.013
Hot mix asphalt concrete	0.015
Sprayed seal	0.018

4.5. Covering of Drains

Secondary and tertiary drains constructed in congested sectors of the urban area should be covered with precise RCC slabs of suitable size wherever needed. RCC Slabs in smaller lengths capable of lifting by 1 – 2 persons are precast with lifting hooks. After proper curing these slabs are placed over the drain and joined with cement plaster. When the drains are required to be cleaned, these slabs can be removed easily at suitable intervals and cleaning operation can be done. Even secondary and primary drains of larger section, it will be uneconomical to cover them instead they can be fenced along their edges or small parapet may be constructed to protect children or men falling in them. However, if resources permit ULB may undertake to cover such drains if it is deemed expedient in favor of public welfare.

Figure 59: Box drain

RCC box drains are constructed along drainage reserve of heavy vehicular traffic. These drains are designed to withstand vehicular load and carry the large storm water volume to the safe disposal point. Street inlets are provided between 15 – 30 m interval in order to admit storm water in the box drain. They are laid 200 – 300 mm below ground level in suitable gradient having access holes.

4.6. Calculating Design Flow for the new drains

In order to design a drain, it is first necessary to calculate the maximum stormwater flow that it will be required to carry. This involves the following steps.

(a) Decide on the appropriate return period and concentration time.

(b) Find the maximum rainfall intensity for those conditions(Z mm/h).

(c) Calculate the catchment area served by the drain (A ha).

(d) Estimate the runoff coefficient for that catchment (O).

(e) From *I, A* and G, calculate the peak flow — the maximum quantity of water to be drained per second.

These steps are discussed below.

(a) Return period and concentration time.

(b) **Rainfall intensity**. Ideally, this should be found from an intensity—duration graph. However, a graph compiled for one city should not be used for another city without professional advice.

Rainfall data can be obtained from the department of Meteorology. If intensity—duration data are not available, an estimate can be made using the maximum daily rainfall for the appropriate return period. In each climatic zone, maximum rainfall in 15 minutes is a fairly constant percentage of the maximum daily total — typically between 10% and 40%.

(c) ***Catchment area.*** This is most conveniently estimated froma map. First the edges of the catchment area are drawn. Some investigation in the field may be needed to ascertain the full extent of the area from which surface water will run to the drainbeing designed. The area on the map can then be measured with a planimeter, or estimated by dividing it into squares. Squares whose sides are equivalent to 100 m on the map will each have an area of 1 ha. For smaller areas, smaller squares can be used. Each 10 x 10 m square will have an area of 0.01 ha.

(d) ***Runoff coefficient.*** As indicated previously, the runoff coefficient depends on soil conditions, terrain and land use. The first step isto determine the runoff coefficient (C_u) for the uncovered areas, that is, for the areas which are not paved or covered by buildings. Values of Ci, are given in Table below. Then an estimate must be made of the percentage (N) of the total catchment area that is covered by impermeable pavements or the roofs of buildings. This could be done from an aerial photograph, but the process is very laborious. A reasonable estimate can be made from the population density using Table below. Then the overall runoff coefficient for the catchment area (C) can be derived

(e) **Peel flow**. For small catchments, this is best calculated using the "rational method", expressed by the formula: Q = 2.78 CIA

Semi-Arid Regions

Table 9: Values of C, the runoff coefficient for areas not paved or covered with buildings

Average ground slope	Soil Permeability			
	Very low (rock & clay)	Low (clay loam)	Medium (sandy loam)	High (sand & gravel)
Flat:0-1%	0.75	0.40	0.0f	0.0
Gentle:1-4%	0.85	0.55	0.20	0.0
Medium:4-10%	0.95	0.70	0.30	0.0
Steep 10%	1.00	0.80	0.50	0.05

Table 10: Typical values of the percentage of impermeable paved and covered areas in low-income urban settlements (P)

Population density Residents/ha	P(%)
0-50	0-12
100	25
200	50

300	75
Greater than 400	100

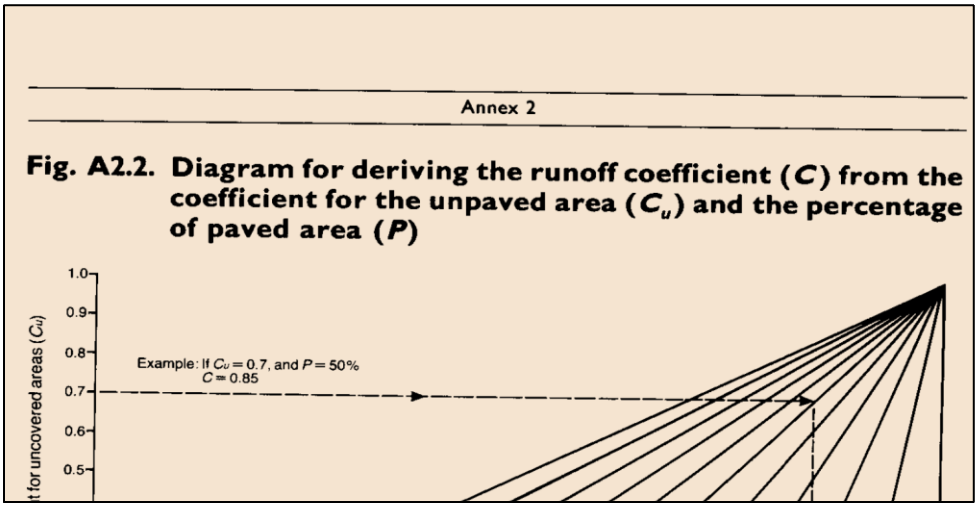

Figure 60: Diagram for deriving the runoff coefficient (C) from the coefficient for the unpaved area (C) and the percentage of paved area (P)

where Q= flow (lbs)
C= runoff coefficient
/= rainfall intensity (mm/h)
A —— catchment area (ha).
For catchment areas larger than about 5 ha, other calculation methods are more accurate, but they tend to be rather more complex.

4.6.1. Calculating Drain Size

Once the flow has been determined, it is possible to derive the required dimensions of the drain cross-section. Engineers often do this using the Manning formula:

Where
Q = flow in the drain (m°/s)
A —— area of the channel cross-section (m')
R = the "hydraulic radius" of the drain cross-section (m); to calculate this, divide the cross-sectional area by the "wetted perimeter", that is, the length of the perimeter of the channel cross-section which is in contact with the water, not counting the water surface
S —— slope of the drain; for a 1% slope, S ——0.01
n = a constant that depends on the roughness of the channel lining; typical values of n are:
n= 0.015 for a smooth concrete or plastered brick masonry;
n —— 0.025 for straight unlined channels free of vegetation;
n = 0.035 for unlined channels with short grass and few weeds.
However, many readers will find it simpler to use Fig. above. This is a design chart for a channel with the trapezoidal cross-section shown in the inset, which has no lining or vegetation (ii=0.025). The channel depth D obtained from above figure can be used to derive the dimensions of channels and pipes with other shapes and other types of lining. The procedure then is as follows:

a) Find the maximum flow in 1/s.
b) Find the slope of the section to be designed in % (1 % means a vertical drop of 1 m in every 100 m of drain).

c) Use Fig. above to find the value of D for this slope and flow.

d) If the drain is not a trapezoidal channel, multiply D by the factor given in Fig. above to derive the dimensions for the appropriate shape of cross-section. If the drain cross-section does not correspond exactly to any of the shapes shown in Fig. above, choose the nearest equivalent and follow the method to find the size required for the standard cross-section. Then plan for the dimensions of the drain to have the same cross-sectional area as the standard cross-section design.

e) If the drain is to have a smooth lining, or if the sides and bottom will be covered with short grass, the dimensions will need further adjustment:

- for smooth concrete or plastered brick masonry lining, multiply the dimensions by 0.83 (i.e., reduce by 17%);
- for unlined channels with short grass and few weeds, multiply the dimensions by 1.13 (i.e., increase by 13%);
- for a smooth earth or unplastered masonry lining, no adjustment is needed.

f) Finally, calculate the average speed of flow of the water when the drain is running full. If the flow is so rapid that it would cause erosion of an unlined channel, the channel should be lined, or at least stabilized with grass. Step (e) above should then be repeated for a lined or grassed channel.

On the other hand, too low a speed will fail to achieve self- cleansing and so allow sediment to accumulate.

Calculating the dimensions of various types of drain, using values of channel depth (0) from above figure.

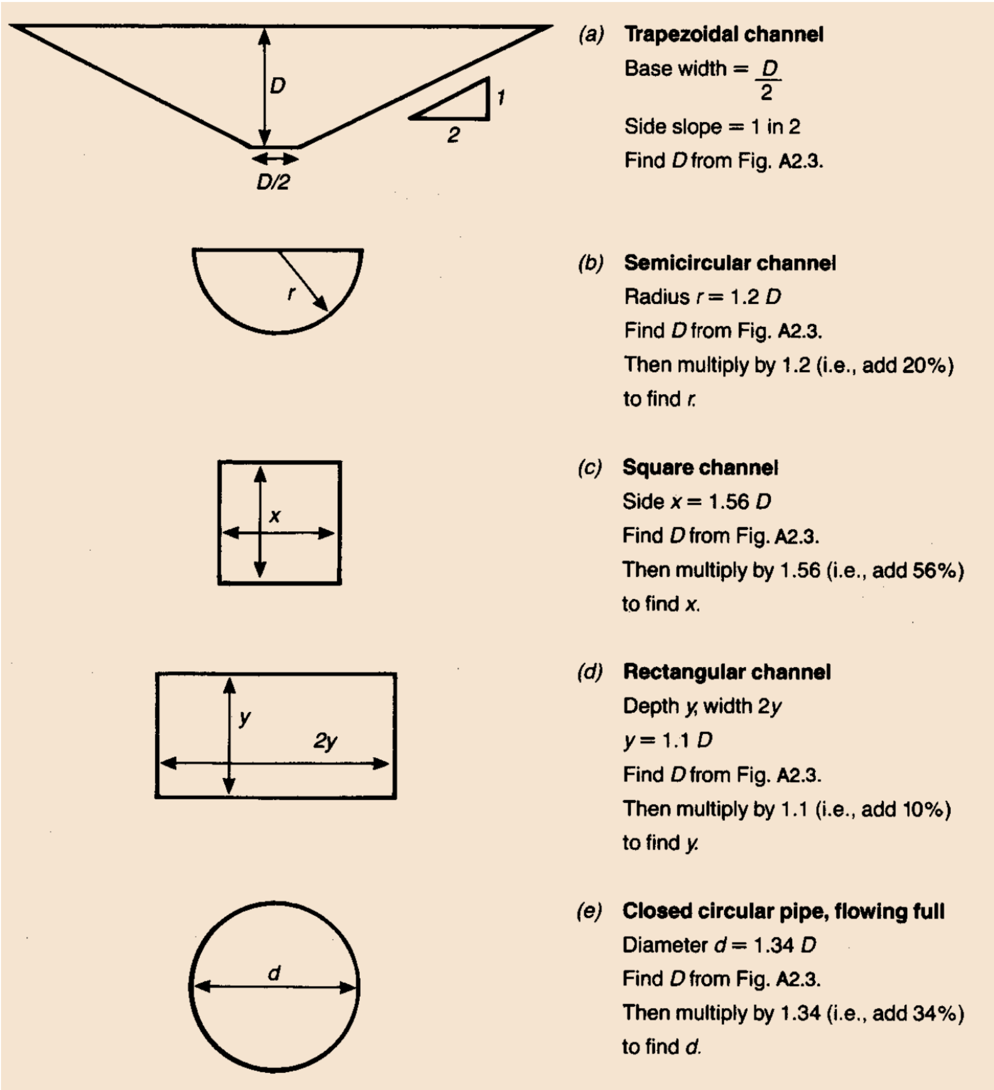

Figure 61: Dimensions of various types of drains

a speed of at least 0.5 m/s should be achieved in all drains whenflowing full. A speed of 1.0 m/s would be better still.

4.7. Checking the Speed of Flow

The speed or velocity of stormwater flow in a channel is crucial for several reasons. If the water flows too quickly, it can lead to erosion of the channel's sides and bottom, jeopardizing its structural integrity and potentially causing sediment pollution downstream. Conversely, if the water flows too slowly, there's a risk of sediment deposition, which can reduce the effective capacity of the channel over time.
The speed of flow is influenced by the channel's gradient, roughness, and shape. To maintain an optimal flow velocity, designers might incorporate features like channel lining (using concrete, rocks, or vegetation), check dams, or flow control structures. Regular velocity checks after construction ensure the channel operates within safe limits and informs any necessary maintenance or adjustments.
In conclusion, the design and construction of stormwater channels are based on scientific principles, engineering expertise, and practical experience. As urban areas evolve and climate patterns shift, it becomes ever more critical to employ adaptive and resilient approaches in stormwater management.

Once the dimensions of a drain have been chosen, the cross- sectional area can be calculated from them. The average speed of flow can be found from the formula: V=10(Q)/A

where U = flow speed in mrs
Q —— flow in lbs
A —— cross-sectional area in cm^2.

If this speed is found to be greater than the corresponding value inTable below. There is a danger of serious erosion unless the drain is lined or provided with check walls Table 4-3 also gives maximum permissible speeds of flow in channels whose sides and base are stabilized by a firm cover of grass.

Table 11: Permissible flow speeds to prevent erosion in unlined drainage channels

Type of soil	Typical particle size (mm)	Permissible speed (m/s)
Fine sand		0.4
Sandy loam		0.7
tedium sand	1.0	0.8
Silty loam		0.8
Ordinary firm loam		1.0
Volcanic ash		1.0
Coarse sand	2.0	1.0
Stiff clay		1.5
Alluvial silt		1.5
Shales and hardpans		1.8
Fine gravel	5	1.5
Coarse gravel	10	1.8
Cobbles and shingles	40	2.4
Grass cover, erodible soils		1.2
Grass cover, stable soi ls		1.8

5. MAINTENANCE OF STORM WATER DRAINAGE SYSTEM

5.1. Issues with Stormwater Drainage System

5.1.1. Capacity issue

A number of storm water drains are flowing to their full capacity even in dry weather and after only a light rainfall these start overflowing and in heavy down pour, the city roads are flooded by sewage water which enters into houses in congested population. In low lying areas commonly known as ponding areas, this sewage stagnates and becomes the breeding places of flies and mosquitoes.

5.1.2. Environmental Hazard due to misuse of storm drains for wastewater

Due to increasing load of wastewater a number of lift stations are constructed along main drains disposing off untreated wastewater into drains. Resultantly open storm water drains have become sullage carriers running with raw wastewater which, consists of harmful bacteria and poisonous gaseous is risk to human life.

Figure 62: Wastewater lift station discharging into storm drain

5.1.2.1. Industrial effluent:

Normally industrial units are scattered throughout the cities and their suburbs. The growth is largely haphazard without any infrastructure planning and availability of common civic facilities such as water supply, sewerage, roads and combined effluent treatment plant. Textile dyeing and finishing units, leather, food and paper manufacturing are major effluent producing industries compared to packaging, garments, stitching, warehouses, electrical panels manufacturing, hosiery, furniture, power looms, engineering works and marble where effluent generation is limited to the sanitary use of water by the labor.

Figure 63: Effluent of an industry discharging directly into Drain

Consequently, all industrial units discharge their untreated effluent into cities drains causing great environmental hazards.

5.1.3. Dumping of Solid Waste in Drains

The storm water drains should be free from solid waste and garbage by provision of separate arrangements for garbage collection and removal. Regular cleaning by operating crew is also needed by providing easy access to these places. Garbage dumping on the banks of drain by the surrounding population is a common practice.

Figure 64: solid was dumped in the drain

5.1.4. Services pipes pass through the drains

The pipes existing across the drain also hinder the flow of floating material in the drain, thereby, resulting in accumulation of garbage material in the drain.

5.1.5. Encroachment of right of way

Just like the irrigation canals the storm water drains should have proper ROW for maintenance and cleaning of storm water drains. Living by the side of raw sewage is the risk of life of the people. Encroachment of ROW is a common issue in the existing drainage system.

Figure 65: Encroachment on right of way

Figure 66: Deteriorated and Damaged Sections of Storm Water Drains

5.1.6. Narrow/Constricted Sections of Main Drains

Drain reaches with constricted cross- sections and reduced discharge capacities create flow obstruction during Monsoon.

5.1.7. Ponding points not connected to any drain

There are a number of critical ponding points which are not connected with drains causing ponding on the roads.

5.1.8. Roads without roadside drains

There are a number of roads in the cities without having adequate storm water drainage facility. Care is not taken during construction of city roads about storm water drainage.

5.1.9. Roads were not designed as a drain with uniform slope

Many roads have uneven slope resulting in pockets capable enough to stagnate water during rains.

5.1.10. Rainwater connected to sewers causes deficit of their capacity and overflow.

Local Governments connect ponding points with sewers which are already full during rain and start overflowing. Proper way is that every road side drain and ponding point must be connected with some main drain.

5.1.11. Disposal stations capacity is inadequate

- In wet weather more sewage volume than planned value flows into Disposal Station (DS), because generally rain water in plots of household is connected to a sewer service pipe.
- It is difficult to increase the pump capacity because the actual amount of rainwater to sewers is not taken into consideration in the plans.
- Actually, in wet weather sewage that matches the capacity of the main sewer pipe flows into the DS.
- If sewage/rainwater volume that exceeds the capacity of the main sewers flows into the branch sewers, the branch sewers will overflow.

5.2. Causes of Failure of Partially Combined Storm Drainage System

Partially combined systems handle both stormwater runoff and wastewater, which can lead to specific challenges. Overflows are a primary concern, often occurring when heavy rainfall overwhelms the system, causing untreated sewage to be released into water bodies.
Additionally, sediment and debris accumulation can block these systems. Poor separation mechanisms might result in increased pollutants entering natural water systems, leading to ecological damage.

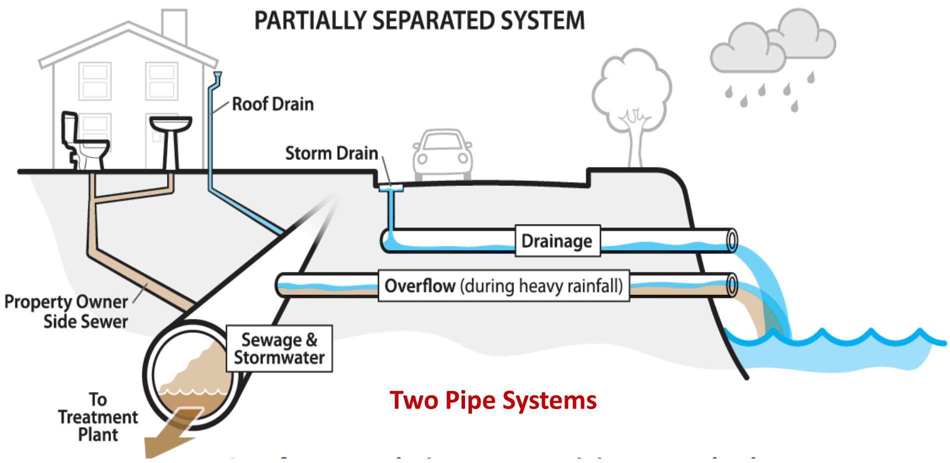

Figure 67: Partially combined system

a. It is emphasized that the earlier method of combined sewerage system collecting storm water and sewage in the same pipe network is resulting in several adverse effects in the process of treatment, operation, maintenance and also on the environment. Therefore, it is always recommended that for collection and treatment, sewage should be separated from the storm water drainage system as it is currently in practice all over the world.
b. Storm water open channels if not covered are prone to the dumping of garbage and other waste, encroachment, etc. that may cause choking and disruption of flow causing street flooding and

inconvenience to the residents of the area. It would be advisable in such circumstances to construct underground storm water conduits that shall remain immune to such practices and shall provide extra space on the surface.

c. The current project of storm water drainage in 16 cities has taken care of this aspect as well while planning and executing it.

Figure 5-7 Garbage accumulation causing blockage in Drain

5.3. Causes of Drainage Failure

Failure can result from various factors such as clogging from sediment, trash, or vegetation; structural degradation due to aging materials, corrosion, or tree root intrusion; improper design that doesn't account for the area's actual hydrological needs; and changes in the surrounding landscape, such as increased impervious surfaces or altered topography that introduces more water than the system was designed for.

Blockages can occur when leaves, trash, sediment, or other debris accumulate in pipes, culverts, or open channels. Blockages can significantly reduce the flow capacity of a drainage system, leading to overflows during storm events, causing localized flooding. Regular maintenance activities, including cleaning and debris removal, are critical to preventing blockages and ensuring the drainage system functions effectively.

Drainage systems must be designed to accommodate the volume of water expected during significant storm events. If a system was designed based on outdated rainfall data, or if an area has been developed and altered the flow patterns without corresponding upgrades to the drainage system, the capacity may prove insufficient, causing the system to be overwhelmed during significant rainfall events. This can lead to widespread and severe flooding

Drainage failures can also occur when the original installation was not performed to appropriate standards. This may include poorly joined pipes, inappropriate materials, improperly graded channels, or the use of substandard construction materials. Quality control during construction, adherence to design specifications, and inspections after construction are vital steps to prevent such issues.

Natural factors, such as earthquakes, landslides, or extreme weather events (e.g., hurricanes or intense rainfall), can overwhelm and damage drainage systems, rendering them temporarily or permanently ineffective. Climate change, in particular, is leading to more frequent and severe weather events, which is increasing the stress on many existing stormwater systems. Adapting to these changing conditions may require significant upgrades and redesigns for some systems.

Some localities suffer from drainage problems not because they have no drains, but because the existing drainage system has collapsed, become blocked, or is otherwise in need of repair and rehabilitation. Many more will find that the nearest convenient point of discharge for a new drainage system is an existing primary drain that needs attention if it is to function properly.

5.3.1. Collapse and blockage

Collapse and blockages are the principal types of drainage failure. Each of these can have several causes. Collapse of drains can occur through:

- erosion of the bottom and sides of the drain (scouring);
- excessive pressure of water in the ground beneath and beside thedrain lining;
- vehicles passing over or too close beside the drains;
- root growth, especially from nearby trees
- crown corrosion in closed drains containing sewage.

The causes of blockage can be:

- accumulation of refuse, leaves and earth in the drain;
- structures such as houses or bridge piers erected in the drain andobstructing the flow;
- excessive vegetation growing in drainage channels;
- silt deposited in low sections owing to misalignment or where theslope is insufficient and cleaning is not regular enough.

If rehabilitation of a failed system is to have a good chance of success, diagnosis and elimination of the original causes of failure are required as well as treatment of the immediate symptoms. Each possible cause of collapse has its cure.

a). Erosion

In a lined drain, erosion can mean the lining itself is not robust enough, and a more resistant lining is needed. A common weak point is at the joints between channel or pipe elements, which should be sealed with cement mortar. Where the slope is greater than 10%, baffles or steps of some kind are needed.

Figure 68: Baffles at a steep drain

Figure 69: Steps at a steep drain

b). Scouring on the outside of a channel lining can mean that water is not entering the drain but running parallel to it. If the lining rises above ground level, it needs notches in the sides so that the water can flow in. Small earth banks running diagonally across the road will also help to divert water to the drain at the side. Alternatively, scouring beside the drain can mean that its over- flows during storms, indicating that more frequent cleaning, a larger drain, or more frequent turnouts are required.

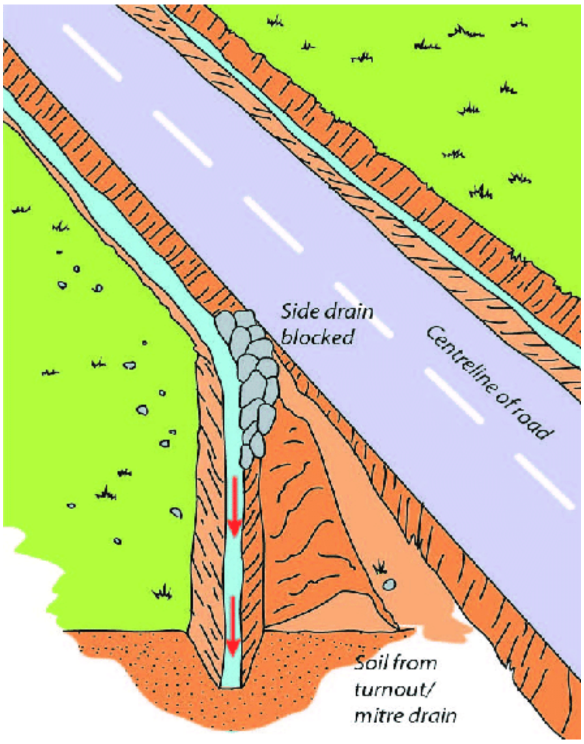

Figure 70: Turnout miter drain

c). Overloaded closed drains

In closed drains that are overloaded, water can escape into the ground through the joints owing to the pressure inside the pipe. When the pressure drops, the water runs back into the drain, carrying soil with it and excavating a cavity over the drain which will eventually collapse. The solution is to seal the joints with cement grout or, preferably, to build a larger drain.

Water pressure from the outside or pressure resulting from the swelling of clay can be controlled by using a sand bedding (see Fig. below) and providing weep holes in the lining.

Figure 71: Water pressure in a closed drain

d). Vehicles can easily damage open drains. If vehicle damage recursfrequently, the drains should be protected by some form of barrier such as a rail or a kerb stone. If the damage is due to vehicles attempting to cross the drain, then an adequate vehicle crossing should be built over it. Vehicle damage to covered drains indicates that they should either be laid deeper or be protected by concrete.

e). Roots from nearby trees will tend to grow into drains, especially if they contain standing water and the linings are not impermeable. The most effective protection, if the problem persists, is to remove all trees within 5 m of the drain.

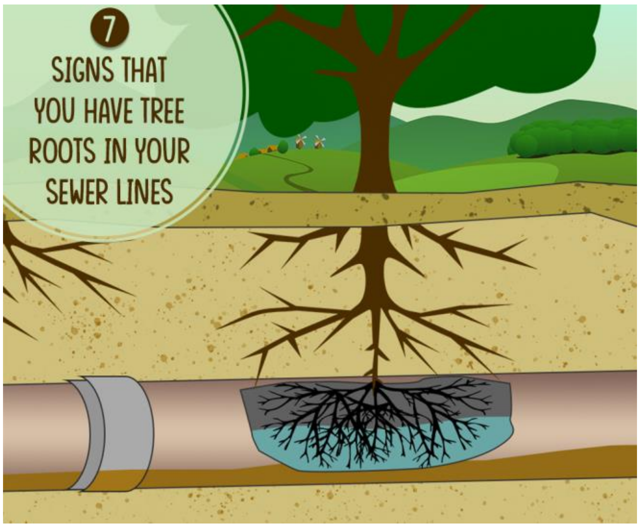

Figure 72: Roots of a tree inserted into sewer pipe

f). Crown corrosion occurs in closed drains containing sewage, where gases from the sewage can attack and weaken cement, particularly over the crown or cover of the drain.

The cures for most of the causes of blockage are fairly easy to see: collection of refuse, removal of structures, and clearing of vegetation. If the drains have an even and adequate slope, it should not be necessary to remove silt; clearing the vegetation, whose roots hold the silt in place, should enable the next heavy flow in the drain to wash it away.

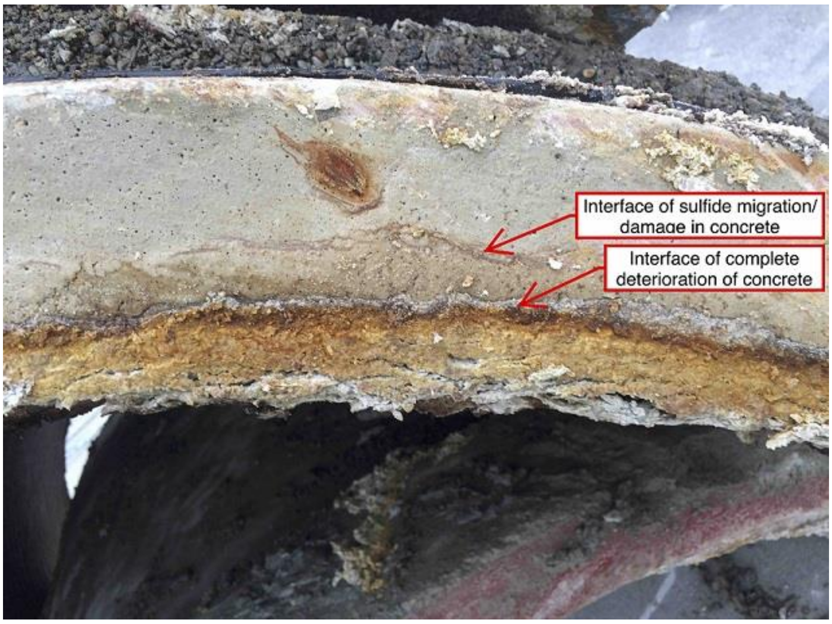

Figure 73: Crown corrosion

5.4. Mitigation of Urban Inundation

To reduce urban flooding, a multipronged approach is required. This involves upgrading drainage systems, implementing green infrastructure like permeable pavements and green roofs, constructing retention and detention ponds to temporarily store excess water, and restoring natural waterways and wetlands to enhance water absorption and reduce runoff. Regular maintenance and timely upgrades of drainage infrastructure are equally vital.

The depressed areas in urban localities are formed due to inadequate capacity of sewer/drains. The rainfall runoff rushes to these locations and gets accumulated to form ponding areas which remains stagnated there for many days and weeks. Due to inadequacy of the existing drainage system some of the depressed locations in thickly populated and commercial areas in cities have emerged as critical points. This condition is of much inconvenience to traffic and renders damage to property. Strategies may be formulated to mitigate these ponding locations as discussed below;

- Identification of low-lying ponding areas
- Connecting roads with storm drains properly and effectively
- Widening of drains
- Desilting of drains
- Removal of encroachments from banks of the drains
- Capacity building of MC staff
- Deployment of self-start auto prime heavy duty dewatering sets (engine driven)
- Backup power for disposal pump stations
- Getting prepared for rainy season
- Connecting roads with storm drains properly and effectively

5.4.1. Road drainage:

Roads may be constructed with arrangement of proper slope towards drains for storm drainage. Roads may be connected with drains on a proper slope through constructed links (small drains) at regular intervals to evacuate storm water from the roads automatically and promptly.

Figure 74: Road connected with drain at proper slope through small drains

5.4.2. Widening of drains

There are many narrow sections developed on open channels with the passage of time due to poor maintenance which, may be attended to restore the original section of the drain or, at least, may be tried to expand it as much as possible. It would affect a lot on achieving better capacity during rains.

5.4.3. Desilting of drains

Desilting activity is a continuous activity which should remain in progress round the year. It is the most practicable process to restore the capacity of the drains.

Figure 75: Desilting activity

5.4.4. Removal of encroachments from banks of the drains

Figure 76: Encroachment at the banks of the drain

Encroachments along the right of way of drains has created the worst problem in maintaining the flow and capacity of drains. This encroachment never allows the cleaning of drains especially with mechanical equipment.

5.4.5. Rehabilitation

Before a new system is envisaged, the first step is to ascertain whether a drainage system already exists and whether it can be rehabilitated. Local residents will normally know if one exists in their area, but they may not be aware of existing main drains, especially closed drains, which are outside their neighborhood, and into which a future local micro-drainage system could discharge.
Municipal records, including old drainage master plans, shouldbe consulted for details of any previous drainage construction in thevicinity, and the area should be visited on foot to check their accuracy and to look for tell-tale signs such as old manholes, orpieces of pipe or concrete exposed by erosion, especially along majorstreets and downstream of the area where better drainage is needed.
Remove cover slabs from drainage channels, taking care that thereis no risk of pedestrians' or vehicles' falling into them accidentally. Starting at the downstream end, remove silt and solids.

Some sections may require complete rebuilding, but others may only need to be cleared of obstructions and flushed with water. Deteriorated or cracked concrete or masonry should be made good, care being taken to avoid major irregularities, especially at joints, which may hold back solid objects and cause blockage. The surface to be repaired should be roughened by hitting it with a sledge hammer, and then plastered with good quality cement mortar. If plastering is needed on the bottom of the drain, first divert the waterflow away from the working area by building a small dam of earth orsandbags and digging a temporary parallel channel or by pumping. Some fittings may be damaged or have disappeared, especially metallic ones such as manhole covers, inlet screens and grilles,which may have been stolen and sold as scrap metal. The community may decide to replace these with concrete equivalents, or to fix metal screens into concrete. This makes drain maintenance a littleless easy, but minimizes theft if it is a problem. If closed sections arefrequently blocked by refuse, additional screens should be installedat the upstream end to keep the refuse out. Existing covers and inlets should be cleaned, and repaired or replaced if necessary, and steel fittings painted with two coats of tar or primer paint.

If the drainage system has sluice gates, the handle, plates and guide channels in the frame should be checked. Rust and old paint should be removed with a steel brush. Any holes should be patched by welding a steel plate over them. The gate and frame should be painted with three or four coats of an epoxy or other equally durable type of paint. The stem and guide plates should be well greased.

Figure 77: Penstock Gates

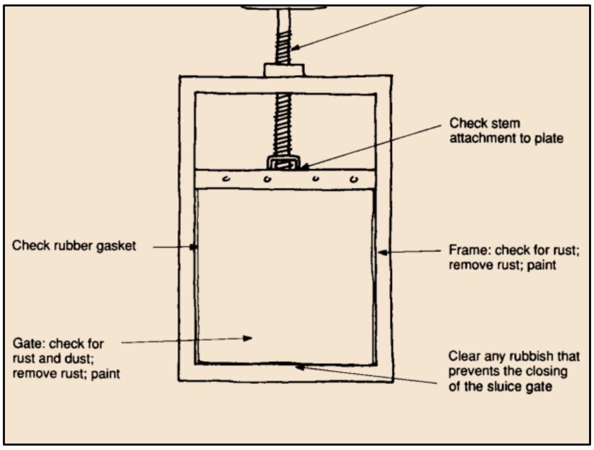

Figure 78: Design of Penstock Gate

5.4.6. Maintenance of drains

The most important maintenance task is to remove refuse, silt and other solid material from the drains. All drains should be cleaned at least twice a year, preferably at the start and end of the rainy season.Some drains, especially the secondary drains and house connections,will need to be cleared more frequently. Small open channels in flat areas are likely to require cleaning on a weekly basis. Unlined channels need to be regularly cleared of vegetation.

It is important to establish the cleaning of drains as a routine activity at regular intervals, and not wait until the system fails as a result of blockage. Repairing the damage done when the system fails, including damage to the drains themselves, can cost far more than regular preventive maintenance.

Drain clearing must be coordinated with the collection and disposal of solid waste, so that solid material removed from the drains will not be left where rain can wash it back or where it can be a nuisance and a health hazard, encouraging the breeding of rats and flies.

5.4.6.1. Desilting equipment used for mechanical desilting

Table 12: Equipment for Mechanical Desilting

S. No.	Description
1	Excavators
2	Dump Trucks
3	Back Hoes
4	Tractor Trolleys
5	Front End Loaders
6	Trenchers
7	Wheel Loaders
8	Sludge Suction machines

5.4.6.2. Maintenance of Primary drains

Keeping drains free of refuse poses a problematical obstacle. Unfortunately, it is commonly believed that a drain is a convenient place for depositing solid waste, wastewater, greywater and even faecal sludge, especially where there is no adequate refuse or wastewater collection service. Refuse and faecal matter in drains quickly becomes malodorous as it decomposes and poses as a suitable medium for flies and mosquitoes for egg-laying and as a hospitable site for many pathogenic bacteria and viruses. Removal of such material from the drains is not a popular task (WHO 1992), but crucial for protecting the public health.

Figure 79: Routine drain cleaning

The main duties and responsibilities for operation and maintenance of an open channel drainage system are (WHO 1991):

- Reporting of defects and blockages
- Semiannual inspection
- Repairs
- Payment for maintenance
- Passing of by-laws regarding the use of drains
- Enforcement of by-laws.

Health aspects: Open drain bear a high health risk because they are very often used illegally for the discharge of domestic and/ or industrial wastewater, and solid waste. Moreover, ponding water forming pools encourage mosquito breeding, and children have a tendency to play in them. Ponding is likely to occur where: the terrain is flat and the drain slope small, where the drains are rough and unlined so that water collects in depressions, where solid waste is deposited in the drains leading to a clogging effect and where drains are filled to allow vehicles or pedestrians to cross (WHO 1992). This is a high risk for the public health. Also, defecation into those drains is not an unusual habit and needs to be circumvented by the community.

5.4.6.3. Maintenance of Road side drains (Tertiary drains

Type of Desilting

- Manual (desilting of road side drains with manual labor)
- Mechanical (desilting of primary and secondary drains with machinery

Figure 80: Manual Desilting

Figure 81: Mechanical Desilting

Cleaning of open channels is usually done manually, with the help of spades, hoes, shovels and scoops. It can be disagreeable and strenuous work if it is done with the wrong tools, especially if the drains are deep. It is worthwhile having some special tools that can clean the drains over their whole length, such as shovels that just fit into the drain.

One tool that has proved to be useful for cleaning deep and narrowdrains is an agricultural hoe with an extra-long handle.

Another tool is the Ahmed-Davis shovel. This was developed in Tunisia, where it was found to reduce cleaning time by 30°/ . One person pushes the shovel deep into the drain using the handle, and then the other pulls it forward and upward using the steel wires attached to the front end. The size and shape of the shovel are determined by the size and shape of the drains. It may help to pierce several small holes in the bottom of the shovel so that water in the solids from the drain can run out when the shovel is lifted.

The responsibility for maintenance of a system of drainage channels is often divided between several residents, neighborhoods or work teams, each responsible for a particular section. If so, it is advisable to install grilles across the channels at the downstream endof each section. This ensures that solids are not carried along to the next section, imposing an excessive burden on that section's team.

5.4.6.4. Maintenance of Closed Drains

The most common tool used in removing silt and solids is a bucket tied in the middle of a steel cable. The cable should be at least twice as long as the longest distance between manholes. One end is threaded into the drainage line with the bucket facing down- stream, and wound on to a windlass on the ground beside the next manhole. As the bucket is pulled down the line, it scoops the solids and silt. The bucket diameter must be at least 5 cm smaller than the internal diameter of the drainage pipe to allow excess solids to pass around it, and ensure that the bucket does not become jammed against obstructions.

Excessive force should not be used to pull the bucket if it sticks, as this may compress the solids, making them still more difficult to remove. Instead, it should be winched back and a smaller bucket or an auger (described below) used for the first pass. When the bucket reaches the downstream manhole, it should be removed with the solids and detached from the cable. The cable is wound back and the bucket reattached. The procedure is repeated until the drain is cleaned.

If the drainage line is blocked, or the solids are too stiff to be removed using the bucket, the line can be cleared by an auger. The auger is like a large drill bit, and is rotated by means of a lever inserted into one of a chain of connected driving rods. The rods are normally 10—15 mm in diameter and made of stainless steel. Water trapped upstream of the blockage does not have to be re- moved. When the auger penetrates the solids obstructing the line, this water will help to flush the solids away.

Figure 82: Cleaning of closed drains using a bucket

5.4.6.5. Maintenance — institutional aspects

The need to coordinate drainage maintenance with solid waste disposal has already been mentioned. Coordination is necessary for two reasons. First, the solids removed from the drain must be adequately disposed of. Second, the drains cannot be kept clear without effective solid waste disposal. If solid wastes are not collected regularly, residents will have little choice but to throw their rubbish into the drainage channels, or to dump it in the streets and open spaces where it will be dispersed by stormwater, wind and animals, much of it eventually reaching the drains. The most effective way to ensure good coordination between drainage maintenance and refuse disposal is for both these activities to be the responsibility of the same municipal department or neighborhood committee.
Maintenance, including the inspection, cleaning and repair of the drainage system, must be institutionalized if it is to be kept up throughout the life of the system. For this reason, the ultimate responsibility should preferably be with the municipality, which has paid staff who can carry out the work. It is much more difficult to mobilize a community on a voluntary basis to carry out a routine task, year after year, than to win their active participation for the limited period required for construction. Nevertheless, there is ample scope for participation by the community in drainage maintenance.

5.4.6.6. Deployment of self-start auto prime heavy duty dewatering sets (engine driven)

Normally the dewatering sets used in MCs for storm water evacuation at remote points are low capacity and manual start type which make lot of trouble in starting especially during rain. This project of PMDFC has tried to provide good quality auto prime and auto start Trailor mounted dewatering pumps of 2 cusec, 3 cusec, 4 cusec and even bigger capacity.

a) Self/Auto priming trailer mounted engine Dewatering sets

- Capacity available from 1 cusec to 15 cusec
- Suction Pipe size from 2 inch to 20 inch
- Solids passing size from 38mm to 80mm

Types of self-priming

- **Dry prime centrifugal pumps:** The pump system consists of a centrifugal pump and a separator, which enables air to be separated from the liquid and be sucked by a vacuum pump – making automatic priming possible.

  Wet prime pumps: It uses an air-water mixture to reach a fully-primed pumping condition.

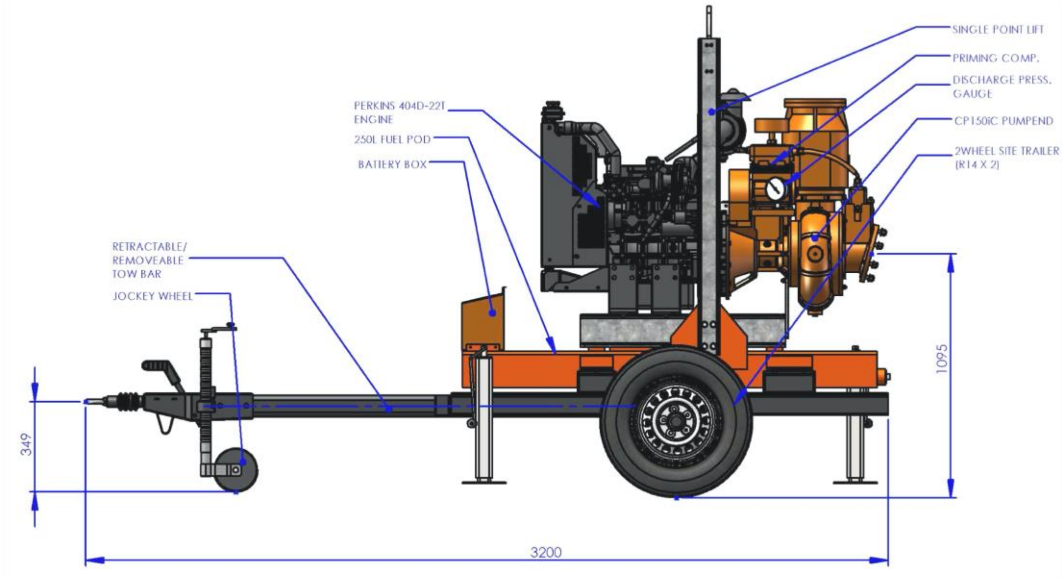

Figure 83: Self prime dewatering set

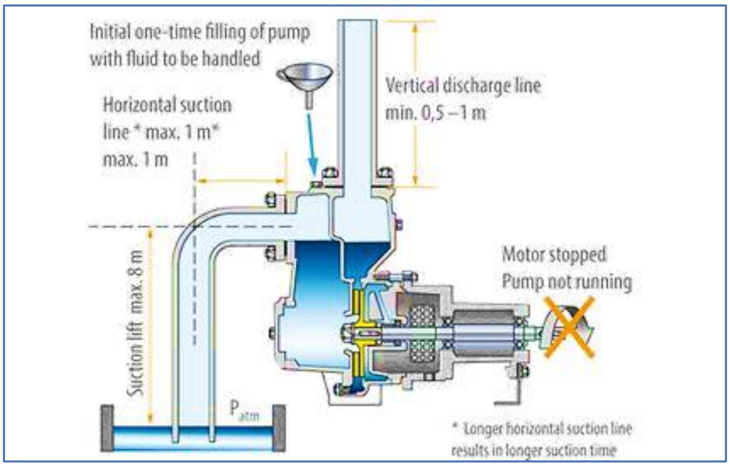

Figure 84: Wet prime pumps

Figure 85: Wet prime dewatering set

- The impeller and volute casing is essentially surrounded by a tank so that it can always be immersed in a liquid sufficient to get the pump started.
- It is important that a self-priming centrifugal pumps reservoir is filled correctly with liquid after installation. “Even a ‘self-priming’ centrifugal pump will not operate when dry.

- In its priming mode, the pump essentially acts as a liquid-ring pump. The rotating impeller generates a vacuum at the impeller’s ‘eye’ which draws air into the pump from the suction line.
- At the same time, it also creates a cylindrical ring of liquid on the inside of the pump casing. This effectively forms a gas-tight seal, stopping air returning from the discharge line to the suction line. Air bubbles are trapped in the liquid within the impeller’s vanes and transported to the discharge port. There, the air is expelled and the liquid returns under gravity to the reservoir in the pump housing.
- Gradually, liquid rises up the suction line as it is evacuated. This process continues until liquid replaces all the air in the suction piping and the pump. At this stage, the normal pumping mode commences, and liquid is discharged.

Figure 86: Dry primed sets

Figure 87: Dry primed sets

- The main difference in a dry-prime pump is its ability to prime without the need to add fluid.
- Prime is maintained by a vacuum unit, diaphragm, compressor or other priming device. An integral compressor creates vacuum through a venturi educator to achieve proper suction prime.
- A dry-prime pump’s rapid priming coupled with higher volumes results in a great efficient compared to wet-prime pumps. With the improved efficiency and performance comes a higher price tag, usually about 40% more than a wet-prime unit.

Why your self-priming pump won’t prime?

- Air leak in suction line
- Debris in the impeller
- Pump is air bound
- Plugged recirculation port
- Lift too high for pump speed or impeller diameter

5.5. Inspection of closed Drains

Regular inspections are crucial for closed drainage systems. This typically involves using CCTV cameras mounted on crawlers that provide a real-time view of the drain's interior, highlighting any structural issues, blockages, or sediment build-ups. Periodic inspections help in identifying problems early, ensuring timely interventions.

Here are the steps which need to be followed during inspection and maintenance activity

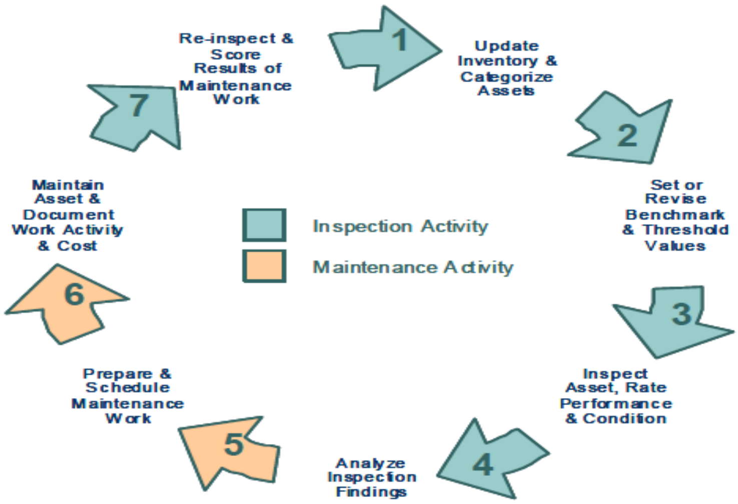

Figure 88: Flow Chart for Inspection and Maintenance Activity

The inspection of closed drains is more difficult and dangerous, and should be carried out under expert supervision.

5.5.1. Draw a sketch map

The first step is to draw a sketch map of the system, if record drawings are not available. The map should show all existing manholes, inlets and other drainage structures. If the gap between any two manholes is very long compared to that between most others, it is likely that one or two other manholes have been buried or destroyed between them.From the regular manhole spacing, it should be possible to calculate the most likely location of a missing manhole. Local residents, who may know of buried manholes, should also be consulted. The probable sites of missing manholes should be excavated, to uncover them.

5.5.2. Ventilation of existing manholes

No one should enter any manhole until it has been adequately ventilated. As a precaution, the manholes upstream and downstreamof the section to be inspected should be opened at least two hours beforehand. To save time, a number of manholes can be opened simultaneously. Further ventilation can be achieved by introducing the air hose from a compressor, if one is available. Inspection should start as far downstream as possible, and work upstream. Water in flooded manholes should be pumped out to the next manhole down-stream using a sump pump, of the type used by construction firms for excavations. Alternatively, the water could be bailed out with buckets or removed with a siphon, but this is likely to take a very long time.

Once the manhole has been ventilated, a further safety check is necessary to ensure that it is safe to enter. A lighted candle or a miner's safety lamp is lowered into the manhole. If the flame dies, it means that there is insufficient oxygen inside and that anyone entering the manhole could be suffocated by the gases produced by sewage and sediment. However, no naked light should be used until the manhole has been ventilated, as it could cause those gases to explode.

5.5.3. Lifeline

A final safety precaution, no less necessary, is that no one should enter a manhole without a lifeline. A spare lifeline should be ready for use if necessary. Access steps in an old manhole are liable to be seriously corroded and much less secure than they appear. They are often slippery. At least two people should remain above ground to pull out the third member of the party in case of emergency. They should *never* follow the third member into the manhole, even in an emergency, as they could all be killed. Even if the manhole is properly vented, the person inspecting it should disturb the settled sludge and silt as little as possible. These sometimes contain poisonous gases, which could be released when the sediment is agitated. Ifa drain is completely blocked so that it cannot be inspected, material should be removed only from the upstream end. These safety precautions are illustrated in Figure below

Figure 89: Safety Precautions Pic 1

Figure 90: Safety Precautions Pic 2

5.5.4. Alignment of a closed drain

The alignment of a closed drain can be checked by two people in consecutive manholes using a flashlight and a mirror, as shown in figure below Checking the alignment of closed drains

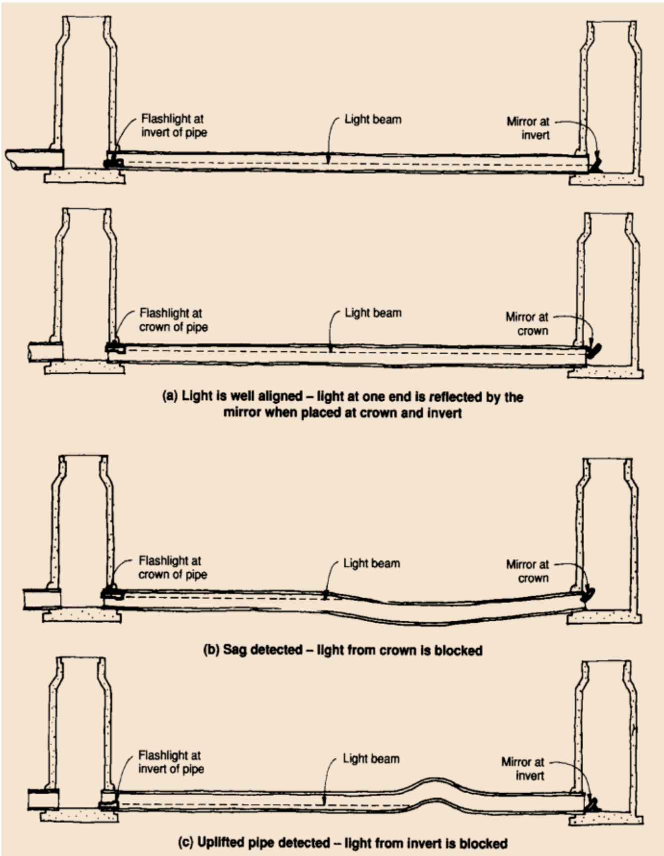

Figure 91: Checking alignment

First the flashlight and the mirror are held within 5—10 cm of the bottom of the pipe (known as the invert), and then they are both raised to just below the crown. If there is any irregularity in the vertical alignment of the drain pipe, it will be detected in one of these positions, since it will obscure the flashlight beam. This procedure will also make minor defects and obstructions visible.

The most likely place to find cracks and misalignment is immediately adjacent to the manhole, owing to uneven settlement of the ground after pipe-laying (Figure below).

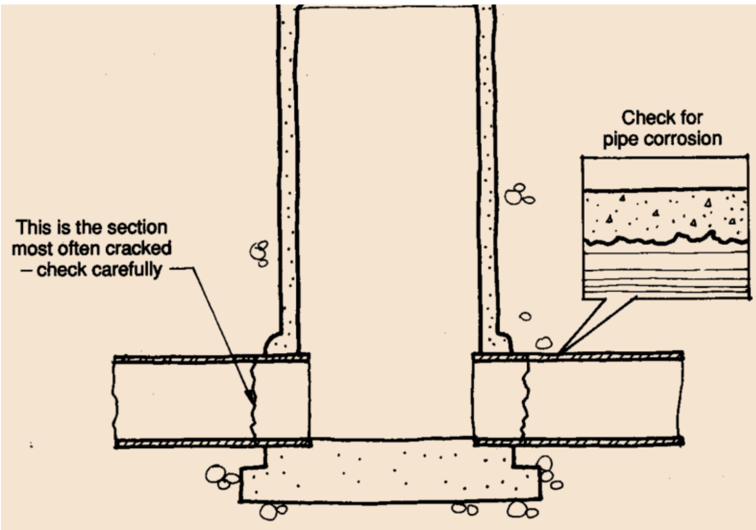

Figure 92: Common failures sites in closed drains

5.5.5. Checking Crown corrosion

Another problem to look for is crown corrosion, which can easily be discovered by attempting to dig into the pipe material at the sides and top with a penknife or a large nail.

Drainage pipes of less than 1 m in diameter cannot be entered safely, and great care should be taken in entering larger drains. The dangers include poisonous gas, cave-ins, sudden rushes of water from clogged sections or from storms, and even wild animals. Naked lights such as matches or candles should not be used in a closed sewer or within 3 m of any open manhole. A miner's safety lamp is preferable to a flashlight, to avoid the risk of explosions.

5.6. Cleaning, dredging and Clearing of Storm Drains and Inlets

The catch basin, also known as a storm drain inlet, is an opening to the storm drain system. Grate or curb inlets are some of the main features of the storm drain system. Storm water passes through the grate or curb inlets to enter the catch basin.

Within the catch basin, a sump catches all the present sediments, debris and other related pollutants. The main role of the catch basin is to prevent trash as well as other floatable objects from making their way into the drainage system by means of hooded outlets. Catch basins are the pretreatment for other treatment practices as they allow large sediments to settle in the basic sump zones.

Figure 93: catch basin

5.6.1. Catch basin maintenance

Maintenance of the catch basin helps prevent storm sewer blockages. It reduces the number of pollutants that enter into the storm sewer and end up discharging into the local streams and rivers. In addition, maintenance minimizes clogging in catch basins that causes ponding water along streets and parking lots. Ponding water causes terrible nuisance to motorists, pedestrians and businesses. Therefore, maintenance not only keeps the streets and parking lots clean but also gives a safe and healthy environment for motorists, pedestrians as well as businesses to carry out their activities.

Removal of trash and sediments that accumulate in the sump using a catch basin cleaner is one the simplest ways of cleaning. Usually, effective cleaning takes place when you use the catch basin with a vector truck or clamshell bucket. Regular cleaning of the catch basin forms the largest percentage of maintenance. Other additional maintenance activities invariably happen when necessary. It includes making repairs to the catch basin's brickwork, covers, frames as well as hoods.

To optimize basic cleaning and repair efforts in catch basin maintenance, it is paramount to incorporate a computerized work management system. The systems play a vital role in tracking all the cleaning and maintenance activities that take place in the catch basin. Vital information such as actual date of cleaning and maintenance repair is collected and recorded in the system making it viable to optimize maintenance efforts. Consequently, the system significantly lowers street flooding, nuisance foul smell and averts waterway pollution.

To maintain the ability of catch basins to trap sediments and provide effective drainage for storm water, you need to clean the catch basin periodically. Aforementioned, removal of decaying debris, sediments as well as other detrimental pollutants has aesthetic value and water quality merits. Here is more on cleaning catch basins.

5.6.2. Working on the grates

Leaves and other kind of trash usually collect at the grates. If they build up over the course of time, they result in clogging. It is therefore imperative to ensure that you remove the leaves and other kind of trash from the grates to avoid clogging.

5.7. Debris and Trash Removal

Storm grates direct stormwater from the street into the underground pipe system. Sometimes in the fall, leaves cover grates leading to localized flooding and pedestrian, bicycle, and motor vehicle accidents.

Figure 94: Debris at grating Pic 1

Figure 95: Debris at grating Pic 2

Rotting leaves also diminish the life span of the asphalt underneath them, leading to premature repair needs. Village crews watch for this occurrence and clear leaves and litter when grates become clogged.

In areas that do not have a curb and gutter, the swale is designed to hold stormwater when it can no longer soak into the ground to maintain a dry roadbed, filter runoff, and reduce pollutants. It is critical that you continue regular swale maintenance to minimize flooding.

5.8. Vegetation Management

Figure 96: Vegetation at drains

There are many complexities tied with stormwater vegetation management that may lead to confusion. From nuisance weeds to vegetation used to promote hydrology and pollutant removal, where do stormwater professionals draw the line? There have been countless articles released in the recent decade highlighting the benefits of having plant life in stormwater systems. However, proper maintenance often involves the removal of vegetation. The short answer is that it depends and typically relates to the stormwater system's initial design and plans.

Implementing stormwater solutions that involve planting beneficial vegetation has become a popular stormwater management strategy. Low-Impact Designs (LIDs) are designed to utilize plants' water retention abilities and other porous surfaces by mimicking the site's natural hydrology. Examples of LIDs include rain gardens, green roofs, and bioswales. These systems utilize plants' ability to absorb water through their roots, holding liquid in the canopy and slowly releasing it through evapotranspiration. A study published in the Journal of Environmental Quality estimated that 46 to 72% of bioswale water output was released through its vegetation. Trees and other plants have been shown to help above ground by acting as a natural net to catch trash, sediment, and debris, reducing the number of pollutants reaching local waters. root systems stabilize soil, reducing erosion and acting as a filter to remove chemical pollutants from the These systems are designed with plants in mind, generally establishing littoral shelves of beneficial native vegetation.

when and why should vegetation ever be removed?

There must be a synergy between the vegetation and the overall stormwater system. Systems not intended to utilize vegetation lacks the littoral shelves generally used to accommodate for the plants. If the stormwater system was not originally intended or designed to harbor vegetation, especially large or woody vegetation, the stormwater system cannot function as designed. Intruding roots are known to invade stormwater structures, such as inlets and outlets, clogging, cracking, and causing other concerns that could compromise the system, leading to expensive and avoidable repairs. Nuisance and invasive plants may invade stormwater systems if there is no management plan in place, leading to adverse effects on the environment and the stormwater system. Overgrown vegetation can even inhibit inspection site lines and eliminate the aesthetic appeal of certain stormwater assets

5.9. Erosion Control Measures Maintenance

Erosion can destabilize channels, leading to failures. Regularly inspecting and maintaining erosion control measures, such as riprap, silt fences, and erosion control blankets, is essential to ensure their effectiveness. Restoring native vegetation can also help stabilize soil.

Figure 97: Riprap layer around Banks

5.9.1. Control measures should meet the following requirements

- The control measures must be designed using Good Engineering, Hydrologic and Pollution Control Practices.
- The control measures must be maintained in effective operating conditions.
- The control measures must be adequate for the permitted construction site.
- The control measures require routine maintenance to prevent potential failure.
- The control measures must minimize pollutant release outside of the permitted project area.

Different factors should be assessed prior to the start of construction activities:

- **Topography:** This is the primary factor to be considered in determining the control measures to be used at the site. Soils, vegetation, and hydrologic features must also be taken into account.
- **Grading:** This will determine the slope gradient and slope length. After grading is completed, areas that remain exposed to precipitation and runoff will require the inclusion of additional control measures. The appropriate control measures will be a function of the duration of exposure and whether grading is interim or final.
- **Soil conditions:** Identifying these will allow to determine erosion potential and suitability for revegetation. A detailed analysis of soil-erosion potential is not necessary because all soils will be subject to erosion and can be generalized as equivalent for the design of control measures. This analysis is also useful to determine fertilizer requirements for vegetation establishment.
- **Existing Vegetation:** As most vegetation will be removed from a construction site during clearing and grading operations, an assessment of existing onsite vegetation is of limited use when post-development landscaping and irrigation are planned but can be useful in selecting grasses when non-irrigated revegetation is intended. Streams and other hydrologic features: These are important in the design of control measures. The drainage basins upslope and within the site should be assessed, the configuration of hillslope areas and drainageways, in the context of planned roads and buildings, will determine the necessary erosion and sediment controls. The location of permanent drainage channels and other elements of the drainage system should be defined as part of the plan.

5.9.2. Avoidance and Minimization

Vegetation is the most effective way to control erosion. During construction activities, soil disturbance typically removes this natural protective measure, exposes soils and increases their erosion potential. Avoiding disturbance is the optimal measure to control erosion and sedimentation; clearing and grubbing should only be conducted in portions of the site that are necessary for construction, preserving most of the existing vegetation elsewhere. Trees, bushes, and strips of natural vegetation in the area of construction should be preserved, as these natural elements will help hold soil particles in place, absorb the impact of rainfall, encourage infiltration, and slow the velocity of runoff. All feasible measures to avoid or minimize soil disturbances should be incorporated as early as the design phase of the project. Avoidance and minimization reduce the need for structural control measures. Examples of avoidance and minimization measures include:

- Providing a clear span bridge over a receiving water.
- Installing retaining walls adjacent to sensitive areas to avoid impact.
- Providing designated entries and exits as part of work access plan to the extent of land disturbance.
- Diverting offsite runoff away from construction areas.

- Defining areas of existing vegetation for protection on the plans.
- Designing roadway alignments to minimize impacts to sensitive areas.
- Prohibit staging and stockpiling material in wetlands and threaten and endangered habitats.

5.9.3. Control Measure Classification

- The recommended control measures explored in this chapter have been classified into four major categories. These categories include the use of structural and non-structural control measure devices and also encompass the use of management strategies for materials and waste products. The four categories include:
- **Erosion Control Measures:** These measures aim to minimize the amount of erosion occurring on disturbed areas until the site is fully stabilized.
- **Sediment Control Measures:** These Structures aim to capture sediments that have been eroded before they leave the construction site or enter state waters

Figure 98: Rock check dam along lined drainage ditch

Temporary Use of Permanent Water Quality Structures: The use of existing permanent water quality structures may be permitted in a case-by-case basis; the use of these structures aims to minimize the amount of sediment laden water released into state waters or storm sewer systems.

- **Materials and Waste Management Strategies:** These management strategies aim to provide a better management framework to handle, store and mitigate potential pollution from the use of materials and chemicals during the construction of transportation project.

a). Mulching

Mulching is a temporary control measure used for interim and permanent stabilization that consists of mechanically placing a uniform layer of agricultural straw or hay mulch that is crimped in and sprayed with tackifiers over disturbed construction areas. It protects disturbed areas immediately after seeding from the forces of rainfall impacts; it also increases infiltration. Mulching assists with germination success of seeded areas by conserving moisture and protecting against temperature extremes until permanent vegetation is established.

Figure 99: Agriculture Straw

Figure 100: Mulching on disturbed surface

Rough Cut Street Control Measures use Aggregate Bags, Silt Dike, or Temporary Berms along dirt- or road-base stabilized roadways that are under construction or are being used as construction access routes. These control measures are used to intercept and redirect flow away from the roadway.

b). Soil retention blankets

Figure 101: Soil Retention Blanket application on slopes

c). Surface Roughening and Vertical Tracking (SR)

Surface Roughening and Vertical Tracking (also referred to a temporary stabilization) are control measure practices that manipulate the subsoil by either creating different textures over the unfinished grade or using a tracked vehicle to drive over the surface, creating horizontal grooves and ridges. Surface roughening texture to the soil surface will reduce runoff velocity, encourage infiltration, and trap sediment.

Figure 102: Surface roughing

D). Temporary Berms

Temporary Berms are temporary control measure barriers made of compacted subsoil or other approved materials such as embankment or sand bags. Their function is to intercept and divert sheet surface runoff away from areas not yet stabilized, prevent erosion, manage sheet flow, and reduce sediment transport

Figure 103: Temporary Berm along access road

e). Temporary Diversions

Temporary Diversions are control measures used to reroute water from an existing stream or stormwater drainage path and restrict flows from entering a designated area while construction activities are underway. Temporary Diversion control measures aim to protect water quality by passing uncontaminated upstream flows around active construction areas.

Figure 104: Temporary diversion

f). Aggregate Bags

Aggregate Bags are small temporary control structures consisting of crushed stone or recycled- rubber-filled woven geotextile bags. They may be used in multiple scenarios to trap sediment from polluted stormwater runoff resulting from construction activities.

Figure 105: Aggregate bags

g). Erosion Bales

Erosion Bales are temporary sediment control structures consisting of a row of entrenched and anchored weed free straw or hay bales.

Figure 106: Erosion bales

h). Temporary Slope Breaks

Temporary Slope Breaks are practices aimed to create breaks to effectively shorten the uninterrupted flow path length of surface runoff on slopes steeper than 4H:1V. As sheet flow runoff moves down a long slope, the potential for erosion increases. Typical practices include installation of rolled erosion control measures or the application of grading techniques to create relatively flat terraces separating steep slope segments. Interceptor ditches are ditches constructed at top of slope to divert run-on water from above drainage basin from flowing over slope. The temp or permanent ditch conveys water to a Temporary Slope Drain or permanent embankment protector. Erosion Logs and Silt Dikes are typically used to construct this control measure.

Figure 107: Slope breaks

i). Turfing

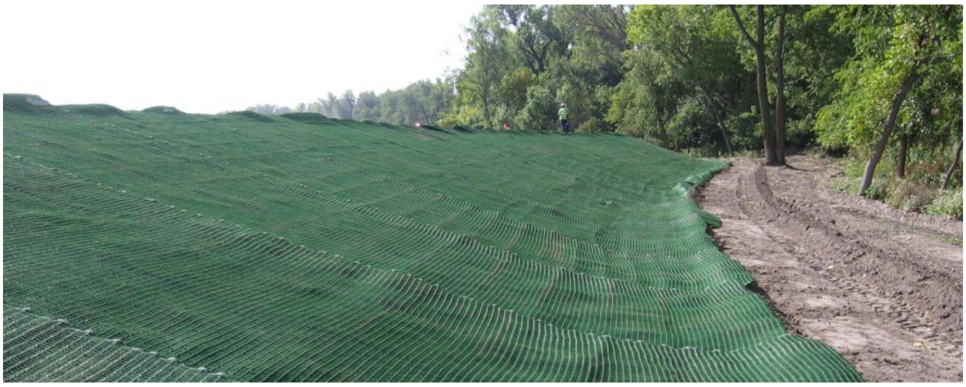

Figure 108: Turfing

- Turfing can be one of the most effective forms of instant erosion control.
- Turf must not be placed on excessively compacted soils.
- If high velocity flows are likely/expected over the turfed area within the first 2- weeks, then the turf should be anchored with wooden pegs.
- Metal staples (commonly used to anchor erosion control blankets) should not be used to anchor turf (for reasons of pedestrian safety).

j). Rock Pad

Figure 109: Typical layout of a rock pad for a single pipe outlet

k). Gully bags and Filter rock sediment trap

Gully bag

Gully bags (GB)

- A supplementary sediment trap.
- Commercial gully bags are generally considered to perform better than sediment traps placed on the road surface.
- They are typically used when it is considered unsafe to cause ponding or sediment deposition on the roadway.
- The types of gully traps include the flexible filter bags (left) and solid filter boxes lined with filter cloth.

Filter sock sediment trap

On-grade kerb inlet sediment traps (OG)

- A supplementary sediment trap.
- 'On-grade' inlets require a different sediment control system to 'sag' inlets.
- A series of sediment traps may be required to achieve optimum performance.

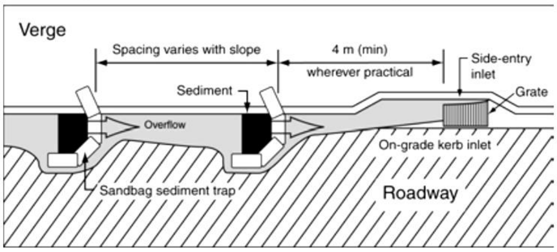

Figure 110: Gully bags and sediment trap

5.10. Culvert and Cross-Drainage Structure Maintenance

5.10.1. Culvert

The culvert is a small cross drainage structure spanning six meters or less between the inner face of the wall. It may be like a bridge designed to allow carrier or pedestrian traffic to cross the stream providing adequate clearance from high flood levels. Depending upon the project's requirements like traffic volume, embankment height and high flood level, it may be a single cell or multicell box culvert with round, elliptical, flat-bottomed shapes, open-bottomed, pear-shaped, and box-like structure.

Culverts and other cross-drainage structures can be compromised by sediment buildup, structural degradation, or blockages. Regular inspections, cleaning, and, if necessary, structural repairs or replacements ensure that these components function effectively, directing water where it's intended to go and preventing road or pathway washouts.
In summary, regular inspection and maintenance of stormwater drainage systems are imperative for their longevity and effectiveness. A proactive approach, rather than a reactive one, can save significant resources in the long run and ensure the safety and well-being of urban populations.

As a consequence of its function, the stormwater conveyance system collects and transports urban runoff that may contain certain pollutants. Maintaining catch basins, stormwater inlets, and other stormwater conveyance structures on a regular basis will remove pollutants, prevent clogging of the downstream conveyance system, restore catch basins' sediment trapping capacity, and ensure the system functions properly hydraulically to avoid flooding.

Figure 111: Drain culvert

Culverts are provided to convey water from the upstream side of the road to the downstream side. They may be built on the line of existing watercourses or to carry the build-up of water which results from the presence of the road. In either case, silting, choking by debris or structural collapse will usually result in over-topping and damage to the road. Maintenance comprises keeping the waterway clear, controlling scour and repairing structural damage.

Erosion of outlet channels from culverts is a common problem and if not dealt with promptly is likely to result in damage to the culvert and the road. This is caused by high discharge velocities from the outlet, and solutions which do not take account of this are not likely to be permanently effective. If the discharge velocity cannot be reduced by increasing the area of cross-section of the culvert and reducing its gradient, perhaps with a drop- inlet, then some type of energy-dissipating outlet should be used. As a first step, a fan discharge constructed with masonry or concrete should be tried. Stone gabions or mattresses downstream of the outlet may be a cheap alternative. Drop outlets are good, but on many sites, there is insufficient height to construct these.

The checking and removal of debris from culverts can be difficult, particularly if the culverts are small. Long-handled shovels or shovels attached to rods are useful for clearing out culverts which are too small for a man to get inside. Trees or branches blocking culvert entrances should be sawn into convenient sized pieces to help their removal and carting away. Culverts which get regularly blocked by debris should have a grill constructed at their upstream entrance.

Culverts made with corrugated metal pipes can be abraded by water carrying silt and sand which can wear away the protective zinc coating. This will result in the culvert pipe rusting away. If the culvert is large enough for a man to enter, the rust can be removed with a wire brush and the pipe coated with a thick layer of hot bitumen or tar. Alternatively, a flat concrete invert can be constructed.

Culverts made from concrete rings can be subject to differential settlement. This is a construction fault and major settlement problems can only be corrected by reconstruction. Minor mis-alignments should be repaired by grouting the joints in the pipes with concrete to provide a waterproof seal.

5.10.2. Cross drainage

Cross drainage works is a structure constructed when there is a crossing of canal and natural drain, to prevent the drain water from mixing into canal water. This type of structure is costlier one and needs to be avoided as much as possible. Cross drainage works can be avoided in two ways:

- By changing the alignment of canal water way
- By mixing two or three streams into one and only one cross drainage work to be constructed, making the structure economical.

5.10.2.1. Types of Cross Drainage works:

There are three types of cross drainage works structures:

Type – 1: Cross drainage work carrying canal over the drain

The structures falling under this type are

- Aqueduct
- Syphon Aqueduct

Type – 2: Cross Drainage work carrying Drainage over the canal

The structures falling under this type are

- Super passage
- Canal Syphon

Type –3: Cross drainage works admitting canal water into the canal

The structures falling under this type are

- Level Crossing
- Canal inlets

a) Type – 1: Canal over drainage [HFL < FSL]

Aqueduct:

In an aqueduct, the canal bed level is above the drainage bed level so canal is to be constructed above drainage. A canal trough is to be constructed in which canal water flows from upstream to downstream. This canal trough is to be rested on number of piers. The drained water flows through these piers upstream to downstream. The canal water level is referred as full supply level (FSL) and drainage water level is referred as high flood level (HFL). The HFL is below the canal bed level. Aqueduct is similar to a bridge, instead of roadway or railway, canal water is carried in the trough and below that the drainage water flows under gravity and possessing atmospheric pressure.

Figure 112: Aqueduct

Syphon Aqueduct:

In a syphon aqueduct, canal water is carrier above the drainage but the high flood level (HFL) of drainage is above the canal trough. The drainage water flows under syphonic action and there is no presence of atmospheric pressure in the natural drain. The construction of the syphon aqueduct structure is such that, the flooring of drain is depressed downwards by constructing a vertical drop weir to discharge high flow drain water through the depressed concrete floor. Syphonic aqueducts are more often constructed and better preferred than simple Aqueduct, though costlier.

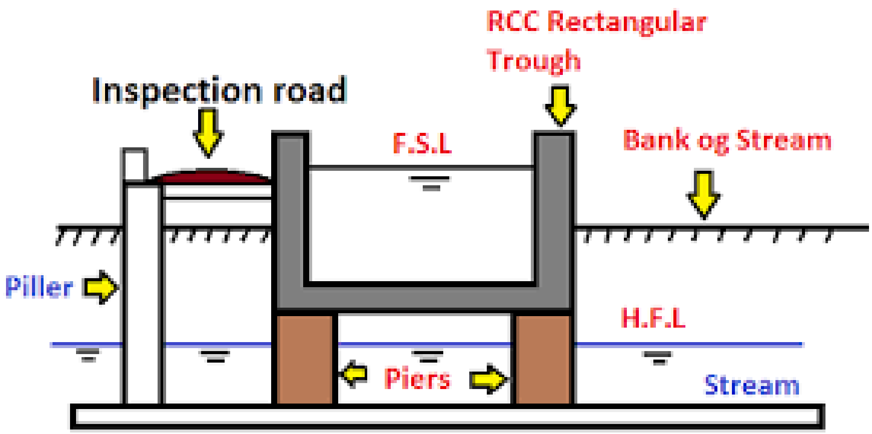

Figure 113: Syphon Aqueduct

b) Type – 2: Drainage over canal (HFL > FSL)

Super Passage:

Super passage structure carries drainage above canal as the canal bed level is below drainage bed level. The drainage trough is to be constructed at road level and drainage water flows through this from upstream to downstream and the canal water flows through the piers which are constructed below this drainage trough as supports. The full supply level of canal is below the drainage trough in this structure. The water in canal flows under gravity and possess the atmospheric pressure. This is simply a reverse of Aqueduct structure.

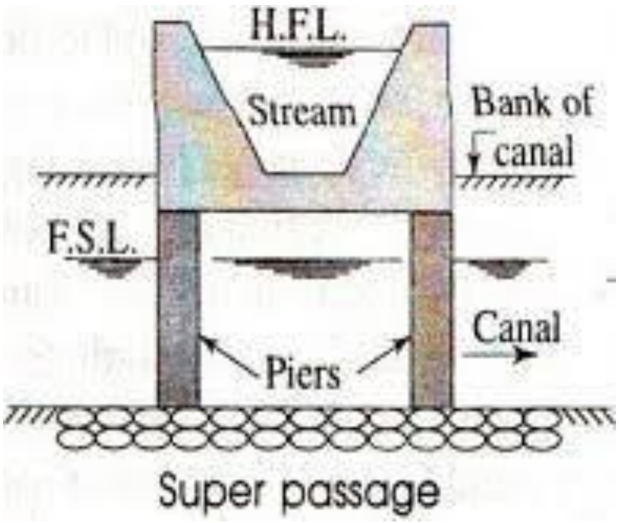

Figure 114: Super passage

Canal Syphon:

In a canal syphon, drainage is carried over canal similar to a super passage but the full supply level of canal is above than the drainage trough.so the canal water flows under syphonic action and there is no presence of atmospheric pressure in canal. When compared, super passage is more often preferred than canal Syphon because in a canal Syphon, big disadvantage is that the canal water is under drainage trough so any defective minerals or sediment deposited cannot be removed with ease like in the case of a Syphon Aqueduct. Flooring of canal is depressed and ramp like structure is provided at upstream and downstream to form syphonic action. This structure is a reverse of Syphon aqueduct.

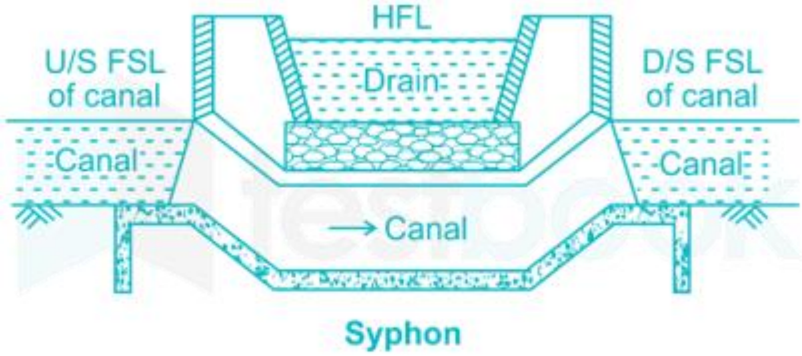

Figure 115: Canal Syphon

c) Type –3: Drainage admitted into canal (HFL = FSL)

In this case, the drainage water is to be mixed up with canal water, here the cost of construction is less but silt clearance and maintenance of canal water becomes really difficult. So, the structures falling under this category are constructed with utmost care.

Level Crossing:

When the bed level of canal is equal to the drainage bed level, then level crossing is to be constructed. This consists of following steps:

1. Construction of weir to stop drainage water behind it
2. Construction of canal regulator across a canal
3. Construction of head regulator across a Drainage

Functioning of a level crossing: In peak supply time of canal water parallel to drainage, both the regulators are opened to clear the drainage water from that of canal for certain time interval. Once the drainage is cleared, the head regulator is closed down. Anyhow, cross regulator is always in open condition throughout year to supply canal water continuously.

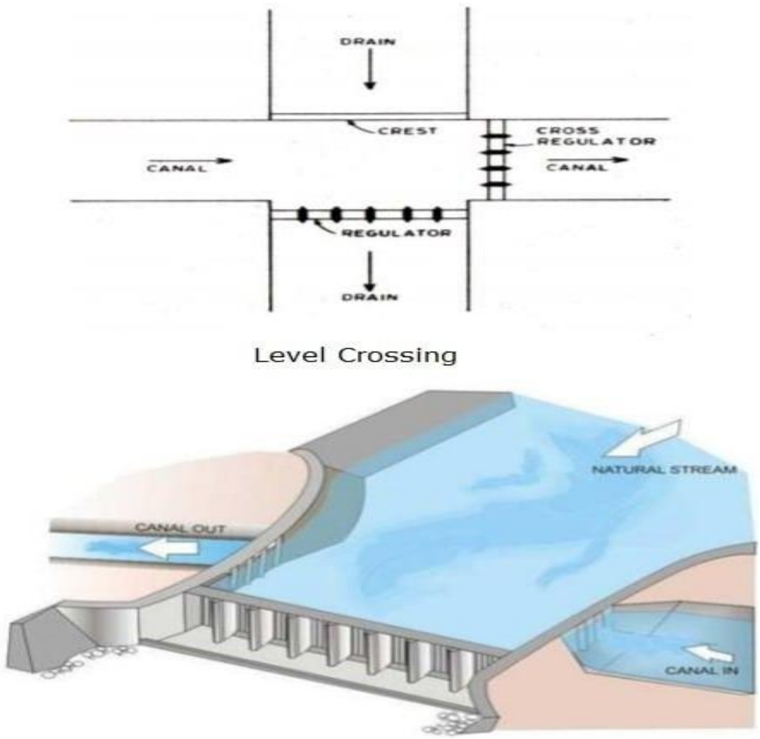

Figure 116: Level crossing

6. REPAIR AND REHABILITATION OF STORM WATER DRAINAGE SYSTEM

6.1. Structural Repairs of Storm Drains and Culverts

6.1.1. Patch Repairs:

Patch repairs are a targeted approach to fix specific damaged areas within storm drains and culverts. The first step involves thorough cleaning of the damaged area to remove any debris, sediments, or contaminants. This often involves power washing or scraping the surface to create a clean, solid base. The patch material, often made from high-strength, durable materials like specialized concrete or epoxy, is then applied to the compromised area. This material adheres firmly to the existing structure and cures over time, forming a strong, permanent repair.

Patch repairs are a cost-effective solution when the overall integrity of the storm drain or culvert remains sound, but a localized section has been compromised due to factors like cracking, corrosion, or wear and tear. Moreover, patch repairs are usually quick to implement and minimally disruptive to the surrounding area.

6.1.2. Lining

Pipe lining, or cured-in-place pipe (CIPP) lining, is a trenchless rehabilitation method that revolutionized pipe repairs. It involves inserting a resin-saturated felt tube made of polyester, fiberglass cloth, or another resin-impregnating material into the damaged pipe. This liner is then inflated, causing the resin to bond with the existing pipe as it cures. Once cured, this creates a new pipe within the existing damaged pipe, effectively sealing any leaks or cracks and restoring structural integrity.

CIPP lining has the advantage of being significantly less disruptive than traditional methods, as it does not require full excavation of the damaged pipe. This method often results in substantial cost savings, reduced environmental impact, and minimized social inconvenience due to construction activities.

6.1.3. Grouting

Grouting is an effective technique used to seal cracks, joints, and defects in storm drain pipes and surrounding soil. In this process, chemical grouts - such as acrylamides, urethanes, or other sealant materials - are injected into the cracks and void spaces in and around the pipe. These grouts expand as they cure, effectively sealing the defects and “gluing” the pipe back together.

This method is particularly effective for reducing or eliminating the infiltration of groundwater into the stormwater system, which can otherwise overburden the system, especially during heavy rainfalls. Grouting is often a preferred option when the integrity of the pipe is generally good, but there are leaks at the joints or cracks in the pipe walls.

6.1.4. Reconstruction

When the damage to a storm drains or culvert is extensive and the structural integrity is significantly compromised, full reconstruction may be the best or only viable solution. This process involves the complete removal of the old, damaged structure and the installation of a new one. Reconstruction is a comprehensive approach that ensures the entire system is brought up to current standards, which can include improvements in materials, design, and capacity. Due to its extensive nature, this option is typically the most costly and disruptive. It is usually reserved as a last resort when other repair methods are deemed insufficient or impractical. Reconstruction ensures a long service life and is often necessary when safety is a concern, or the existing structure is beyond repair.

6.2. Replacement of Damaged Components

6.2.1. Pipes and Conduits

When pipes are damaged beyond the point of repair, they need to be replaced. This might involve excavating around the damaged pipe, removing it, and installing a new pipe made from durable materials designed to withstand the site-specific conditions. (Like HDPE or reinforced concrete).

Replacement of damaged pipes is very critical keeping in view the following points

6.2.1.1. Public Safety and Health

Damaged stormwater pipes can result in flooding and stagnant water pooling, which pose safety risks to the public, such as slip and fall accidents or vehicle accidents due to water on roadways. Standing water can also become a breeding ground for disease vectors like mosquitoes, affecting public health. Replacing damaged pipes is vital to maintain public safety and health.

6.2.1.2. Preventing Further Damage

A small breach in a stormwater pipe can lead to soil erosion and significant damage over time, affecting roadways, building foundations, and landscapes. Replacing these damaged components as soon as damage is identified can prevent more extensive and costly problems later.

6.2.1.3. Maintaining System Functionality

Stormwater drainage systems are designed to efficiently move water away from urban areas during rainfall events. Damaged pipes can disrupt this flow, leading to ineffective drainage and localized flooding. Replacing damaged pipes is essential for maintaining the normal functionality of a stormwater drainage system.

6.2.1.4. Cost Savings

Although replacing damaged stormwater pipes and conduits incurs an immediate cost, it often results in long-term savings. Allowing these components to remain damaged can lead to much more expensive issues, such as extensive flood damage, which is likely to be far costlier to address than simply replacing a pipe or conduit.

6.2.1.5. Compliance and Liability

Local and national regulations often require that stormwater drainage systems be maintained to certain standards. Failing to replace damaged components can result in non-compliance, which can lead to fines, penalties, or legal action. Moreover, if a known issue is not addressed, it can increase the liability of the municipality or property owner in the event of an accident or health issue due to flooding.

6.2.1.6. Environmental Protection

Leaking stormwater pipes can lead to the loss of soil and the pollution of waterways with urban runoff, which often contains oil, pesticides, and other contaminants. Replacing damaged pipes is thus a critical step in responsible environmental stewardship.

6.2.1.7. System Efficiency and Reliability

Damaged stormwater pipes can reduce the efficiency of a drainage system, causing backups and overflows during rain events, and increasing the risk of flooding. Replacing these components can improve the overall efficiency and reliability of the drainage system, ensuring it performs optimally when needed.

6.2.1.8. Property and Infrastructure Value

Maintaining the integrity of a property's stormwater drainage system is key to preserving its value. Prospective buyers or tenants may be keen to know that the drainage system is in good working order, and the replacement of damaged pipes and conduits is a fundamental part of this maintenance.

The replacement of damaged pipes and conduits in a stormwater drainage system is a critical aspect of urban and infrastructure maintenance. It is essential for ensuring public safety, health, and environmental protection. It is also a prudent investment, helping to maintain the functionality, efficiency, and value of public and private properties while potentially saving significant costs in the long run by preventing more severe damages due to flooding and erosion.

Figure 117: A damaged Sewage Pipe

6.2.2. Inlets and Outlets

These components are crucial for the functionality of storm drains. They guide stormwater into and out of the system. If they are severely damaged, replacement might involve removing the existing structure and installing a new inlet or outlet designed to handle the anticipated water flow.

6.2.3. Manhole Covers and Frames

The prime function of gutter in the design of paved roads/streets is to facilitate the channeling of stormwater between source controls and treatment systems. Over time, manhole covers can become damaged due to traffic loads, corrosion, or other factors. Replacing these involves removing the old frame and cover and installing a new, typically stronger and more corrosion-resistant, frame and cover.

Figure 118: Damaged Manhole Cover

Figure 119: A new Manhole Cover

6.3. Upgrading and Retrofitting Measures:

6.3.1. Capacity Enhancement

As urban areas develop, the original design capacity of stormwater systems may become insufficient. Upgrading to enhance capacity may involve enlarging existing pipes, adding additional pipes or channels, or constructing storage facilities like detention ponds that can temporarily hold stormwater during peak flows, releasing it slowly back into the system.

6.3.2. Green Infrastructure Integration

Retrofitting with green infrastructure, such as green roofs, permeable pavements, and bioretention systems, is a modern approach to stormwater management. These systems use natural processes to slow down, filter, and infiltrate stormwater, reducing the burden on traditional drainage systems and improving water quality.

Figure 120: Green roofs

6.3.3. Improving Resilience

Climate change is introducing new challenges for stormwater management, with more frequent and severe storm events. Upgrades for resilience might include installing tide gates or backflow preventers at regulating structures at drainage stations to protect against storm surges, or redesigning system components to better withstand extreme conditions, such as heavy rainfall or drought.

Repairing and rehabilitating stormwater drainage systems is a complex task that requires a thorough understanding of the current system's condition, anticipated future conditions, and the various repair options and their respective costs and benefits. It often involves a combination of engineering expertise, innovative technologies, and community engagement to develop and implement effective, sustainable solutions.

6.3.4. Improve public health and safety

Steep-sided drains present a potential safety risk, particularly to children who play near or attempt to climb into the drain and may fall down the bank. Retrofitting drains to 'living streams' involves reducing the grade of steep banks to a gentle slope and more natural waterway shape. A living stream has stable vegetated banks, diverse habitat and an ability to support a healthy ecosystem (see Section 6.2.9 and Case Study 7.4 for further information). Vegetation or fencing can be used in sections to form a barrier and discourage access to the water. Formalised access points, such as a crossing or riffle, can be used to allow public access to the stream at safer locations.

Retrofitting the drainage system can assist in the control of disease and nuisance vector insects (i.e. mosquitoes and midges) by reducing nutrient and pollution levels in stormwater and receiving water bodies. Shading cools the water, which reduces mosquito and midge numbers. Techniques that reduce the area of stagnant water, for example using flowing streams rather than stagnant pools, will also reduce the opportunity for mosquito breeding. Infiltrating or drawing down the water to prevent pooling for longer than four days will prevent completion of the mosquito larval life cycle. Refer to Chapter 9 for further detail on designing stormwater systems to reduce the risk of mosquitoes and midges.

6.3.5. Improve water quality

Retrofitting works can improve water quality by controlling pollutant inputs at source, reducing the mobilization and conveyance of pollutants and treating stormwater by trapping or removing pollutants. The issue of water quality is not restricted to the main stormwater channels and receiving water bodies. Many minor tributaries and drains within the catchment can be a major source of pollutants. Historic sources of pollution, such as groundwater contamination seeping into stormwater channels, may continue to impact on water quality. Retrofitting projects need to be implemented in the context of a holistic approach to water management. Catchment management strategies, such as improved management of fertilizer use, are essential to address the problem at source to improve water quality in the long-term.

6.3.6. Restore and conserve environmental condition

One of the aims of retrofitting is to create a stormwater management system that also protects or restores environmental values. Retrofitting projects can incorporate revegetation and restoration of natural habitats (e.g., wetlands, waterways and bushland). Increasing the diversity of habitats in the urban landscape will result in improved biodiversity. Vegetated areas also improve stormwater treatment (e.g., nutrient removal) through increased stormwater filtration.

Retrofitting can increase stormwater retention/infiltration, which recharges the groundwater system. This can help restore groundwater dependent ecosystems, such as some wetlands that are degrading because of declining groundwater levels in response to low rainfall and high groundwater abstraction rates. Many waterways are also degraded because of the installation of dams and reduction in flows. Redirecting clean stormwater to provide environmental flows can potentially improve waterway health.

Infiltration of stormwater and re-use through garden bores can help manage the local water balance, limiting consequential environmental impacts from urban developments. Maintaining the water cycle balance can prevent problems associated with acid sulfate soils, salinity and waterlogging.

Retrofitting projects can result in greater redirection of stormwater into the groundwater system, essentially making it available for use during drier periods through garden and council bores, while helping to conserve scheme water. Retrofitting projects can also include the installation of rainwater tanks that collect runoff from roofs, where the water can be used for non-potable purposes such as toilet flushing, washing machine use, vehicle washing and garden irrigation. In some circumstances, carpark runoff can be used for garden/ reserve irrigation. However, rainfall patterns need to be considered when garden irrigation is planned because large runoff storage tanks or supplementary water supplies might be required.

6.3.7. Flooding issues

Open drains and sumps/compensating basins can be retrofitted where there is adequate space, or the systems are larger than the required capacity. The Water Corporation is the owner of the majority of the main drainage network in the Perth metropolitan area and has a responsibility to meet the requirements of their operating license (administered by the Economic Regulation Authority) with respect to flood mitigation. Any works in the stormwater system cannot compromise the flood capacity or protection of property. Additionally, the trend of increased urban infill may also raise the demand on drainage systems. The requirement to meet future flood control and mitigation expectations needs to be considered.

7. MAINTENANCE OF STORM WATER PUMPING STATIONS

7.1. Pump Maintenance and Inspection

A). HOW DOES A CENTRIFUGAL PUMP WORK?

Before we dive into our recommended centrifugal pump maintenance schedule, let make sure you a good grasp of how the pump itself works. In its simplest form, a centrifugal pump is made from a housing with an inlet and outlet. There is an impeller that is located inside the housing, and a motor or drive that is responsible for rotating the impeller. The pumps casing (outer shell) is designed to create a gradually widening channel which is known as the volute. When the motor (or drive) rotates the impeller, it is creating centrifugal force.

- It creates a reduced pressure area at the eye of the impeller, which acts like a vacuum. This provides a flow of liquid to the pump impeller.
- On the other side, the volute causes the fluid to slow down and the pressure inside the pump's housing begins to increase. This increase in pressure forces the liquid out the discharge (outlet) of the pump and then on to the piping systems of the process.

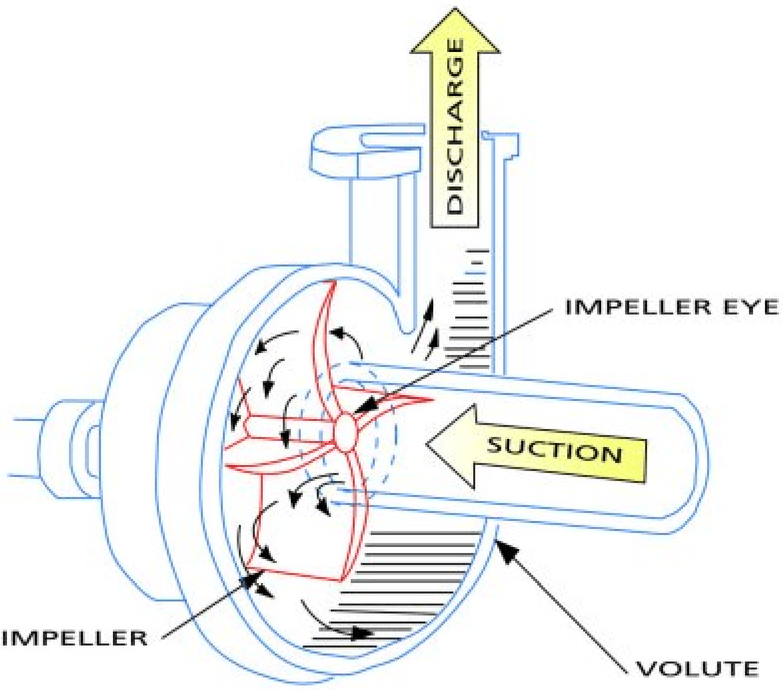

Figure 121: Centrifugal Pump

B). What are the main parts that make up a centrifugal pump?

Now that we have an understanding of how centrifugal pumps operate, we can give an overview of its most common parts:

- **Casing (Volute)** – As we learned earlier, this acts as a pressure containment vessel. It directs the flow of liquid in and out of the centrifugal pump. It slows down the speed of the fluid while increasing the pressure within the casing.
- **Impeller** – This is a rotor that is used to increase the kinetic energy of the flow.
- **Motor (drive)** – Power source of the pump. It is responsible for driving the shaft.

- **Shaft (rotor)** – The impeller is mounted on a shaft. This component uses torque from the motor to transfer energy to the impeller.
- **Shaft Seals** – These are packing rings or mechanical seals which help prevent any leakage of the pumped fluid.
- **Bearings** – work to reduce friction between the rotating shaft and the pump and keep the impeller spinning in place.
- **Bearing Frame and Foot** – inspect for cracks, roughness, rust or scale. Machined surfaces should be free of pitting or erosion.
- **Bearing Frame** – inspect all tapped connections for dirt. Clean and chase threads as necessary. Remove all loose or foreign material. Inspect lubrication passages to be sure that they are not blocked.
- **Shaft And Sleeve** – inspect for grooves or pitting. Check bearing fits and shaft runout, and replace the shaft and sleeve if worn or if the shaft runout is greater than 0.002 inches.
- **Casing** – inspect for signs of wear, corrosion or pitting. If wear exceeds a depth of 1/8-inch, the casing should be replaced. Check gasket surfaces for signs of irregularities.
- **Impeller** – inspect the impeller for wear, erosion or corrosion damage. If the vanes are bent or show wear in excess of 1/8-inch deep, replace the impeller.
- **Frame Adapter** – inspect for cracks, warping or corrosion damage and replace if any of these conditions are present.
- **Bearing Housing** – inspect for signs of wear, corrosion, cracks or pits. Replace housings if worn or out of tolerance.
- **Seal Chamber/Stuffing Box Cover** – check for pitting, cracks, erosion or corrosion. Inspect for any wear, scoring or grooves that might be on the chamber face. Replace if worn more than 1/8-inch deep.
- **Shaft** – check the shaft for any evidence of corrosion or wear and straightness. Noting that the maximum total indicator reading (TIR) at the sleeve journal and coupling journal should not exceed 0.002 inches.

7.1.1. Pumps Maintenance:

a) Leakage from Packing Seals

A seal is used to prevent water leaking out along the shaft. There are two types of seals commonly used:

- This leakage must be controlled for two reasons:
    a. to prevent excessive fluid loss from the pump, and
    b. to prevent air from entering the area where the pump suction pressure is below atmospheric pressure.
- The amount of leakage that can occur without limiting pump efficiency determines the type of shaft sealing selected. Shaft sealing systems are found in every pump. They can vary from simple packing to complicated sealing systems.
- Packing is the most common and oldest method of sealing. Leakage is checked by the compression of packing rings that causes the rings to deform and seal around the pump shaft and casing. The packing is lubricated by liquid moving through a lantern ring in the center of the packing. The sealing slows down the rate of leakage. It does not stop it completely, since a certain amount of leakage is

necessary during operation. Mechanical seals are rapidly replacing conventional packing on centrifugal pumps.

b). Grease packing is commonly used as gland seals.

Figure 122: Grease packing for a pump

Figure 123: Packing Material

- The shaft sleeve is a sacrificial component that protects the more expensive pump shaft.
- Because packing needs to contact the shaft it will eventually wear a groove into it, which can be costly to repair or replace.
- Inspect every 150 hours of operation for excessive leakage. Adjust as required

Sizing Grease packing?

- Simply measure the inner diameter of the bore of the stuffing box and subtract from it the outside diameter of the shaft. The figure obtained be divided by 2 to get your gland packing size.

Standard sizes

- But generally, the following sizes of the gland packing are recommended for the different shaft sizes as follows:
- For shafts of size 50 to 75 mm diameter the gland packing of size 12.5 mm is used
- For shafts of size 75 to 120 mm diameter the gland packing of size 16 mm is used

Lubrication

- Lubrication of the pump packing is extremely important.
- The quickest way to wear out the packing is to forget to open the water piping to the seals or stuffing boxes.
- Be sure there is always a slight trickle of water coming out of the stuffing box or seal.
- Rapid wear of the packing will be caused by roughness of the shaft sleeve.

c). Mechanical seal

- ***Some of the reasons for the use of mechanical seals are as follows:***
  - Leaking causes bearing failure by contaminating the oil with water. This is a major problem in engine-mounted water pumps.

- Properly installed mechanical seals eliminate leak off on idle (vertical) pumps. This design prevents the leak (water) from bypassing the water flinger and entering the lower bearings.

d). Motor-Pump alignment

It should be an important part of any maintenance program. Most pump distress events or failures) have their root cause in the misalignment of the pump to motor. Misaligned pumps can even consume up to 15% more energy input than well-aligned pumps.

Even small pumps can generate big losses when shaft misalignment imposes reaction forces on shafts, even if the flexible coupling suffers no immediate damage. The inevitable result is premature failure of shaft seals and bearings.

Performing precise alignment, therefore, pays back through preventing the costly consequences of poor alignment. Indeed, using precise alignment methods is one of the principal attributes of a reliability focused organization.

Good alignment has been demonstrated to lead to:

- Lower energy losses due to friction and vibration
- Increased productivity through time savings and repair avoidance
- Reduced parts expense and lower inventory requirements
- Further, in order to insure good alignment, the alignment must be checked and correctly set when:
- A pump and drive unit are initially installed (before grouting the baseplate, after grouting the baseplate, after connecting the piping, and after the first run).

After a unit has been serviced.

- The process operating temperature of the unit has changed.
- Changes have been made to the piping system.
- Periodically, as a preventive maintenance check of the alignment, following the plant

e). Operating procedures for scheduled checks or maintenance.

Proper shaft alignment is achieved by moving the motor. The motor is shimmed vertically to achieve the proper elevation to align it to the pump, both parallel (offset) and angular. The motor is them moved horizontally to achieve proper horizontal placement for aligning the shaft centerlines, both parallel and angular. The motor is moved horizontally by the use of jacking bolts, or by the use of pry bars, hammers, or other tools.

Motors are normally easier to move, since the motor is not piped into a process system. A short run of flexible conduit is most often used to run the electrical wiring from a local disconnect, or a rigid conduit, to the motor termination box. This allows for ease of movement of the motor.

Motor-Pump alignment is critical for these reasons:

- It minimizes the forces of misalignment acting upon the bearings and seals of both components.
- It minimizes wear of the coupling.
- It can help reduce energy costs.
- It maximizes the life of the machine components by minimizing wear, increasing time between failures, and reducing vibration.

f). The pump coupling serves two main purposes:

- It couples or joins the two shafts together to transfer the rotation from motor to impeller.
- It compensates for small amounts of misalignment between the pump and the motor.

Remember that any coupling is a device in motion. If you have a 4-inch diameter coupling rotating at 1800 rpm, its outer surface is traveling about 20 mph. With that in mind, can you think of safety considerations?

There are three commonly used types of couplings:

- **Rigid Coupling**

Rigid couplings are most commonly used on vertically mounted pumps. The rigid coupling is usually specially keyed or constructed for joining the coupling to the motor shaft and the pump shaft. There are two types of rigid couplings: the flanged coupling, and the split coupling.

- **Flexible Coupling**

The flexible coupling provides the ability to compensate for small shaft misalignments. Shafts should be aligned as close as possible, regardless. The greater the misalignment, the shorter the life of the coupling. Bearing wear and life are also affected by misalignment.

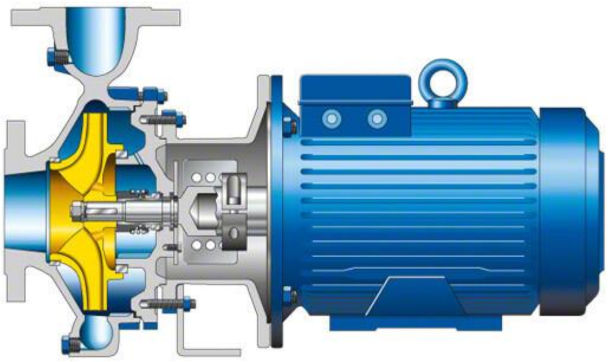

Figure 124: Closed Coupled Pump

- **Alignment of Flexible and Rigid Couplings**

Both flexible and rigid couplings must be carefully aligned before they are connected. Misalignment will cause excessive heat and vibration, as well as bearing wear. Usually, the noise from the coupling will warn you of shaft misalignment problems.

Different couplings will require different alignment procedures. We will look at the general procedures for aligning shafts.

I. Place the coupling on each shaft.

II. Arrange the units so they appear to be aligned. (Place shims under the legs of one of the units to raise it.)

III. Check the run-out, or difference between the driver and driven unit, by rotating the shafts by hand.

IV. Turn both units so that the maximum run-out is on top.

Now you can check the units for both parallel and angular alignment. Many techniques are used, such as: straight edge, needle deflection (dial indicators), calipers, tapered wedges, and laser alignment.

Shaft misalignment is responsible for as much as 50 percent of all costs related to rotating machinery breakdowns.

g). Worn Wear Ring/ Wear Plate

Device used to seal the pressure leakage of the liquid between the inlet of the impeller and the pump casing. ... Excessive Clearances: If clearances are too wide for the type of fluid pumped, excessive slip will occur.

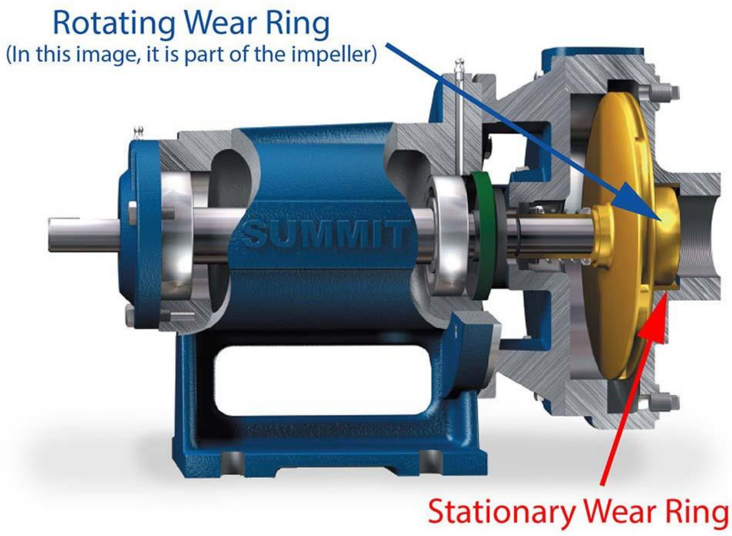

Figure 125: Wear Ring

h). Bearings:

The most important part in pump failure is bearing. There are various studies showing high rate of failures due to defects in bearings. Some of them are illustrated below:

Types of bearings commonly used

There are three types of bearings commonly used: ball bearings, roller bearings, and sleeve bearings. Regardless of the particular type of bearings used within a system--whether it is ball bearings, a sleeve bearing, or a roller bearing--the bearings are designed to carry the loads imposed on the shaft.

Bearings must be lubricated. Without proper lubrication, bearings will overheat and seize. Proper lubrication means using the correct type and the correct amount of lubrication. Similar to motor bearings, shaft bearings can be lubricated either by oil or by grease.

(a) Lubrication is required

- The surfaces of bearing rolling elements and rings (inner ring and outer ring) are finished extremely smooth. But however smooth they are their surfaces still have unevenness. When a bearing rotates, the convex regions of the bearing rings and the rolling elements come in contact with each other. This contact between the convex regions leads to friction and wear, inhibiting the smooth rotation of the bearing. In order to prevent this friction and wear, oil or some other substance is applied between the contact regions. This is called "lubrication

Procedure for lubrication

Lubricate pump bearings every year of operation. Frequent lubrication is not required

- Many applications call for only a ¼ to ½ ounce of grease every month, which translates to;
- “One or two strokes on a standard grease gun. (Annually 0.17 KG per bearing or 0.34 KG per pump)”

- A general way to determine how much grease to replenish is to multiply the outside diameter of the bearing in millimeters by the bearing width in millimeters, then multiply by 0.005. This will give you the re-lubrication amount expressed in grams.

Factors Causing High Bearing / Lubricant Temperatures

- The load on the bearing: High relative bearing loads will increase bearing temperature. Factors that can increase the bearing load include:
- Higher oil viscosity increases oil and bearing temperatures, so the oil grade should not be higher than necessary. Synthetic oils will often allow lower oil grades. Higher oil viscosity also increases the power loss from the bearings, which slightly increases life cycle costs.
- Too much grease: Greased bearings will generally run hotter than oil lubricated bearings, and over-greasing will increase the bearing temperature even further.
- Higher speed pump operation increases the bearing temperature and,

Water contamination

If bearings are dipped into leakage water in the pump house, cooling of the housing with water will restrict the expansion of the bearing outer race, increasing the internal bearing load and overheating.

Factors affecting life of pump bearings

- Wrong fitting (loose or tight fit)
- Stuffing box leakage on bearings
- Low quality greasing
- Over greasing
- Shaft vibrations
- Sinking of pumps in leakage water
- Swear vibration jerks due to sudden blockages and delayed stopping of pumps

7.1.2. Trouble shooting pumps

7.1.2.1. Causes of pump vibration

- Misalignment
- Bent shaft
- Clogged, eroded, or unbalanced impeller
- Insufficient suction pressure
- lack of rigidity in the foundation

7.1.2.2. Causes of Pump requires excessive power

- Misalignment
- Bent shaft
- Wrong wearing ring
- Shaft bearing worn
- Gland too tight resulting in no flow of liquid to lubricate gland
- Bearings rusted up due to flooding of water in dry well
- Excessive grease

7.1.2.3. Causes of Stuffing box leaks excessively

- Misalignment
- Pump (impeller) shaft bent
- Shaft or shaft sleeves worn or scored at the packing
- Gland packing improperly installed
- Incorrect type of gland packing for operating conditions

- Shaft running off center because of worn bearing or misalignment
- Rotor out of balance, causing vibration
- Failure to provide cooling liquid to water cooled stuffing boxes

7.1.2.4. Causes of Pump not delivering any liquid

- Insufficient priming
- Partially closed valve or some other obstruction in the discharge line
- Excessive suction lift
- Clogged impeller
- Wrong direction of rotation
- Clogged suction
- Ruptured suction line

7.1.2.5. Insufficient Discharge

- Air leak into suction pipe
- Air leak into pump through gland packing
- Concentric reducer in suction line causing air pocket (Replace with eccentric one)
- Casing not air-tight and therefore breathing in
- Total head of system higher than design head of pump
- Pump main clogged
- Line valve malfunctioning
- Impeller locking pin loose

7.1.2.6. Pump vibrates or is noisy at low flow

- Pump not fully primed
- Check clogging on suction side
- Suction lift too high
- Suction bell mouth insufficiently submerged

Regular cleaning is essential as stormwater often carries debris that can clog or damage the pumps. This process involves the removal of foreign materials such as leaves, plastic, and sediment from the pumps and associated components. Scheduled preventative maintenance, which might include lubricating bearings, replacing worn seals, and calibrating equipment, is vital to avoid unexpected breakdowns and ensure that the pumps are always ready to operate effectively during a storm event.

7.2. Electrical Systems and Controls

The electrical systems and controls of a stormwater pumping station are the nerve center of the facility. They enable the pumps to operate automatically based on various conditions, such as water levels. Regular inspections and testing of electrical components, including wiring, switchgear, and control panels, are critical to ensure the reliability of the system.

Maintenance might include tightening electrical connections, testing and replacing faulty components, and calibrating sensors and control systems. It is also essential to ensure that all electrical systems are adequately protected and grounded to prevent electrical surges from damaging sensitive equipment.

7.2.1. Major types of electrical control panels

I. Change over Switch
II. Electrical Distribution panel
III. Motor Control Unit (MCU)
IV. Power factor improvement (PFI) Panel

Figure 126: ASD Panel

Types of Faults

- Over voltage
- Under voltage
- Phase failure
- Changed phase sequence
- Electrical surges
- Short circuit

Table 13: Troubleshooting electric panel

Fault	Remedy
Does main circuit breaker trip?	Check all phases (if working then motor is faulty otherwise replace Circuit Breaker)
Does thermal relay trips?	Is current within range (if not then motor is faulty otherwise replace thermal relay)
Does under/over voltage relay trips?	Is voltage within range? (if not in range inform Electric Company otherwise replace relay)
Are there any loose connection?	Check for wiring sequence and rectify the fault
Switch on function working	Switch on the contactors (if switched on does not work, replace the contactor)

7.2.2. The most common causes of motor failure

- **Electrical Overload** (Overcurrent): This can be caused by a low supply voltage, short circuited conductors. Install effective overcurrent protection relay

- **Low Insulation Resistance**
- It is caused by the degradation of the insulation of the windings due to overheating, corrosion, or physical damage and Moisture.
- **Over-Heating**
- Around 55% of insulating failures in motors occur due to overheating caused by poor power quality (low voltage), or a high temperature operating environment.
- **Contamination**
- Contamination from dust, dirt and chemicals is one of the leading causes of motor failure. Foreign bodies can dent bearing raceways and balls
- **Vibration**
- The motor positioned on an uneven or unstable surface often causes vibration. Vibration can also be a result of loose bearings, misalignment, or corrosion.
- Poor lubrication

Table 14: Electric Motor: Trouble Shooting

S.No.	Problem	Possible Solution
1	Leakage of oil or grease on winding	• Clean the spilled oil on winding. Replace oil seal. • Reduce quantity to correct extent. • Grease should be filled up to maximum half space in bearing housing.
2	Hot bearings	• Replace bearings. • Remetal shaft/housing or replace shaft or bearing housing. • Remove old grease, wash bearings thoroughly with kerosene and replace with new grease. Reduce quantity of grease.
3	Motor stalls	• Check any excessive rubbing or clogging in pump • Correct voltage to rated value. • Fuses blown, check overload relay, starter and push button.
4	Motor vibrates	• Realign • Strengthen base plate/ • foundation; tighten holding down bolts. • Replace bearing • Rotor unbalanced • Single phasing • Unbalanced terminal voltage. • Motor may be overloaded.

7.3. Backup Power Systems

A reliable backup power system is essential for a stormwater pumping station, especially during extreme weather conditions when the power grid may be unreliable. These systems, often diesel or natural gas generators, need to be regularly inspected and tested under load conditions to ensure they will function when needed.

Maintenance for backup power systems includes checking fuel levels and fuel quality, testing batteries and starting systems, changing oils and filters, and ensuring that all components are operating effectively. The backup power system must be engaged promptly when there is a power failure to ensure the continued operation of the stormwater pumping station.

Diesel generators are used in our cities for power back up.
An early warning is generated by the generator before the occurrence of many troubles. One should keep special intension to the device during operation, maintenance and regular inspection to avoid major problems. Some of the problems are narrated here:

a. Engine misfires
b. Vibration
c. Unusual engine noise
d. Sudden changes in engine operating temperatures
e. Excessive smoke
f. Increase in oil consumption
g. Increase in fuel consumption

Daily Maintenance Checks

- ✓ External coolant leaks
- ✓ Belt condition-cracked or loose
- ✓ Block heater – on constantly or leaking
- ✓ Hoses – leaking, soft, brittle
- ✓ Radiator – Leaking, plugged, broken fan

7.3.1. Troubleshooting and Maintenance of generator

Table 15: Engine Relate Faults

Sr. #	Problem	Potential Cause	Remedies
1	Engine does not start	Lack of fuel/Fuel tank empty	Fill it
		Air in fuel injection system	Bleed the air
		Check Battery with Multi-meter	Replace or Charge battery
		Water contaminants in the fuel	Change it
		Fault in the fuel lift pump, cold stat system	Repair and adjust it
		Wrong grade of fuel used	Change & use proper
		Fault in fuel injection pump	Check & repair
		Timing of fuel injection pump is incorrect	Correct is as required
		Bad compression, Shut-off valve closed	Inspect rings & pistons and adjust valve clearances
		Fuel connections are loose on suction side of the fuel pump	Check & tight the connections
2	Engine difficult to start	Lack of fuel., Fuel tank empty	Fill it
		Air in fuel injection system	Bleed the air
		Water contaminants in the fuel	Change it
		Starter motor defective	Repair or replace it

		Restriction in filter/ cleaner or in air induction system	clean or replace it
		Restriction in fuel vent	Remove & clean
		Restriction in exhaust pipe	Remove & clean exhaust system

Table 16: Alternator Related Faults

Sr. #	Problem	Potential Cause	Remedies
1	If Generator voltage below 400V & not adjustable via potentiometer	Drive speed too low	Check speed control of drive engine
		Voltage regulator defective	Replace voltage
2	Generator voltage too low (say less than 100V)	Interruption of excitor circuit	Tighten connections according to connection diagram
		Surge suppressor faulty	Replace the suppressor
		Rotating rectifier faulty	Repair the diodes of the rectifier
3	If Generator voltage above 450 V & not adjustable via potentiometer	Drive speed too high	Check engine speed and adjust it to 1500 rpm
		Interruption of AVR	Check AVR Connections
		Voltage regulator defective	Replace voltage regulator

Table 17: Daily and Periodic Maintenance Sheet

Sr. No.	Activities	Service Type				Last Activity Date	Year____ Month____				
		Daily	Weekly	Monthly	6 Months		1	2	3	4	5
1	Visual Inspection	·									
2	Check Coolant Level	·									
3	Check Oil Level	·									
4	Check Fuel Level	·									
5	Check Charge Air Piping	·									
6	Check and Clean Air Cleaner		·								
7	Check Battery Charger		·								
8	Drain Fuel Filter		·								
9	Drain Water from Fuel Tank		·								
10	Check Coolant			·							

11	Check Drive Belt Tension			·							
12	Drain Exhaust Condensate			·							
13	Check Starting Batteries			·							
14	Change Oil and Filter				·						
15	Change Coolant Filter				·						
16	Clean Crankcase Breather				·						
17	Change Air Cleaner Element				·						
18	Check Radiator Hoses				·						
19	Change Fuel Filters				·						
20	Clean Cooling System				·						

7.4. Emergency Operation Protocols

Every stormwater pumping station should have a set of detailed emergency operation protocols. These protocols outline the steps that operators should take in various emergency situations, such as power failures, extreme flooding, or equipment failure.

Regular training and drills are necessary to ensure that all staff are familiar with these protocols and can implement them effectively under stressful conditions. The protocols should be reviewed and updated periodically to reflect changes in staff, equipment, and risk factors. In an emergency, these protocols guide the actions of the station's personnel, helping to ensure that the facility continues to operate as effectively as possible under challenging conditions.

In summary, the maintenance of a stormwater pumping stations is a multi-faceted task that requires regular and meticulous attention to the mechanical, electrical, and operational components of the system. Ensuring that pumps are in good working condition, electrical systems are reliable, backup power is ready to go at a moment's notice, and staff are prepared to respond to emergencies is essential for the effective operation of these critical flood control facilities. Regular maintenance and preparedness drills can significantly reduce the risk of catastrophic failure during severe weather events, which is the time when the community relies on these systems the most.

7.4.1. Emergency Operation Protocols

a) When the mains power fails, the generator should be started in time.

b) Check that the oil, diesel, battery, and voltage are normal before starting. Is the water level in the water tank sufficient?

c) Check if the blades and drive belts are normal, check for oil leaks and other loose connections throughout the fuselage.

d) The starting time should not exceed 5 seconds. The interval should be 2 minutes after the two consecutive starts are unsuccessful. If it cannot be started after three times, the cause should be found.

e) After the generator is powered normally, it should be observed that the operation of each instrument is normal. If abnormal conditions are found, stop and the inspection be made immediately.

f) Keep the unit load not exceeding 80% during operation.

g) After the mains supply resumes power supply, the mains is converted by reverse operation according to the startup procedure. Keep running at no load for more than 5 minutes before stopping.

h) During operation, pay attention to turning on the blower.

i) After the emergency generator is started, the voltage, current, oil pressure and water temperature should be recorded.

j) In operation, to ensure the normal and safe operation of the generator set, the unit must be inspected by a combination of watching, listening, smelling and touching.

8. COMMUNITY ENGAGEMENT AND PUBLIC AWARENESS

8.1. Educating the Public about Storm Water Management

Public education is a vital component of effective stormwater management. People are generally unaware of where their stormwater goes and how it affects their community's rivers, lakes, and coastal areas. An educated public is more likely to support necessary public investments in stormwater infrastructure and to engage in behaviors that protect these systems.

Education campaigns may utilize a variety of mediums, such as websites, social media, brochures, community meetings, and school programs to inform the public about how the stormwater system works, why it is essential, and how improper disposal of waste can lead to system failures and environmental pollution. These campaigns can also teach people about the small things they can do to reduce stormwater pollution, such as proper disposal of household hazardous waste, the benefits of using rain barrels or installing rain gardens, and why they should pick up after their pets. Effective public education is about not only disseminating information but also fostering an ethic of environmental stewardship.

8.2. Encouraging Citizen Participation in O&M (Operation & Maintenance) Efforts

Encouraging citizen participation in the operation and maintenance of stormwater management systems can be a potent tool for local governments. Citizen participation can take the form of volunteer groups that help with the cleaning and maintenance of local waterways and stormwater facilities, adopt-a-drain programs where residents commit to keeping a storm drain in their neighborhood clear of debris, or community 'watchdog' programs where trained volunteers monitor local waterways for signs of pollution. These volunteers can act as an early warning system for problems that might require government intervention, and they can provide valuable labor that complements the work of paid staff.

Furthermore, when people are personally invested in the care of their community's environment, they are more likely to engage in behaviors that protect it and to support public policies that prioritize its care. Engaging citizens in the O&M of stormwater systems does not only help maintain the infrastructure but also strengthens the community's connection to their local environment and fosters a culture of stewardship.

In summary, community engagement and public awareness are integral to the sustainable and effective management of stormwater systems. Educating the public about the importance of stormwater management helps to build a knowledgeable and supportive citizenry, while encouraging active participation empowers individuals to take part in the preservation and improvement of their communities. This approach cultivates a sense of responsibility and ownership among residents, thereby enhancing the overall success and longevity of stormwater management initiatives.

8.2.1. Community institutions

Community participation is not a spontaneous, automatic process. It requires an initiative to launch it, and management to organize it. In practice, communities can participate only through community institutions. On the other hand, these institutions do not need to be created out of nothing. A low-income urban community is not the unorganized mass it may seem to outsiders. Usually, a variety of institutions are already in existence, some of them with a high degree of organization and considerable power to influence people's attitudes and behavior. They are of many different kinds, such as the following:

- residents' associations and amenity groups,
- women's organizations,
- political parties,
- labour unions,
- religious bodies,
- cultural associations,

- burial societies,
- schools, parent—teacher associations,
- health posts, health committees, community health workers.

Some of them may be formally recognized and affiliated to regional or national bodies. Others may have developed informally in response to specific local needs. Their activities and influence often range much wider than the purposes for which they were originally established. They are often far more active and influential in low-income communities than the corresponding institutions in wealthier neighborhoods. In addition, some individuals may be recognized informally as leaders in the community owing to their education, wealth, age or experience.

The initiative to start discussion of the possibility of drainage improvements will often come from an individual who already playsa prominent role in one of these organizations, such as the school- teacher, religious leader or party secretary. When the initiative comes from an outside body such as the municipality, these institutions are valuable “entry points” through which a first approach to the community can be made. Indeed, many residents may feel slighted if the approach is not made through the existing community institutions.

8.2.2. The drainage committee

It will normally be necessary to establish a drainage committee to organize the community’s contribution to a drainage project. This is most likely to succeed if it is not a completely new structure, but is built on to existing community institutions whose authority is generally accepted. The drainage committee will enjoy the established authority of the community’s leaders if it is answerable to them.

The committee should be representative of the community. Its task will be easier if it includes women and members from the principal ethnic and religious groups in the community, and from various parts of the neighborhood. On the other hand, it should not be too large as this can make it harder to reach consensus decisions and to ensure that all the members play an active role. It is prefer- able to have fewer than 10 members. The active participation of the committee members can be encouraged by allocating specific roles among them, such as Chairperson, Secretary and Treasurer, with other members responsible for technical aspects, liaison with the municipality, public relations, organization of voluntary labour, relocation of affected houses, and so on. Some of these may have deputies if the number of members is sufficient.

In many cases, the members of the committee will be willing to work on a voluntary basis, but there are circumstances in which some remuneration for the work done on a drainage committee can be justified. This is especially the case when the work of the drainage committee permits significant cost savings to the municipality.

One of the first steps for the committee is to approach the local municipality to seek its help, either directly or through local leaders. Even if the municipal authority cannot afford to provide material resources, it may be able to offer other kinds of assistance, such as technical guidance, advice regarding possible sources of funds, and liaison with other relevant bodies, including other communities which have successfully undertaken drainage improvements. In addition, the municipality can help to avoid conflict with the police. While community meetings and participation are encouraged in most countries, there are some cases where a group of people meeting regularly in a low-income high-density housing area could be suspected of subversive activity.

If the municipal authority is willing to help, every effort should be made to ensure close collaboration between it and the committee. The drainage committee, for its part, should brief municipal officials on its decisions and send them minutes of meetings or, better, invite representatives of relevant departments to attend. It could also offer to assist with data collection and other tasks. The municipality, on the other hand, should consult the committee about planning and design decisions, allowing it time to consult the community before replying. It can arrange regular briefings for committee members on the progress of the project.

8.2.3. Creating awareness

A prerequisite for a community's active and willing participation in a drainage scheme is an awareness of the need for it, of its feasibility, and of the benefits it can bestow. In many low-income communities there is no lack of awareness of the problem; drainage often figures first on the list of felt needs for community infrastructure. However, the drainage committee (or anyone wishing to set one up) will need to develop public awareness that the community itself can and should do something to improve the situation. A further requirement is to generate a climate of responsibility for the drainage system once it has been built.

A range of methods can be used to give publicity to the drainage committee and its objectives, including public meetings, posters and door-to-door canvassing. Schoolchildren are a particularly valuable resource. They are usually more ready to accept new ideas, they have time and energy which can be mobilized for various activities, and they can influence their families at home.

However, people's attitudes and behavior are not easily influenced by a one-way flow of information and exhortations to participate. A far more effective strategy is to stimulate discussion insuch a way that residents come to see for themselves the advantagesof contributing towards a drainage scheme and the importance ofa responsible attitude towards it.

Four principal incentives can help motivate people to participate in a drainage project:

- comfort and safety,
- financial gain,
- status,
- group pressure.
- A low-income community will get, after construction of a proper drainage system, a good locality atmosphere.

8.2.4. Comfort and safety

An effective argument for drainage is the prospect of no longer having to walk through pools of stagnant water and sewage, or of having no more collapsing houses and landslides. These improvements make it worthwhile for residents to undertake improvements to their houses, and open the way for other aspects of infrastructure such as water supply and sanitation. Improved drainage makes access easier for vehicles, even if few residents own a motor car, many will be taken to ensure easy access for emergency vehicles such as ambulances and fire engines. The prospect of reduced mosquito nuisance is a further inducement, once people have been shown that mosquitos breed in stagnant water. The health benefits of drainage and should be explained to the community.

9. DATA MANAGEMENT AND RECORD-KEEPING

9.1. Maintenance Records and Logs

Maintenance records and logs are vital tools in the effective management of a stormwater drainage system. These documents provide a historical record of all activities related to the upkeep of the system, including inspections, cleaning, repairs, replacements, and upgrades. Each entry typically includes details such as the date of the activity, the personnel involved, the location and component of the system that was serviced, the nature of the work performed, and any significant findings or issues that were identified. Maintaining comprehensive and accurate logs helps to ensure that the system is serviced at appropriate intervals and enables managers to identify recurring problems that may suggest a need for more significant intervention or redesign.

Furthermore, these records can be invaluable when responding to inquiries or audits from regulatory agencies, demonstrating that the organization is in compliance with all relevant maintenance requirements. In the event of a system failure, these logs can also help to identify the cause of the problem and may protect the managing entity from liability by demonstrating that it maintained the system responsibly and diligently. Necessary records and logs are proposed as follows:

9.1.1. General Data of drains

Table 18: Primary drains

Sr.No	Name of drain	Starting point	End point	Size in feet Lengthx width x Depth	Length in KM

Table 19: Secondary drains

Sr.No	Name of drain	Starting point	End point	Size in feet Lengthx width x Depth	Length in KM

Table 20: Road side drains

Sr.No	Name of drain	Reach		Total length and size		Connected with	Type	Remarks
		From	To	Length in RFT	Size	Sewer or drain	Open/covered	

9.1.2. Progress Of Desilting Of Primary And Secondary Drains

Table 21: Progress of desilting of main drains

Sr. No.	Name of Drain	From	To	Length (KM)	Up to Date Progress (KM)
1					
2					
3					
4					
Total Length					

9.1.3. Progress Of Desilting and Data Of Road Side / Tertiary Drains In Mc----------

Table 22: Progress of desilting and data of Road side drains

Sr. No	Name of Drain	Reach desilted		length			Connected with	Type to Drain
		From	To	Length in Rft	K.M	Size	Sewer/drain	Open/Covered

9.1.4. Identification of low-lying ponding areas

- Low lying areas may be identified and necessary data may be gathered.
- Plan may be made to eliminate these ponding points with minimum possible resources. The plan may be like a sample plan given below:

Table 23: Example List of ponding areas

Point	Reason of ponding	Possible Remedial measures	Status of proposal	Remarks
A	Point not connected with any drain/sewer.	Proposal prepared to construct a piped drain towards open drain passing about 100 meters away	Submitted for approval	
B	Road drainage problem. Road slope is not provided towards sewer/drain	Road maintenance department requested to make correction. Proposal prepared to connect this point with road side through gully grating and piped drain	Proposal being implemented	
C	Gully grating damaged	Gully grating to be repaired before Monsoon	Proposal being prepared	
D	No road side drain	Road side drain to be constructed		
E	Manhole is raised above road	Manhole to be corrected and lowered to road surface		

9.1.5. Preparation of critical points maps

Every critical point may be marked on a map and a list may be prepared with following information for each rainfall:

Table 24: Critical ponding areas

Date	Rain start /stop time	Rainfall (mm)	Ponding point	Ponding (inch)	Clearance time (Hours)

9.2. Storm Event Reports and Documentation

Storm event reports and documentation are critical components of stormwater data management and are essential for understanding the performance of the stormwater system during and after significant rain events or storms. These reports typically include detailed information about the storm, such as its duration, intensity, and total precipitation, as well as the response of the stormwater system. This might include data on water levels in various components of the system, the operation of pumps and other control devices, and any instances of flooding or system overflows.

The reports should also document any problems that occurred, such as equipment failures or blockages, and the steps that were taken to address these issues. Post-storm documentation is not only a record of what happened but is also a powerful tool for learning and improvement. By thoroughly documenting the system's performance during each significant storm event, managers can identify weaknesses in the current system and make data-driven decisions about where to invest resources for improvements. Furthermore, these reports are often essential for securing federal or state funding after severe storms, as they provide the necessary documentation to demonstrate the impacts of the event and the need for aid.

In summary, data management and record-keeping are foundational aspects of effective stormwater management. Maintenance records and logs serve as a detailed chronicle of the care and servicing of the system, which is essential for ongoing operations, regulatory compliance, and liability protection. Storm event reports and documentation, on the other hand, provide invaluable insights into the system's performance under stress, offering lessons that can guide future investments and improvements. These records, when maintained meticulously and analyzed thoughtfully, form the backbone of a proactive, responsive, and responsible stormwater management program.

Table 25: Storm event report

Storm event report dated------------				
Sr No	**Town**	**Rain Gauge location**	**Rain start/stop time**	**Rain fall(mm)**

10. STAFF TRAINING AND SKILL DEVELOPMENT

10.1. Staff Training for O&M (Operation & Maintenance) Activities

Training of staff for operation and maintenance activities is a critical aspect of managing a stormwater drainage system effectively. Such training ensures that all personnel are fully aware of their roles and responsibilities, understand the operation of various system components, and are competent in the use of the tools and equipment necessary for their work. Initial training for new hires typically includes a mix of classroom instruction, hands-on practice, and field observation. Regular refresher training sessions are also important, to update staff on new techniques, equipment, or regulations and to reinforce best practices.

Training should cover a broad range of topics, including:

a. system inspection protocols,

b. cleaning and clearing procedures,

c. equipment operation, and emergency response plans.

d. Repair procedure

e. Monsoon operation

Effective training is vital not just for maintaining the stormwater system itself but also for the safety and effectiveness of the workforce. By training staff thoroughly and continuously, an organization can ensure that its stormwater system is maintained to a high standard, which can prolong the lifespan of the infrastructure, improve its resilience and reduce the risks of catastrophic failures.

10.1.1. Institutional Arrangement and Capacity Building

Creation of storm water drain infrastructure is one aspect, but its periodic maintenance is the key to provide the desired level of services on a sustainable basis. An efficient organization is very important for planning, design, and sustainable operation and maintenance of infrastructure. Therefore, measures must be taken for institutional strengthening and internal capacity building so that the efforts made can be sustained over a period of time and the system put in place can be well managed. Institutional strengthening can be done by adequately decentralizing the administration, delegating adequate powers at the decentralized level, inducting professionals into the administration, and providing adequate training to the existing staff.

10.2. Safety Training and Protocols

Safety training and protocols are an essential aspect of staff development in stormwater management. The nature of stormwater system O&M activities often involves working in confined spaces, handling heavy and potentially hazardous equipment, and exposure to unsanitary water and debris. As such, it is critical that all staff are trained on the risks associated with their work and the precautions necessary to mitigate those risks. Safety training should cover topics such as the proper use of personal protective equipment (PPE), confined space entry procedures, electrical safety, hazard communication, and emergency response procedures in case of accidents or exposure to harmful substances.

Regular drills and refresher courses should be part of the training exercise to ensure that safety remains a top priority at all times. Protocols, or step-by-step action plans, should be established and routinely updated to guide workers in various situations, ensuring that they have a clear and well-practiced plan to follow to protect themselves and others. By rigorously training staff on safety protocols, an organization not only protects its workforce but also reduces its liability and ensures that its operations are compliant with relevant occupational health and safety regulations.

In summary, staff training and skill development are indispensable components of an effective stormwater management program. For O&M activities, comprehensive training ensures that staff are competent, effective, and prepared to manage the complex systems for which they are responsible. Safety training and protocols, on the other hand, ensure that staff can perform their duties without compromising their health and well-being. These programs represent an investment in the human resources that are as critical to the success of a stormwater management system as the physical infrastructure itself. Regular, high-quality training is a sign of a responsible and forward-thinking stormwater management operation that is committed to excellence, efficiency, and the welfare of its staff and community.

It has two parts:

a. **Safety related with drainage features**
b. **Safety of staff working on drainage maintenance**

10.2.1. Correcting Unsafe Drainage Features

There are many drainage features on and along streets and highways. They include the curbs and gutters, drop inlets and catch basins, pipes, culverts, and ditches needed to collect and carry storm drainage away from the road. When these features are located on a roadway or are adjacent to it where a vehicle, bicycle or pedestrian has a chance of traveling over or into the feature, the drainage feature should be designed for safety. Drainage features that have been designed for safety, crash tested, and found to operate safely under the design conditions are usually referred to as crashworthy. Basically, crashworthy means a highway feature or appurtenance will not stop a vehicle abruptly, cause the driver to lose control or cause the vehicle to roll over. This section describes corrective measures that can be taken to mitigate the effects of an identified drainage problem that affects safety.

Figure 127: Deterioration of pavement edge and shoulder

Side slopes, both cut and fill embankments, and ditch sides, are usually constructed in the relatively flat areas. Steeper slopes pose greater safety risk to motor vehicles traveling across or down them. These steeper slopes are also more difficult to maintain.

All slope surfaces should be smooth, free of fixed objects, and free of snagging features, such as headwalls. Vehicles traveling down slopes are difficult to control and may strike, roll over or drop into a feature such as a pipe end, which can cause a vehicle to halt abruptly, become unstable and roll over, or strike the back of the slope. Erosion scars on a side slope can also initiate vehicle instability by tripping the vehicle's wheels and initiating overturning. Therefore, eroded slopes should be graded and seeded. When rip rap is used to control and spread the flow of water, it should have shallow inverts and be placed flush with the existing ground. Additionally, the roadside conditions should be checked to determine why erosion is taking place and the problems resolved. Side slope erosion can cause rollovers.

10.2.2. Correcting the Effects of Erosion on Roadway Hardware

Soil erosion can have a detrimental effect on safety appurtenances, such as guardrail, sign supports, and highway light supports. The deposit of several inches of eroded soil or the erosion of several inches can significantly reduce crashworthy characteristics. Soil deposited around breakaway appurtenances can cause them to malfunction or simply not break away. Additionally, run-off can result in the erosion of soil around these safety features, reducing their operational characteristics, such as deflection on impact rather than breaking away. This can cause a vehicle to roll over or abruptly stop.

Figure 128: Side slope erosion can cause rollovers

10.2.3. Correcting the Effects of Erosion on Culvert and Pipe Ends

Pipes and culverts may have headwalls or special pipe end sections. Headwalls tend to channel water around their edges and can cause erosion gullies to develop. The storm flow from the pipe or culvert can also erode the sides of a paved channel or the bottom of a graded channel. If these water channels erode, they can create gullies on the side slopes that can trip the wheels of an errant vehicle or bicycle causing instability, loss of control or initiating a vehicle rollover. Pipe and culvert ends should be checked annually or after major storms. Debris that can divert water flow should be removed and eroded areas re-established with soil/aggregate mixtures and reseeded. Additional measurers may need to be taken to reduce erosion, such as paving the channel in areas where erosion continues.

10.2.4. Correcting the Effects of Erosion on Ditches

Roadside ditches and channels are often cut into the roadside immediately adjacent to the roadway. There are designs for ditches that ensure their travers ability, meaning a vehicle or bicycle can pass over the ditch or channel at the travel way speed without abruptly stopping, losing control or being rolled over. Recommendations for ditch cross sections (front slope, bottom, depth, and back slope) can be found in the current edition of the Roadside Design Guide. The choice of a traversable ditch section depends on the amount of run-off, the grade of the roadway, slope and soil conditions and speed of vehicles on the highway.

Figure 129: Deep ditches such as this are a safety hazard

Both earth and lined ditches require maintenance to remove debris and prevent erosion that can create roadside hazards and/or reducing the effectiveness of the drainage system. It is important when repairing eroded earth ditches and shoulders to restore them to their original safety shapes. Ditch side slopes that are too steep and ditches that are too deep can initiate instability in a vehicle causing it to roll over or cause the vehicle to snag against the ditch back slope and abruptly stop or vault the vehicle into the air.

Roadside ditches, along with the other drainage features such as drop inlets, should be checked annually and after major storms to ensure they are not clogged with debris or eroded. Roadside ditches that are not traversable by design, as a result of previous maintenance actions or because of erosion.

Figure 130: A non-traversable drainage ditch

Even traversable drainage features can become hazards when storm run-off or maintenance operations, such as dressing side slopes, result in the feature extending above the surrounding ground. These features are rigid objects that can snag the undercarriage of a vehicle leaving the roadway or initiate vehicle rollover.

Raised roadside drop inlets, sometimes referred to as table top inlets, provide a vertical opening in their sides for large volumes of run-off and debris removal. They are usually located in low- depressed or sump areas. Raised inlets located in areas where an errant vehicle or bicycle can drive into or over them should be no higher than 4 inches above the surrounding ground. Drop inlets that extend more than 4 inches above the surrounding ground can snag the undercarriage of a vehicle in the same way a raised headwall can, causing it to abruptly stop, go out of control, or roll over. A safer drainage treatment is to use a grated inlet that is close to the ground as shown below.

Figure 131: V-shaped grate in median.

10.2.5. Eliminating or Improving Hazardous Drainage Headwalls

Headwalls are common features on many local roadways. The headwalls are often used to support the shoulder and maintain the roadway edge, prevent the end of the pipe from being crushed or broken when overridden, collect and disperse water flows and occasionally delineate the ditch or channel. Headwalls, by their nature, are generally rigid structures capable of abruptly stopping a motor vehicle if hit. When they are located on side slopes, they may be potential hazards, causing loss of control, ramping or vehicle roll over.

Figure 132: Culvert headwall is a roadside hazard

To minimize the potential of vehicle snagging on the end of a pipe, it is necessary to provide a traversable end section, ensuring that either the pipe end is cut flush with the ground line, or when used, that the steel grating is sloped flush with the surface.

Figure 133: Grated inlet flush with ground over a culvert end

A second safety consideration, important to all large pipe and culvert ends located in the clear zone, is the size or width of the opening. Pipes and culverts can trap a vehicle wheel if the opening is too large, causing it to stop abruptly or initiate overturning. Generally, openings that are larger than 30 inches are considered potential hazards; however, vehicles may safely traverse over openings up to 30 inches. In crash tests of vehicles at normal highway speeds it was demonstrated that vehicle tires could cross over openings of 30 inches provided that the opening has been cut to match a traversable side slope.

10.2.6. Maintaining and Improving the Safety Characteristics of Inlets

Drop inlets and catch basins in and adjacent to roadways are one of the most common drainages features especially in urban and suburban areas where curb and gutter design is used. Inlets are designed to carry surface run-off from the road and roadside away from the roadway.

Drop inlets located in or adjacent to the path of motor vehicles, pedestrians and bicycles require grates that can accommodate run-off while preventing vehicles, bicycles and pedestrians from falling into the inlet. When bicycle traffic exists, grates should prevent the tires of a bicycle from slipping into and being caught in the grate. Therefore, bicycle safe grates should be used whenever bicycle traffic is expected. The photo below shows a preferred treatment for a drop inlet located on or near a bicycle travel way. With a flush bicycle-safe grate, a bicycle tire cannot get caught in the grate because of the cross pattern of supports which results in only small openings.

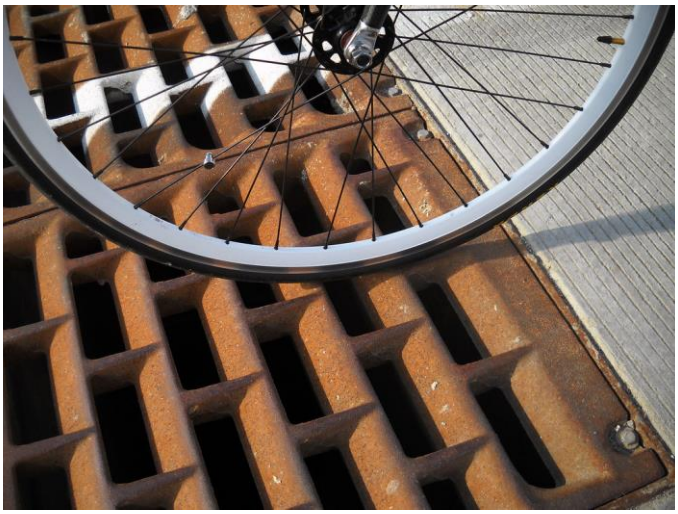

Figure 134: Bicycle safe grate with drop inlet

Drop inlets should not be in the path of pedestrians. To avoid run- off across a pedestrian crosswalk it is desirable to locate the catch basin and inlet before the crosswalk as depicted on next page. To avoid run-off across the pedestrian path, it is desirable to locate drop inlets before crosswalks

Figure 135: Run-off across the pedestrian path

10.2.7. Workers Safety

The first consideration during any installation or maintenance of drainage features is the safety of both the work crew and the motorist. Therefore, remember to follow these safety procedures:

- Assure workers have proper Personal Protective Equipment.
- Before any excavation begins, determine if underground utilities are in the area.
- Follow safe trenching operation techniques.
- Comply with confined space requirements.
- Be aware of crushing hazards and pinch points.
- Be aware of loose materials, excavation drop-offs, tripping hazards, uneven ground.
- Avoid walking and working under suspended loads.
- Determine escape routes in case of emergency.

10.2.8. Typical Work Zone Layouts for Safety

10.2.8.1. Typical Traffic Control Layout for Work Beyond the Shoulder

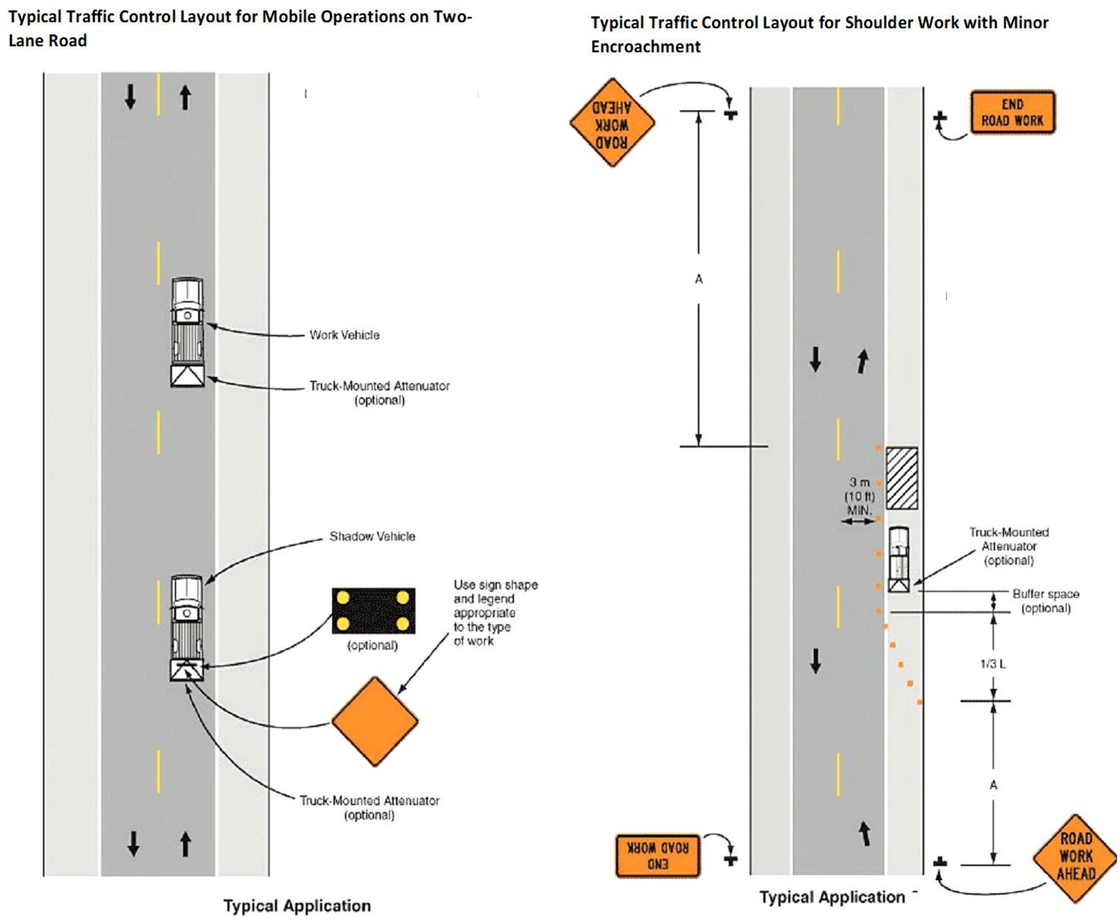

Figure 136: Typical work zone layouts

10.2.8. Conduct A Risk Assessment

High-pressure drain jetting equipment should never be operated close to customers, the public or animals. To reduce the risk of unauthorized access to the work area, contractors should position warning signs and beacons, and create a cordon around the jetting site using protective barriers. When working in public areas, this should also include using hose covers to protect the public against tripping or injury due to hose failure.

Before commencing jetting activities, operatives should carry out a full risk assessment of the jetting site, including checking for any loose items to avoid projectiles, and ensuring that the surface underfoot is safe and not slippery.

These checks also include evaluating the effects of the noise pollution created by high-pressure jetting activities and any actions that can be taken to reduce it. This has been a careful consideration in the development of equipment, with portable, trailer, and van-pack jetters designed with protective cases to reduce engine noise, while the all-electric machine, powered by six Li-ion batteries, offers virtually noiseless operation.

When working at night or in bad light, operators should utilise a range of lighting to ensure that the work area is well lit before commencing any jetting operations. A wide range of lighting solutions, including warning lights, beacons, work area and interior lights can be installed in van-pack jetters and jetvac combination units.

Figure 137: Jetting machine working

10.2.9. Wear The Correct Personal Protective Equipment

Water jets as low as 100 psi can penetrate and cut through skin, so it is essential to always wear the correct PPE (personal protective equipment).

Figure 138: Personal Protective Equipment

Splash back from jetting operations may contain contaminants and hard debris travelling at speed, therefore wearing the correct PPE can greatly minimize the risk of serious injury and disease. When working with water pressures above 2000 psi, operators should wear a full-face shield as a jet travelling at this speed is capable of removing an eyeball from its socket.

Before beginning any drain jetting tasks, you should ensure that you are wearing a range of protective clothing including:

- **Ear Protection** (LWA 109dB)
- **Eye Protection** – Helmet with Chin Guard or Visor, Goggles, and Face Shields
- **Hand Protection** – Rubber or Waterproof Heavy-Duty Gloves
- **Waterproof, High-Visibility Clothing**
- **Rubber Spray Boots** with Metatarsal (Foot) and Toe Guards
- **Head Protection** – Hard Hats

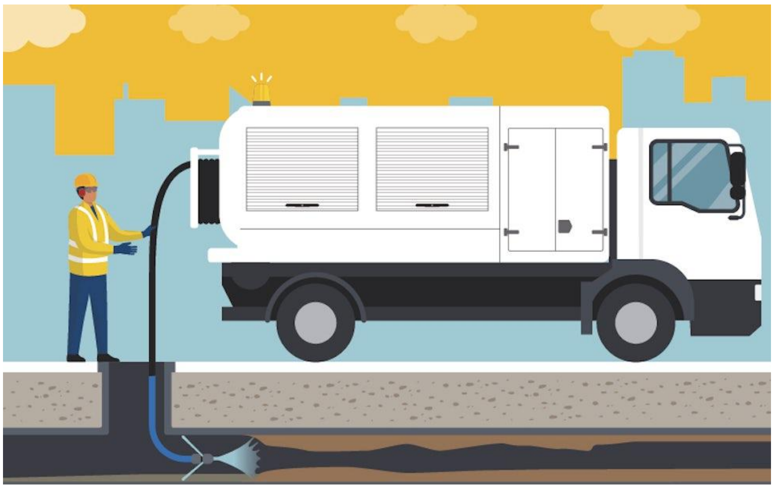

Figure10-13 jetting machine installed correctly

10.2.10. Ensure Equipment Is Operated Correctly

Personnel that operate high-pressure equipment should be suitably qualified and authorised to use the machine. It is most often the responsibility of the contractor to ensure that operators are issued with the correct documentation before commencing any jetting works.

Based on near misses and engineer experiences, below is are tips for the safe operation of equipment:

- Never operate a jetter that has not been regularly serviced in line with the manufacturer's guidelines.
- Never operate high-pressure equipment if you are under the influence of alcohol or other substances.
- Always check the high-pressure jetting hose and attachments to ensure that they are free from kinks, blockages and damage before turning on the jetting machine.
- The high-pressure pump should not be engaged until the jetting nozzle is at least three feet from the entrance to the drain or sewer.
- Use either a metal guidance ring or leader hose attachment to provide a visual warning when the jetting nozzle is close to the pipeline opening.
- Control the high-pressure hose or hose attachment with both hands.
- Do not block the control levers or hydraulic parts when in use – this includes leaning on machinery or resting additional equipment on the machine.
- Fully ventilate the drainage van while the jetting machine is in use to prevent fires and carbon monoxide poisoning.
- Always turn off the supply to the high-pressure jetting nozzle before it is removed from the pipe opening.
- Always depressurise the high-pressure circuit unit before commencing jetting work and when you have finished using it.
- Set the pressure of the spray gun to half the maximum pressure before the machine is started and never exceed the maximum pressure marked on the manometer.
- Never place your fingers in front of the jetting nozzle or into the venturi pump inlet.

10.2.11. Use Safety Equipment Accessories

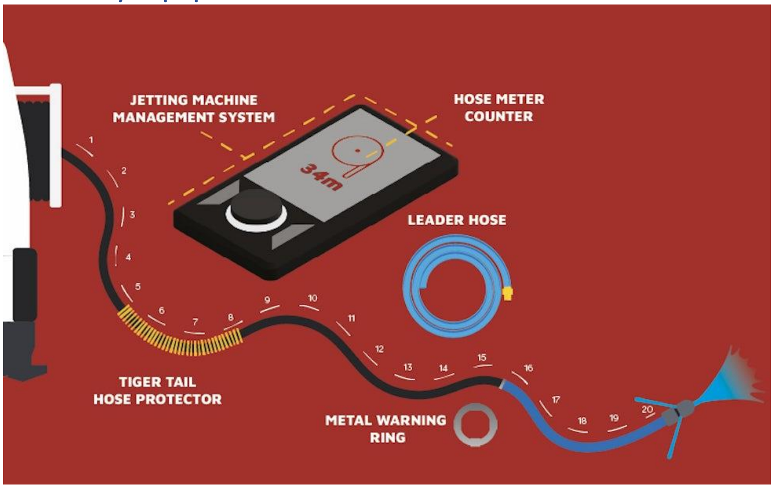

Figure 139: Safety equipment accessories

Safety technology in the drainage industry has developed rapidly to enable safer working practices. Below are a few examples of equipment designed with safety as a priority:

- **Jetting Machine Management System** – Machine Management systems, such as the Econtrol Touch, provide essential system warnings that help avoid critical failures in machinery and parts, and accurate real-time readings of water usage, pressures and flows. When used in conjunction with Radio Remote Controls, machine management systems can also send warning messages to operatives even when controlling the machine at a distance.
- **Leader Hose or Hose Warning Ring** – A leader hose is a short (3m or 5m) length of brightly colored hose that connects directly to the end of the main jetting hose as a warning to the jetting operative that the jetting nozzle is close to the entry of the sewer or drain. Similarly, some manufacturers include a metal ring positioned at 5m from the hose end to provide a visual warning of when the nozzle is nearing the manhole.
- **Hose Meter Counter** – A Hose Meter Counter measures the amount of hose that has travelled down the drain and can be used as an indicator of when the jetting nozzle is close to the drain or sewer opening.
- **Whip Checks** – Whip Checks are an important safety device used to prevent high-pressure hoses from whipping back towards the jetting operative if the hose becomes separated from its fitting. Attached to the join of two hoses or fixed to a pump or hose attachment, this device restricts the movement of the pressurized jetting hose.
- **Tiger Tail Protector** – 'Tiger Tail' sleeves, such as the Rio Protect, are a cost-effective way of extending the life of high-pressure hoses that are subject to wear on contact with drain and sewer openings.
- **Roller-Upper** – Used to carefully lower or retrieve hoses and cable from pipelines, this easily adjustable accessory is placed over the entrance to the drain or sewer and is particularly useful in restricted access areas and situations where the hose reel cannot be placed close to the pipe entrance.

10.2.12. Safety protocol of an excavator operating for desilting of a big open drain

Table 26: safety protocol of an excavator operation

Task sequence	Identified hazards in task	Precautions/PPE required
Pre-start checks	Roll-over protection Fuel and fluids Tyers (rubber tyre units) Tracks Buckets Hydraulics	Wear eye and hand protection. Wear gloves.

Entry and exit	slipping and falls	Safe means of access must be provided
Travel	Loss of control	Slow down
Maintenance	Burns Over-exertion/strain injury Crush injury from falling object	Hand protection should be worn. Use mechanical aids to remove or replace wheel and tyre assembly. Wear type1 footwear.
Operation	Overturning, moving machinery, crush injury, Overstressing of parts	Use packing where ground surface is uneven or unable to support weight of machine. Keep load close to machine when swinging.
Transport of buckets	Moving objects	Buckets should be carried "upside down "to prevent movement.

10.2.13. Install A Welfare Station

Protecting workers and customers against bacterial contamination and the biological hazards of drain cleaning is extremely important. Drains harbor dangerous bacteria and other infectious micro-organisms and materials that can cause serious illnesses or death.

To minimise the risk of contamination, operators should always wear the correct PPE and avoid exposing their eyes, hands, nose, mouth and ears to any wastewater, including any cuts or abrasions. Jetter water tanks should also undergo thorough cleaning at least every six months with water above 70 degrees (160 Fahrenheit) to prevent bacteria that may cause Legionnaire's Disease.

On-board welfare stations are an increasingly common addition to modern multipurpose vehicles to further protect operatives from the dangers of drain and sewer jetting. If necessary, operatives should flush their mouth, eyes and nose with clean water, wash their hands and arms, and clean any clothing and surfaces that have come into contact with any potentially infectious materials. On-board welfare stations most commonly comprise the following:

- Hand wash units
- Eyewash stations
- First aid kits
- Fire extinguishers and blanket

11. EMERGENCY RESPONSE AND CONTINGENCY PLANS FOR MONSOON

11.1. Developing Emergency Response Plans

Preparing for monsoon storms requires the development of comprehensive emergency response plans. These plans should outline the procedures that will be followed before, during, and after intense rainfall events to protect lives, property, and the stormwater system itself.

The planning process should begin with a risk assessment, identifying the areas and assets most vulnerable to flooding and establishing the likely scenarios that the plan will need to address. Based on this assessment, the plan should specify the actions required at each stage of an event. Before the monsoon season, this might include inspecting and clearing the stormwater system, securing loose debris that could clog drains, and educating the public on steps they can take to protect their properties.

During an event, the plan should set out the protocols for monitoring the storm and the status of the stormwater system, activating flood control measures (such as pumps and gates), and coordinating with emergency services. After the event, the plan should guide the assessment of damage, the prioritization of repairs, and the process of learning from the event to improve future responses. A well-crafted emergency response plan should be specific, actionable, and regularly updated based on new information and insights from past events. It should be designed to be as clear and simple as possible so that in the midst of a crisis, personnel have a clear and effective blueprint to follow.

11.1.1. Things to do well before start of monsoon season:

I. Complete one round of desilting of sewers and drains
II. Repair all defective machinery at disposal stations/lift stations including stand by diesel generators.
III. Repair all defective engine driven dewatering sets
IV. Arrange daily use material during emergency like torches, rope, tents and desilting tools etc.
V. Arrange necessary maintenance material for pumping machinery
VI. Appoint daily wages staff for monsoon if shortage of regular staff for emergency requirement.

11.1.2. Installation of storm water gratings to eliminate ponding on Roads

Table 27: List of Storm water gratings

Sr. No.	Town	No. of points

11.1.3. Before start of Monsoon season: Issue following office orders/Sops:

I. Issue office orders for establishment of Monsoon Monitoring Cell
II. Issue SOP for Monsoon to be followed automatically by all concerned officers and staff.
III. List out Sore Points and depute staff for monitoring of monsoon.
IV. List of Underpasses

11.1.4. At start of Monsoon season

I. Establish Emergency Camps at critical drains with staff round the clock for attending drainage complaints during rains.
II. Issue necessary T&P for the staff at emergency camps
III. Issue the dewatering plan and the locations of dewatering sets and duty roster of operators deputed for the operation of dewatering.

IV. Issue the orders for the locations of deployment of suction machines and duty roster of drivers deputed on the machines.

Table 28: Deployment of suction machines

Sr. No.	Location/Sore point
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	

V. Creation/deputing of mobile squad for the trouble shooting of dewatering sets

VI. Certificate from officer in charge for the up keeping of machinery installed at major disposal stations, lift stations and drainage stations

Table 29: Establishment of Emergency drainage camps and deployment of staff

Sr. No.	POINTS TO MONITOR	DEPLOYMENT OF STAFF		
		1st Shift	2nd Shift	3rd Shift

11.1.5. During monsoon operation

I. Operation of Disposal Stations

II. Ensure smooth flow & intake of Channels, clean gratings/manholes.

III. Dewatering operation from low lying pockets

IV. Monitoring through Monsoon control cell

V. Liaison with Public Representatives

11.1.6. Establishment of Monitoring Cell in MC Office for Monitoring of Monsoon

11.1.6.1. Depute Staff for Monsoon Monitoring Cell comprising the following:

- An officer/Sub Engineer in 3 shifts to attend phone calls from deputed field staff as well as public and maintain data.
- Computer operator to keep record of each complaint and monitoring record of monsoon
- To Keep Constant liaison with Met office regarding rain forecasts.

11.1.7. On receipt of Short-Term Rain Forecast (2 Hours before)

All concerned deputed on the designated duty points will ensure:

I. To ensure effective operation of all sewage pumping stations and reporting to CMC.

II. To get reports about smooth functioning of all Sewage Pumping Stations and maintain minimum level in wet wells.
III. To manage all water supply tube wells to curtail sewage load on sewerage system.
IV. To deploy suction machines at specified locations of the city.
V. Deployment of sewerage staff on specified ponding locations
VI. Ensure presence of operators at all dewatering locations
VII. Getting reports about rain start from all important locations.
VIII. Presence of drainage staff on all emergency drainage centers.
IX. Presence of Sub Engineers/SDOs with skilled staff on major disposal stations.

11.1.8. Reports generation during rain by the Monsoon Monitoring Cell

- Rain Record: Frequency: (After 30 min)
- Ponding Clearance time report: Frequency :(After 30 min)
- Ponding report (Before /After): Frequency :(After clearance of any sore point)
- Disposal Report Frequency :(After 30 min)

a) Rainfall/Ponding report dated-------

Table 30: Rainfall ponding report

Sr.No	Location	Rainfall start time	Rainfall stop time	Rainfall mm	Ponding inch	Clearance Time Hrs

b) Disposal stations Report

Table 31: Disposal stations report

Sr.No	Name of D/S	Water level in feet	Pumps in operation	Power source

11.2. Coordination with Local Authorities

Coordination with local authorities is a critical component of effective emergency response planning for monsoon storms. Stormwater management systems are often interconnected with other critical infrastructure, such as roads, electrical systems, and public buildings, and effective response to a major storm event is typically beyond the scope of any single agency. Therefore, it is crucial that stormwater management agencies establish strong relationships with other local authorities, such as municipal governments, emergency services, and public utilities. Regular meetings should be held before, during, and after the monsoon season to align plans, share information, and establish clear roles and responsibilities.
These collaborative relationships allow for the pooling of resources and expertise, ensuring that the response to a monsoon storm is coordinated and effective. In the heat of a crisis, pre-established

relationships and plans are invaluable. They mean that agencies are not meeting each other for the first time under stressful conditions but are executing a plan that they have all had a role in shaping. Effective coordination ensures that efforts are not duplicated and that critical tasks are not overlooked.

In summary, preparing for monsoon storms through emergency response planning and coordination with local authorities is vital for minimizing the risks associated with intense rainfall events. Developing robust, actionable, and regularly updated emergency response plans ensures that stormwater managers are ready to act swiftly and effectively when a storm strikes. These plans, combined with strong coordination with local authorities, form a comprehensive strategy for managing the challenges posed by monsoon storms. This approach ensures that resources are used efficiently, that the response is greater than the sum of its parts, and that communities are as protected as possible from the dangers of severe weather events.

11.2.1. Keep close liaison with local authorities:

- Commissioner
- Deputy Commissioner
- Mayor
- Members of National and Provincial Assembly
- Any other authority in the City
- Media members

11.2.2. Liaison with relevant departments

- Pakistan Metrological Department
- Power distribution Company
- City Traffic Police
- Waste Management Company
- Development Authority of the City

11.2.3. Be prepared for surprise visits.

Arrange visits of MNAs and MPAs to take them on board regarding your preparations for monsoon and operation of machinery during monsoon. This will build your image in the eyes of the authorities.

Liaison with public representatives may be to keep them in touch and aware of ongoing monsoon operation. The visits of following activities may be arranged:

- Desilting of drains and sewer pipes
- Operation of pumping stations
- Operation of dewatering sets
- Deployment of suction machines
- Presence of staff at sore points for monsoon operation
- Any improvement done for early clearance of rain water
- Any new gratings installed
- Monsoon Monitoring Cell to show them the monitoring process

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