GUAM TRANSPORTATION STORMWATER DRAINAGE MANUAL

AUGUST 2010

Department of Public Works
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Michael W. Cruz, M.D.
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December 17, 2010

Mr. Gene Niemasz
Project Manager
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Subject: Storm Water Drainage Master Plan

Dear Gene,

The Guam Department of Public Works has reviewed and approves the Stormwater Drainage Master Plan dated December 2010.

Sincerely,

FOR ANDREW S. LEON GUERRERO
Director

RECEIVED
DEC 21 2010
PARSONS

ACKNOWLEDGEMENTS

This Transportation Stormwater Drainage Manual discusses approaches, methods, and assumptions applied in the design and analysis of highway drainage structures. PARSONS TRANSPORTATION GROUP developed this manual for the Guam Department of Public Works (DPW). This manual is intended for use by DPW's highway staff involved in design and construction projects, and consultants and contractors involved in projects that require work within DPW highway rights-of-way, or projects that connect or discharge to DPW highways.

We wish to acknowledge the Guam Environmental Protection Agency and DPW for their significant contributions in the production of this manual. The development of this manual was facilitated and funded by the Federal Highway Administration (FHWA).

Prepared By-

PARSONS TRANSPORTATION GROUP

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Guam Islandwide Program Management Services

Transportation Stormwater Drainage Manual for the Department of Public Works

August 2010

The Honorable Felix P. Camacho, Governor

The Honorable Michael W. Cruz, M.D., Lieutenant Governor

public works
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ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Term
AASHTO	American Association of State Highway and Transportation Officials
ACP	Asphalt Concrete Pavement
AHD	Allowable Headwater Depth
AHW	Allowable High Water
ASTM	American Society for Testing and Materials
BFM	Bonded Fiber Matrix
BMPs	Best Management Practices
BOD	Biochemical Oxygen Demand
BST	Bituminous Surface Treatment
CAVFS	Compost-Amended Vegetated Filter Strip
CCS	Cellular Confinement System
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CESCL	Certified Erosion and Sediment Control Lead
CN	Curve Number
COE	U.S. Army Corps of Engineers
CSBC	Crushed Surfacing Base Course
CWA	Clean Water Act
DAWR	Guam Division of Aquatic and Wildlife Resources
DHW	Design High Water
DPW	Department of Public Works
DSA	Disturbed Soil Area
EGL	Energy Grade Line
EPA	U.S. Environmental Protection Agency
EPP	Environmental Protection Plan
ESA	Endangered Species Act
ESC	Erosion and Sediment Control
FAA	Federal Aviation Administration
FC	Freeboard Check
FEMA	Federal Emergency Management Agency

FHWA	Federal Highway Administration
GEPA	Guam Environmental Protection Agency
HDPE	High-Density Polythethylene
HGL	Hydraulic Grade Line
IDF	Intensity-Duration-Frequency curve
IPM	Integrated Pest Management
MEP	Maximum Extent Practicable
MFD	Media Filter Drain
N	Newton's Measure of Force
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	Non-Point Source Pollution
NRCS	USDA National Resources Conservation Service (Formerly known as the Soil Conservation Service or SCS)
NWI	National Wetlands Inventory
OHW or OHWL	Ordinary High Water Level
PCC	Portland Cement Concrete
PCCP	Portland Cement Concrete Pavement
PGIS	Pollution-Generating Impervious Surfaces
PLS	Pure Live Seed
PS&E	Plans, Specifications, and Estimates
RCRA	Resource Conservation Recovery Act
RE	Resident Engineer
RECP	Rolled Erosion Control Product
RSP	Rock Slope Protection
SA	Surface Area
SBUH	Santa Barbara Urban Hydrograph method
SCA	Sanitary Control Area
SCR	Special Contract Requirements
SDM	Stormwater Drainage Manual
SDWA	Safe Drinking Water Act
SF	Safety Factor
SPCC	Spill Prevention, Control, and Countermeasures

SWPE	Solid Wall Polyethylene
SWPPP	Stormwater Pollution Prevention Plan
Tc	Time of Concentration
TESC	Temporary Erosion and Sediment Control
TLUC	Territorial Land Use Commission
TSS	Total Suspended Solids
UH	Unit Hydrograph
UIC	Underground Injection Control
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDOT	U.S. Department of Transportation
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UV	Ultraviolet
WHPP	Wellhead Protection Program
WPC	Water Planning Committee
WQS	Water Quality Standards
WRCA	Guam Water Resources Conservation Act
WSEL	Water Surface Elevations

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GLOSSARY

Term	Definition
80 percent capture rule	The 80 percent capture rule is based on an analysis of the rainfall frequency spectrum. It is the impervious surface runoff from a design storm that produces 80 percent of all average annual rainfall from a statistical viewpoint.
90 percent capture rule	The 90 percent capture rule is based on an analysis of the rainfall frequency spectrum. It is the impervious surface runoff from a design storm that produces 90 percent of all average annual rainfall from a statistical viewpoint.
Areal Extent	The magnitude of an area.
Artificial Channels	Man-made channels, including ditch, interceptor ditch, swale, median ditch, outfall ditch, lateral ditch, and canal.
Backwater	A body of water in which the flow is slowed or turned back by an obstruction such as a bridge or dam, an opposing current, or the movement of the tide.
Baffle	A vertical divider placed across the entire width of the wet pond, stopping short of the bottom.
Biofiltration	A pollution control technique using living material to capture and biologically degrade process pollutants. Common uses include processing wastewater, capturing harmful chemicals or silt from surface runoff, and microbiotic oxidation of contaminants in the air.
Biofiltration Swales	Vegetation-lined channels designed to remove suspended solids from stormwater.
Bioinfiltration	A surface infiltration system covered with grass, but possibly trees or shrubs.
Bioinfiltration Ponds	Also known as bioinfiltration swales, combine filtration, soil sorption, and uptake by vegetative root zones, removes stormwater pollutants by percolation into the ground.
Buffer Strip	Refers to an area of natural indigenous vegetation that can be enhanced or preserved as part of a riparian buffer or stormwater dispersion system.
Check Dams	Reduce scour and channel erosion by reducing flow velocity and encouraging sediment settlement. A check dam is a small device constructed of rock, gravel bags, sandbags, fiber rolls, or other proprietary product placed across a natural or man-made channel or drainage ditch.
Clear Water Diversion	A system of structures and measures that intercept clear surface water runoff upstream of a project site, transport it around the work area, and discharge it downstream, with minimal water quality degradation for either the project construction operations or construction of the diversion.

Combination Inlets	Consist of both a curb opening inlet and a grate inlet placed in a side-by-side configuration, but the curb opening may be located in part upstream of the grate.
Critical Areas	Defined as wetlands, floodplains, aquifer recharge areas, geologically hazardous areas, and those areas necessary for fish and wildlife conservation.
Crown	A crown is defined as the highest point of the internal surface of the transverse cross section of a pipe.
Curb Opening Inlets	Vertical openings in the curb covered by a top slab.
Development	The term development encompasses all categories of construction and earth-moving, as well as other types of land use and water-oriented construction. For the purposes of roadways, development is defined as the creation of new impervious area.
Downgradient	The direction that stormwater flows.
Engineered Dispersion	Similar to natural dispersion, this BMP can be used for impervious or pervious surfaces that are graded to drain via sheet flow or are graded to collect and convey stormwater to engineered dispersion areas after going through a flow-spreading or energy-dissipating device. Engineered dispersion uses the existing vegetation or landscaped areas, existing soils or engineered compost-amended soils, and topography to effectively provide flow control and runoff treatment. Site selection is very important to the success of this BMP.
Eutrophication	The enrichment of water by nutrients, especially nitrogen and/or phosphorous, which can cause accelerated growth of algae and higher plant life that produce changes in the ecological balance and deterioration in water quality.
Evapotranspiration	The total loss of water from a crop into the air. Water evaporates from any moist surface into the air unless the air is saturated. Water surfaces in contact with air, such as lakes, plant leaves, and moist soils, all evaporate water.
Fiber Rolls	Consists of wood excelsior, rice or wheat straw, or coconut fibers rolled or bound into a tight tubular roll and placed on the toe and face of slopes to intercept runoff, reduce its flow velocity, release the runoff as sheet flow, and provide removal of sediment from the runoff.
Flow Control BMPs	Reduce the peak rate of runoff during a storm event by storing the flow and releasing it at a slower rate, thus protecting stream ecosystems from excessive erosion (typical examples are detention ponds and dry vaults).
Flow Splitter	A hydraulic structure used to maintain the stormwater quality treatment volume or flow to an off-line treatment facility while bypassing larger flows. Usually a manhole or catch basin structure having internal weir and orifice controls.
Frontal Flow	The water flowing in a section of gutter inlet occupied by a grate.

Froude Number (Fr)	A dimensionless number comparing inertia and gravitational forces. It may be used to quantify the resistance of an object moving through water, and compare objects of different sizes. Named after William Froude, the Froude number is based on his speed/length ratio.
Grate Inlets	Consist of an opening in the gutter or ditch, covered by a grate.
Gravity Bag Filter	Is also referred to as a de-watering bag and is a square or rectangular bag made of non-woven geotextile fabric that collects sand, silt, and fines.
Guar	Guar is a nontoxic, biodegradable, natural galactomannan-based hydrocolloid treated with dispersant agents for easy field mixing.
Hydraulic Matrix	A combination of wood fiber mulch and a tackifier applied as a slurry.
Hydraulic Mulch	Hydraulic mulch consists of applying a mixture of shredded wood fiber or a hydraulic matrix and a stabilizing emulsion or tackifier with hydroseeding equipment, which temporarily protects exposed soil from erosion by raindrop impact or wind. This is one of five temporary soil stabilization alternatives to consider.
Hydrology	For the Highway Designer, the primary focus of hydrology is the water that moves on the Earth's surface and, in particular, that part that crosses transportation arterials (i.e., highway stream crossings). Hydrology is the science and art of converting rainfall to runoff for design purposes.
Hydroperiod	The cyclical changes in the amount or stage of water in an aqueous habitat.
Hydroseeding	Typically consists of applying a mixture of wood fiber, seed, fertilizer, and stabilizing emulsion with hydromulch equipment, which temporarily protects exposed soils from erosion by water and wind. This is one of five temporary soil stabilization alternatives to consider.
Hyetograph	A graphical representation of the distribution of rainfall over time.
Infiltration	The preferred method for flow control and runoff treatment and offers the highest level of pollutant removal.
Infiltration Ponds	Infiltration ponds are usually earthen impoundments used for the collection, temporary storage, and infiltration of incoming stormwater runoff to groundwater. Infiltration ponds can also be designed to provide runoff treatment.
Isolation Techniques	Methods that isolate near-shore work from a water body.
Kinematic Wave Equations	A mathematical equation used to determine overland flow travel times.

Manning's Equation	The Manning equation is an open-channel flow equation used to find either the depth of flow or the velocity in the channel where the channel roughness, slope, depth, and shape remain constant (steady uniform flow).
Mean High-Water Mark	The highest point that the water may reach for a navigable waterway, lake, or ocean.
Mean Low-Water Mark	The average low tide.
Media Filter Drain (MFD)	A linear flow-through stormwater runoff treatment device that can be sited along highway side slopes. MFDs have four basic components: a gravel no-vegetation zone, a grass strip, the MFD mix bed, and a conveyance system for flows leaving the MFD mix.
Minimum Requirements	Nine requirements intended to achieve compliance with federal and Guam water quality regulations, while catering to the unique linear features of most transportation projects.
National Pollutant Discharge Elimination System (NPDES)	Construction usually requires a NPDES permit.
National Wetlands Inventory (NWI)	Provides information on the characteristics, extent, and status of the nation's wetlands and deep water habitats and other wildlife habitats. The inventory is conducted by the U.S. Fish and Wildlife Service.
Nomograph	A graph consisting of three coplanar curves, each graduated for a different variable so that a straight line cutting all three curves intersects the related values of each variable.
Oil Containment Boom	A weather-resistant, hydrophobic, absorbent-filled boom for removing hydrocarbon sheens from water.
Open Channel	An open channel is a watercourse that allows part of the flow to be exposed to the atmosphere. Classified as those which occur naturally or those which are man-made or improved natural channels.
Operational BMPs	Nonstructural practices that prevent or reduce pollutants from entering stormwater.
Ordinary High-Water or Ordinary High-Water Level (OHWL)	For stormwater design purposes, this level is identified by environmental biologists based on vegetation types. The surface boundary is then identified, surveyed, and used as the control for project impacts to the waterbody.
Overside Drains	Overside drains are conveyance systems used to protect slopes against erosion.
Permanent BMPs	Permanent BMPs are used to quality treat or flow control highway stormwater for the design life of the project site.
Piezometer	A small-diameter observation well used to measure the hydraulic head of groundwater in aquifers.
Plans, Specifications, and Estimates (PS&E)	Plans, Specifications, and Estimates usually relating to a final set of construction contract documents.

Pollution-Generating Impervious Surfaces (PGIS)	PGIS is any impervious surface expected to generate pollutants, such as bike lanes, travel lanes, and shoulders. An example of an impervious surface not expected to generate pollutants is sidewalks that are sloped away from the roadway. If the sidewalk slopes towards the roadway, then it contributes to the quantity of stormwater coming from the PGIS.
Presettling Basin	Process of allowing stormwater to settle the larger pollution particulates prior to entering a primary stormwater quality treatment or flow control facility.
Presumptive Approach	Meaning that projects that follow the stormwater BMPs contained in the SDM are presumed to have satisfied the water quality requirements and are not required to provide technical justification to support the selection of BMPs.
Projecting End	A projecting end is a treatment where the culvert is simply allowed to protrude out of the embankment.
Psyllium	Psyllium is composed of the finely ground mucilloid coating of plantago seeds that is applied as a dry powder or in a wet slurry to the surface of the soil.
Regression Equations	The equation representing the relation between selected values of one variable and observed values of the other.
Reynold's Number	A dimensionless number, the ratio of intertial forces to viscous forces, equal to pvl/n where p is density, v is velocity, n is viscosity relative to some length l, e.g., radius of pipe. For steady flow, the flow lines take the same form at a given Reynold's number.
Sandbag Barrier	A temporary linear sediment barrier consisting of stacked sandbags, designed to intercept and slow the flow of sediment-laden sheet flow runoff.
Santa Barbara Urban Hydrograph method (SBUH)	The SBUH method is based on the curve number (CN) approach, and also uses USDA National Resources Conservation Service equations for computing soil absorption and precipitation excess. The SBUH method converts the incremental runoff depths into instantaneous hydrographs which are then routed through an imaginary reservoir with a time delay equal to the basin time of concentration.
Sediment/Desilting Basin	A sediment/desilting basin is a temporary basin formed by excavating and/or constructing an embankment so that sediment-laden runoff is temporarily detained under quiescent conditions, allowing sediment to settle out before the runoff is discharged.
Sediment Trap	A temporary containment area that allows sediment in collected stormwater to settle out during infiltration or before the runoff is discharged through a stabilized spillway.

Silviculture	The art and science of controlling the establishment, growth, composition, health, and quality of forests to meet diverse needs and values of the many landowners, societies and cultures.
Slotted Inlets	Consist of a pipe cut along the longitudinal axis, with bars perpendicular to the opening to maintain the slotted opening.
Slope Drain	A pipe used to intercept and direct surface runoff or groundwater into a stabilized watercourse, trapping device, or stabilized area.
Slope Rounding	A design technique to minimize the formation of concentrated flows.
Soil Binders	Materials applied to the soil surface to temporarily prevent water-induced erosion of exposed soils on construction sites. Soil binders also provide temporary dust, wind, and soil stabilization (erosion control) benefits.
Source Control BMPs	Include operational and structural BMPs. See also operational BMPs and structural BMPs.
Spill Prevention, Control, and Countermeasures (SPCC)	A set of plans that must be prepared and followed by the contractor, once approved.
Starch	Starch is non-ionic, cold-water soluble (pre-gelatinized) granular cornstarch.
Storm Drain	The portion of the highway drainage system that receives surface water through inlets and conveys the water through conduits to an outfall. It is composed of different length or sizes of pipe or conduit connected by appurtenant structures.
Stormwater Pollution Prevention Plan (SWPPP)	The SWPPP is prepared by the contractor and includes the TESC and SPCC plans.
Straw Bale Barrier	A temporary linear sediment barrier consisting of straw bales, designed to intercept and slow sediment-laden sheet flow runoff.
Straw Mulch	Straw mulch consists of placing a uniform layer of straw and incorporating it into the soil with a studded roller or anchoring it with a stabilizing emulsion.
Structural BMPs	Physical, structural, or mechanical devices or facilities intended to prevent pollutants from entering stormwater.
Tailwater	Defined as the depth of water downstream of a culvert or other conveyance discharge measured from the outlet invert.
Temporary BMPs	Designed to prevent the introduction of pollutants into runoff for the duration of the construction project and are concurrent with construction of the permanent BMPs. Common examples of temporary BMPs include the mulching of bare ground, silt fencing, and spill control and containment.

Temporary Erosion and Sediment Control (TESC) Plans	Plans that describe the measures used during construction to protect state waters from degradation.
Territorial Seashore Reserve	A distinct and valuable natural resource, existing as a delicately balanced ecosystem, protected by the Territorial Seashore Protection Act.
Turbidity Curtain	A fabric barrier used to isolate the near-shore work area.
Vegetated Surface	A permanent perennial vegetative cover on areas that have been disturbed.
Wet Pond	Constructed basins containing a permanent pool of water throughout the wet season.

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1 PURPOSE AND SCOPE

The purpose of this Guam Transportation Stormwater Drainage Manual (TSDM) is to provide guidelines for the planning and design of stormwater management facilities for transportation projects on the island of Guam. Transportation projects include any new development, redevelopment, reconstruction, rehabilitation, or restoration of highways, roadways, and parking, including the appurtenant structures such as bridges and culverts. Conformance to the provisions of this TSDM will result in consistent design procedures and should support acceptance of stormwater planning by regulatory agencies. These guidelines take into account the variations in climatic, geologic, and hydrogeologic conditions of the island.

This TSDM establishes the guidelines and provides uniform technical criteria for avoiding and mitigating impacts to water resources associated with the development of roadways and the associated infrastructure. This TSDM will be updated regularly to reflect changes in regulations and advances in stormwater management technology, and to clarify issues.

The intended users of this TSDM are the Department of Public Work's (DPW's) consultants, site planners, engineers, contractors, reviewers, maintenance staff, and construction managers who design and construct transportation drainage systems.

The design criteria established in this TSDM supersedes other previously-published stormwater drainage manuals and guidelines used by DPW.

Transportation stormwater management requirements for Guam have been developed to help mitigate the effects of hydrologic change and water quality degradation that can occur from project development on receiving waters of Guam and the United States.

This TSDM follows a presumptive approach to achieve compliance with federal and local water quality regulations. Projects that follow the stormwater Best Management Practices (BMPs) contained in this TSDM will be better suited to satisfy Guam EPA (GEPA) and federal requirements. This TSDM includes documentation guidelines that will be necessary for the permitting review process.

1.1 THE IMPORTANCE OF STORMWATER MANAGEMENT

Land development changes the physical, chemical, and biological conditions of waterways and water resources. The addition of buildings, roadways, parking lots, and other impervious surfaces can reduce natural infiltration, increase runoff, and provide additional sources of pollution.

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

Without proper planning and design, development and impervious surfaces reduce the amount of water that infiltrates into the soil and groundwater, thus reducing the amount of water that can recharge aquifers and feed stream flow during periods of dry weather. Unmanaged stormwater from development and urbanization affects both the quantity and quality of the runoff. Development can increase the concentration and types of pollutants carried by runoff.

Linear in nature, transportation projects tend to encompass multiple drainage basins and impact multiple receiving waters. Even though the runoff from highways may be a fraction of the runoff affecting nearby water bodies, it can contribute to the cumulative degradation of those waters unless suitable BMPs are utilized.

The construction of roadway projects can contribute to surface runoff contamination, primarily due to suspended solids associated with soil erosion. Without suitable controls, construction activities can also result in the contamination of stormwater that results from vehicle operations and maintenance; use and storage of fuels, solvents and paints; and uncured asphalt and concrete. Those impacts can be severe and long-lasting if appropriate actions are not taken to control construction site runoff quality.

1.2 MANAGEMENT OF RUNOFF FROM TRANSPORTATION PROJECTS

Federal and Guam regulations call for the implementation of both operational and technology-based BMPs to reduce the discharge of pollutants in stormwater to the maximum extent possible, before discharging back to natural waterways.

The application of BMPs is the key to managing stormwater runoff from transportation projects. The term BMP refers to operational activities or physical controls that control flows and velocities and/or reduce pollution that would otherwise impact the receiving water bodies.

BMPs identified as temporary and permanent have been classified into four categories, as shown in Table 1-1 below. Pollution prevention BMPs are the incorporation of good engineering practices during design and planning to limit a project's adverse affect on the natural ground cover and flow patterns. Oftentimes, additional planning in the layout and staging of a project can reduce the disturbed ground area and maintain more natural runoff patterns then what typically might be expected.

Runoff treatment BMPs are the application of long-term facilities that control flow rates and/or remove pollutants from runoff. This is typically accomplished by using detention storage and ground infiltration. Other BMPs use gravity settling of particulate matter, vegetative and physical filtration, biological uptake, and soil absorption to remove pollutants. Flow control BMPs reduce the peak rate of runoff during a storm event by either infiltration into the soil profile or by storing the flow and releasing it at a slower rate. This helps to maintain the existing and more natural flow rates to limit erosive effects on downstream waterways. Permanent BMPs are used to treat highway runoff for the design life of the project site.

Construction site BMPs are temporary measures designed to prevent the introduction of pollutants into runoff for the duration of the construction project. These measures also include infiltration, filtration, and particulate settling devices, which are installed and functioning prior to the start of construction. Common examples of temporary BMPs include bare- ground mulching, silt fencing, sedimentation basins, and spill control.

Maintenance BMPs are the long-term maintenance of the roadway project area and the associated BMPs to keep them operating at proper efficiencies. These can include such maintenance activities as sweeping and mowing to remove pollutants at the source. Other typical long-term maintenance activities include keeping ponds and storm sewers clean of debris and sediments. This TSDM only discusses maintenance guidelines for stormwater BMPs. General maintenance activities are not listed in detail in this TSDM, because they are the subject of separate DPW guidelines.

BMP	Description
Design Pollution Prevention BMPs	Minimizing flow and quality impacts by improved design and planning
Runoff Treatment BMPs	Permanent quality treatment and flow control devices and facilities
Construction Site BMPs	Temporary sediment and waste control during the construction process
Maintenance BMPs	Long term regular maintenance of the transportation facilities and associated BMPs

Table 1-1: BMP Classifications

1.3 ORGANIZATION OF THIS MANUAL

This TSDM is divided into eight chapters for the aid of the designer. Chapter 1 gives background information on the development of this TSDM and an overview of the stormwater problems associated with roadways and other parts of the transportation infrastructure.

Chapter 2 provides an overview of the design process and how the stormwater/drainage design elements should be integrated into that process. Guidelines are provided for gathering pre-design data, reviewing design alternatives, and finalizing the selected alternative.

Chapter 3 describes the minimum requirements that apply to the planning and design of stormwater facilities and BMPs. Guidelines are provided to determine which of the nine minimum requirements must be met for a given transportation project. The purpose and applicability of the minimum requirements are also described in this chapter.

Chapter 4 discusses transportation hydrology; the conversion of rainfall to runoff as needed for conveyance; and BMP engineering purposes. This chapter lists which analysis methods to use, providing the required data and assumptions.

Chapter 5 contains a discussion and guidelines on stormwater hydraulic design. This chapter also contains criteria on the selection, sizing, and documentation of the stormwater conveyance systems.

Chapter 6 guides the designer through the process of selecting and designing permanent stormwater quality treatment and flow control BMPs that are applicable for Guam's transportation conditions. This chapter includes details of the design and construction criteria for each BMP.

Chapter 7 includes criteria for selecting appropriate Temporary Erosion and Sediment Control (TESC) measures. Appropriate TESC BMPs are required for all transportation projects and should also be included in the contractor's stormwater pollution prevention plan, when required.

1.4 HOW TO USE THIS MANUAL

The designer should follow the guidelines included in Chapter 2 for integrating the planning and design of stormwater-related project elements into the context of the project development process. This process should be completed prior to using the guidelines in Chapter 3 to determine which minimum requirements must be satisfied for a specific project. In most instances, this process will prompt design of the post-construction BMPs according to the criteria provided in Chapters 4, 5, 6, and 7. Most projects lend themselves to a relatively straight-forward application of one or more of the BMP options presented in this TSDM. Finally, while working from a constructability point of view in accordance with the project construction staging plan and schedule, the designer will prepare a TESC plan in accordance with Appendix I.

1.5 REVIEW PROCESS AND REGULATORY STANDING OF THIS MANUAL

This TSDM provides guidelines for the planning and design of stormwater management facilities for transportation projects on the island of Guam. This TSDM meets the level of stormwater management established by GEPA in its Draft GEPA 2010 Stormwater Management Regulations and the Guam Water Quality Regulations; however, GEPA reserves the right to enforce regulatory compliance as provided for in Guam statutes and regulations. See Appendix IA.

2 STORMWATER PLANNING AND GUAM DRAINAGE POLICIES

This chapter provides guidelines for integrating the planning and design of stormwater-related project elements into the context of the Department of Public Work's (DPW's) project development process. It also describes various federal and local policies that regulate stormwater discharges. This Guam Transportation Stormwater Drainage Manual (TSDM) makes all attempts to adhere to all current regulations. Because regulations evolve with time, this TSDM will be updated to remain current with regulations.

2.1 DRAINAGE MASTER PLANNING AND PROJECT DEVELOPMENT

Stormwater master planning is an important tool a designer can use to assess and prioritize both existing and potential future stormwater problems, as well as consider alternative stormwater management solutions.

Stormwater planning is often used to address specific single functions such as drainage provisions, flood mitigation, cost-benefit analyses, or risk assessments. Multi-objective stormwater master planning broadens this traditional definition to potentially include land use planning and zoning, water quality, habitat, recreation, and aesthetic considerations.

The integration of stormwater planning and design is crucial to DPW's project development process. How the process applies to a specific project depends on the type, size, and complexity of the project. The project development process consists of the distinct phases described below. In practice, the phases actually overlap, and some design modifications may occur during the construction phase. Consultants may or may not be involved in any phase, but inclusion of this process into this TSDM reinforces DPW's commitment to integrate stormwater planning and design into project development.

***Scoping phase*:** Development of this phase is based on the general project description and early estimates of needs and costs. Under this phase, a number of project alternatives may be evaluated and reviewed. Based on the relative merits of the alternatives, the better alternatives are selected and included in a summary document. The environmental section of the project summary establishes the environmental classification of the project and the level of environmental documentation required for the project.

***Preliminary design phase*:** Based on the summaries and cost estimates completed as part of the scoping and programming work, DPW will make a decision as to a selected alternative for additional storm drainage refinement and environmental assessment work to be performed. This is the preliminary design phase during which the stormwater design is further progressed; the Best Management Practices (BMPs) selected; and the environmental assessments completed. The subsequent hydraulic and environmental documentation is reviewed, and upon acceptance, DPW issues a "start work" order for both the permit applications and preparation of the final design and construction bid documents.

***Environmental permitting and final plans, specifications, and cost estimates (PS&E) phase*:** The final design and construction cost estimate for the stormwater BMPs is accomplished during this phase. All environmental commitments are incorporated and the final project permits are obtained, while the final design plans and specifications are finalized and submitted ready for construction bidding.

The design and environmental process continues during construction as part of shop drawing reviews, design support for change orders, and Requests for Information (RFIs).

DPW should be consulted at each phase of the project development process for reviews and approvals, and to gain feedback regarding any project-specific requirements. Adhering to the minimum requirements and the BMP selection process discussed in this TSDM plays a critical role in the project development process, because it minimizes costly design changes, reduces delays in obtaining permits, and keeps the project in compliance during construction, operation, and maintenance activities. Table 2-1 describes the project development process.

Scoping ⇒	**Scope Approval** ⇒ **Preliminary Design, Refinement, and Documentation**	**Concept Approval** **Environmental Permitting and Final Design**
Preliminary identification of water quality and hydrologic impacts; conveyance and project flow patterns; and potential treatment and flow control BMP alternatives	Selection and refinement of stormwater conveyance and BMP facilities Provide drainage design support for the environmental assessments	Final design of stormwater facilities Obtain environmental permits
Project storm drainage summary including: • Conducting preliminary stormwater summary and scope • Providing support for environmental reviews • Identifying additional right-of-way needs • Listing potential utility conflicts	Project design report and environmental permit applications as supported by: • Hydraulic Report including drainage calculations, soils analysis report, percolation test results, property maps, site plans, wetlands delineation map, drainage flow maps with land contours, etc. • Environmental Assessment Reports and Impact Statements as supported by stormwater design and coordination	PS&E package: • Temporary Erosion and Sedimentation Control (TESC) plans (Appendix I) • Provisions for Spill Prevention, Control, and Countermeasures (SPCC) plans • Stormwater plans and details • Specifications and special provisions • Project cost estimate and schedule Contractual bids, selection of contractor, and start of construction
Cost estimates for stormwater facility design and construction alternatives	Project conceptual (preliminary) plans and cost estimate	Stormwater design support during construction

Table 2-1: Project Stormwater Development Process

2.1.1 SCOPING AND PLANNING

This section describes various stormwater planning activities that should be undertaken to scope a project. The assessment and documentation of stormwater impacts and mitigation measures begins during project scoping. Project type, size, and complexity are key factors in the development of the stormwater strategy.

2.1.1.1 SITE ASSESSMENT

Understanding each site's drainage patterns is essential to optimizing stormwater design for a project. The design team must identify all natural areas and off-site flows coming to the site, including streams and stormwater discharges. This information is shown on a "drainage map". The drainage map should be prepared to sufficient detail and scale to show the entire watershed (in particular, the upstream watershed limits) that the project may be intersecting. The map should include the types of ground cover, soil types, elevation contours, flow paths, existing wetlands and streams, existing conveyance, existing cross-culverts, right-of-ways and easements, and existing water quality treatment and flow control facilities. The map is the key planning tool for design of the project stormwater facilities by including the project drainage basins and sub-basins, discharge locations, critical areas, downstream impact locations, and potential BMP sites. The map is also the basis for determining runoff calculation parameters such as times of concentration, drainage areas, curve numbers, and conveyance slopes.

Further, as the design is developed, the proposed improvements, drainage conveyance, and BMPs are added to the map. The drainage map becomes the main exhibit in the project's hydraulic report, which is part of the design and construction record.

The transportation facility should allow for the passage of all off-site flows. The designer should work to maintain the existing flow patterns as much as possible. To minimize conveyance and BMP costs, it is generally best to keep off-site flows separate from the highway runoff. Most importantly, runoff from the project should not adversely impact downstream receiving waters and properties.

The conservation of natural areas helps to minimize project impacts. Some of these areas may be used as part of the project's stormwater management approach, especially if they are appropriate areas for dispersion and infiltration.

2.1.1.2 GEOTECHNICAL EVALUATIONS

Understanding the soils, geology, geologic hazards, and groundwater conditions is the first step to good drainage planning and design. The stormwater designer should provide input as to what is needed in regards to the stormwater planning when the design team scopes the overall geotechnical investigation work. The main items needed for drainage are geotechnical evaluations of geological hazards and groundwater issues, especially where existing problems have been identified. The geotechnical investigations should include soil characteristics in the project vicinity, including estimates of infiltration rates and groundwater depths at potential stormwater BMP locations. Specific soil investigations will be required for any proposed hydraulic structures, and for new storage or infiltration facilities.

Seasonal variations of the groundwater table for infiltration and treatment pond designs require the installation of piezometers. One year of monitoring is desirable, but at a minimum, water level readings should be taken through one rainy season. Critical issues to consider include the following:

- Depth to water table (including any seasonal variations)
- Presence of soft or otherwise unstable soils
- Presence in soils of shallow bedrock or boulders that could adversely affect constructability
- Presence of existing adjacent facilities that could be adversely affected by construction of the stormwater facilities
- Presence of geologic hazards such as earthquake faults, abandoned mines, landslides, steep slopes, or rock fall
- Adequacy of drainage gradient to ensure functionality of the system
- Potential effects of the proposed facilities on future corridor needs
- Maintainability of the proposed facilities
- Potential impacts on adjacent wetlands and other environmentally sensitive areas
- Presence of hazardous materials in the area
- Whether or not the proposed stormwater plan will meet the requirements of resource agencies
- Infiltration capacity (infiltration and percolation rates for project sites)

2.1.1.3 RIGHT-OF-WAY

Examine the proposed layout of the project, and determine the most suitable sites available to locate the stormwater facilities. Typically, the stormwater designer should be able to fit the required conveyance systems, treatment and detention facilities, and outfalls within the existing right-of-way. However, infiltration and detention ponds may require additional plots outside of DPW's boundaries. The locations and specifics for additional right-of-way should be established as early as possible, as the acquisition process is lengthy and will contribute heavily to the project's cost. Often times, the designer is required to provide a legal right-of-way survey, drawings, and other support for the property acquisition process.

2.1.1.4 UTILITIES

A search of utility company records should be conducted to obtain information about locations and easements of existing utilities (and utilities planned to be installed in the near future) that may be impacted by the project. These records are assembled into an "Existing Utility Plan" for planning and future design use. Potential conflicts must be further evaluated and resolved prior to the start of construction. While it is usually best to try and plan stormwater facilities to avoid conflicts with existing utilities, sometimes the utility must be relocated. Depending on the existing utility agreement with DPW, the relocation may be a project cost or the obligation of the utility company. Often times, relocation involves either establishing or providing new easements for the utility company. Early planning of the drainage to minimize utility impacts will also help to limit the overall project costs and reduce impacts to the schedule.

2.1.1.5 MAINTENANCE REVIEW

There are several design reviews that should be completed with DPW's maintenance staff. The first review is usually completed during the preliminary scoping or preliminary design phase to determine locations having specific drainage issues. This review helps to define locations that have frequent flooding, flow over-topping, sediment and debris buildup, groundwater issues, and erosion problems. This is also the time to obtain the maintenance staff's preferences and procedures with regards to regular maintenance work. Understanding their approach to maintenance work, the type of equipment used, frequency of work, and access requirements will be critical when deciding on locations, types, and features of the selected stormwater facilities.

Once the preliminary design for the project is finished, the features of the stormwater facilities should be reviewed with the maintenance staff. Their input will be critical in finalizing the permanent conveyance and treatment systems with regards to ease of access for inspections and cleaning. Maintenance work becomes an overall long-term cost to the project, and design coordination with the maintenance staff will help to minimize those costs.

2.1.1.6 ENVIRONMENTAL SUPPORT

The thorough documentation of stormwater-related environmental impacts and tracking of stormwater design commitments is a required element of the National Environmental Policy Act (NEPA), as well as other environmental laws and environmental permitting agencies.

As a project's scope is defined by the design team, a parallel effort is made by the environmental specialists to define the project's impacts on the environment and methods to avoid or otherwise mitigate those impacts. The environmental evaluations will become the basis for the permitting applications and agency reviews. After the initial scope is approved, a more formal environmental assessment is made and documented; environmental commitments are made; and permit applications are prepared. Much of the environmental assessment is based on the project's temporary and permanent impacts due to stormwater runoff.

The stormwater designer should be prepared to support the project's environmental specialist team during both the scoping and preliminary design phases, by providing the proposed stormwater configuration layouts, BMP types and locations, and discharge locations. Information typically needed by the environmental team is drainage basin and sub-basin areas; discharge locations for each drainage basin; acres of existing and new impervious surfaces; locations and areas of impacts to wetlands and waterways; area and volume of fill in waterways below the ordinary high water level; areas of new and existing pavement runoff being treated by watershed or drainage basin per outfall location; types of treatment; pavement areas having runoff flow control; pre- versus post-pollution loading calculations; quantities of fill in floodplains; and upstream and downstream hydraulic impacts due to cross-drain and culvert work. The information provided will need to be supported with exhibits and calculations.

To limit impacts to critical areas, the stormwater designer should coordinate with the environmental specialist frequently while locating stormwater facilities and outfalls. Early discussions between the designer and specialist may help to avoid later permit issues with regards to such things as bridge and culvert placement, aquatic habitats and fish passage, erosion and sedimentation control, groundwater or potable water well contamination, local vegetative mitigation, and project pollution loadings.

Through the final design, the coordination between the environmental specialist and the stormwater designer continues as the designer prepares the TESC plans and designs facilities that meet the environmental permit commitments and requirements. The stormwater designer often supports construction and/or the contractor's environmental manager in the preparation of water monitoring plans, pollution and spill control plans, and TESC updates.

2.1.1.7 STORMWATER SUMMARY

Stormwater documentation during the scoping phase of project development is referred to here as the stormwater summary and scope. This package contains the information used to predetermine stormwater impacts and the initial selection of stormwater BMPs. It is the source of stormwater information needed to complete the project summary documents. This package must include a brief summary report containing the following:

- Identification of the project program
- Brief project description
- Synopsis of data gathered during the site assessment
- Drainage map
- Basin and sub-basin identification

- Discharge area delineations indicating flow paths and outfalls to receiving waters
- Area determinations
- Applicable minimum requirements
- Other applicable regulatory requirements related to stormwater
- Design criteria required for flow control and runoff treatment
- Known problems and commitments
- Design alternatives and assumptions for flow control and runoff treatment
- Cost estimates

The stormwater summary report documents the design efforts and decisions made during the scoping phase of the project's development, and must be retained and easily-retrievable. Once the project is reviewed, alternatives are selected, and the designer is selected by DPW, the file and report become the starting point for the preliminary design phase. Note that the report is internal to DPW and its consultants, and serves as a starting point for preliminary design.

2.1.2 PRELIMINARY DESIGN

The preliminary design develops the preferred stormwater drainage alternatives (alternatives that were identified in the scoping phase) into a workable concept with enough detail to enable preparation of cost estimates. As part of the preliminary design process, data is developed to support the parallel environmental assessment and permit application preparation efforts.

2.1.2.1 HYDRAULIC REPORT

The hydraulic report is intended to serve as a complete record containing the engineering justification for all drainage design and design modifications that occur as a result of project construction. The report documents the pre-project existing hydraulic conditions, as well as the post-project stormwater management facilities. The report contains all of the designer's intent, criteria, and calculations for the stormwater design. The hydraulic report is the basis for approval of the project drainage facilities by DPW. This report is then updated during construction, with any modifications, to act as a permanent as-built record of the project's stormwater management facilities. Appendix II contains detailed instructions and a sample outline required for preparation of the hydraulic report.

During the preliminary design phase, a draft (or preliminary) hydraulic report is prepared. This preliminary hydraulic report is an expansion of the stormwater summary report developed as part of the scoping phase. The preliminary hydraulic report contains the existing condition descriptions and the layout and general support calculations for the selected stormwater management alternatives. At this stage of the project development, the stormwater flows, general conveyance routing, and BMP types and sizes are finalized, from which the cost estimates and right-of-way requirements can be determined. However, the preliminary report lacks many of the final sizing and design details prepared during the final design phase. The preliminary hydraulic report must be reviewed and approved by DPW prior to start of the final stormwater design.

The final hydraulic report is a detailed compilation of the final stormwater management design. This final report contains detailed descriptions and calculations for all hydraulic design assumptions and decisions. It also includes the development of the TESC plans for construction, as well as the permanent post-development facilities.

If any changes are made to the final stormwater design during construction, the changes are documented with all supporting calculations, plans, and exhibits as attachments to the hydraulic report. Major revisions require separate documentation and approval by DPW. Minor revisions are assembled and included as a final attachment to the hydraulic report as an as-built record of the project's stormwater management development.

2.1.3 FINAL DESIGN

The final design of the project follows the approval of the preliminary design, cost estimates, and environmental documentation by DPW. The project's permit applications and final design preparation is usually completed on a parallel schedule, typically taking approximately the same amount of time. The final design work can proceed by two different procedures in accordance with DPW's direction and according to the type and suitability of the project. The first method is a final design prepared for the traditional design-bid-build method of project implementation. The second is a final design prepared for a design-build project approach.

2.1.3.1 DESIGN-BID-BUILD

In the design-bid-build method, the designer develops the preliminary plans into a detailed set of plans and specifications ready for contractor bidding. The stormwater management facility designs are brought up to a level of plan and detail that describes the specific requirements the contractor must meet with regard to layout, levels, grades, and materials. While not telling the contractor exactly how to conduct its operations, the plans, details, and specifications describe as precisely as possible the level of performance and testing standards that must be met. As part of the process, the designer also prepares a construction schedule and cost estimate for DPW's use to assist in defining the contractual time limit to complete the work, and to compare against the contractor bids.

Although not part of the contractual bid package, the stormwater designer must prepare a final hydraulic report. The designer will obtain DPW's final approval of the stormwater facility plans and supporting calculations, accomplished through review and approval of the final hydraulic report. This report confirms that DPW's drainage criteria, environmental commitments, and permit requirements have been met.

The stormwater designer is usually responsible for a number of elements in the final project design package. These normally include:

- Drainage plans: Show proposed roadway alignment and edge of pavement; existing stormwater system including proposed conveyance structures, pipes, ditches, and channels; and proposed stormwater quality treatment and flow control facilities. Each structure and pipe is uniquely numbered for reference in the quantities tables and profile detail sheets. Deletions of the existing systems and other construction constraints are shown by notes.
- Drainage profile details: The details for installation of the stormwater conveyance facilities are shown on pipe profile sheets. Each structure, ditch, and pipe is shown in profile, with existing and proposed ground surfaces; layout station and offset; type; size or dimension; pipe length; slope; and any specific requirements such as rock protection at outlets, unique connection collars, headwalls, type of grate or cover, connection to existing, etc. Each pipe, ditch, and structure is identified by its corresponding number on the plan sheets.
- Drainage details: Most drainage structural and installation details are contained in DPW's Standard Drawings. These are referred to on the profile sheets and by reference in the contract documents. However, most projects will require unique hydraulic structure designs requiring specifically-detailed design sheets. Other items requiring more detail for construction are items such as stormwater treatment and flow control BMPs, where each facility requires a unique design to fit the site.
- Quantity sheets: The contractual plan set includes a listing of pipes, structures, and earthwork in tablature. Each item is identified by its corresponding number on the plan sheets. The stormwater designer is responsible for assembling a detailed listing of stormwater structure, pipe, and earthwork quantities.
- TESC plans: The stormwater designer prepares a detailed TESC plan set for the project. The plan includes details for controlling and minimizing sediment in the stormwater runoff during construction for each major construction phase. The plans are prepared in close coordination with the project schedule and staging designers. These plans are sometimes prepared earlier, in support of the environmental permit application review process. After award of the contract, the contractor will modify these plans as applicable to fit its specific staging and work elements. Appendix I contains detailed instructions and a sample outline required for preparation of the TESC plans.
- Stormwater Pollution Prevention Plans (SWPPP): The SWPPP usually consists of the TESC and spill prevention, control and countermeasures (SPCC) plans. The details of SWPPP are usually a requirement of the contractor to produce. However, most plan and specification contract packages will have an example plans or details of what will be required.

- Specifications: Most of the performance and other technical standards are included in DPW's Standard Specifications. However, there are always unique elements in every project that require a new specification be prepared. These are called Special Provisions, and are written in a standard format that includes the unique item description, performance requirements (materials and installation), and measurement and payment methods.
- Bid list: The project items to be constructed are summarized by type in accordance with the appropriate specification pay item description. The quantities are summarized for the contractor to enter its bids into the tablature format. The stormwater designer is responsible for assembling the stormwater and TESC items and quantities.
- Construction cost estimate: The stormwater designer will prepare a construction cost estimate based on the quantity of each pay item in the project. Each item is assigned a unit price estimate of materials and installation cost by a contractor. The pricing of items is based on experience with past project and construction methods, using prices from other recent bids by DPW or other similar projects nationally. This cost estimate is for DPW's use and is kept confidential until after the contractual bids are opened.
- Construction schedule: The stormwater designer will provide input as to how the project can be staged during construction, with estimates on how long it takes to perform the work, for an overall estimated construction schedule. This schedule becomes the basis for the contractual time length and for DPW's monitoring of the contractor's work.

The stormwater designer will provide support during the contractual bidding process to answer any stormwater questions by the bidders and to further review any required bid submittals after bid opening in regard to contractor qualifications and procedures that contribute to the final selection of a contractor.

The stormwater designer is usually required to support the construction management process by responding to the contractor's or DPW's RFI on the design, and help to prepare any required change orders that pertain to drainage work. The designer should also finalize any modifications to the drainage design and the as-built drawings as an amendment (attachment) to the final hydraulic report.

2.1.3.2 DESIGN-BUILD

For the design-build project delivery method, the designer assembles the preliminary plans (often called concept plans) and prepares a set of performance specifications. The final design is the responsibility of the design-build contracting company. DPW maintains control of the performance specifications for the design by only allowing the design-builder to make changes from the conceptual plans to within limited performance-type boundaries.

As part of the design-build process, the bidding process requires each design-build contractor to further develop the conceptual drawings with additional design, such that they can develop a lump sum bid .The uniqueness of this process is that the contractor can develop its own design (within specified limits) to match its own methodologies and scheduling, to ultimately obtain the best price possible. Usually, selection of the best design-build contractor is based on a combination of the lump sum price and a rating system of the proposed methods and schedules to perform the work.

The stormwater designer will support the bidding process by answering the design-build contractor's questions. The designer will also review the various proposals for conformance to the specifications and rate the methods and procedures of the drainage work for comparison and contractor selection.

It will be the design-builder's (usually contractors partnered with design consultants) responsibility to prepare the final design and specifications for construction. For stormwater drainage, this includes the calculations and supporting documentation as a final hydraulic report. Typically, DPW will review the design-builder's designs at the preliminary, final, and released for construction stages. The designs are generally only accepted with comments, and not approved until the final handover of all project requirements. However, the design is usually performed in close coordination with DPW's project management staff during over-the-shoulder type reviews. Depending on DPW's project management organization, the stormwater designer will typically be involved in reviews of the design-builder's stormwater submittals.

2.2 SPECIAL DESIGN CONSIDERATIONS

2.2.1 CRITICAL AND SENSITIVE AREAS

Critical areas are defined as wetlands (including streams and lakes), floodplains, shorelines and reefs, aquifer recharge areas, sink holes, well heads, geologically hazardous areas, and those areas necessary for fish and wildlife conservation.

2.2.2 WETLANDS

Altering land cover and natural drainage patterns may alter stormwater input into surrounding wetlands. Hydrologic changes have more immediate and greater effects on the composition of vegetation and amphibian communities than do other environmental changes, including water quality degradation. Wetlands are protected under federal law and any project encroachment or impacts to the wetlands and their buffers must be mitigated. Project stormwater facilities should attempt to maintain the same flow patterns, rates, and quality of runoff to the wetlands as the existing conditions.

Wetland ecosystems are highly effective managers of stormwater runoff. They effectively and naturally remove pollutants, attenuate flows, and recharge groundwater. Minimum Requirement 7 (see Chapter 3) addresses wetland protection. Note that natural wetlands cannot be used for temporary or permanent project stormwater quality treatment and flow control facilities as required under the minimum requirements in Chapter 3.

All projects with the potential to adversely affect wetlands should be evaluated by biologists who assess possible impacts and provide guidance to design teams. The evaluation should include a determination of each wetland's classification, characteristics, quality, and functions. Wetland boundaries are delineated and surveyed when they are close to or overlap with project work areas. The surveyed wetland boundaries should be included on the plans for the project.

Upon completion of the field review, a wetland report is prepared for each project, documenting the information gathered on wetlands in the project area, and summarizing the nature and extent of project impacts.

The design professionals should follow strict protocols requiring avoidance of all wetland impacts or, where avoidance is not practical, minimization to the greatest extent practical. Special emphasis should be placed on avoiding impacts to high-quality wetlands. When the objectives of a transportation project cannot be met without adverse impacts to wetlands, a wetland mitigation plan detailing how lost wetland functions will be compensated should be prepared. Subsequently, wetland mitigation plans are submitted to one or more regulatory agencies, typically the U.S. Army Corps of Engineers (USACE) and local governments, for their review and permit approval. Even when the impacts are insignificant enough to fall below regulatory thresholds, the department follows a "no-net-loss" directive requiring compensatory mitigation for any wetland loss.

2.2.3 FLOODPLAINS

Hydraulic flood plain storage that is displaced by roadway fill or other structures will result in a corresponding increase in floodplain water surface levels. This increase may also change wetland hydrodynamics; cause upstream property damage; increase downstream stream flows; and produce additional channel erosion, downstream flooding, and decreased infiltration and summer base flows. Projects may be required to mitigate the loss of hydraulic storage by creating new storage elsewhere within the floodplain.

Stormwater discharge from the project area’s new impervious surfaces or changed discharge patterns may also impact the floodplain water surface levels. As part of the downstream analysis, impacts should be checked and mitigated. Refer to the requirements for Minimum Requirement Number 4 in Chapter 3.

Stormwater quality treatment and flow control facilities should be placed above the 50-year floodplain level. Stormwater quality treatment facilities should be designed such that flood levels cannot flush the previously-removed pollutants back into the natural water bodies. It is also pointless to install detention facilities that reduce the floodplain storage volume, which must be mitigated elsewhere.

2.2.4 AQUIFERS AND WELLHEADS

In general, it is desirable to recharge the underlying limestone bedrock aquifer in the northern Guam area. However, roadway runoff must be pre-treated prior to infiltration into the aquifer. The infiltration BMP description protects the aquifer by requiring pre-treatment prior to the infiltration facility, with the infiltration being through at least 2 ft. of soil depth above the limestone bedrock. The soil interaction with the stormwater provides entrapment, oxidation, and vegetative absorption of the stormwater pollutants. Where less than 2 ft. of soil exists above the limestone bedrock or the groundwater table, the runoff must pass through a prescribed quality treatment BMP prior to infiltration. Likewise, any project discharge to a limestone area sinkhole must be quality treated using an appropriate BMP.

The project should be of sufficient distance or provide barriers for physical protection of well heads and limestone area sinkholes. Untreated stormwater from the project area should not be allowed to discharge or infiltrate closer than 1000 ft. to a well.

2.2.5 STREAMS AND RIPARIAN AREAS

Similar to protection of wetlands, the project's environmental specialist will establish the boundaries of the stream and its buffer. The stream boundary is usually identified by its Ordinary High Water Level (OHWL or OHW), which is determined by field observation of the vegetative and flow-level indications by the environmental specialist.

Similar to the wetlands, the streams are protected by federal law and any project encroachments and impacts to stream channels and their boundaries must be mitigated. Where at all possible, avoid any filling within the OHWL boundaries. For roadway widenings, often times culvert extensions can be avoided by using headwalls, with no need for embankment fill below the OHWL. Other measures to minimize the project's impacts is using flow spreaders on stormwater outlets for a more natural sheet flow across the stream bank and buffer area into the water body. DPW also prefers using the vegetative erosion protection measures, such as tree stakes and grasses, as a more sensitive alternative to structures or riprap.

The design professionals should follow strict protocols requiring avoidance of all riparian impacts or, where avoidance is not practical, minimization to the greatest extent practical. When the objectives of a transportation project cannot be met without adverse impacts to stream and riparian habitats, a mitigation plan detailing how lost riparian functions will be compensated should be prepared. Subsequently, stream and riparian mitigation plans are submitted to one or more regulatory agencies, typically the USACE and local governments, for their review and permit approval.

2.2.6 ENDANGERED SPECIES

A biological evaluation or biological assessment must be prepared whenever it is suspected that Endangered Species Act (ESA)-listed species inhabit the vicinity of a project. The scoping team must contact the biologist early in the scoping process to request assistance in determining ESA-related issues and how these issues and needs affect project design and cost considerations.

2.2.7 AIRPORTS

Special consideration must be given to the design of stormwater facilities for projects located near airports. Roadside features, including standing water (such as wet ponds) and certain types of vegetation, can attract birds both directly and indirectly. The presence of large numbers of birds near airports creates hazards for airport operations and must be avoided. Before planning and designing facilities for a project near an airport, contact the airport and the Federal Aviation Administration (FAA) for wildlife management manuals and other site-specific criteria.

2.2.8 BRIDGES

Because the over-water portion of the bridge surface captures only the portion of rainfall that otherwise would fall directly into the receiving water body, that portion of the bridge makes no contribution to the increased rate of discharge associated with surface runoff to the water body.

Bridges are typically so close to receiving waters that it is often difficult to find sufficient elevations or areas in which to site a stormwater quality treatment solution. In the past, bridges were constructed with small bridge drains that discharged the runoff directly into the receiving waters by way of downspouts. Since this practice is no longer allowed, it becomes challenging to incorporate runoff collection, conveyance, and treatment facilities into the project design.

Sometimes the treatment can be completed by treating runoff from another equivalent pavement area that drains into the same waterway.

The use of suspended pipe systems to convey bridge runoff must be avoided whenever possible because these systems have a tendency to become plugged with debris and are difficult to clean. The preferred method of conveyance is to hold the runoff on the bridge surface and intercept it at the ends of the bridge with larger inlets. This method requires adequate shoulder width to accommodate flows so that they do not spread farther into the traveled way than allowed. In cases where a closed system must be used, it is recommended that bridge drain openings and pipe diameters be larger, and that 90-degree bends be avoided to ensure the system's operational integrity. Early coordination with DPW's maintenance staff is essential if a closed system is being considered.

2.3 OVERVIEW OF FEDERAL, TERRITORIAL, AND LOCAL ORDINANCES

The list of laws, regulations, and ordinances below are provided only for guidance. It should not be read as a complete list of applicable regulations. Regulations are evolving on a continuous basis. The reader should contact individual agencies for permit requirements.

FEDERAL ACTS

Federal Clean Water Act (CWA)

The objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. It established broad and comprehensive rules, regulations, and authorities for the protection, maintenance, and improvement of water quality for all waters of the United States; and it established specific actions to carry out necessary water pollution prevention efforts by federal and state governments. The applicable sections are:

- §104 - Authorizes the U.S. Environmental Protection Agency (EPA) to establish programs for the prevention, reduction, and elimination of pollution.
- §303 - Requires states to establish Water Quality Standards (WQS) and identify those waters that do not comply with standards.
- §304 - Requires the U.S. EPA to issue guidance to states for identifying and evaluating the extent of Non-Point Source Pollution (NPS) pollutants and methods to control NPS discharges from agriculture, silviculture, construction, and hydromodification.
- §305 - Requires states to submit biennial reports describing the quality of all navigable waters within the state, including a description of the nature and extent of the NPS source of pollution and recommendations to control such sources.
- §314 - Requires federal government entities to comply with local requirements to the same extent as any nongovernmental entity.
- §401 - Requires any applicant for a federal license or permit conducting an activity that may cause a discharge to navigable waters to acquire a water quality certification from the state indicating that such discharges will not violate the state's WQS.
- §402 - National Pollutant Discharge Elimination System (NPDES) permits – Require federal permits for point source dischargers.
- §404 - Requires individuals/entities conducting construction activities within all jurisdictional waters to acquire a Section 404 permit from the USACE and a Section 401 water quality certification from the state.

Federal Safe Drinking Water Act (SDWA)

- §1428 - Requires states to create a Wellhead Protection Program (WHPP). This is an effective means for local governments to protect and manage groundwater resources. Preventing groundwater from becoming contaminated protects the public health and the environment, and is cost-effective.

- §1424 - Allows for the designation of principal or sole-source aquifers. In 1978, the groundwater lens of northern Guam was defined as a "principal source aquifer" by the U.S. EPA.

Federal Coastal Zone Act - Reauthorization Amendments of 1990

- §6217 - Led to the establishment of the Guam Non-Point Source Pollution Management Plan, which has received conditional federal approval. This plan is a coordinating document with the goal of controlling NPS through the use of various management measures, and should be adopted and implemented with legal authority. Oversight is provided by the U.S. EPA and the National Oceanic and Atmospheric Administration (NOAA).

Federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

- CERCLA regulates the investigation and cleanup strategies of hazardous materials and groundwater contamination resulting from military activities.

Federal Resource Conservation Recovery Act (RCRA)

- This act includes hazardous waste and underground storage tank provisions (see 40CFR, Part 280, for relevant regulations).

TITLE 10 OF THE GUAM CODE ANNOTATED

10 GCA, Chapter 46. Guam Water Resources Conservation Act (WRCA)

WRCA requires the conservation and beneficial use of all surface and underground water resources; the management of such resources to prevent operation modifications, over-pumping by maintenance, abandonment, and destruction; and the avoidance of contamination of water wells as a result of extraction. WRCA established all water resources as the property of the people of Guam.

- Controls the drilling and operation of wells
- Authorizes the Groundwater Management Program

10 GCA, Chapter 47, Water Pollution Control Act

This requires that the Government of Guam conserve, protect, maintain, and improve the quality and potability of public water supplies for the propagation of wildlife, fish, and aquatic life, and for agricultural, industrial, recreational, and other beneficial uses through the prevention, abatement, and control of new or existing water pollution sources.

- Guam's soil erosion and sediment control regulations
- Guam's feedlot waste management regulations
- Guam's WQS

10 GCA, Chapter 48, Toilet Facilities and Sewage Disposal

- Sewer connection regulations
- Individual wastewater system regulations

10 GCA, Chapter 49, Air Pollution Control Act

- Air pollution standards and implementation plan

10 GCA, Chapter 50, Guam Pesticide Act

- Guam pesticide regulations

10GCA, Chapter 53, Safe Drinking Water Act (SDWA)

- Guam's SDWA.
- §7289(f) - Underground Injection Control Regulations and Program, which protects underground sources of drinking water from contamination.
- Guam's WHPP, approved in 1993, provides for three levels of protection: 1) the 1,000-foot radius around each drinking water production well; 2) the groundwater protection zone; and 3) the whole northern Guam lens.

10 GCA, Chapter 51, Solid Waste Management and Litter Control

- Solid waste and hazardous waste regulations

TITLE 21 OF THE GUAM CODE ANNOTATED

21 GCA, Chapter 61, Zoning Act

- The Guam Territorial Land Use Commission (TLUC) and Application Review Committee (ARC), under the Department of Land Management, review all projects with respect to the 1996 Guam Zoning Law and Regulations.

21 GCA, Chapter 61, Subdivision Act

- The TLUC and ARC, under the Department of Land Management, review all projects with respect to the 1997 Guam Subdivision Rules and Regulations.

OTHER PUBLIC LAWS AND EXECUTIVE ORDERS

Protection of Wetlands - Guam Executive Order 90-13

This executive order declares that the National Wetlands Inventory Map, produced by the U.S. Fish and Wildlife Service, serves as the official, interim wetland map for Guam, and that all government agencies use the map in the review of physical development projects. It further directs the appropriate government agencies including the Guam Environmental Protection Agency (GEPA), the Department of Agriculture, and the Bureau of Planning, to complete a study of wetlands; prepare public information; and draft necessary legislation, rules, and regulations, and/or an executive order to protect wetland resources, including water quality and wildlife habitat. During 1999, GEPA released a contract to complete this mandate.

Territorial Seashore Protection Act, Public Law 12-108, 1974

This declares that the Territorial Seashore Reserve is a distinct and valuable natural resource, existing as a delicately-balanced ecosystem, and that the permanent protection of natural, scenic, and historical resources in the reserve is of paramount importance. This act specifies four primary actions that must be accomplished: 1) studying the seashore reserve to determine the ecological planning principals required to ensure conservation; 2) preparing a comprehensive and enforceable plan based on the study for the long-range conservation, management, and development of the reserve; 3) ensuring interim development will be consistent with this law; and 4) mandating the Board of Directors of the Territorial Seashore Protection Commission to implement the provisions of the law. The Bureau of Planning recently provided funds to the Department of Land Management to complete the plan. The plan will mandate guidelines for approving each development permit for Guam's seashore reserve areas, regardless of zoning. (Seashore reserves include all land between the 10-fathom contour seaward and 100 meters inland from the mean high-water mark.) It will include development setbacks for erosion control and allowable uses that will minimize impacts.

Watershed Protection Executive Order - Guam Executive Order 99-09

This order affirms the Water Planning Committee's (WPC) work on watersheds; provides emphasis and direction for agency directors to participate in this important endeavor; emphasizes that watershed protection should be approached from a multiple-ownership and use perspective; directs GEPA to review the statutory fit and applicability of the watershed approach locally; and directs appropriate data management.

Interim adoption of Stormwater Management Criteria for Department of Public Works and Other Government of Guam Projects- Guam Executive Order -2005-35

This order affirms adoption of CNMI and Guam Stormwater Management Criteria in interim for all Government of Guam projects, to include new roads and road repairs. It also directs DPW to use the new criteria to design stormwater management systems. The interim adoption precludes private development from adoption of the new criteria.

2.4 DRAINAGE SUBMITTALS AND REVIEW PROCEDURES

A drainage review is the evaluation by DPW's staff of a proposed project's compliance with the drainage requirements of this TSDM. All DPW projects that have the following minimum characteristics require drainage design submittals in accordance with Section 2.1:

- Disturbs 5,000 sq. ft. or more of land
- Located within the limestone bedrock aquifer recharge area of northern Guam
- Disturbs any existing drainage facilities

- Any project that requires additional stormwater facilities to meet treatment criteria for at least 40 percent of the impervious surface
- Have a culvert replacement or extension
- Have previously-identified drainage or groundwater problems
- Located adjacent to a natural water body, shoreline, wetland, or stream
- Located within a floodplain

Reviews and Approvals

Reviews performed by DPW are required for stormwater management alternatives identified during the project scoping phase. Approval will be required before proceeding to the preliminary or concept development phase. DPW's approval of the selected alternatives and the concept designs should be obtained before proceeding with final designs and contractual documents. The final drainage design plans must be reviewed and approved by DPW prior to advertising the construction document package for bids.

DPW's approval does not supersede the designer's obligations to perform within the ethics and standards normally acceptable for the engineering profession. The designer is also obligated to prepare the work to project permit commitments and requirements, federal laws, and local ordinances and regulations.

2.5 SUBMITTAL REQUIREMENTS FOR DRAINAGE REVIEW

2.5.1 QUALIFICATIONS OF ENGINEERS

The project stormwater designs should be prepared directly by or under the direction of a graduate engineer having direct experience in stormwater management design. The engineer should be a Professional Engineer with a current Territory of Guam license. All plans, specifications, reports, calculations, and other submittals that will become part of the permanent record of the project must be dated and bear the Professional Engineer's official seal and signature.

2.5.2 HYDRAULIC REPORT

All drainage designs should have a hydraulic report. The hydraulic report will be the basis for DPW's review and approval of the project's stormwater management facilities. The hydraulic report is intended to serve as a complete documented record containing the engineering justifications for all drainage modifications that occur as result of the project. See Appendix II for additional requirements and an outline of the hydraulic report.

2.5.3 PLAN COMPONENTS

This section defines the general requirements for stormwater plans, reports, and other documents submitted to DPW for review.

- Each submittal to DPW for review should be accompanied by a cover letter stating the purpose of the submittal; a list of the attachments; the project identification titles and numbers; the requested action; the authority of the person making the submittal; and the time limit for review comments. Submittals should be made in both hard copy and electronic format.
- Each design submittal should be made in standard DPW formats, with a title page and index.
- Each design submittal should include a vicinity map. The vicinity map should show the project's general location on Guam, with a blow-up to further define the location by showing the village name, adjacent streets and roads, and recognized local landmarks. An additional blow up to scale should show the project's limits, with enough detail so that beginning and end stations and main project features can be identified in a site visit. For drainage design submittals, the main watercourses, drainage basins, and water bodies should be shown.
- Depending on the nature of the type of report or design submittal, reports should start with either a description and purpose section, or with an executive summary stating the purpose, problems, proposal, and conclusions. Reports should be prepared with clear and precise wording, further supported with exhibits, graphs, charts, and tables, as much as possible. Reports should be formatted to 8.5 x 11-inch paper size with fold out exhibits on 11 x 17-inch size as necessary. Hardcopies should be neatly bound with a protective cover.
- Design plans and details should be submitted in an 11 x 17-inch paper format with scale and text that allows for easy reading. The design plans should be prepared to DPW's standard formats with regard to borders, layout, and components. DPW CADD preferences can be supplied. All layout plans should include a north arrow, a bar scale, and identifying features to locate the sheet within the plan set and the proposed components by survey on the site. Details and sections should be clearly identified as to what view they are and where the section is taken.
- If a final design submittal, the cover of reports and specifications should be signed and sealed by the Engineer of Record. Each final design and detail drawing sheet should be signed and sealed by the Engineer of Record for that discipline's work. If a draft submittal, then each sheet should be marked "draft" in large letters on the cover and in the header or footer of each following page. Draft design plans and detail drawings should be marked "draft - not for construction" in prominent lettering on each sheet. All project plan and detail design sheets should be prepared using a recent version of MicroStation or AutoCAD compatible with DPW's CADD systems.
- All designs should use English standard units. Tables, graphs, scales, and other grids should be divisible by ten.

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3 MINIMUM REQUIREMENTS

3.1 INTRODUCTION

Each of the Department of Public Work's (DPW's) roadway development projects should be reviewed against the Minimum Requirements listed in this chapter. These Minimum Requirements are intended to achieve compliance with federal and Guam water quality regulations, while catering to the unique linear features of most transportation projects. There are nine Minimum Requirements, as follows:

1) Stormwater planning
2) Construction stormwater pollution prevention
3) Source control of pollutants
4) Maintenance of natural drainage
5) Runoff treatment
6) Flow control
7) Wetlands protection
8) Watershed-based planning
9) Operation and maintenance

All of the minimum requirements apply to every project, unless the project is exempted (see Section 3.1.1 below). The minimum requirements apply to the entire project area or limits. The project limits are defined as the length of the project and the width of the right-of-way.

3.1.1 EXEMPTIONS

The Permitting Authority can allow exemptions. The following activities may be exempted from meeting the minimum requirements if the authority determines that the scope and size of the activity will not create either erosion or other hazards to Guam's surface waters or marine waters, and reports that determination in writing:

- Pothole and square-cut patching
- Disturbs less than 5,000 sq. ft. of land
- Cleaning and general maintenance of stormwater conveyance, quality treatment, and flow control facilities
- Overlaying or replacing the existing impervious roadway and parking surfaces without expanding the area of coverage, provided stormwater management facilities already exist that meet the requirements of this TSDM
- Edge of pavement (shoulder) grading/shaping
- Roadway surface crack sealing

- Vegetation maintenance
- Exploratory excavations for the purpose of soils testing, provided that no grubbing or grading is to be performed
- Clearing of land for the purpose of making topographic surveys and hand-clearing trails for survey lines and access for soil exploration equipment

3.2 MINIMUM REQUIREMENTS

This Section describes the Minimum Requirements that must be met by non-exempt transportation projects.

3.2.1 MINIMUM REQUIREMENT 1: STORMWATER PLANNING

See Chapter 2, Section 2.1 for the details of incorporating stormwater planning into project development. The integration of stormwater planning and design is crucial to DPW's project development process.

All non-exempt DPW transportation projects will require stormwater planning and a positive method to deal with the stormwater within the project limits. Project area runoff must be contained within the project limits, treated, detained, and either infiltrated or conveyed for discharge to a natural water body (stream, river, wetland, tidal water, pond, or lake). Prior to infiltration or discharge, the project area stormwater may be subject to additional treatment and flow control requirements, as discussed in these Minimum Requirements. Project stormwater is not allowed to flow off site to damage or flood neighboring properties.

3.2.1.1 GUIDELINES

The basic steps involved in stormwater planning are as follows:

STEP 1- Collect and analyze information on existing conditions.

STEP 2- Prepare a drainage map with conceptual layout.

STEP 3- Perform an off-site analysis.

STEP 4- Prepare a permanent stormwater management plan.

STEP 5- Prepare a temporary erosion and sedimentation control plan. This plan will be incorporated into the contractors' Construction Stormwater Pollution Prevention Plan (SWPPP).

STEP 6- Prepare a hydraulic report.

STEP 7- Check compliance with all applicable minimum requirements.

STEP 1 – Collect and Analyze Information on Existing Conditions

Collect and review information on existing site conditions including topography; drainage patterns; soils; ground cover; and the presence of any critical areas, adjacent areas, existing development, existing stormwater facilities, and adjacent on- and off-site utilities. Then analyze the data to determine the site limitations, including:

- Areas with a high potential for erosion and sediment deposition (based on soil properties, slope, etc.)
- Locations of sensitive and critical areas (e.g., vegetative buffers, wetlands, steep slopes, floodplains, geologic hazard areas, streams, etc.)

Prepare an Existing Conditions Summary that will be submitted as part of the Hydraulic Report. The information collected in this step should be transferred to the drainage map prepared as part of Step 2.

STEP 2 – Prepare a Preliminary Project Layout and Drainage Map

Based on the analysis of existing site conditions, locate the topographic features for the proposed project and prepare a conceptual stormwater layout.

- Fit the project to the terrain to minimize land disturbance; and confine construction activities to the least area necessary and away from critical areas.
- Define drainage basins that the project intersects. Define on-site sub-basins and points of discharge.
- Preserve areas with natural vegetation, especially forested areas, as much as possible.
- Minimize impervious areas.
- Maintain and utilize the natural drainage patterns, and locate the project outfalls.
- Locate drainage constraints such as high and low points on the project profile, sites that may be available for stormwater quality treatment or flow control, and the locations of steep grades or cross-slopes, etc.
- Prepare a drainage map showing the basins, sub-basins, cross drains, soil types, project layout, various ground cover conditions, elevation contours, main flow paths, outfalls, sensitive areas, and right-of-ways.

STEP 3 – Perform an Off-Site Analysis

An off-site analysis is required for all projects. The objective of the off-site analysis is to evaluate and identify:

- Conveyance system capacity problems, both cross-drains and on-site collection systems
- Localized flooding
- Upland erosion impacts, including landslide hazards
- Stream channel erosion at the outfall location

- Existing downstream flow conditions, for use when reviewing project impacts

STEP 4 – Prepare a Permanent Stormwater Management Plan

Select stormwater control Best Management Practices (BMPs) and facilities that will serve the project site in its developed condition. This selection process is presented in detail in Chapter 6 of this Guam Transportation Stormwater Drainage Manual (TSDM). The permanent stormwater management system should contain the following main items:

Permanent Stormwater Management Plan – Existing Site Hydrology

If flow control facilities are proposed to comply with Minimum Requirement 6, provide a list of assumptions and site parameters used in analyzing the existing site hydrology. The soil types, existing streams and water bodies, existing drainage features, and land covers affected by the project should be included on the drainage map. Additional exhibits showing areas in more detail may be needed. The drainage map should also include:

- Contour intervals with basin and sub-basin boundaries shown accurately
- The delineation and acreage of basins and sub-basins
- The conceptual water quality treatment and flow control facility locations
- Outfalls
- Overflow routes

The direction of flow and the project right-of-ways and limits should be indicated. Each basin within or flowing through the site should be named for reference when performing the hydrology calculations.

Permanent Stormwater Management Plan: Developed Site Hydrology

Totals of pre-development and post-development impervious and pervious surfaces must be tabulated for each drainage basin within the project limits. These are needed to confirm the threshold limits for the application of treatment facilities (Minimum Requirement 5) and flow control facilities (Minimum Requirement 6) for the project.

Provide narrative, mathematical, and graphic presentations of hydrology input parameters selected for the pre-developed and post-developed site conditions, including basin acreages, soil types, and land covers. The basin descriptions should be cross-referenced to the naming convention shown on the drainage map and to any calculation sheets and computer printouts. Pre-development and post-development basin flows should be tabulated, and will apply to both on- and off-site basins that the project intersects or otherwise impacts.

Any documents used to determine the developed site hydrology should be included. Whenever possible, maintain the same basin name as used for the pre-developed site hydrology. If the boundaries of a basin have been modified by the project, that modification should be clearly shown on a map and the name modified to indicate the change. Final grade topographic maps should also be provided.

Permanent Stormwater Management Plan: Performance Standards and Goals

If quality treatment facilities are proposed, provide a tabulation of the water quality criteria used. If flow control facilities are proposed, provide a confirmation of the flow control standard being achieved. Provide full support or backup for the reasons why the BMPs were selected, how they were sized, and any other constraints that were taken into account during the design process. Document efforts to limit stormwater discharge by infiltrating as much of the runoff as possible within the project limits.

Permanent Stormwater Management Plan: Flow Control System

Provide a drawing of the flow control facility and its appurtenances. This drawing must show the basic measurements necessary to calculate the storage volumes available from zero to the maximum head, all orifice/restrictor sizes and head relationships, control structure/restrictor placement, and placement on the site.

Include all final computer modeling printouts, calculations, equations, references, storage/volume tables, and graphs, as necessary, to show the results and methodology used to determine the storage facility volumes.

Permanent Stormwater Management Plan: Stormwater Quality Treatment System

Provide a drawing of the proposed stormwater quality treatment BMPs. The drawing must show the overall measurements and dimensions, placement on the site, and locations/details of inflow, bypass, and discharge systems.

Include any computer modeling printouts, calculations, equations, references, and graphs, as necessary, to show that the facilities are designed to be consistent with the TSDM requirements.

Permanent Stormwater Management Plan: Conveyance System Analysis and Design

Present an analysis of any existing conveyance systems and the analysis and design of the proposed stormwater conveyance system for the project. This information should be presented in a clear, concise manner that can be easily followed, checked, and verified. All pipes, culverts, catch basins, channels, swales, and other stormwater conveyance appurtenances must be clearly labeled and correspond directly to the engineering plans. More complicated storm drain systems should be sized by routing the flow hydrographs using a hydraulic modeling program.

Main cross-drains should be identified by name on the drainage map and all other calculations and exhibits cross-referenced to that name.

STEP 5 – Prepare Construction TESC Plan

See Appendix I for the development of the Temporary Erosion and Sedimentation Control (TESC) plans, which are incorporated into the construction SWPPP.

STEP 6 – Complete the Hydraulic Report

This document encompasses the entire drainage management plan, which is reviewed by DPW prior to the start of construction. See Appendix II for the hydraulic report outline and additional preparation guidelines.

STEP 7 – Check Compliance with All Applicable Minimum Requirements

A correctly designed and implemented permanent stormwater management plan should specifically fulfill all minimum requirements applicable to the project. The plan should be reviewed to check that these requirements are satisfied.

3.2.2 MINIMUM REQUIREMENT 2: CONSTRUCTION STORMWATER POLLUTION PREVENTION

All projects with a disturbance of 1 acre or more, or smaller projects that are part of a larger program plan greater than 1 acre, are required to prepare and implement a SWPPP in accordance with the National Pollutant Discharge Elimination System (NPDES) Phase II Stormwater Program. The USEPA Web site is located at http://cfpub.epa.gov/npdes/stormwater/swphases.cfm. The NPDES Notice of Intent application page is located at http://cfpub.epa.gov/npdes/stormwater/application_coverage.cfm. In addition, a SWPPP will be required where the project impacts a Guam Environmental Protection Agency (GEPA) designated stormwater "hotspot". The EPA's construction stormwater permit and SWPPP template can also be found at http://cfpub.epa.gov/npdes/stormwater/const.cfm. The stormwater hotspot is defined as a land use or activity that generates higher concentrations of hydrocarbons, trace metals, or toxins than are found in typical stormwater runoff, based on monitoring studies (See Section 2 of the *Commonwealth of Northern Mariana Islands* (CNMI) and the *Guam Stormwater Management Manual, Vol. 1: Final – October 2006*, for more details on GEPA-designated hotspots). The two main components of the SWPPP are:

- Temporary Erosion and Sedimentation Control (TESC)
- Spill Prevention, Control, and Countermeasures (SPCC) planning

Together, TESC and SPCC plans should satisfy the construction SWPPP requirements. The objective of SWPPP preparation is to ensure that construction projects do not impair water quality by allowing sediment discharge from the site or allowing pollutant spills.

Further to the project areas requiring a SWPPP (as listed above), a TESC plan and report must be prepared for all DPW projects that are not otherwise exempt in accordance with Section 3.1.1. An initial TESC design is usually included in the bid package. After project award and before construction, the contractor will be required to accept or update the bid document's TESC plan. The TESC plan may need to be modified to fit the contractor's staging and work plan elements.

DPW exempt projects must still fully-address construction erosion control and the 12 elements of TESC. However, a stand-alone TESC report and plan is not required.

See Appendix I for details on each element of TESC (See Chapter 7 for design and applicability guidelines for TESC BMPs). Below are the 12 TESC elements:

ELEMENT 1 - Mark clearing limits

ELEMENT 2 - Establish construction access

ELEMENT 3 - Control flow rates

ELEMENT 4 - Install sediment controls

ELEMENT 5 - Stabilize soils

ELEMENT 6 - Protect slopes

ELEMENT 7 - Protect drain inlets

ELEMENT 8 - Stabilize channels and outlets

ELEMENT 9 - Control pollutants

ELEMENT 10- Control de-watering

ELEMENT 11- Maintain BMPs

ELEMENT 12- Manage the project

All construction site measures should be designed to accommodate (i.e., safely convey without creating erosive conditions) the 10-year frequency storm. All temporary sediment trapping devices should be designed to treat runoff from a minimum of the three-year frequency storm.

All projects involving mechanized equipment or construction material that could potentially contaminate stormwater or soils require SPCC plans. The SPCC plan is another element of the contractor's SWPPP, (prepared by the contractor) and contains the following:

- Site information and project description
- Spill prevention and containment
- Spill response
- Material and equipment requirements
- Reporting information
- Program management
- Plans to contain preexisting contamination, if necessary

3.2.3 MINIMUM REQUIREMENT 3: SOURCE CONTROL OF POLLUTANTS

All known, available, and reasonable source control BMPs must be applied and must be selected, designed, and maintained in accordance with the TSDM. The primary objective of this requirement is prevention. It is more cost-effective to prevent pollutants from coming in contact and mixing with the stormwater rather than removing pollutants after they have mixed with runoff.

Source control BMPs include operational and structural BMPs. Operational BMPs are practices that prevent (or reduce) pollutants from entering stormwater. Examples include preventive maintenance procedures (such as sweeping pavements, cleaning of sediment traps and catch basins, etc.), spill prevention and cleanup, and the inspection of potential pollutant sources.

Structural BMPs are physical, structural, or mechanical devices or facilities intended to prevent pollutants from entering stormwater. Examples include installing vegetation for temporary and permanent erosion control, putting roofs over outside storage areas, and putting berms around potential pollutant source areas to prevent both stormwater run-on and pollutant runoff. See Chapter 7 for criteria on the design of source control BMPs.

3.2.4 MINIMUM REQUIREMENT 4: MAINTAINING THE NATURAL DRAINAGE SYSTEM

The objective of this minimum requirement is to preserve and use natural drainage systems to the fullest extent because of the multiple stormwater benefits these systems provide, and to prevent erosion at and downstream of the discharge location.

Discharges from the project site should occur at the natural location, to the maximum extent practicable. The runoff must avoid adverse impacts to downstream receiving waters and down-gradient properties. All outfalls must be reviewed for erosion potential and energy dissipation applied as necessary. The designer must use the best available design practices to maintain hydrologic function and drainage patterns based on site geology, hydrology, and topography.

Project area stormwater should infiltrate and/or discharge into the same watershed per watershed boundary encompassing that portion of the project. Moving of project area runoff from one watershed to another is not allowable.

It is desirable and usually most cost effective to keep on-site stormwater separated from off-site flows prior to the project area runoff treatment and discharge (or infiltration). Stormwater management plans should attempt to maintain off-site flows in the existing or natural waterway with the least disturbance or change in hydraulic conditions possible.

See also Section 3.2.6, Minimum Requirement 6: Flow Control, for additional criteria and details.

3.2.5 MINIMUM REQUIREMENT 5: RUNOFF TREATMENT

The primary objective of runoff treatment is to reduce pollutant loads and concentrations in stormwater runoff using physical, biological, and chemical removal mechanisms to maintain or enhance the beneficial uses of receiving waters.

Additional requirements include:

- Infiltration is considered a treatment for northern Guam; however, all stormwater infiltrated should be performed in accordance with the appropriate infiltration BMP requirements listed in Chapter 6.
- Refer to Chapter 2 for incorporating the stormwater treatment strategy into the project development process.
- Select the appropriate BMPs in accordance with the guidelines in Chapter 6. The BMPs should be sized in accordance with the hydrology and hydraulics methods listed in Chapters 4 and 5.

3.2.5.1 RUNOFF TREATMENT EXCEPTIONS

Runoff treatment is not required on:

- Projects where the only work involved is the addition of paved surfaces not intended for use by motor vehicles, such as sidewalks or bike trails, and that are separate from the adjacent roadway.
- Maintenance-related activities such as fixing of potholes.
- Exemptions upon request by demonstrating and documenting a physical limitation that would make implementation impractical.

3.2.5.2 CRITERIA

The stormwater quality treatment volume for new development (i.e., new transportation facility where no roadway presently exists) should meet the following criteria:

- All project area stormwater should be contained on site and treated prior to discharge and/or infiltration. Infiltration is a preferred BMP. The designer should make all efforts possible to use infiltration over discharge.
- The stormwater quality treatment volume should meet the 90% Rule, when discharge is to high quality waters and/or involving hotspot land uses. The stormwater quality volume should meet the 80% Rule where project discharge is to moderate quality waters. High quality waters, hotspot land uses, and moderate quality waters are defined in Volume I, Chapter 2 of the CNMI and *Guam Stormwater Management Manual, Vol. 1: Final – October 2006*. See Figure 3-1 for a delineation of the high quality and moderate quality water body areas.

The stormwater quality treatment volume for redevelopment (i.e., any transportation project involving improvements to an existing facility or roadway) should meet the following criteria:

- All project area stormwater should be contained on site and the appropriate amounts of pavement area runoff treated prior to discharge and/or infiltration.
- Provide stormwater treatment BMPs where they do not currently exist for at least 40 percent of the impervious cover. Applicability of the 90% or 80% Rules should be governed by the discharge location.

The 80% and 90% Rules: The stormwater quality volume is the amount of stormwater to be treated in accordance with the runoff from a storm event that corresponds to the 90 or 80 percentile amount of total annual average rainfall. In accordance with the statistical analysis of the rainfall for Guam. The 80 percent amount corresponds to 56 percent of the two-year, one-hour storm precipitation depth, whereas the 90 percent amount corresponds to 72 percent of the two-year, one-hour storm precipitation depth. Flow-based quality treatment BMPs should be designed for the peak runoff flow rate from the two-year, one-hour storm event.

See Chapters 4 and 5 for methods to calculate these runoff volumes and corresponding flow rates. See Chapter 6 for additional guidelines on the applicability and criteria for the associated treatment BMPs.

As much of the project area stormwater as practical should be infiltrated, in particular within the limestone bedrock regions of Guam. Pre-treatment of stormwater is required before infiltration. The designer should also investigate the possibility of using soil amendments to enhance the suitability of sites for infiltration for GEPA-defined hotspot locations. One hundred percent of the project area stormwater requires quality treatment before infiltration. See the applicable infiltration BMP descriptions in Chapter 6 for more details.

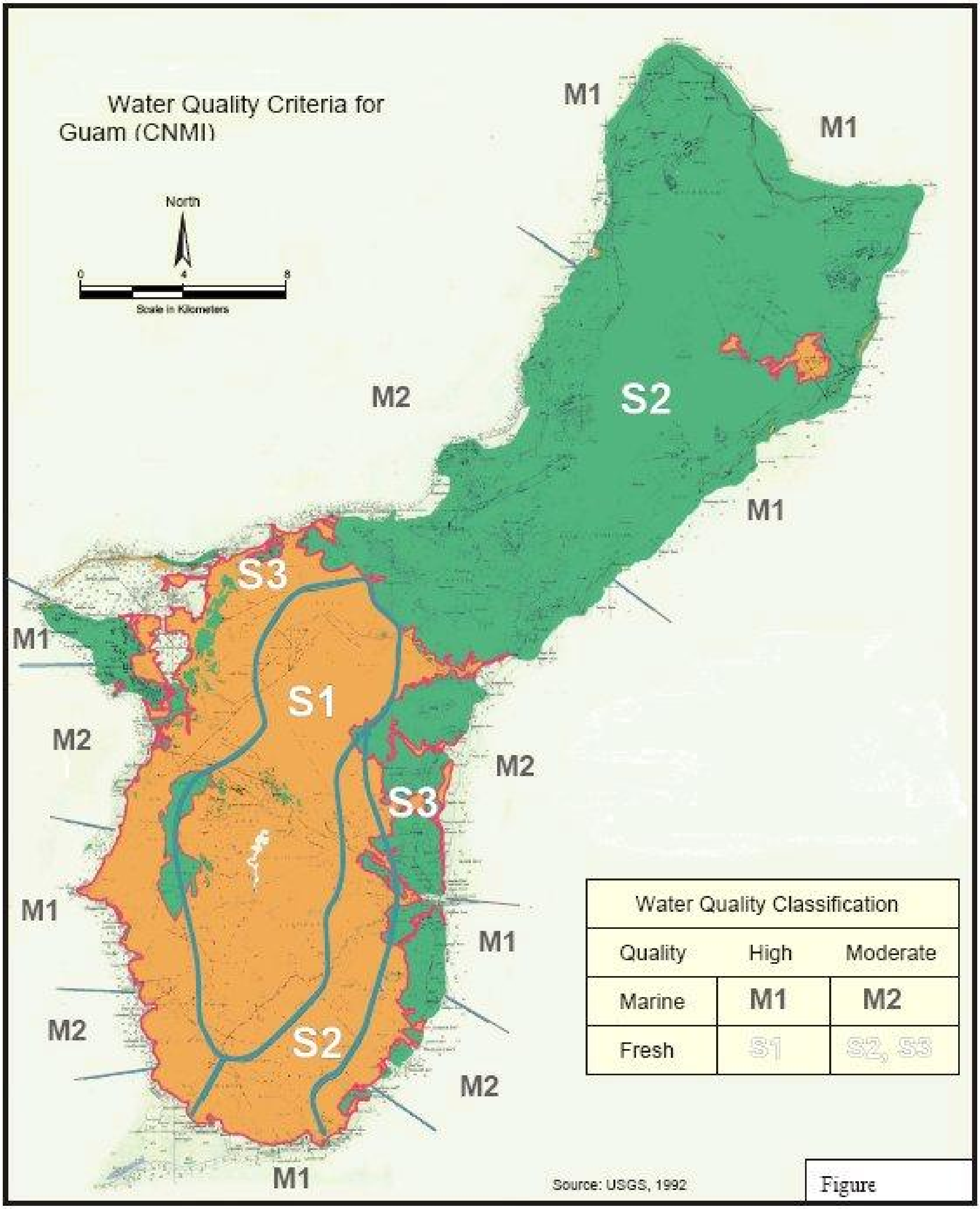


Figure 3-1: Water Quality Classification – Water Bodies of Guam

3.2.6 MINIMUM REQUIREMENT 6: FLOW CONTROL

Projects must provide flow control to reduce the impacts of stormwater runoff from impervious surfaces and land cover conversions. This requirement applies to all nonexempt projects that discharge stormwater directly or indirectly through a conveyance system to a surface freshwater body. The objective of flow control is to prevent increases in the stream channel erosion rates beyond those characteristics of natural existing conditions.

3.2.6.1 CRITERIA

Flow control requires 24 hours of detention of the post-developed, one-year, one-hour storm event runoff from the project area. The one-year, one-hour storm event runoff is captured and released over a 24-hour period. Also, the post-development project discharge rates must not exceed pre-development peak discharge rates for the 25-year, one-hour storm event. Detention volumes for the 25-year, one-hour storm event should be emptied within a 72-hour period from the start of the design storm event.

Depending on the shape and land use of a watershed, it is possible that upstream peak discharge may arrive at the same time as the project is releasing its peak discharge (even with detention), thus increasing the total downstream discharge. A downstream analysis is thus required for projects over 50 acres with on-site impervious cover greater than 25 percent or when deemed appropriate by the reviewing authority when existing conditions are already causing a problem (such as known flooding or channel erosion problems). The downstream analysis is a hydrologic and hydraulic evaluation extended downstream to the point where the site represents 10 percent of the total drainage area. If the flow rates and velocities increase by more than 5 percent, then the project detention must be redesigned to lessen the impacts.

It is desirable and usually more cost effective to infiltrate project area stormwater to the maximum extent possible, particularly in the limestone bedrock area of northern Guam. All project stormwater must be contained and conveyed on site for detention (prior to discharge to a natural water body) or infiltration within the project limits. Project stormwater facilities should be checked for the 100-year event, and provided with a suitable over-topping type discharge point to a natural water body without damage or flooding of neighboring properties. Where project stormwater discharge is by infiltration alone, without a suitable over-topping discharge site, then the 100-year storm runoff volume should be contained.

See Figure 6-2 in Chapter 6 for the selection of flow control BMPs, in the event flow control is required.

3.2.6.2 EXEMPTIONS

- Projects able to disperse stormwater without discharging runoff either directly or indirectly through a conveyance system to surface waters, such as infiltration and dispersion BMPs.
- Projects discharging runoff to coastal waters subject to tidal action.

- Project areas from over-water structures like bridges, docks, and piers (the portion of an over-water structure over the ordinary high-water mark).
- Projects that discharge through man-made conveyance directly to a large reservoir or lake, or a stream or river with a contributory drainage area greater than 5 square miles.
- Exemptions upon request by demonstrating and documenting a physical limitation that would make implementation impractical.

3.2.7 MINIMUM REQUIREMENT 7: WETLANDS PROTECTION

This requirement is in place to ensure that wetlands receive the same level of protection as any other waters of Guam. Wetlands are extremely important natural resources that provide multiple stormwater benefits, including groundwater recharge, flood control, and stream channel erosion protection. They are easily impacted by development unless careful planning and management are conducted.

Wetlands can be severely degraded by stormwater discharges from urban development due to pollutants in the runoff, and also due to disruptions of the natural hydrologic functioning of the wetlands system. Changes in water levels and the frequency and duration of inundations are of particular concern and should not be altered by the project.

Wetlands and streams should be protected by limiting clearing within 25 ft. from top of bank, with perimeter sediment controls during construction. Stormwater discharges should be performed using low impact type spreader trenches or swales for a more natural non-erosive sheet flow into the water body.

These requirements apply to projects where stormwater discharges into a wetland, either directly or indirectly, through a conveyance system. All project area discharge to a wetland must meet the requirements of Section 3.2 5 for quality treatment and Section 3.2.6 for flow control.

3.2.8 MINIMUM REQUIREMENT 8: INCORPORATING WATERSHED PLANNING INTO STORMWATER MANAGEMENT

This requirement is meant to promote watershed-based planning as a means of developing and implementing comprehensive water quality protection measures. The primary objectives of watershed-based planning are to reduce pollutant loads and hydrologic impacts to surface water and groundwater in order to protect beneficial uses.

Although Minimum Requirements 1 through 7 establish general standards for individual sites, they do not evaluate the overall pollution impacts and protection opportunities that could exist at the watershed level. In order for a watershed plan to serve as a means of modifying the Minimum Requirements, the following conditions must be met:

- The plan must be formally adopted by all jurisdictions with responsibilities under the plan

- All ordinances or regulations called for by the plan must be in effect

3.2.9 MINIMUM REQUIREMENT 9: OPERATIONS AND MAINTENANCE

The objective of this requirement is to ensure that stormwater control facilities can be adequately maintained and operated properly. This will better ensure that preventive maintenance and performance inspections are completed regularly.

Chapter 6 describes some of the general maintenance requirements that are identified with specific BMPs. In addition, the designer should review the stormwater management concepts with DPW's maintenance staff for adequacy of access to allow for regular and convenient maintenance and inspection of facilities. This review will further improve the designer's ability with the BMP configurations, where specific design parameters are based on maintainability factors.

4 HYDROLOGIC ANALYSIS

4.1 GENERAL HYDROLOGY

Hydrology is often defined as the science that addresses the physical properties, occurrences, and movements of water in the atmosphere, on the surface of the Earth, and in the outer crust of the Earth. For the Highway Designer, the primary focus of hydrology is the water that moves on the Earth's surface and, in particular, that part that ultimately crosses transportation corridors (i.e., highway stream crossings). A secondary interest is providing interior drainage for roadways, median areas, and interchanges.

The runoff of water over land has long been studied, and some rather sophisticated theories and methods have been proposed and developed for estimating flood flows. Most attempts to describe the process have been only partially successful at best. This is due to the complexity of the process and interactive factors. Although hydrology is not an exact science, it is possible to obtain solutions that are functionally acceptable to form the basis for the design of roadway drainage facilities.

Regardless of the size or cost of the drainage feature, the most important step prior to hydraulic design is estimating the discharge (rate of runoff) or volume of runoff that the drainage facility will be required to convey or control. The extent of such studies should be commensurate with the importance of the highway, potential for damage to the highway, loss of property, and hazard to life associated with the facilities. The choice of analytical method must be a conscious decision made as each problem arises. To make an informed decision, the Highway Engineer must determine:

- What level of hydrologic analysis is justified?
- What data are available or must be collected?
- What methods of analysis are available, including the relative strengths and weaknesses in terms of costs and accuracy?

For example, cross drainage design normally requires more extensive hydrologic analyses than what is necessary for roadway drainage design. The well-known and relatively simple Rational Method is generally adequate for estimating the rate of runoff for the design of on-site roadway drainage facilities and the removal of runoff from highway pavement. Alternately, more complex hydrograph or modeling methods are usually required for estimating flows from larger off-site watersheds.

4.1.1 GENERAL PROCEDURES

Drainage studies often follow a similar sequence of calculations for all procedures because precipitation must be routed through watersheds, channels, and reservoirs. In most cases, stormwater runoff will be estimated using the following general procedure:

- Divide the watershed into appropriate sub-areas to correspond with homogenous land use conditions and the placement of drainage facilities such as inlets, ponds, and open channels.
- Collect and analyze watershed data. Every drainage problem is unique, so the need for a field survey that appraises and collects site-specific hydrologic and hydraulic data cannot be overstated. Any historical and maintenance records should also be collected.
- Establish design storm characteristics (frequency, rainfall depth, and intensity) as appropriate for the structural element and design procedure selected.
- Calculate the peak runoff rate or determine the time distribution of rainfall excess. No further calculations are generally required if only the peak runoff rate is desired.
- Develop a Unit Hydrograph (UH) for the watershed if a runoff hydrograph is desired and the procedure selected uses a UH.
- Develop the direct runoff hydrograph or rainfall excess determined above, as appropriate.
- Perform downstream channel and reservoir routing as appropriate.

4.1.2 PROCEDURE SELECTION

Stream flow measurements for determining peak runoff rates for pre-project conditions are usually unavailable. In such cases, it is accepted practice to estimate peak runoff using several different methods. In general, results should be compared, not averaged, and the method that best reflects project conditions should be used, with the reasons well documented.

A consideration for peak runoff rates for design conditions is generally adequate for conveyance systems such as storm drains or open channels. However, if the design must include flood routing (e.g., storage basins or complex conveyances), a flood hydrograph is usually required. Although the development of a runoff hydrograph is often accomplished using computer programs, only desktop procedures are presented in this Transportation Stormwater Drainage Manual (TSDM).

Applicable methods for determining peak runoff rates and flood hydrographs for various size drainage basins are presented in Table 4-1.

Applicable Runoff Determination Methods

Rational Method: The Rational Method provides peak runoff rates for small and intermediate urban or rural watersheds, but it is best suited for urban storm systems. It should be used with caution if the Time of Concentration (Tc) exceeds 30 minutes. Where the Tc exceeds 30 minutes, the basin should be broken down by topographic and/or land cover conditions and the separate flows routed through the conveyance to the point of interest.

Guidelines for Selecting Peak Runoff Rate and Flood Hydrograph Methods									
Peak Runoff Rates							Flood Hydrographs		
No	**Watershed category**	**Stream Flow Analysis**	**Rational Method**	**Natural Flow Regression Equations**	**SCS Synthetic Unit Hydrograph Methods and CN Method**	**SCS TR-55 Method**	**Unit Hydrograph Theory**	**Santa Barbara Urban Hydrograph Method**	**SCS TR-55 Method**
1	**Small Urban 0-200 acres**	X	X		X	X	X	X	X
2	**Large Urban + 200 acres**	X	X[1A]		X		X		
3	**Small Rural 0-200 acres**	X	X	X	X	X	X	X	
4	**Medium Rural 0-1,000 acres**	X	X[1A]	X	X		X		X
5	**Large Rural 1,000 acres-6.5 square miles**	X		X	X		X		
6	**Major + 6.5 square miles**			X	X		X		

1A: Can be utilized for areas larger than 200 acres if the watershed is broken down into smaller areas and each area's runoff is routed through the conveyance reach.

Table 4-1: Guidelines for Selecting Peak Runoff Rate and Flood Hydrograph Methods

Regression Equations: Regression equations are alternative runoff calculation methods for natural flow conditions. Regression equations are developed for specific watersheds having recorded peak flow data by using statistical analytical techniques. These equations (with appropriate adjustments) can then be used for adjacent watersheds with similar characteristics.

Curve Number and Unit Hydrograph Methods: The USDA, National Resources Conservation Service (NRCS) runoff equation, Curve Number (CN), and UH procedures can be adapted to a variety of conditions for both rural and urban watersheds. The NRCS combined CN method and runoff equation is widely used in estimating direct runoff volume because of its simplicity, flexibility, and availability. The only input parameter needed is CN, and the hydrologic data used to estimate CN are normally available for most un-gauged watersheds. Because the CN is the only parameter required, the runoff prediction is entirely dependent on the accuracy of the CN. A runoff hydrograph and the peak discharge rate can be calculated directly from the runoff equation using the NRCS UH procedures.

TR-55: The NRCS Technical Release TR-55 (TR-55) is a good reference with regards to application of the CN runoff equation. However, the graphical and tabular methods presented in the technical release are not applicable to the Guam transportation projects, since they are based on the NRCS standard rainfall distribution 24-hour storms. See Section 4.2 for the applicable Guam design storms. Note that the CN runoff equation is usually restricted to estimating peak runoff volume for homogenous areas less than 300 acres.

Santa Barbara Urban Hydrograph: The Santa Barbara Urban Hydrograph (SBUH) method will develop a synthetic runoff hydrograph, applicable to small and large urban watersheds, as long as an appropriate delineation of homogenous land use areas is performed. The SBUH was developed by the Santa Barbara Flood Control and Water Conservation District in California as a short cut to the NRCS UH. The primary difference between the SBUH and the NRCS UH method is the use of the unit hydrograph in computing the runoff hydrograph. The SBUH replaces the unit hydrograph with an algorithm. The SBUH method greatly simplifies the computation of runoff hydrographs and is particularly applicable for computer modeling.

Hydrology Modeling Programs: The use of computer programs, which usually allow both hydrology and hydraulic analyses, is highly recommended for the routing of complex systems. There are a number of programs available, including public domain programs such as WinTR20, that use the NRCS CN and UH methods for developing the flow rates and volumes. Most hydrology/hydraulic modeling programs will also allow the use of the SBUH method for developing the runoff hydrographs.

4.1.3 PRECIPITATION CHARACTERISTICS IN DRAINAGE CALCULATIONS

The characteristics of precipitation typically considered in drainage calculations include:

- Intensity
- Duration
- Time distribution of rainfall (hyetograph)
- Storm shape, size, and movement
- Frequency

Intensity: Intensity is the rate of precipitation, commonly given in units of inches per hour. In any given storm, the instantaneous intensity is the slope of mass rainfall curve at a particular time. From the standpoint of drainage calculations, intensity is perhaps the most important of the rainfall characteristics because discharge from a given watershed will increase as the intensity rises. See Figure 4-1 for the intensity curves to use on Guam Transportation Projects.

Duration: Duration is the time length of the precipitation event. The precipitation durations used in Figures 4-1 and 4-2 have been selected based on statistical analysis of recorded precipitation events (see Appendix III). The Department of Public Works (DPW) is using a one-hour storm event as the standard storm duration for design and analysis purposes of a surface water management system for transportation projects.

Time Distribution of Rainfall or Hyetograph: A hyetograph provides a distribution of incremental precipitation versus time. In practice, depth duration data for particular design frequency are generally used to develop a synthetic design storm event. A design storm distribution with a one-hour duration will be used for transportation projects on Guam (see Figure 4-2).

Shape, Size, and Movement: Storm shape, size, and movement are normally determined by the type of storm. All three factors determine the areal extent of precipitation and the size of the drainage area that contribute over time to the surface runoff.

Rainfall varies spatially on the island owing to orographic effects (increases in rainfall with altitude). Mean annual rainfall is less than 90 in. on some coastal lowland areas and greater than 115 in. on mountainous areas in southern Guam. Since temperature and humidity are fairly uniform throughout the year, the variations of wind and rainfall are what define the seasons in Guam.

Highly seasonal rainfall and wind patterns in the region provide Guam with distinctive wet and dry seasons. The dry season (January through May) is dominated by northeasterly trade winds with scattered and light showers. Rainfall during the dry season accounts for 15 to 20 percent of the total annual rainfall. The wet season (July through November) accounts for an average of 65 percent of the annual rainfall. During the rainy season, westerly-moving storm systems and occasional typhoons bring heavy, steady rain and strong winds.

Monthly rainfall totals vary from less than 1 in. from February to April to more than 20 in. from August to November. Exceptionally dry years recur about once every four years in correlation with episodes of El Nino Southern Oscillation in the Pacific.

Frequency: Frequency quantifies the likelihood of the recurrence of precipitation with a given duration and average intensity. The major concern of highway design is with the frequency of occurrence for the surface runoff resulting from precipitation and, in particular, the frequency of the peak discharges. See Chapter 5, Section 5.2 for a more detailed description of the frequency policy for Guam transportation projects.

Refer to Chapter 2 of the FHWA publication *Hydraulic Design Series-2, Highway Hydrology* (HDS-2) for additional information on precipitation characteristics.

4.1.4 RUNOFF COMPONENTS

The four main components of runoff generally considered in stream flow data analysis are:

- Overland flow
- Channel precipitation
- Interflow
- Groundwater flow

Overland flow travels over the ground surface to the stream channel. Channel precipitation is direct rainfall on the water surface. Runoff that enters a stream channel by traveling laterally through the upper layer of soil is called interflow, while stream flow generated by the occurrence of water table conditions above the channel bottom is called groundwater or base flow.

This chapter addresses the relationships between precipitation and overland flow. Precipitation that does not convert to overland flow is lost to evaporation, soil storage, and infiltration. The infiltrated portion becomes interflow and groundwater flow.

Refer to Chapter 2 of the FHWA publication HDS-2 for detailed information on runoff characteristics.

4.2 DESIGN STORM SELECTION

Stormwater management facilities must be sized to create a logical balance between the safety of the project and the economics of installation, maintenance, and replacement. Accordingly, different aspects of stormwater conveyance, quality treatment, and flow control are designed to different levels or frequencies of storm events. These design storm events are selected based on an updated statistical analysis of the Guam precipitation records. The details of the statistical analysis and discussion on the selection of the design storms are discussed in Appendix III.

A one-hour duration storm will be used for the design of transportation stormwater facilities for Guam. The one-hour storm duration was selected from statistical analysis that showed that most precipitation on Guam occurs during intense, short duration storms. The probability of getting storms longer than a one-hour duration, as well as having more than one one-hour storm in a day, is statistically remote.

The one-hour storm distribution is a hybrid curve based on an analysis of the 15-minute rainfall records using a partial duration statistical series, and the lesser 30- and 60-minute precipitation amounts determined from the one-hour storm statistical series. The subsequent intensities for durations shorter than 15 minutes are somewhat conservative, while the longer duration intensities closely match the statistically-predicted rainfall depths.

Stormwater management systems that are developed using the selected design storm events and intensity curves will size the drainage facilities to match actual rainfall conditions. This will help in preparing an efficient design that provides for the public safety, while minimizing project costs.

One-hour precipitation values and intensity-duration curves for the design storm frequencies are shown in Figure 4-1. These precipitation intensities should be used for design of the transportation stormwater management facilities. Figure 4-2 is the standard one-hour storm distribution to use for design purposes. The standard one-hour storm distribution is also shown in a tabular format in Table 4-2. Figure 4-3 shows the precipitation depths in inches for different statistical recurrence intervals for the one-hour duration storm.

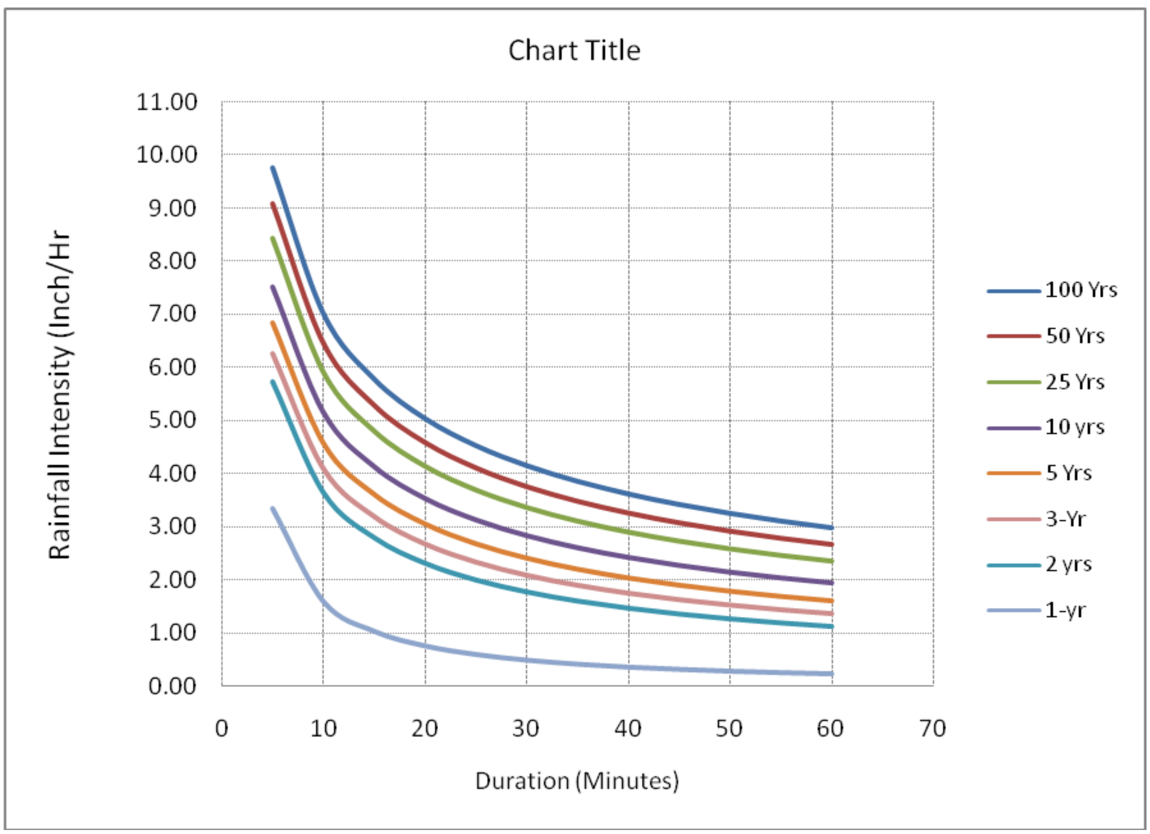


Figure 4-1: Intensity-Duration-Frequency (IDF) Curves for a One-Hour Duration Storm

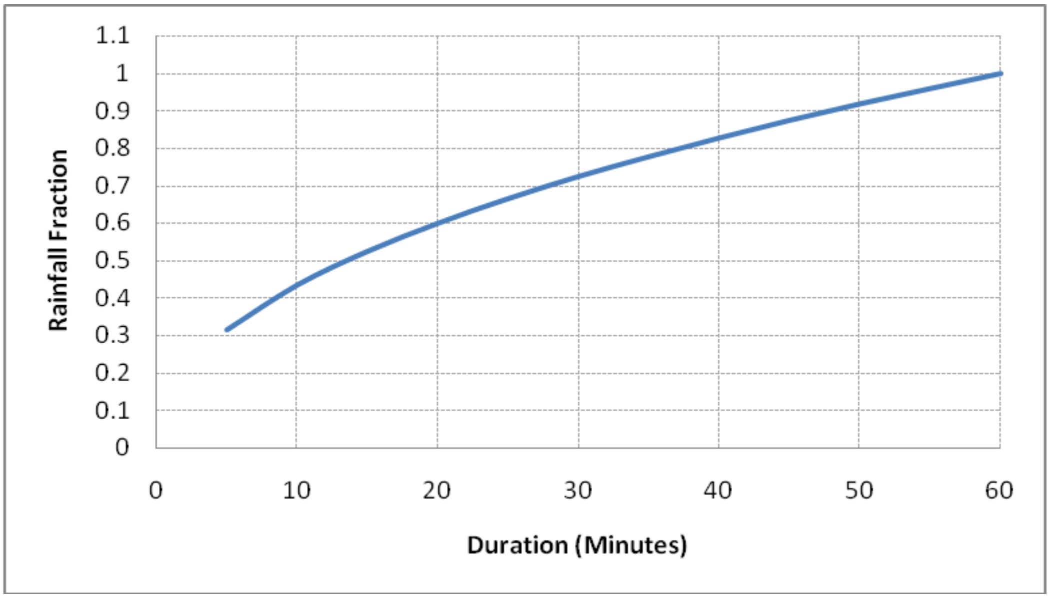


Figure 4-2: Design Rainfall Distribution for a One-Hour Duration Storm

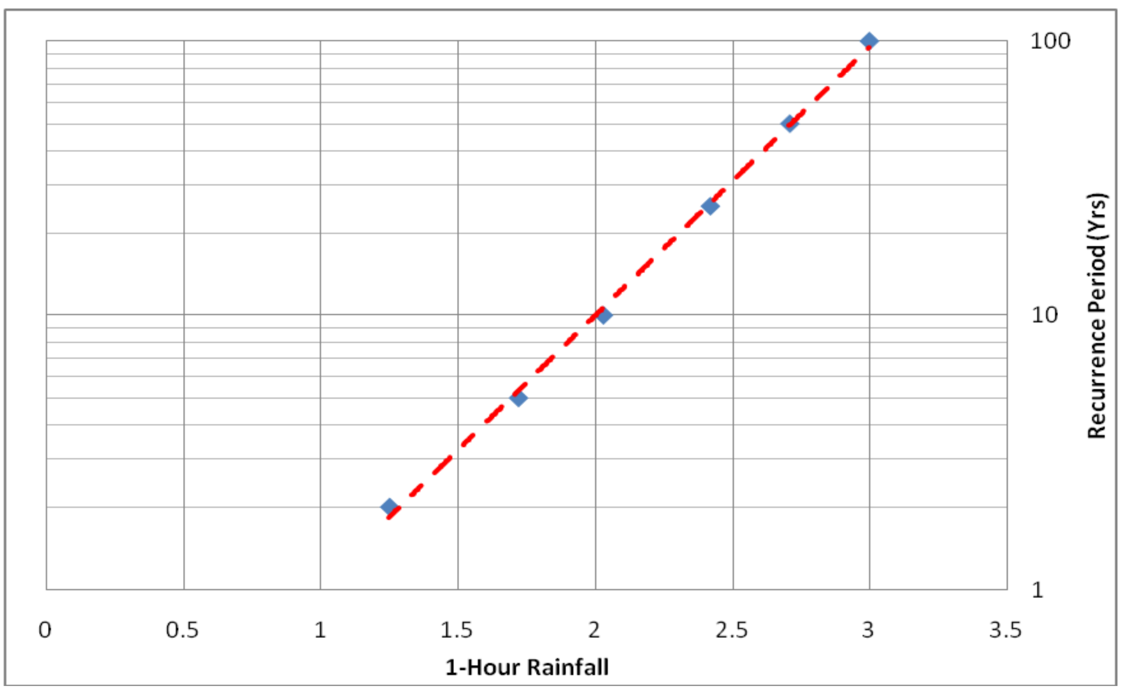


Figure 4-3: Rainfall (inches) per Recurrence Period for a One-Hour Duration Storm

Time (Minutes)	Rainfall Fraction
5	0.315
10	0.435
15	0.525
20	0.600
25	0.666
30	0.725
35	0.778
40	0.828
45	0.875
50	0.919
55	0.960
60	1.000

Table 4-2: One-Hour Storm Distribution

4.3 TIME OF CONCENTRATION

The Tc is the time required for a hydraulic wave to travel across a watershed. It is often approximated as the time required for runoff to travel from the most hydraulically remote part of the watershed to the point of interest. Most peak discharge, hydrograph, and channel routing calculation methods use computed travel times. Thus, estimating travel times are central to a variety of hydrologic design problems.

A segmental approach for calculating the Tc, commonly known as the velocity method, is recommended for most applications. The velocity method of estimating the Tc typically requires an evaluation of three flow components:

- Overland flow
- Rill, shallow channel, and street gutter flow
- Open channel flow

Overland flow is sheet flow over plane surfaces, usually limited to a maximum length of 300 ft. After 300 ft., overland flow generally becomes concentrated into rills, small channels, or gutters. Open channel flow is appropriate when the main conveyance system is encountered.

After short distances, sheet flow tends to concentrate in rills and then gullies of increasing proportions. Such flow is usually referred to as shallow concentrated flow. The flow in gullies is usually collected by channels or pipes.

The travel time for any flow segment can be estimated as the ratio of flow length to the velocity of flow, as follows:

$$t_i = \frac{L_i}{60V_i}$$

Equation 4-1

Where:

t_i = Travel time for velocity segment i in min.

V_i = Average velocity for segment i in ft./s

L_i = Length of the flow path for segment i in ft.

The number of flow segments or flow components considered should best represent the actual flow path of the watershed being evaluated. The relationship for calculating the time of concentration is expressed as:

$$T_c = t_1 + t_2 + t_3 + \ldots t_n$$

Equation 4-2

Where:

T_c = Watershed time of concentration in min.

t_1 = Overland flow travel time in min.

t_2 = Rill, shallow channel, street gutter flow travel time in min.

t_3 = Open channel flow travel time in min.

t_n = Travel time for segment i in min.

If the calculated Tc is less than five minutes, a minimum of five minutes should be used as the duration. Procedures for estimating the average flow velocities and travel times are discussed in Section 2.6 of the FHWA publication HDS-2.

4.4 PROCEDURES FOR DETERMING PEAK RUNOFF FLOW

Peak discharge is the maximum rate of the flow of water passing a given point during or after a rainfall event. Peak runoff rates are automatically obtained when a flood hydrograph is developed. However, in some situations, a peak runoff rate can be obtained without developing a complete flood hydrograph through the use of the Rational Method, regression equations, NRCS curve number equations, and UH relationships.

Design discharges, expressed as the quantity (Q) of flow in cubic feet per second are the peak discharges that a roadway drainage structure is sized to handle. Some of the more commonly used empirical methods for estimating runoff are as follows:

4.4.1 RATIONAL METHOD

Undoubtedly, the most popular and most often misused empirical hydrology method is the rational formula:

$$Q = C\,I\,A$$

Where:

Q = Design discharge in ft.^{3}/s

C = Coefficient of runoff; function of watershed cover, and flood frequency

I = Rainfall intensity in in./hr

A = Drainage area in acres

Assumptions

The assumptions in the rational formula are as follows:

- The drainage area should be smaller than 200 acres.
- Peak discharge occurs when the entire watershed is contributing.
- A storm that has a duration equal to Tc produces the highest peak discharge for this frequency.
- The rainfall intensity is uniform over a storm time duration equal to the Tc. The Tc is the time required for water to travel from the most hydrologically remote point of the basin to the outlet or point of interest.
- The frequency of the computed peak flow is equal to the frequency of the rainfall intensity. In other words, the 10-year rainfall intensity, i, is assumed to produce the 10-year peak discharge.

4.4.1.1 RUNOFF COEFFICIENTS

The runoff coefficient, C, is a function of ground cover. It represents the percent of water that will run off the ground surface during the storm. Commonly accepted runoff coefficients are discussed in Table 5.7 of FHWA publication HDS-2.

Should the basin contain varying amounts of different covers, a weighted runoff coefficient for the entire basin can be determined as:

$$Weighted\ C = \frac{\sum C_i A_i}{A}$$

Where:

C_i = Runoff coefficient for cover type i that covers area A_i

A = Total area

4.4.1.2 RAINFALL INTENSITY

After the appropriate storm frequency for the design has been determined (see Chapter 5) and the time of concentration has been calculated, the rainfall intensity can be calculated. Designers should never use a time of concentration that is less than five minutes for intensity calculations, even when the calculated time of concentration is less than five minutes. The five-minute limit is based on two ideas:

1. Shorter times give unrealistic intensities. The Intensity-Duration-Frequency (IDF) curves are constructed from curve-smoothing equations and not based on actual data collected at intervals shorter than 15 minutes. Making the curves shorter involves extrapolation, which is not reliable.
2. It takes time for rainfall to generate into runoff within a defined basin; thus, it would not be realistic to have less than five minutes for a time of concentration.

It should be noted that the rainfall intensity at any given time is the average of the most intense period enveloped by the time of concentration and is not instantaneous rainfall. Figure 4-1 contains the IDF relationships to be used for design, where the duration in the graph matches the Tc (in minutes) calculated for the drainage basin. Table 4-3 lists the equations of the curves shown in Figure 4-1, where x is the duration in minutes and y is the rainfall intensity in inches per hour. Note that these equations are only applicable for durations from 5 to 60 minutes.

RETURN PERIOD (Yrs)	IDF Equation
100	$y = 20.971x^{-0.476}$
50	$y = 20.04x^{-0.492}$
25	$y = 19.187x^{-0.512}$
10	$y = 18.086x^{-0.545}$
3	$y = 16.781x^{-0.613}$
2	$y = 16.322x^{-0.651}$
1	$y = 18.591x^{-1.067}$

Table 4-3: Rainfall Intensity Equations for a One-Hour Duration Storm

4.4.2 NRCS CURVE NUMBER METHOD

In the early 1950s, the USDA Soil Conservation Service (now called the National Resources Conservation Service or NRCS) developed a method for estimating the volume of direct runoff from storm rainfall and evaluating the effects of land use and treatment changes on the volume of direct runoff. The method is often referred to as the CN method, and it was empirically developed from small agricultural watersheds. However, the procedure, if carefully utilized, is applicable to other areas. This CN method provides results in terms of depth (convertible to volume by multiplying depth by the area) of runoff, but it is not applicable to the estimation of peak design discharge unless the design hydrograph is developed. For a description of the hydrograph development method used by the NRCS, see NRCS publication *National Engineering Handbook, Section 4, Hydrology*, dated 1985. See also the NRCS publication *Technical Paper TP-149*, dated 1973. The routing of hydrographs through a watershed is explained in NRCS *Technical Release TR-20*, dated 1973. TR-20 has now been updated as a public domain computer program which will develop runoff hydrographs and route them through a watershed.

The use of TR-20 (WinTR20 computer program) is most applicable for determining flows from larger basins, such as streams, where sizing of cross-culverts or bridge openings is needed. The design one-hour storm precipitation (Figure 4-3) and storm rainfall distribution (Table 4-2) can be applied directly in the program.

Simplified procedures for estimating runoff volumes from small urban watersheds is presented in NRCS publication *Technical Release TR-55, Urban Hydrology for Small Watersheds,* June 1986. This publication provides a description of the runoff CN method.

Note that the graphical peak flow and tabular hydrograph methods presented in TR-55 (and associated WinTR55 computer program) cannot be directly applied to Guam transportation projects, since the TR-55 methods use the NRCS standardized 24-hour rainfall distributions.

Alternately, peak discharge using the TR-55 CN formula with the Guam one-hour storm distribution (Table 4-2) can be closely approximated by computing the runoff volume (runoff depth multiplied by drainage area) for short time increments during the one-hour storm duration, where the amount of precipitation for each time increment is based on the fraction of rainfall from Table 4-2. The easiest way to do this is by tabulating the incremental calculations in a computer spreadsheet where the volume of runoff for each time period can be accumulated to form a simple runoff hydrograph. Each time increment should be equal in length and not longer than a few minutes. The spreadsheet can be further expanded as needed to determine constraints for simple routing and required detention storage for pre- versus post-development conditions (sample spreadsheets for use as design aids may be available from DPW representatives on a case-by-case basis).

The TR-20 public domain computer program and user manual can be downloaded at:

http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/tool_mod.html

4.4.3 UNIT HYDROGRAPH (UH)

A dimensionless UH is defined as the direct runoff hydrograph resulting from a rainfall event that has a specific temporal and spatial distribution, and that lasts for a unit duration of time. The ordinates of the UH are such that the volume of direct runoff represented by the area under the hydrograph is equal to 1 in. of runoff from the drainage area. In the development of a UH, there are several underlying assumptions made, such as uniform rainfall intensity and duration over the entire watershed.

The NRCS has developed a UH procedure that has been widely used for watershed flows and flood estimating purposes. The UH used by this method is based on an analysis of a large number of natural UHs from a broad cross section of geographic locations and hydrologic regions. This method is easy to apply. The only parameters that need to be determined are the peak discharge and the time to peak. A standard UH is constructed using these two parameters.

Procedures for estimating the runoff volume using UH methods are discussed in Section 6.1 of FHWA publication HDS-2.

4.4.4 SANTA BARBARA URBAN HYDROGRAPH (SBUH) METHOD

The SBUH was developed by the Santa Barbara Flood Control and Water Conservation District in California as a short cut to the NRCS UH method. The primary difference between the SBUH and the NRCS UH method is the use of the unit hydrograph in computing the runoff hydrograph. The SBUH replaces the unit hydrograph with an algorithm. The SBUH method greatly simplifies the computation of runoff hydrographs.

The SBUH uses two steps to synthesize the runoff hydrograph:

1. Compute the instantaneous hydrograph
2. Compute the runoff hydrograph

The instantaneous hydrograph, I_t, in cubic feet per second (cfs), for each time step dt, is computed as follows:

$$I_t = 60.5 R_t A / dt$$

Where

- R_t=total runoff depth at time increment dt (inches)
- A=area in acres
- dt=time interval in minutes

The runoff hydrograph, Q_t, is then obtained by routing the instantaneous hydrograph, I_t, through an imaginary reservoir with a time delay equal to the Tc of the drainage basin. The following equation estimates the routed flow, Q_t:

$$Q_{(t+1)} = Q_t + w\left[I_t + I_{(t+1)} - 2Q_t\right]$$

Where:

$$w = dt \Big/ \left(2Tc + dt\right)$$

This procedure is best applied using a spreadsheet, described as follows:

Column	Description
1	Time step number. This is a column starting with zero and incrementing by one.
2	Time in minutes. For a time step of 10 minutes, the column would increment from zero, 10, 20, 30 etc.
3	Rainfall distribution as a percent of the total precipitation.
4	Incremental rainfall (inches). This is the total precipitation multiplied by column 3. Be sure to divide by 100, since column 3 is in percent.
5	Accumulated rainfall (inches). Sum the previous column. (Generally, the rainfall distribution is provided as an accumulated distribution, meaning at time zero, there is zero rainfall and at the last time step, the rainfall is one or 100 percent accumulated. If that is the case, column 3 can be omitted, column 4 can be the accumulated rainfall ratio, and column 5 can be the total precipitation multiplied by column 4.)
6	Accumulated runoff calculated using the CN equation for the pervious area. This column also checks to see if column 5 is less than 0.2s. If it is, then zero is returned; otherwise, the abstraction is returned.
7	Incremental runoff. Subtract the previous row in column 6 from this row in column 6.
8	Accumulated runoff calculated using the CN equation for the impervious area.
9	Incremental runoff. Subtract the previous row in column 8 from this row in column 8.
10	Total runoff, which is ((PERVIOUS area / Total area) x column 7) + ((IMPERVIOUS area / Total area) x column9).
11	Instant hydrograph. This is where the SBUH method diverges from the NRCS Unit Hydrograph method. For the SBUH method, apply the equation: (60.5 x column 10 x A) / dt Where A is the total project area and dt is the time increment.
12	Design hydrograph. Apply the remainder of the SBUH method equation: Column 12 of Previous Time Step + (w x [Column 11 of the Previous Time Step+ Column 11 of the Present Time Step - (2 x Column 12 of the Previous Time Step)])

Table 4-4: SBUH Spreadsheet Method

The SBUH method assumes that the impervious portion of the watershed is directly connected to the drainage system. It is also important to note that, unless depression storage is specified for the impervious area, the SBUH method assumes that 100 percent of the rain that falls on the impervious area becomes runoff. Although the volume of depression storage on an impervious surface is small, it is not always reasonable to discount it. The specific magnitude of depression storage is generally not measured in the field; however, depression storage depths for paved areas can range from 0.06 in. to

0.26 in. on typical flat slopes, and the designer might want to make an estimate based on their field experience.

The SBUH is usually available in many hydraulic modeling computer programs, being particularly useful in design of off-site or more complicated roadway conveyance systems.

4.4.5 USGS REGRESSION EQUATIONS

Regional analysis methods use records for streams or drainage areas in the vicinity of the watercourse under consideration that have similar characteristics to develop peak volume estimates. Using recorded flood flow data, statistical analysis techniques are used to determine the watercourse flood flow return frequencies from which regression equations are developed for site-specific watershed, with the variables of slope, land use, precipitation amount, excess rainfall, shape, and area. These regression equations can then be used for estimating flood flows in similar, nearby watercourses. At present, there are limited available stream flow records.

The U.S. Army Corps of Engineers (COE) developed regression equations based on actual stream flow data (limited records prior to 1980) to use for un-gauged watersheds in southern Guam. These were published in the COE's Guam Storm Drainage Manual dated September 1980. These published equations were statistically compared against more recent stream flow data as part of the development of this TSDM. The equations were found to still be valid. They are shown in Table 4-5.

$$Q_{50\%} = 820 \times (DA)^{0.805}$$

$$Q_{20\%} = 1240 \times (DA)^{0.818}$$

$$Q_{10\%} = 1540 \times (DA)^{0.825}$$

$$Q_{5\%} = 1840 \times (DA)^{0.830}$$

$$Q_{2\%} = 2250 \times (DA)^{0.836}$$

$$Q_{1\%} = 2580 \times (DA)^{0.840}$$

Table 4-5: USGS Regression Equations for Guam

Where, Q = flow in cubic feet per second and DA = drainage area in square miles.

The COE 1980 Guam Storm Drainage Manual also included flows per return frequencies for nine gauged streams. These are listed in Table 4-6 for reference purposes.

Stream	Stream Flow in CFS								
	Exceedance Frequency (%)	0.01	0.10	2	5	10	20	50	99
	Recurrence Interval () Yrs.	1,000	100	50	20	10	5	2	1.01
Ugum River		21,316	12,419	10,244	7,604	5,887	4,316	2,370	452
Pauliluc River (Tinaga)		6,901	4,044	3,322	2,490	1,933	1,418	786	153
Almagosa Springs		1,419	862	744	573	457	348	205	48
Umatac River		16,121	10,148	8,595	6,666	5,354	4,102	2,455	594
Geus River		9,500	5,086	4,048	2,884	2,145	1,494	749	110
Finile Creek		539	418	380	332	294	254	191	88
Pago River		14,118	10,405	9,297	7,888	6,826	5,721	4,083	1,602
Ylig River		8,482	6,530	5,929	5,150	4,550	3,912	2,929	1,314
Imong River		6,103	4,592	4,147	3,547	3,100	2,631	1,920	803

Table 4-6: Frequency of Flows for Nine Rivers on Guam

4.4.6 HYDROLOGIC COMPUTER PROGRAMS

The rapid development of computer technology in recent years has resulted in the development of many mathematical models for the purpose of calculating runoff and other hydrologic phenomenon.

Hydrograph methods can be computationally involved, so computer programs such as HEC-1, HEC-HMS (developed by COE), TR-20 (developed by NRCS), StormShed and HYDRAIN (developed by FHWA), are almost exclusively used to generate runoff hydrographs. Many of these programs will also hydraulically route these hydrographs, which is important in the design of stormwater detention, other water quality facilities, and pump stations. They can also be used to evaluate conveyance flows by routing through large storm drainage systems to more precisely reflect flow peaking conditions in each segment of complex systems. Since the above-referenced techniques require a large amount of time and data to perform basin-wide computer simulation and rainfall-runoff modeling, these should be reserved for larger or special projects that justify applying the additional time and manpower. The additional time and cost must be balanced against the need for a higher level of detail and accuracy that can be obtained. As a word of caution, the designer should refrain from accepting the computer generated input without questioning the reasonableness of the results obtained from a hydrologic viewpoint.

Depending upon the amount of detail and accuracy of the input data, these models can be very efficient at showing conveyance system response to particular designs and assist the designer in preparing an adequate conveyance or flood protection system in the most efficient and cost effective manner.

5 HYDRAULICS ANALYSIS

5.1 GENERAL

Stormwater drainage design is an integral component of overall stormwater management. Good drainage design must strive to maintain compatibility and minimize interference with existing drainage patterns; control flooding of property, structures, and roadways; and minimize the environmental impacts.

Highway drainage design is much more than the application of technical principles of hydrology and hydraulics. Good drainage design is a matter of properly balancing technical principles and data with the environment, while giving due consideration to other factors such as safety and economics. Such design can only be accomplished through the liberal use of sound engineering judgment. A goal in highway drainage design should be to perpetuate natural drainage, insofar as it is practical.

Various types of drainage facilities are required to protect the highway against surface and sub-surface water. Drainage facilities must be designed to convey the water across, along, or away from the highway in the most economical, efficient, and safe manner, while protecting the highway and without impacting or damaging the adjacent property.

The purpose of this chapter of the Guam Transportation Stormwater Drainage Manual (TSDM) is to provide hydraulic analysis requirements specific to highway design on the Island of Guam.

5.2 FREQUENCY POLICY

A range of runoff discharges from a range of storm recurrence intervals are used to evaluate drainage facilities. The rate of runoff from a drainage area will vary depending on the recurrence interval of the storm being analyzed. The recurrence interval defines the frequency that a given event (e.g., rainfall or runoff) is equaled or exceeded on average, once in a period of years. For example, if the 25-year frequency rainfall is 2.4 in., a storm event of this size or greater would be expected to occur on average once every 25 years over an infinite time period. The exceedance probability, which is the reciprocal of the recurrence interval of this 2.4-in. storm, would have a 0.04 probability, or a 4 percent chance of occurrence in any given year.

Drainage frequencies that are commensurate with the relative importance of the highway, associated risks, and possible damage to adjacent property should be selected. When selecting a storm frequency for design purposes, consideration is given to the potential degree of damage to the roadway and adjacent property; the potential hazard and inconvenience to the public; the number of users on the roadway; and the initial construction cost of the hydraulic structure. The way in which these factors interrelate can become quite complex. The policy regarding design storm frequency for typical hydraulic structures is listed in Table 5-1. Thus, the designer does not have to perform a risk analysis for each structure on each project.

Type of Structure	Storm Frequency (years)
Gutters	10
Storm Drain Inlets – On Longitudinal Slope	10
Storm Drain Inlets – Vertical Curve Sag	50
Storm Drain Laterals	10
Storm Drain Trunk Lines	25
Ditches – Roadside	10
Ditches – Outfall and canals	25
Culverts	50-year for main routes and 25-year for secondary routes.
Bottomless Culverts	50
Culverts – Check for Overtopping	100
Bridges – Design for Flow Passage and Scour	100 Maintain 2 ft. clear between HW and lowest member. For spill through abutments, try to maintain 10 ft. between top edge of channel and toe of abutment.
Main Routes	10-year: Flow spread width not to exceed shoulder and 2 ft. of the adjacent lane. 100-year: No overtopping at bridges and culverts; one lane in each direction passable for emergency vehicles. Check for flow damage and provide protection as required.
Secondary Routes	10-year: Flow spread width not to exceed half of the inner lane. 100-year: Passable for emergency vehicles. Check for flow damage and provide protection as required.

Table 5-1: Recommended Frequency for Design of Hydraulic Structures

The designer should carefully consider the application of the structure design storm frequency as related to the overall intent of the stormwater conveyance and discharge system. The interconnecting storm drainage conveyance, treatment, detention, and discharge system needs to operate in a balanced condition. For example, although the stipulated design frequency storm for a roadside ditch is 10 years, that may not be sufficient if that ditch needs to convey flows to a detention facility requiring a 25-year frequency design. The ditch needs to be able to deliver up to the peak flows that the detention facility is designed for, or the overall drainage system will not function properly. Likewise, a project in the limestone area of northern Guam may not have a suitable overtopping discharge location requiring that the 100-year frequency storm volume be contained within the project limits until it can fully infiltrate. For this case, the individual drainage system components may require sizing to a different performance level (i.e., different from the capacity required using the design frequency shown in Table 5-1) depending on their location and function within the interconnecting system.

5.3 ROADWAY DRAINAGE

Water on the pavement will slow traffic and contribute to accidents from hydroplaning and loss of visibility from splash and spray, so removal of water on pavement in an expeditious and efficient manner is important. Pavement drainage design will provide for effective removal of water from the roadway surface.

Pavement drainage design is typically based on a design discharge and an allowable spread of water across the pavement. Design features such as cross slope, longitudinal slope, and gutter section can affect the size, type, and spacing of inlets. This Section provides the fundamentals of gutter flow, inlet interception capacity, bridge deck drainage, and an evaluation of the potential for hydroplaning.

The level of service of facilities that provide for the drainage of roadway surfaces should be consistent with the level of service being provided by the roadway. Guidelines are given for evaluating roadway features as they relate to pavement drainage, and for selecting an appropriate design frequency. Procedures for performing gutter flow calculations are based on a modification of the Manning Equation. Inlet capacity is discussed for curb opening inlets, grated gutter inlets, combination inlets, slotted pipe and trench drain, and bridge deck drains.

5.3.1 ROADWAY FEATURES

Roadway features considered during gutter, inlet, and pavement drainage calculations include:

- Longitudinal slope
- Cross slope
- Curb and gutter
- Ditches
- Bridge decks

5.3.1.1 LONGITUDINAL SLOPE

A minimum longitudinal gradient is important for curbed pavement because it is susceptible to stormwater spread. Flat gradients on uncurbed pavement can lead to a spread problem if vegetation is allowed to build up along the pavement edge.

Desirable gutter grades should not be less than 0.5 percent for curbed pavements, and not less than 0.3 percent on very flat terrain. Minimum grades can be maintained on very flat terrain through the use of warping the cross slope or rolling the profile.

To provide adequate drainage in sag vertical curves, a minimum slope of 0.3 percent should be maintained within 50 ft. of the low point of the curve. This is accomplished where the length of the curve divided by the algebraic difference in grades in percent (K) is equal to or less than 167. This is represented as:

$$K = L/(G_2 - G_1)$$

Equation 5-1

Where:

K = Vertical curve constant in m/percent (ft./percent)

L = Horizontal length of curve in m (ft.)

G_i = Grade of roadway in percent

5.3.1.2 CROSS SLOPE

The American Association of State Highway and Transportation Officials (AASHTO) policy on geometric design is standard practice and should be consulted for more details. Table 5-2 indicates an acceptable range of cross slopes. These cross slopes are a compromise between the need for reasonably steep cross slopes for drainage and relatively flat cross slopes for driver comfort and safety.

Surface Type	**Range of Cross Slopes (ft. /ft.)**
Travel Way	
Two Lanes	0.015 - 0.025
Three or More Lanes	0.015 minimum for the two upslope lanes; increase 0.005 to 0.010 per lane downslope to a 0.04 maximum
Shoulders	0.025 - 0.060
Parking	0.005 minimum

Table 5-2: Recommended Pavement Cross Slope

The use of cross slopes steeper than 2 percent on pavements with a central crown line is not desirable. On multi-lane roadways where three lanes or more are sloped in the same direction, it is desirable to counter the resulting increase in flow depth by increasing the cross slope of the outermost lanes. The two lanes adjacent to the crown line should be pitched at the normal slope, and successive lane pairs, or outward portions thereof, should be increased by 0.5 percent to 1 percent. The maximum pavement cross slope should be limited to 4 percent.

Additional guidelines related to cross slope are:

- Although not encouraged, inside lanes can be sloped toward the median if conditions warrant.
- Median and off-site areas should not be drained across travel lanes.
- The number and length of flat slope pavement sections in cross slope transition areas should be minimized. Consideration should be given to increasing cross slopes in sag vertical curves, crest vertical curves, and in sections of flat longitudinal grades.
- Shoulders should be sloped to drain away from the pavement, except with raised, narrow medians and along superelevations.

5.3.1.3 CURB AND GUTTER

Curbing at the outside edge of pavements is normal practice for urban roadway facilities. Curbs can be combined with formed concrete gutters. The gutters are generally 12 in. to 30 in. wide (refer to the Department of Public Work's [DPW's] standard construction drawings for additional details), matching the pavement cross slope on the high side and depressed with a steeper cross slope on the low side, usually at 8 percent. Typical practice is to place curbs at the outside edge of the traveled way, the shoulders, or the parking lanes, depending on the type of roadway. The gutter width is normally included as a part of the pavement width.

Shoulder gutters are used to protect fill slopes from erosion caused by water from the roadway pavement. Shoulder gutters are required on all fill slopes higher than 10 ft. where the side slope is steeper than 3 horizontal to 1 vertical. Shoulder gutters are also required at the bridge ends where concentrated flow from the bridge deck would otherwise run down the slope or over a retaining wall/abutment. Shoulder gutters are formed by placing a curb at the edge of the shoulder under the face of the guardrail, or by concrete barriers such as those used at bridge approaches and on high fills.

5.3.1.4 DITCHES

Roadside channels and ditches are commonly used with uncurbed roadway sections to convey runoff from the highway pavement and from areas that drain toward the highway. Due to access and right-of-way limitations, roadside ditches cannot be used on most urban arterials. They can be used in cut sections, depressed sections, and other locations where sufficient right-of-way is available and driveways or intersections are infrequent.

Curbed roadway sections are relatively inefficient at conveying water, so the area tributary to the gutter section should be kept to a minimum to reduce the hazard of water on the pavement. Where practicable, the flow from the major area draining toward the curbed pavement should be intercepted by ditches or other pipe/inlet systems, as appropriate.

It is preferable to slope the median areas and inside shoulders to a center swale to prevent drainage from the median area running across the pavement. This is particularly important for facilities with two or more lanes of traffic in each direction. In some cases, detention can be included in shallow medians to reduce the size of runoff facilities.

5.3.1.5 BRIDGE DECK

Bridge deck drainage is similar to that of curbed roadway sections. It is often less efficient because cross slopes are flatter; parapets collect large amounts of debris; and smaller drainage inlets or scuppers have a high potential for becoming clogged by debris. Bridge deck constructability usually requires a constant cross slope, so the usual guidelines do not apply. Because of the difficulties in providing and maintaining adequate deck drainage systems, gutter flow from roadways should be intercepted before it reaches a bridge. In many cases, deck drainage must be carried several spans to the bridge-end disposal.

Zero gradients and sag vertical curves should be avoided on bridges. The minimum desirable longitudinal slope for bridge deck drainage should be 0.2 percent. When bridges are placed on a vertical curve and the longitudinal slope is less than 0.2 percent, the gutter spread should be checked to ensure a safe, reasonable design.

Piped and grated scupper-type inlets are the recommended method for deck drainage because they can reduce the problems of transporting a relatively large concentration of runoff in an area of generally limited right-of-way. They also have a low initial cost and are relatively easy to maintain. However, the use of scuppers should be evaluated for site-specific concerns, and scuppers should always be piped in down drains to stable and erosion-protected runoff points. Runoff collected and transported to the end of the bridge should generally be collected by inlets and down drains, although paved flumes may be used for minor flows in some areas.

5.3.2 HYDROPLANING

Hydroplaning occurs when a tire is separated from the roadway surface by a layer of fluid. Hydroplaning is a function of the water depth, roadway geometrics, vehicle speed, tread depth, tire inflation pressure, and conditions of the pavement surface. In problem areas, hydroplaning may be reduced by the following:

- Design the highway geometries to reduce the drainage path lengths of the water flowing over the pavement. This will prevent flow build-up.
- Increase the pavement surface texture depth by methods such as grooving Portland Cement Concrete (PCC). An increase of pavement surface texture will increase the drainage capacity at the tire pavement interface.

- The use of open-graded asphaltic pavements has been shown to greatly reduce the hydroplaning potential of the roadway surface. This reduction is due to the ability of the water to be forced through the pavement, under the tire. This releases any hydrodynamic pressures that are created, and the potential for the tire to hydroplane.
- The use of drainage structures along the roadway to capture the flow of water over the pavement will reduce the thickness of the film of water and reduce the hydroplaning potential of the roadway surface.

5.3.3 SPREAD

The design frequency for pavement drainage should be consistent with the frequency selected for other components of drainage systems.

5.3.3.1 SPREAD CRITERIA

Spread is dependent on the road classification, as noted in Table 5-3 below:

Road Classification		Design Frequency	Design Spread
Main Routes	With Shoulder	10 years	Shoulder + 2 ft.
	Without Shoulder	10 years	Gutter + 3 ft.
	Sag Location	50 years	Shoulder + 2 ft.
Collector and Local Streets	With or Without Shoulders	10 years	Half of Outside Driving Lane
	Sag Location	50 years	Half of Outside Driving Lane

Table 5-3: Allowable Spread Criteria

5.3.4 GUTTER FUNDAMENTALS

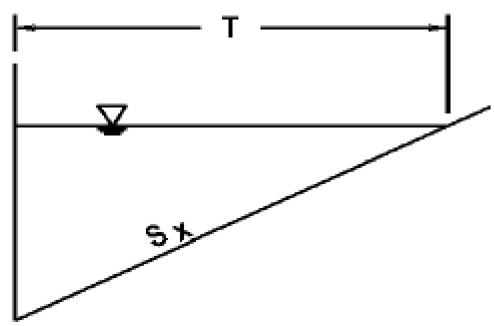
A pavement gutter is the section of a roadway normally located at its outer edge to convey stormwater runoff. It may include a portion of a travel lane or be a separate section at the edge of the traveled way or at the edge of the shoulder, but it usually has a triangular shape, defined by the cross slope and curb. In lieu of curbs, it is possible to use a V-shaped monolithic pavement section; but only when traffic control is unnecessary, such as with a low-volume residential street.

Major components of the typical gutter section include:

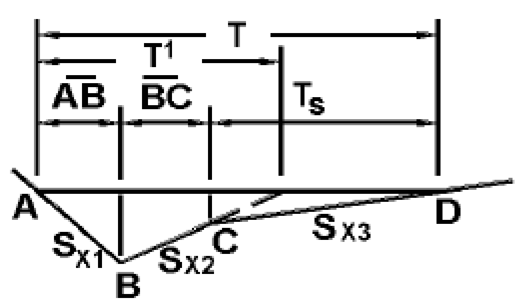
- Pavement cross slope (S_x)
- Longitudinal slope (S_L)
- Width of flow or spread (T)
- Width of depressed gutter flow (W)
- Depth of gutter flow (d)
- Cross slope of depressed gutter (S_w)

Sketches showing the relationship of these components for three typical sections are presented in Figure 5-1. The first sketch shows a curb and gutter section with a straight cross slope; the second, a V-shaped section without a curb; and the third, a depressed curb and gutter section of width (W) and cross slope (SW). These sketches are provided to define fundamental parameters and are not intended to be used as the Guam Department of Public Works' (DPW) standard details.

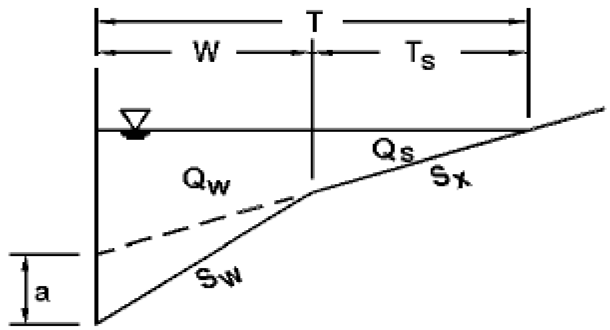
Gutter flow is a form of open-channel flow that should be analyzed using a modified form of the Manning Equation. Application details and example problems can be found in Section 6.2 of FHWA publication *HDS 4, Introduction to Highway Hydraulics, No. FHWA-NHI-08-090, June 2008*.



Curb with Straight Cross Slope



No Curb, V-Shaped Gutter



Curb with Depressed Gutter

Figure 5-1: Typical Gutter Sections

5.3.4.1 FLOW IN SAG VERTICAL CURVES

As gutter flow approaches the low point in a sag vertical curve, the flow can exceed the allowable design spread values as a result of the continually decreasing gutter slope. The spread in these areas should be checked to ensure it remains within the allowable limits. If the computed spread exceeds the design values, additional inlets should be provided to reduce the flow as it approaches the low point.

5.3.5 INLET FUNDAMENTALS

Storm drain inlets are used to collect runoff and discharge it to an underground storm drainage system. Inlets are typically located in gutter sections, paved medians, and roadside and median ditches. Inlets used for the drainage of highway surfaces can be divided into the following three classes:

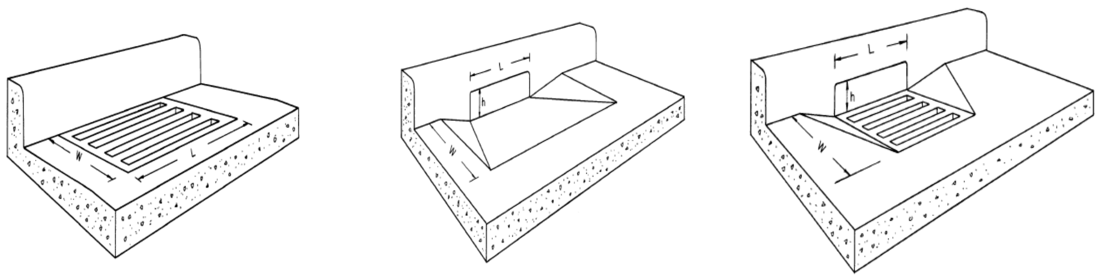
- Grate inlets
- Curb opening inlets
- Combination inlets

Grate inlets consist of an opening in the gutter or ditch, covered by a grate. Curb opening inlets are vertical openings in the curb, covered by a top slab. Slotted inlets consist of a pipe cut along the longitudinal axis with bars perpendicular to the opening to maintain the slotted opening. Combination inlets consist of both a curb opening inlet and a grate inlet placed in a side-by-side configuration, but the curb opening may be located, in part, upstream of the grate.

Curb opening inlets are openings in the curb face that are generally placed in a gutter section. They are more effective on flatter slopes, in sags, and with flows that typically carry significant amounts of floating debris. The interception capacity of curb opening inlets decreases as the gutter grade steepens.

Combination inlets are composed of both a curb opening and a gutter type. These are high-capacity inlets. The use of combination inlets will be required in sags and on grades of less than 3 percent.

Figure 5-2 illustrates each class of inlet. For the general case, inlets should meet the types included in the Standard Plans. These are grated inlets on continuous longitudinal grades, and combination curb opening and grated inlets with a depression of the gutter at sag locations. However, for specific approved cases, curb opening inlets without the grate may be used, slotted drains may also be used with grates, and each type of inlet may be installed with or without a depression of the gutter.



Grate — Curb Opening Inlet — Combination Inlet

Figure 5-2: Perspective View of Gutter and Curb Opening Inlets

Pavement inlets can be placed either on a continuous grade or in a sump or sag condition. If pavement drainage can enter an inlet from only one longitudinal direction, a continuous grade condition exists. Alternatively, if the inlet is located at a point where flow enters it from two directions, a sump condition exists.

The interception capacity of an inlet is the gutter flow that enters an inlet under a given set of conditions. The capacity changes as those conditions change.

The efficiency of an inlet is the percent of total gutter flow that inlet will intercept for a given set of operating conditions. In mathematical form, efficiency is defined as:

$$V = \frac{Q_i}{Q}\,(100)$$

Where:

E = Efficiency of an inlet in percent

Q_i= Intercepted flow in ft.³/s

Q = Total gutter flow in ft.³/s

Flow that is not intercepted by an inlet is called bypass or carryover and is expressed mathematically as:

$$Q_b = Q - Q_i$$

Where:

Qb = Bypass flow in ft.³/s

Qi = Intercepted flow in ft.³/s

Q = Total gutter flow in ft.³/s

In most cases, an increase in total gutter flow causes an increase in the interception capacity of an inlet and a decrease in efficiency.

Pavement inlets do not provide an efficient method for collecting large quantities of stormwater. Therefore, non-pavement drainage should be collected upstream of the pavement, where possible.

Chapters 7 and 8 of FHWA publication *HEC 12, Drainage of Highway Pavement, No. FHWA-TS-84-202, March 1984* should be used for calculating the interception capacity of inlets.

In accordance with the Standard Plans, generally only two types of inlets will be used for curb and gutter sections. The Grated Inlet Type 1 or Type 1A will be used on continuous grades. The Combination Curb and Grate Inlet-Type 2 will be used at sag locations.

5.3.5.1 CONTINUOUS GRADE: GRATE INLETS

The water flowing in a section of gutter inlet occupied by grate is called frontal flow. When gutter flow velocity is low enough, the grate inlet intercepts all of the frontal flow and a small portion of the side flow, which occurs along the length of the grate. As the gutter flow velocity increases, water may begin to skip or splash over the grate, and the efficiency of the inlet may be reduced. If splash-over does not occur, the capacity and efficiency of a gutter inlet will increase with an increase of the longitudinal slope.

For interception calculations used for gutter spread analysis, the side flow portion should be ignored, and only that portion of the gutter flow passing directly over the top width of the grate will be accepted as intercepted flow. The remaining gutter flow will be considered to be bypass flow.

5.3.5.2 SAG LOCATIONS: COMBINATION INLETS

Combination inlets consisting of a grate and a curb opening are required for use in sags where hazardous ponding can occur. The interception capacity of the combination inlet is essentially equal to that of a grate alone in weir flow, unless the grate opening becomes clogged. Because of the potential for clogging, assume no less than 60 percent of the grate area is clogged. In orifice flow, the capacity is equal to the capacity of the unclogged grate opening plus the capacity of the curb opening.

5.3.6 INLET LOCATIONS

There are a number of locations where inlets may be necessary, with little regard to the contributing drainage area. These locations should be marked on the plans prior to any computations regarding discharge, water spread, inlet capacity, or flow bypass. Examples of such locations are:

- At all low points in the gutter grade
- Immediately upstream of median breaks, entrance/exit ramp gores, cross walks, and street intersections (i.e., at any location where water could flow onto the traveled way)
- Immediately upgrade of bridges (to prevent pavement drainage from flowing onto bridge decks)
- Immediately downstream of bridges (to intercept bridge deck drainage)
- Within 10 ft. upgrade of cross slope reversals (i.e., the flat cross slope location of super elevation transitions)
- Immediately upgrade from pedestrian crosswalks
- At the end of channels in cut sections
- On side streets immediately upgrade from intersections
- Behind curbs, shoulders, or sidewalks to drain low areas

In addition to the areas identified above, runoff from areas draining toward the highway pavement should be intercepted by roadside channels or inlets before it reaches the roadway. This applies to drainage from cut slopes, side streets, and other areas along the pavement. Curbed pavement sections and pavement drainage inlets are inefficient means for handling extraneous drainage.

In addition, it is good engineering practice to place flanking inlets on each side of the low-point inlet when in a depressed area that has no outlet except through the system. The purpose of the flanking inlets is to relieve the inlet at the low point if it should become clogged or if the design spread is exceeded.

Flanking inlets can be located so they will function before water spread exceeds the allowable spread at the sump location. The flanking inlets should be located so that they will receive all of the flow when the primary inlet at the bottom of the sag is clogged. They should do this without exceeding the allowable spread at the bottom of the sag. If the flanking inlets are the same dimension as the primary inlet, they will each intercept one-half of the design flow when they are located so that the depth of ponding at the flanking inlets is 63 percent of the depth of ponding at the low point. Figure 5-3 below illustrates the logic.

If the flanker inlets are not the same size as the primary inlet, it will be necessary to either develop a new factor or find a trial-and-error solution using assumed depths with the weir equation to determine the capacity of the flanker inlet at the given depths.

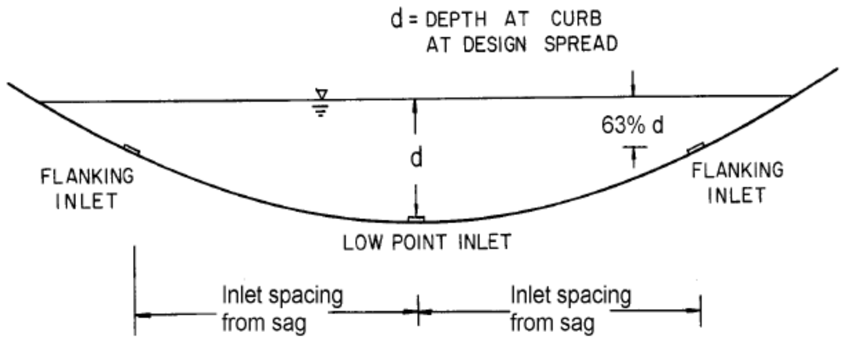


Figure 5-3: Flanking Inlets

5.3.6.1 INLET SPACING ON CONTINUOUS GRADE

Inlets must be located using a trial and error procedure to maintain the depth and spread of flow within allowable limits along the curb line. The last inlet (downgrade location) in a series should intercept all of the flow to that point, with a bypass not to exceed 0.10 cfs for the typical situation. In order to design the location of inlets on a continuous grade, the computation sheet shown in Table 5-4 should be used to document the analysis. A step-by-step procedure follows:

Step 1. Complete the blanks at the top of the sheet to identify the project, route, date, and your initials.

Step 2. Mark on a plan the location of necessary inlets, even without considering any specific drainage area, such as the locations described in Section 5.3.6.

Step 3. Start at a high point at one end of the job, if possible, and work toward the low point. Then begin at the next high point and work backward toward the same low point.

Step 4. To begin the process, select a trial drainage area approximately 300 to 500 ft. long below the high point, and outline the area on the plan. Include any area that may drain over the curb, onto the roadway. However, where practical, drainage from large areas behind the curb should be intercepted before reaching the roadway or gutter.

Step 5. Column 1 describes the location of the proposed inlet by number and station; record this. Identify the curb and gutter type in Column 19 in accordance with the Standard Plans.

Step 6. Compute the drainage area (acres) outlined in Step 4, and record the information in Column 3.

Step 7. Determine the runoff coefficient, C (Rational Equation) for the drainage area (see Chapter 4). Select a C value or determine a weighted C value, and record the value in Column 4.

Step 8. Compute the Time of Concentration (Tc) in minutes, for the first inlet, and record it in Column 5. The Tc is the time for the water to flow from the most hydraulically remote point of the drainage area to the inlet, as discussed in Chapter 4. The minimum Tc is 5 minutes.

Step 9. Using the Tc, determine the rainfall intensity from the Intensity-Duration-Frequency (IDF) curve for the design frequency (see Chapter 4). Enter the value in Column 6.

Step10. Calculate the flow in the gutter using the equation Q=CIA. The flow is calculated by multiplying Column 3, times Column 4, times Column 6. Enter the flow value in Column 7.

Step 11. From the roadway profile, enter the gutter longitudinal slope, S_L, at the inlet, taking into account any superelevation, in column 8.

Step12. From the cross section, enter the cross slope, S_x, in Column 9 and the Column 13 grate width, W, in Column 13.

Step13. For the first inlet in a series, enter the value from Column 7 into column11, and because there was no previous bypass flow, enter 0 into Column 10.

Step14. Enter the allowable spread, as determined by the design criteria outlined in Table 5-3, in Column 15. Calculate the spread, 'T' for the actual gutter section using the procedures discussed in Chapter 5 of FHWA publication *HEC 12*, and enter it into Column 14. Also, determine the depth at the curb, 'd', by multiplying the spread by the appropriate cross slope, and enter the value in Column 12.

Compare the calculated spread with the allowable spread and the depth at the curb with the actual curb height. If the calculated spread, Column 14, is near the allowable spread, and the depth at the curb is less than the actual curb height, continue on to Step 15. Otherwise, expand or decrease the drainage area up to the first inlet to increase or decrease the spread, respectively. The drainage area can be expanded by increasing the length to the inlet, and it can be decreased by decreasing the distance to the inlet. Then repeat steps 6 through 14 until appropriate values are obtained.

Step 15. Select the inlet type and dimensions, and enter the values in Column 16.

Step 16. Calculate the flow intercepted by the grate, Q_i, and enter the value in Column 17. Assume that the intercepted flow is the flow prism directly over the grate width.

Step 17. Determine the bypass flow, Q_b, and enter it into Column 18. The bypass flow is Column 11 minus Column 17.

Step 18. Proceed to the next inlet down the grade. To begin the procedure, select a drainage area approximately 250 to 300 ft. below the previous inlet for a first trial. Repeat steps 5 through 7, considering only the area between the inlets.

Step 19. Compute the Tc for the next inlet based upon the area between the consecutive inlets, and record this value in Column 5.

Step 20. Determine the rainfall intensity from the IDF curve based on the Tc determined in Step 19, and record the value in Column 6.

Step 21. Determine the flow in the gutter, and record the value in Column 7.

Step 22. Record the value from Column 18 of the previous line into Column 10 of the current line. Determine the total gutter flow by adding Column 7 and Column 10 together, and record in Column 11.

Step 23. Determine the spread and the depth at the curb as outlined in Step 14. Repeat steps 19 through 23 until the spread and the depth at the curb are within the design criteria.

Step 24. Select the inlet type, and record it in Column 16.

Step 25. Determine the intercepted flow in accordance with Step 16.

Step 26. Calculate the bypass flow by subtracting Column 17 from Column 11. This completes the spacing design for the inlet.

Step 27. Repeat steps 19 through 27 for each subsequent inlet, down to the low point. The bypass for the last inlet should not exceed 0.10 cfs for the typical situation.

INLET SPACING COMPUTATION SHEET	DATE:_______________ PROJECT:____________ROUTE:__________ Computed By: _________ Sheet _____ of _____

INLET		GUTTER DISCHARGE 10 Year Design Frequency					GUTTER DISCHARGE								INLET DISCHARGE			
No.	Sta.	Drain. Area 'A' **(acres)**	Runoff Coefficient 'C'	Time of Conc. 'Tc' (minutes)	Rainfall intensity 'I' (inches per hour)	Q=CIA (cfs)	Long. Slope S_L (ft./ft.)	Cross Slope S_x (ft./ft.)	Previous Bypass Flow (cfs)	Total Gutter Flow (cfs)	Depth 'd' (inches)	Grate Width 'W' (feet)	Spread 'T' (feet)	Allowable Spread (feet)	Inlet type	Intercept flow (cfs)	Bypass Flow (cfs)	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)

Table 5-4: Inlet Spacing Computation Sheet

5.3.6.2 BRIDGE DECK DRAINAGE

Similarities between bridge deck and roadway drainage inlets are understandable because these two types of drainage processes are, as a whole, very similar. The hydraulic fundamental for the inlets are identical; however, design requirements for bridge deck systems differ in the following respects from roadway systems:

- Total or near-total interception is desirable up gradient of expansion joints
- Deck systems are highly susceptible to inlet clogging
- Inlet spacing is often predetermined by bent spacing
- Inlet sizes are often constrained by structural considerations
- To the extent possible, roadway drainage should be intercepted up gradient of a bridge deck

The interception capacity of bridge scuppers can be generally determined as listed above for curb and grated gutter inlets. See FHWA publication *HEC-21 Bridge Deck Drainage*, *May 1993* for additional design considerations.

5.3.7 ROADWAY GRADES

The critical step for establishing roadway grade lines is the determination of a roadway Design High Water (DHW) elevation. The DHW provides an elevation for establishing a roadway base clearance that will adequately protect the base from saturation, consistent with the service requirements of the roadway.

The DHW for setting roadway grades is generally based on a determination of high water surface for the selected storm frequency. Setting the roadway base courses above this DHW level will help to avoid problems with saturation of the subgrade and premature failures of the pavement. The following procedure can provide a framework for such determinations:

a. Establish the drainage feature likely to control the water level. The following features should be considered:

   i. Published flood plain levels

   ii. Streams and culverts.

   iii. Canals, ditches, and swales

   iv. Retention/detention facilities

   v. Reservoirs

   vi. Wetlands

   vii. Pumping facilities- stormwater

viii. Water table

ix. Local hydrogeology

b. Establish the service requirements for the roadway, and select an appropriate design frequency for drainage facilities. Roadway classification will be either the main routes or secondary roads. Use Table 5-1 to select the flood frequency for various structures and conditions (i.e., 50-year for culvert crossing and 10-year for roadway ditch water surface levels for main routes).

c. Based on the drainage feature and design frequency from Step A and Step B, respectively, find the design event water surface elevation. Use procedures discussed in Chapters 4 and 5 as appropriate for this analysis and determination. This elevation is the DHW.

d. The bottom of the pavement aggregate sub-base course should be located above the DHW, or alternately, the drainage conveyance systems should be designed to maintain the DHW below the existing or proposed pavement sub-base level, by a minimum clearance level. This clearance level should be 2 to 3 ft. on the main routes, and no less than 1 foot on secondary roads.

5.3.8 CONSTRUCTION AND MAINTENANCE CONSIDERATION

Visual, surface-level inspections of drainage facilities should be made by maintenance supervisors to identify obvious defects, hazards, or potential problems, and also to monitor known problems. These inspections should be made annually and during and after each major storm. Gutters should be inspected periodically and maintained to permit free flow. Formed gutters should be sealed or repaired to maintain structural integrity.

When curbs fail to perform their function due to settlement, heave, or damage, they should be repaired or replaced. Curbs that are attached to sidewalks should be maintained to the level of the sidewalks, approximately.

When the inlet is located in the clear zone, the designer should place the inlet as close to parallel in the direction of traffic as possible. Placing the inlet at an angle may cause an errant vehicle to overturn.

Quarry spalls should not be placed around inlets. This creates a safety hazard for the maintenance personnel who need good footing to lift the heavy lids. If quarry spall check dams are desired for erosion control, locate them a minimum of 10 ft. away from the grate inlet.

5.4 OPEN CHANNELS AND DITCHES

Open-channel hydraulics provide the basis for evaluating the hydraulic capacity of most roadway drainage facilities. An open channel is a watercourse that allows part of the flow to be exposed to the atmosphere. This type of channel includes rivers, culverts, storm drain systems that flow by gravity, roadside ditches, and roadway gutters. Open-channel flow design criteria are used in several areas of transportation design, including:

- Stream and river changes
- Flood plain analysis
- Stream bank protection
- Culverts and associated inlet/outlet channel revisions
- Roadside ditches
- Conveyance channels
- Storm drains
- Bridge waterways
- Outlet discharge and downstream analysis

Proper design requires that open channels have sufficient hydraulic capacity to convey the flow of the design storm. In the case of earth-lined channels, erosion protection is required if the velocities are high enough to cause scouring.

5.4.1 GEOMETRIC ELEMENTS

Most open-channel flow problems require an evaluation of various geometric elements associated with the shape of the channel. For most artificial or constructed open channels, geometric elements can be determined mathematically in terms of depth of flow and other dimensions for channel shape. However, for most natural channel sections, profile sections based on the actual variations in the depth of flow across the section are generally required. The following geometric terminology is pertinent to the fundamentals of open-channel hydraulics.

Prismatic Channel: An artificial channel with non-varying cross section and constant bottom slope.

Channel Section: The cross section of a channel taken perpendicular to the direction of the flow.

Depth of Flow: The vertical distance of the lowest point of a channel section from the free surface.

Stage: The elevation or vertical distance of the free surface above a given point.

Top Width: The width of the channel section at the free surface.

Flow Area: The cross-sectional area of the flow perpendicular to the direction of the flow.

Wetted Perimeter:	The length of the line of intersection of the channels wetted surface on a cross-sectional plane perpendicular to the direction of flow.
Hydraulic Radius:	The ratio of the flow area to its wetted perimeter.
Hydraulic Depth:	The ratio of the flow area to its top width.
Critical Flow Section Factor:	The product of the flow area and the square root of the hydraulic depth.
Uniform-Flow Section Factor:	The product of the flow area and the hydraulic radius raised to 2/3 power.
Steady Flow:	Steady flow occurs in an open channel when the discharge or rate of flow at any location along the channel remains constant with respect to time.
Unsteady Flow:	Open-channel flow is unsteady when discharge at any location in the channels changes with respect to the time.
Uniform Flow:	Uniform flow occurs only in a channel of a constant cross section, slope, and roughness known as uniform open channel. Generally, uniform flow is also steady flow.
Normal Depth:	When the requirements of the uniform flow are met, the depth of flow for a given discharge is defined as normal depth.
Unsteady Uniform Flow:	Flow in which there are variations of both space and time is the most complex type of flow to evaluate mathematically.
Rapidly Varied Flow:	Also known as local phenomenon, examples of which include hydraulic jump and hydraulic drop. The primary example of gradually varied flow occurs when sub-critical flow is restricted by a culvert or storage reservoir. The water-surface profile caused by such a restriction is generally referred to as a backwater curve.
Laminar Flow:	Generally occurs when the viscous forces are strong relative to inertial forces, causing water to flow in streamlines.
Turbulent Flow:	When viscous forces are weak relative to the inertial forces, the flow can be classified as turbulent.

Reynolds Number: Operational limits for laminar and turbulent flow can be evaluated using a dimensionless parameter known as the Reynolds Number, which is mathematically expressed as:

$$R_e = \frac{(vL)}{\vartheta}$$

Equation 5-2

Where:

Re = Reynolds Number

V= Average velocity of flow in ft./s

L = Characteristic length in feet (pipe diameter for conduit)

ϑ = Kinematic viscosity of fluid in $ft.^2/s$

For pipe flow, laminar flow generally occurs until the Reynolds Number value exceeds approximately 2,000. A transitional zone is then observed between laminar and turbulent flow. The Reynolds Number value at the upper limit of this transitional zone may be as high as 50,000. If the pipe diameter is converted to hydraulic radius for representing characteristic length in the Reynolds Number value, the corresponding transitional range is 500 to 12,500.

Froude Number: The importance of gravity as a driving force in open-channel drainage systems makes its effect on the state of flow a major factor for evaluation. This can be done using a dimensionless parameter known as the Froude Number, which is expressed mathematically as:

$$F_R = \frac{V}{(gL)^{\frac{1}{2}}}$$

Equation 5-3

Where:

F_R = Froude Number

V = Average velocity of flow in ft./s

L = Characteristic length in ft. (hydraulic depth for open channels)

g= Acceleration due to gravity in 32 ft./s^2

If the Froude Number value is greater than one, inertial forces dominate, and the flow is super-critical. The flow in this regime will also tend to be turbulent and unsteady for the general case. If the Froude Number is less than one, gravity forces dominate, and the flow is called sub-critical or tranquil flow. When the Froude Number is equal to one, then flow is defined as the critical flow.

5.4.2 CHANNEL DESIGN CRITERIA

Channels and ditches should be designed to convey the required frequency storm event runoff with a 0.5-foot freeboard. The preferred cross section of a ditch is trapezoidal; however, a V-ditch can also be used where right-of-way is limited and/or the design requirements can still be met. The depth of channel should be sufficient to remove the water while maintaining the required design water surface clearance below the pavement sub-base.

Side slopes can vary but should be limited to no steeper than 2 horizontal to 1 vertical for earth channels with a grassed lining. Roadside ditch side slopes along the roadway should meet the clear zone design requirements and be limited to less than a 2-foot design depth, unless guardrail or barrier traffic protection is provided.

5.4.2.1 CHANNEL TYPES

Open channels can be generally classified as those that occur naturally, are man-made, or improve natural channels. Man-made channels are also called artificial channels, including the following types, in use on most roadway projects:

- Roadside ditch
- Interceptor ditch
- Swale
- Median ditch (swale)
- Outfall ditch
- Lateral ditch
- Canal

Each of these channel types are artificial systems designed to provide specific drainage capacities. In general, roadside and median ditches are relatively shallow trapezoidal channels, while swales and interceptor ditches are shallow triangular channels. These types are designed to handle local surface runoff from the roadway surfaces or to lower the water table elevations by intercepting groundwater.

In most cases, outfall ditches or canals are designed as receptors of runoff from numerous secondary drainage facilities, such as side ditches or storm drains. The use of a roadside ditch as an outfall ditch is not recommended because its probable size and depth could create a potential driving hazard.

5.4.2.2 DESIGN METHODS

The fundamental relationship for performing open-channel capacity calculations will be the Manning Equation. All ditches and channels should be designed using the methods and procedures in FHWA publication *HDS 4*. All channel designs should use the "stable channel concepts" in accordance with Chapter 5 of *HDS 4*.

5.4.2.3 LININGS

Channels should be designed to be stable under the design flow conditions. To maintain the integrity of the channel, earth ditches are usually lined with grass; however, this type of lining is only acceptable for flow velocities less than 5 ft. per second and where the channel is normally dry. For higher velocities with a steeper hydraulic gradient and channel slopes, more protective channel linings may be required.

The three main classifications of open-channel linings are vegetative, flexible, and rigid. Vegetative linings include grass with mulch, sod, and lapped sod. Rock riprap and geotextile or interlocking concrete grids are types of flexible linings, while rigid linings include concrete, asphalt, sand/cement riprap, and soil cement.

Velocity limitations for artificial open channels should be consistent with stability requirements for selected channel linings. Typical guideline velocities for these linings are summarized in Table 5-5.

Lining Type	**Maximum Velocity (feet per second)**
Grass with mulch	Less than 4.0
Sod (well-maintained)	4.0
Lapped sod	5.5
Riprap	6.0
Asphalt	8.0
Geotextile grid	4.0- 8.0*
Rigid	10.0**

*Varies with grid type

** Higher velocities acceptable with provision for energy dissipation

Table 5-5: Permissible Velocities for Various Linings

Linings should be designed using a shear stress approach, and using the calculation guidelines and procedures in Chapter 5 of FHWA publication, *HDS 4*.

5.4.3 CONSTRUCTION AND MAINTENANCE CONSIDERATION

The design of an open channel should be consistent with DPW's standard construction and maintenance practices. If special provisions are warranted, this information should be presented in the design documents.

To prevent cracking and failure, concrete linings must be placed on a firm, well-drained foundation. In saturated soils, empty channels with a rigid lining such as concrete, may float or break up due to the buoyancy of displaced water. The total upward force on an empty channel is equal to the weight of the displaced water. To prevent this, the lining should be increased in thickness to add weight, or if the flow is sub-critical, weep holes may be placed at intervals in the channel bottom to relieve the upward pressure on the channel. When flow is super-critical, sub-surface drainage should be used instead of weep holes, with properly-designed filters to avoid soil piping through the sub-drains.

Open channels rapidly lose their effectiveness unless they are adequately maintained. Maintenance includes repairing erosion damage, mowing grass, cutting brush, and removing any sediments or debris from the channel.

Ditches, outfalls, and detention areas must be provided, with maintenance access.

5.5 STORM DRAINS

A storm drain is the portion of the highway drainage system that receives surface water through inlets and conveys the water through conduits to an outfall. It is composed of different lengths and sizes of pipe or conduit connected by appurtenant structures. A section of conduit connecting one inlet or appurtenant structure to another is termed a "segment" or "run." The storm drain conduit is most often a circular pipe, but it can also be a box or other enclosed conduit shape. Typical structure types include inlets, catch basins, manholes, cleanouts, junction chambers, headwalls, flow controls, energy dissipaters, and outlets.

All storm drain designs should be based on an engineering analysis that takes into consideration runoff rates, pipe flow capacity, hydraulic grade line, soil characteristics, pipe strength, potential construction problems, and potential runoff treatment issues. The majority of time spent on a storm drain design is calculating runoff from an area and designing the enclosed conveyance system to carry the flow. A storm drain design may be performed by hand calculations or by one of several available computer programs and spreadsheets. See Sections 4.4.6 and 5.5.4 for general information on hydraulic modeling programs.

Runoff flows are determined using the procedures in Chapters 2 and 4 of this TSDM. The storm drain hydraulic design should follow the guidelines and procedures in Chapters 7 and 8 of FHWA publication *HDS 4*.

5.5.1 DESIGN FEATURES

Along with determining the required pipe sizes for flow conveyance, storm drain system design incorporates the following features:

1. Soil Conditions — Soil with adequate bearing capacity must be present to interact with the pipes and support the load imparted by them. Surface and sub-surface drainage must be provided to ensure stable soil conditions. Soil resistivity and pH must also be known so the proper pipe material can be used. Pipe installation in poor soil conditions should be performed in accordance with the review and recommendations of a qualified Geotechnical Engineer, to determine additional soil treatments and bedding improvements that may be required.

2. Inlet Spacing and Capacity — Design guidelines are detailed in Section 5.3.5.

3. Junction Spacing — Junctions (catch basins, grate inlets, and manholes) should be placed at all breaks in grade and horizontal alignment. Pipe runs between junctions should not exceed 300 ft. for pipes smaller than 48 in. in diameter, and 500 ft. for pipes 48 in. or larger in diameter. When grades are flat, pipes should be small or there could be debris issues. Designers should consider reducing the minimum spacing.

4. Future Expansion — If it is anticipated that a storm drain system may be expanded in the future, provisions for the expansion should be incorporated into the current design. Additionally, the existing system should be inspected for structural integrity and hydraulic capacity prior to expansion.

5. Velocity — The velocity of flow should be 3 ft. per second or greater to prevent the pipes from clogging due to siltation. Velocity of flow should not be excessively high, because high flow velocities (approaching and above 10 ft. per second) produce very large energy losses in the storm drain system and also cause excessive wear and damage to the pipes and structures due to accelerated abrasion wear and surge impacts. The velocity should be calculated under full flow conditions, even if the pipe is only flowing partially full with the design storm.

The designer should obtain separate approval for any pipes having velocities exceeding 10 ft. per second. The high velocity pipe designs will require features such as restrained joints, thrust blocks, pipe-to-wall thrust collars, special bedding, bedding restraints, pipe types resistant to abrasion damage, energy dissipaters, etc.

6. Grades at Junctions — Pipe crowns of branch or trunk lines entering and exiting junctions should be at the same elevation. If a lateral is placed so its flow is directed against the main flow through the manhole or catch basin, the lateral invert must be raised to match the crown of the inlet pipe. (A crown is defined as the highest point of the internal surface of the transverse cross section of a pipe.)

7. Minimum Pipe Diameter — The minimum pipe diameter should be 12 in., except that pipe located under roadway travel lanes should be 18 in. minimum.

8. Maximum Pipe Diameter – Designers should verify the maximum available pipe diameters per manufacturing type and as suitable for the bedding and cover conditions. Designers should make sure that their selected structure types and sizes are suitable for the size and type of pipe to be attached to it.

9. Energy Losses — Energy losses are calculated to determine the hydraulic grade line. The hydraulic grade line should be established as part of all storm drain systems (other than capacity checks for simple layout systems involving one or two pipes). Energy losses can be significant and of concern for the following situations:

- High flow velocities in the system
- Maintaining sufficient velocity in pipes on flat slopes
- When inlet and outlet pipes form a sharp angle at junctions
- When there are multiple flows entering a junction
- When pipes entering and leaving the junction are very shallow
- High water surface elevations at an inlet and/or outlet
- When the hydraulic grade line is higher than the pipe profile

10. Outfalls — An outfall is where the storm drain system discharges to the natural or existing waterway. Typically, the outfall should be designed to minimize disturbance to streams and wetlands and include erosion protection.

Additional considerations for outfalls include energy dissipaters and tidal gates. Energy dissipaters prevent erosion at the storm drain outfall. Energy dissipation should be in accordance with the guidelines of Chapter 10 of FHWA publication *HDS 4*. Another reference for the design of energy dissipaters is FHWA publication *HEC No. 14, Hydraulic Design of Energy Dissipaters for Culverts and Channels, No. FHWA-NHI-06-086, July 2006*.

The installation of tide gates may be necessary when the outfall is in a tidal area to help limit backflow through the pipe system. Tide gate outfalls need to be sized (diameters and storage bay sizes) using a mass flow procedure. An older, but still available reference on sizing of tide gates is the USDA National Resources Conservation Service (NRCS) *Technical Release No. 1, July 28, 1955*.

In all cases, the flow velocity at the outlet of the dissipater structure should be non-erosive for the existing conditions, and be less than the velocity in the natural/existing channel. When discharging to natural streams and wetlands, consideration should be made to discharge using a level spreader trench located parallel to the wetland or stream vegetated buffer. The spreader trench should be designed as a combination infiltration trench for low flows and to produce non-erosive surface sheet flow for larger storm events.

11. Location — Medians and outer edges of shoulders usually offer the most desirable storm drain location. In the absence of medians or shoulders, a location beyond the edge of pavement on right-of-way or on easements is preferable. When a storm drain is placed beyond the edge of the pavement, it is generally recommended that a one-trunk system with connecting laterals be used instead of running two separate trunk lines down each side of the road.

12. Confined Space and Structures — Any structure (catch basin, manhole, inlet, junction chamber, etc.) more than 4 ft. in depth is considered a confined space. As such, any structure exceeding 4 ft. in depth that could be accessed by personnel must be sized with room for personnel to maneuver and stand up. This requires a minimum inside dimension of 4 ft. wide by 6 ft. high. All confined spaces should meet OSHA regulations for ventilation and access. Structures more than 15 ft. deep should be avoided due to the limitations of cleaning by suction and rodding maintenance trucks. Any design requiring a structure deeper than 15 ft. must have specific review and approval on the access and maintenance aspects.

5.5.2 HYDRAULICS OF STORM DRAIN SYSTEMS

The hydraulic design of storm drainage systems requires an understanding of basic hydrologic and hydraulic concepts and principles, which include flow classification, the conservation of mass, the conservation of momentum, and the conservation of energy. FHWA publication *HDS 4* will be the primary reference used for design reviews by DPW.

5.5.3 STORM DRAIN DESIGN: MANUAL METHOD

It is recommended that storm drain systems be designed using one of the readily-available computer modeling programs that “route” the runoff flows through the system. Basic pipe system designs using handheld calculator methods will be acceptable if documented similar to Table 5-6. The design using Table 5-6 should be further supported with exhibits showing the layouts, contributory drainage boundaries, contours, runoff travel paths, outfalls, and existing/proposed topography. Table 5-6 has five divisions -- location, discharge, drain design, drain profile, and remarks, as follows:

Location

The location section provides all of the layout information for the drain.

Column 1 gives a general location reference for the individual drain lines, typically by the name of a street or a survey line.

Columns 2 and 3 show the stationing and offset of the inlets, catch basins, or manholes — either along a roadway survey line or along a drain line.

Discharge

The discharge section presents the runoff information and total flow into the drain.

Column 4 is used to designate the various drainage areas that contribute to a particular point in the drain system. The drainage areas should be numbered or lettered according to some reference system on the drainage area maps. The type of ground cover (pavement, median, etc.) may be indicated. Because drainage areas must be subdivided according to soil and ground cover types, a drainage area may have several different parts.

Column 5 shows the cumulated drainage area used for the associated pipe section design in acres.

Column 6 shows the Rational Equation runoff coefficient (see Chapter 4). Each individual drainage area must have a corresponding runoff coefficient.

Column 7 is the product of columns 5 and 6. Column 7 is also the effective impervious area for the subsection.

Column 8. is the summation of the product of the coefficient 'C' and the drainage area 'A' of all of the effective areas contributing runoff to the point in the system designated in Column 2. All of the individual CxA values in Column 7 contributing to a point in Column 2 are summed.

Column 9 shows the Tc to the structure indicated in Column 2. Generally, the time chosen here would be the longest time required for water to travel from the most hydraulically remote part of the storm drain system to this point. This would include flow over the drainage basin and flow through the storm drain pipes. The Tc should be expressed to the nearest minute and should never be less than five minutes.

When the runoff from a drainage area enters a storm drain and the Tc of the new area is shorter than the accumulated Tc of the flow in the drain line, the flow in the downstream pipe should be calculated using the overall accumulated Tc with the accumulated areas (both new and upstream areas combined).

The easiest method for determining the Tc of the flow already in the system (upstream of the structure in Column 2) is to add the Tc from Column 9 of the previous run of pipe (this value should be on the row above the row that is currently being filled in) to the time it took the flow to travel through the previous run of pipe. To determine the time of flow (or more precisely, the travel time) in a pipe, the velocity of flow in the pipe and the length of the pipe must be calculated. Velocity is computed using the Manning Equation and is found in Column 16 of the previous run of pipe. The length used is the value entered in Column 18 for the previous run of pipe. Obviously, this calculation is not performed for the very first (most upstream) run of pipe in a storm drain system.

$$T_1 = L/(60V)$$

Where:

T_1 = Tc of flow in pipe in minutes

L = Length of pipe in ft. (m), Column 18

V = Velocity in ft./s (m/s), Column 16 of the previous run of pipe

The designer should note that this calculation assumes that the pipe is flowing full. It is accurate for pipes flowing slightly less than half full up to completely full. It will be slightly conservative for Tc calculations when the pipe is flowing significantly less than half full.

Column 10 shows the rainfall intensity corresponding to the time indicated in Column 9 and the location of the project.

The intensity is in inches per hour to the nearest hundredth. The rainfall intensity used is a 25-year recurrence interval for storm drain laterals and trunks and the 10-year recurrence interval for laterals without trunks. See Chapter 4 for the related intensity charts.

Column 11 shows the amount of runoff to the nearest 10th of a cubic foot per second, up to the point indicated in Column 2. It is computed as the product of columns 8 and 10. This is simply applying the Rational Method to compute runoff from the entire drainage area upstream of the pipe being analyzed.

Column 12 shows any flow, other than the runoff calculated in Column 11, to the nearest 10th of a cubic foot per second that is entering the system up to the point indicated in Column 2. It is rare to have flow entering a system other than runoff from the drainage basin, but this does occur. For instance, this occurs when an underdrain that is draining groundwater is connected to the storm drain. The label for this column indicates that these flows are considered constant for the duration of the storm, so they are independent of the Tc.

This column is also used when the junction is a drywell and a constant rate of flow is leaving the system through infiltration. When this occurs, the value listed in Column 12 is negative. See Chapter 6 for drywell design criteria.

Column 13 is the sum of columns 11 and 12 and shows the total flow in cubic feet per second to the nearest 10th to which the pipe must be designed.

Drain Design Section

This section presents the hydraulic parameters and calculations required to design storm drain pipes.

Column 14 shows the pipe diameter in feet. This should be a minimum of 1 foot. Pipe sizes should never decrease in the downstream direction.

The correct pipe size is determined through a trial-and-error process. The engineer selects a logical pipe size that meets the minimum diameter requirements and a slope that fits the general slope of the ground above the storm drain. The calculations in Column 17 are performed and checked against the value in Column 13. If Column 17 is greater than or equal to Column 13, the pipe size is adequate. If Column 17 is less than Column 13, the pipe does not have enough capacity and must have its diameter or slope increased, after which Column 17 must be recalculated and checked against Column 13.

Column 15, Pipe Slope, is expressed in feet per foot. This slope is normally determined by the general ground slope but does not have to match the surface ground slope. The designer should be aware of buried utilities and obstructions that may conflict with the placement of the storm drain.

Column 16 shows the full-flow velocity. It is determined by the Manning Equation, which is shown below. The velocity is calculated for full-flow conditions, even though the pipe is typically flowing only partially full. Partial flows will be very close to the full-flow velocity for depths of flow between 30 percent and 100 percent of the pipe diameter.

$$V = \frac{0.59}{n} D^{0.67} S^{0.5}$$

$$Q = \frac{0.46}{n} D^{2.67} S^{0.5}$$

Velocities should be within a range of 3 to 10 ft. per second. If higher than 10 ft. per second, additional design considerations must be taken into account. Velocities below 3 ft. per second will create additional maintenance considerations.

Column 17, Pipe Capacity, shows the amount of flow in cubic feet per second, which can be taken by the pipe when flowing full. It is computed using the following formula:

$$Q = A\ V$$

Drain Profile

Columns 18 through 23, the Drain Profile Section, include a description of the profile information for each pipe in the storm drain system. They describe the pipe profile and the ground profile. The ground elevations should be finished elevations, to the 100th of a foot. The items in this section are generally self-explanatory, except for Column 18. The length shown is the horizontal projection of the pipe, in feet, from the center to the center of appurtenances. Generally, profiles should be set to provide a minimum of 2 ft. of cover over the top of the pipe.

Remarks

Column 24, Remarks, is for any information that might be helpful in reviewing the calculations. This space should note unique features such as drop manholes or energy dissipaters, reasons as to non-conventional slopes or grade changes, specific types of pipes due to loading and cover depths, velocity or maintenance considerations, changes in design frequency, etc.

STORM DRAIN COMPUTATION SHEET											DATE____________________ SP_______________ ROUTE____________ Computed By ____________________ Sheet ______ of __________												
Drain located on.	From Station	To Station	Contributing Areas (ac.)	Cum. Drainage Area 'A' (ac.)	Runoff Coefficient 'C'	CA	ΣCA	Tc (min.)	Rainfall Intensity 'I' (in./hr.)	Runoff Flow (cfs)	Con. Inflow (cfs)	Total Flow (cfs) Width	Pipe Diameter (ft.)	Pipe Slope (ft./ft.)	Flow velocity (ft./s)	Pipe capacity (cfs)	Length (ft.)	Elevation Change (ft.)	U/S Ground Elev. (ft.)	D/S Ground Elev. (ft.)	U/S Invert Elev. (ft.)	D/S Invert Elev. (ft.)	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)

Table 5-6: Storm Drain Calculation Sheet

5.5.4 COMPUTER ANALYSIS

Storm drain design by computer analysis offers some distinct advantages over calculations performed by hand. Chief among these advantages is the ability to perform complex flow routings through the system, which can take into account the detention due to storage within the pipes and structures and overlapping of various basin runoff hydrographs. This analysis develops a more accurate picture of the hydraulic grade lines and flow conditions within a storm drain system for the design storm peak conditions.

Most computer programs will have the ability to process various runoff hydrograph calculation methods that use the Rational Method or NRCS curve numbers, as well as the ability to enter storm distributions and rainfall intensity data unique to a specific location. They also will allow selection of different routing methods. Most of these programs will have sub-routines for designing detention within a system or accepting the input of additional detention storage and discharge controls. The designer should develop a full understanding of the various runoff and routing methodologies and in particular, select those that are best for the application when using these programs.

There are several commercially-available computer programs for storm drain design. Two programs accepted by DPW are StormShed by Engenious Systems, Inc. and FlowMaster by Haestad Methods.

5.5.5 PIPE MATERIALS FOR STORM DRAINS

There are various pipe materials that are acceptable for storm drains. Pipe material selection includes hydraulic characteristics, site conditions, geologic conditions, corrosion resistance, safety considerations, and cost. Pipe types appropriate for a project are dependent on several factors, including but not limited to fill height, size, strength, corrosion, abrasion potential, debris passage, and necessary end treatments.

Pipe design and installation is based on two general categories -- rigid and flexible pipes. The designer should be familiar with the design theories for both. The pipe type selection and installation methodology used should be prepared using the appropriate design principle.

Pipe selection should be made in accordance with the following constraints.

5.5.5.1 PIPE MATERIALS

Pipe materials used by DPW can be categorized into three main categories -- storm sewer pipe (or otherwise called storm drain pipe), underdrain pipe, and culvert pipe.

Storm sewer pipe usually ranges from 12 to 48 in. in diameter, and is used to convey roadway runoff or groundwater away from the roadway profile. Types of storm sewer pipes and materials should be selected based on the corrosion resistance and strength requirements suitable for the specific requirements. Pipe types can include concrete, reinforced concrete, metal, corrugated metal, and thermoplastic solid and corrugated wall.

All storm sewer pipes should use gasketed, leak-proof joints, and be pressure-tested after installation to indicate the presence of leaking seams or joints. The design life for storm sewer pipes should generally match the design life of the roadway pavement, or a minimum of 25 years. If the pipe is to be installed in deep fills crossing the roadway section, then the design life should be the same as required for culvert pipe.

Underdrain pipe is smaller diameter, perforated pipe intended to intercept groundwater and convey it away from areas such as roadbeds or from behind retaining walls. Typical underdrain applications use 6- to 8-in. diameter pvc, or polyethylene pipe, both solid wall and corrugated, but larger diameters can be specified. Underdrain pipe is generally used in conjunction with well-draining backfill material and a geotextile filter fabric. The design life of underdrain pipe should be the same as required for storm sewer pipe.

Culvert pipe is a conduit under a roadway or embankment used to maintain flow from a natural channel or drainage ditch. Culverts are often located under high fills and usually cross the roadway making replacement difficult. Because of this, a minimum design life expectancy of 50 year is required for all culverts under the main route roadways. A minimum 25-year design life should be used for other secondary road locations. The type of culvert selected can vary substantially from one location to another due to the hydraulic requirements, loadings, and corrosion resistance. Culverts use storm sewer pipe, reinforced concrete box sections (both rectangular and bottomless), corrugated metal, corrugated plastic pipe, corrugated metal pipe arch, and structural plate.

5.5.5.2 PIPE DURABILITY

Once a designer has determined the pipe classification needed for an application, the next step is to ensure that the pipe durability will extend for the entire design life. There are two main durability factors -- corrosion potential and abrasion resistance.

Corrosion potential will be categorized generally as moderate or extreme. If the soil or water pH is less than 5 and greater than 8.5 and/or with a soil resistivity less than 1,000 ohm-cm then there is a potential for extreme corrosion conditions. All pipe installations in the coastal environment or brackish water conditions can also be considered as extreme corrosion conditions. If the pH and soil resistivity of the installation site is not known, then testing should be performed and pipe material selection made accordingly.

Pipes suitable for the moderate condition include thermoplastic, concrete, and metal. Metal pipes should have protective treatments. These treatments are typically protecting on both sides with asphaltic or polymer coatings. Where abrasion of the bottom of pipes due to high velocities and heavy bed loads is a problem, then additional coatings such as asphalt invert paving is required. Corrugated steel pipe polymer coatings should conform to AASHTO M-246, composed of a minimum of 10 mils thick polyethylene and acrylic acid copolymer. Asphaltic coatings are usually a proprietary manufacturing process, using a spun asphalt lining on the inside for a hydraulically-smooth interior. Galvanized metal is not suitable due to its potential for loading of zinc into the environment. An alternative to asphalt protective treatments for corrugated steel pipes is to increase the wall thickness to compensate for loss of metal for the desired life span.

Pipes suitable for high corrosion potential conditions are thermoplastic and concrete pipes only.

Abrasion is the wearing away of pipe material by water-carrying sands, gravels, and rocks. All types of pipe material are subject to abrasion and can experience structural failure around the pipe invert if not adequately protected. Particular concern would be for streams with high bed loads, and with frequent or steady low flows with velocities 6 to 10 ft. per second. For these conditions, consideration should be given to placing the culverts on flat grades to encourage deposition within the culvert; reducing velocity through the culvert by increasing diameters and flattening grades; providing extra asphaltic paving of the inverts; and increasing wall thickness by at least one or two standard gauges on metal pipes.

Where velocities are greater than 10 ft. per second, asphaltic coatings will have extremely short life expectancies and the wear on concrete inverts can be quite rapid depending on the amount of abrasives in the flow. For these conditions, the use of thermoplastic pipe with restrained joints is recommended. Solid wall High Density Polyethylene (HDPE) pipe with fusion welded joints is probably the most resistant to the abrasion forces. The use of continuous wall HDPE requires additional considerations for the thermo and dynamic forces involved, such as pipe anchors, wall flanges, and surge blocks.

Pipes that have deteriorated over time due to either corrosion or abrasion will significantly affect the structural integrity of the roadway embankment. Once identified, these pipes should be replaced as soon as possible. In particular, they should be replaced as part of a new project's overall construction. Failure of a pipe will usually result in the ultimate failure of a roadway.

5.5.5.3 FILL HEIGHT

Pipe types are constrained by their ability to carry the loadings from live vehicular traffic and longer-term, dead loads from soil cover. Assuming that the pipe is installed in accordance with DPW's standards, the pipe should perform satisfactorily if placed within the limitations shown in the Fill Height Tables 5-7a through 5-7c.

Pipe systems should be designed to provide at least 2 ft. of cover over the pipe measured from the outside diameter of the pipe to the bottom of the pavement. This measurement does not include any asphalt or concrete paving above the top course. This depth tends to provide adequate structural distribution of the live load and also allows a significant number of pipe alternatives to be specified on a contract.

During construction, these minimum cover requirements may not be adequate to protect the pipe from equipment loadings, where additional cover or protected crossings may be required.

Concrete Pipe Diameter (inches)	Maximum Cover in Feet				
	Plain AASHTO M 86	Class II AASHTO M 170	Class III AASHTO M170	Class IV AASHTO M 170	Class V AASHTO M 170
12	18	10	14	21	26
18	18	11	14	22	28
24	16	11	15	22	29
30		11	15	23	29
36		11	15	23	29
48		12	15	23	29
60		12	16	24	30
72		12	16	24	30
84		12	16	24	30

Table 5-7a: Fill Height, Concrete Pipe

Concrete Pipe Diameter (inches)	Pipe Wall Thick. (inches)	Minimum Cover in Feet			
		Plain AASHTO M 86	Class III AASHTO M170	Class IV AASHTO M 170	Class V AASHTO M 170
12	2	1.5	1.5	1.0	0.5
18	2.5	1.5	1.5	1.0	0.5
24	3	1.5	1.5	1.0	0.5
30	3.5	1.5	1.5	1.0	0.5
36	4	1.5	1.5	1.0	0.5
48	5		1.5	1.0	0.5
60	6		1.5	1.0	0.5
72	7		1.5	1.0	0.5
84	8		1.5	1.0	0.5

Table 5-7b: Concrete Pipe for Shallow Cover Installations

Solid Wall PVC	Profile Wall PVC	Corrugated Polyethylene
ASTM D 3034 SDR 35 3 in. to 15 in. dia. ASTM F 679 Type 1 18 in. to 48 in. dia.	AASHTO M 304 or ASTM F 794 Series 46 4 in. to 48 in. dia.	AASHTO M 294 Type S 12 in. to 60 in. dia.
25 ft. All diameters	25 ft. All diameters	15 ft. All diameters

Table 5-7c: Thermoplastic Pipe, Fill Height

Minimum and maximum fill heights for corrugated metal pipe should be based on loading calculations established for flexible pipe theory in accordance with the pipe manufacturer's recommendations for that specific size, corrugation type/size, material type, and wall thickness.

5.5.6 SUB-SURFACE DRAINAGE

Sub-surface drainage is provided for the control of groundwater encountered at roadway locations. Groundwater, as distinguished from capillary water, is free water occurring in a zone of saturation below the ground surface. The sub-surface discharge depends on the effective hydraulic head and on the permeability, depth, slope, thickness, and extent of the aquifer.

Solving sub-surface drainage problems often calls for specialized knowledge of geology and the application of soil mechanics. The designer should work directly with the Geotechnical Engineer regarding the final design of underdrains.

Typical underdrain installations would be those provided for control of seepage in cuts or side hills, or the lowering of the groundwater table for proper subgrade drainage. Sub-surface drainage pipe size should be determined from the Geotechnical Engineer's recommendations, or based on the area of interception, the permeability of the contributing soil layers, and most likely, the internal soil hydraulic grade line. When sub-surface drainage is connected to a storm drain system, the invert of the underdrain pipe should be placed above the operating water level in the storm drain. This helps to prevent reverse flow into the underdrain and in particular flooding of pavement sub-base layers for subgrade underdrains.

5.6 CROSS DRAINAGE

5.6.1 INTRODUCTION

A culvert is a closed conduit under a roadway or embankment used to maintain flow from a natural channel or drainage ditch. A culvert should convey flow without causing damaging backwater, excessive flow constriction, or excessive outlet velocities.

In addition to determining the design flows and corresponding hydraulic performance of a particular culvert, other factors can affect the ultimate design of a culvert and should be taken into consideration. These factors can include the economy of alternative pipe materials and sizes, horizontal and vertical alignment, environmental concerns, and the necessary culvert end treatments.

During a given storm event, a culvert may operate under inlet control, outlet control, or both. Different variables and equations determine the culvert's capacity for each type of control.

5.6.2 CULVERT TYPES

Common culvert shapes generally available and used in highway applications are:

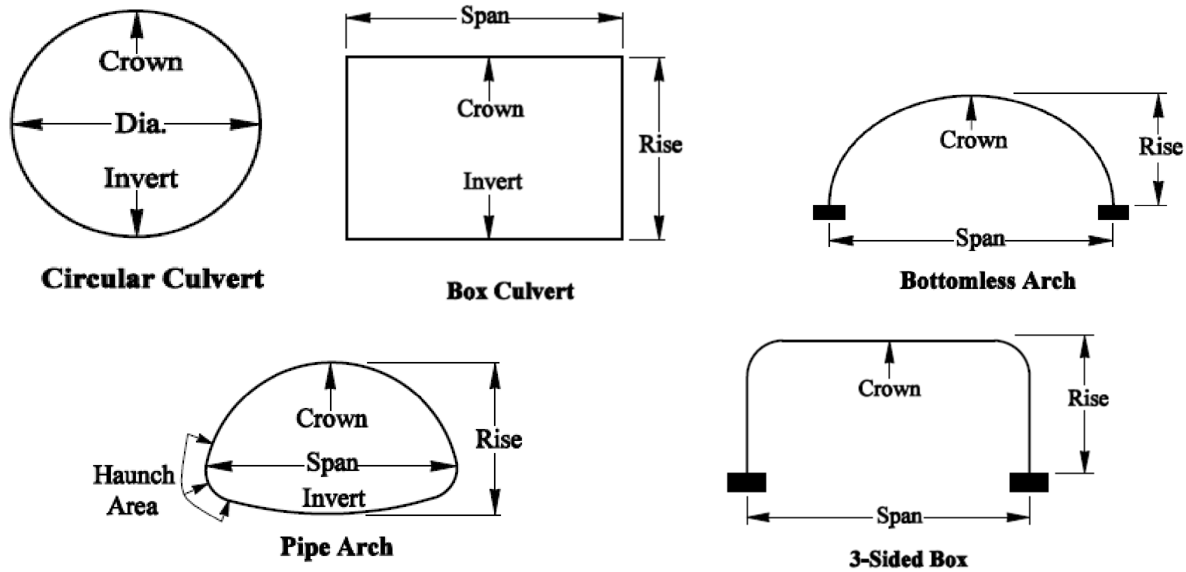


Figure 5-4: Commonly-Used Culvert Shapes

5.6.3 FIELD DATA, PLANNING, AND LOCATION

The collection of field data for culvert hydraulics should be accomplished concurrently with other data collection efforts for the project. The planning and location of a culvert should be consistent with the floodplain encroachment requirements. Below is the list of minimum field data required to complete an engineering analysis of a culvert installation:

- Topographic map showing contours and the outline of the drainage area.
- Description of the ground cover of the drainage area.
- Streambed description and gradation at the proposed site.
- Soils investigation.
- Streambed alignment and profile extending twice the diameter at the proposed site. The distance will vary based on the size of the culvert and the location. If the culvert is 48 in., use two times the diameter for the distance in feet. For example, a 48-in. culvert would require 48 x 2 = 96 ft. upstream and downstream, for a total of 192 ft., plus the culvert length for the stream profile.
- Cross sections of the stream width extending beyond the limits of the floodplain on each side.
- Proposed roadway profile and alignment in the vicinity of the culvert.
- Proposed roadway cross section at the culvert.
- Corrosion zone location, pH, and resistivity of the site.
- Historical information at the site from maintenance or the locals.

- Any other unique features that can affect design, such as low-lying structures that could be affected by excessive headwater or other considerations.
- Inspect and document the physical condition of the existing culvert.

5.6.4 CULVERT FUNDAMENTALS

Flow Conditions — A culvert barrel may flow full over all of its length or partly full. Full flow in a culvert barrel is rare. Generally, at least part of the barrel flows partly full. A water surface profile calculation is the only way to accurately determine how much of the barrel flows full.

Full Flow — The hydraulic condition in a culvert flowing full is called pressure flow. If the cross-sectional area of the culvert in pressure flow is increased, the flow area will expand. One condition that can create pressure flow in a culvert is the back pressure caused by a high downstream water surface elevation. A high upstream water surface elevation may also produce full flow. Regardless of the cause, the capacity of a culvert operating under pressure flow is affected by upstream and downstream conditions and by the hydraulic characteristics of the culvert.

Partly Full (Free Surface) Flow — Free-surface flow or open-channel flow may be categorized as sub-critical, critical, or super-critical. A determination of the appropriate flow regimen is accomplished by evaluating the dimensionless number, Fr, called the Froude Number. When $Fr > 1.0$, the flow is super-critical and is characterized as swift. When $Fr < 1.0$, the flow is sub-critical and characterized as smooth and tranquil. If $Fr = 1.0$, the flow is said to be critical.

Types of Flow Control — Inlet and outlet control are the two basic types of flow control. The basis for the classification system is the location of the control section. The characterization of pressure and the sub-critical and super-critical flow regimens play an important role in determining the location of the control section, and thus the type of control. The hydraulic capacity of a culvert depends on a different combination of factors for each type of control.

Inlet Control — Inlet control occurs when the culvert barrel is capable of conveying more flow than the inlet will accept. The control section of a culvert operating under inlet control is located just inside the entrance. Critical depth occurs at or near this location, and the flow regimen immediately downstream is super-critical. Hydraulic characteristics downstream of the inlet control section do not affect the culvert capacity. The upstream water surface elevation and the inlet geometry represent the major flow controls. The inlet geometry includes the barrel shape, the cross-sectional area, and the inlet edge.

Outlet Control — Outlet control flow occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. The control section for outlet control flow in a culvert is located at the barrel exit or further downstream. Either sub-critical or pressure flow exists in the culvert barrel under these conditions. All of the geometric and hydraulic characteristics of the culvert play a role in determining its capacity. These characteristics include all of the factors governing inlet control; the water surface elevation at the outlet; and the slope, length, and hydraulic roughness of the culvert barrel.

Headwater — Energy is required to force flow through a culvert. This energy takes the form of an increased water surface elevation on the upstream side of the culvert. The depth of the upstream water surface measured from the invert at the culvert entrance is generally referred to as headwater depth.

A considerable volume of water may be ponded upstream of a culvert installation under high fills or in areas with flat ground slopes. The ponding on the upstream of roadway fills is discouraged for the general case unless the ponding is a pre-construction existing case and the ponding has no detrimental effect on upstream structures and other property.

Allowable Headwater — Circular culverts, box culverts, and pipe arches should be designed so that the ratio of the headwater (HW) to diameter (D) during the design flow event is less than or equal to 1.25 ($HW_i/D < 1.25$). HW_i/D ratios larger than 1.25 are permitted, provided that existing site conditions such as available ponding areas on deeper fills, warrant a larger ratio. The maximum allowable HW_i/D ratios should not exceed 3.0.

The headwater that occurs during the 100-year flow event must also be investigated. Two sets of criteria exist for the allowable headwater during the 100-year flow event, depending on the type of roadway over the culvert:

1. If the culvert is under a main highway route that must be kept open during major storm events, the culvert must be designed so that the 100-year flow event can be passed without overtopping the roadway.

2. If the culvert is under a secondary roadway, it is recommended that the culvert be designed so that there is no roadway overtopping during the 100-year flow event. However, there may be situations where it is more cost-effective to design the roadway embankment to withstand overtopping rather than to provide a structure or group of structures capable of passing the design flow.

Bottomless culverts with footings should be designed so that 1 foot of debris clearance from the water surface to the culvert crown is provided during the design flow event. Bottomless culverts should also be designed so that the 100-year event can be passed without the headwater depth exceeding the height of the culvert. Flow depths greater than the height can cause potential scour problems near the footings.

Tailwater — Tailwater is defined as the depth of water downstream of the culvert measured from the outlet invert. It is an important factor in determining culvert capacity under outlet control conditions. Tailwater may be caused by an obstruction in the downstream channel or by the hydraulic resistance of the channel. In either case, backwater calculations from the downstream control point are required to precisely define tailwater. When appropriate, normal depth approximations may be used instead of backwater calculations.

Outlet Velocity — Because a culvert usually constricts the available channel area, flow velocities in the culvert are likely to be higher than in the channel. These increased velocities can cause streambed scour and bank erosion in the vicinity of the culvert outlet. Energy dissipaters and outlet protection devices are oftentimes required to avoid scour at the culvert outlet. All culverts must be designed for downstream channel stability. The velocity of flow from the culvert outlet or energy dissipater/protection section should be laminar, sub-critical, and in no case exceed the natural velocity of the existing channel.

Alignment and Grade — It is recommended that culverts be placed on the same alignment and grade as the natural streambed, especially on year-round streams. This tends to maintain the natural drainage system and minimize downstream impacts. Locate and use headwalls to minimize fill impacts within the existing stream ordinary high water level.

Allowable Velocities — Culverts should be designed for the required life span (50 years on main routes, 25 years on secondary roads), where corrosion and abrasion are the primary cause of pipe failure. The type of culvert material, dimensions, and configurations should be compatible with the velocity to reduce abrasion wear to acceptable levels, while operating within acceptable hydraulic parameters with stable inlets and outlet conditions.

Minimum Spacing — When multiple lines of pipe or pipe-arch greater than 48 in. in diameter or span are used, they should be spaced so that the sides of the pipe are no closer than one-half a diameter or 3 ft., whichever is less, so there is space for adequate compaction of the fill material available. For diameters up to 48 in., the minimum distance between the sides of the pipe should be no less than 2 ft. Utility lines may be closer.

5.6.5 ENGINEERING ANALYSIS

Collected field data should be used to perform an engineering analysis. The intent of the engineering analysis is to ensure that the designer considers a number of issues, including flow capacity requirements, foundation conditions, embankment construction, runoff conditions, soil characteristics, stream characteristics, construction problems that may occur, estimated cost, environmental concerns, and any other factors that may be involved in and pertinent to the design. An additional analysis may be required in floodplain areas to demonstrate that the culvert does not increase upstream levels over existing conditions.

Once the engineering analysis is completed, it will be part of the hydraulic report and should include:

- Culvert hydraulic and hydrology calculations.
- Approved modeling software, such as HY-8, can also be used in lieu of hand calculations. If the designers wish to use different software, prior approval is required prior to submitting final designs.
- Proposed roadway stationing of the culvert location.
- Culvert and stream profile.

- Culvert length and size. The minimum diameter of culvert pipes under a main roadway should be 18 in. Culvert pipes under roadway approaches should have a minimum diameter of 12 in.
- Culvert material (for culverts larger than 48 in., with appropriate n values).
- Headwater depths, Water Surface Elevations (WSEL), and flow rates (Q) for the design flow event (generally, the 25-year event and the 100-year flow event) should appear on the plan sheets for future record.
- Proposed roadway cross section and roadway profile demonstrating the maximum and minimum height of fill over the culvert.
- Appropriate end treatment.
- Hydraulic features of downstream controls, tailwater, or backwater (storage) conditions.

5.6.6 HYDRAULIC DESIGN OF CULVERTS

A complete theoretical analysis of the hydraulics of a particular culvert installation is time consuming and complex. Flow conditions vary from culvert to culvert and can also vary over time for any given culvert. The barrel of the culvert may flow full or partially full depending on upstream and downstream conditions, barrel characteristics, and inlet geometry. The design of all culverts should be done in accordance with FHWA publication *HDS 5, Hydraulic Design of Highway Culverts, No. FHWA-NHI-01-020, September 2001*.

5.6.7 CULVERT END TREATMENTS

The type of end treatment used on a culvert depends on many interrelated and sometimes conflicting considerations. The designer must evaluate safety, aesthetics, debris capacity, hydraulic efficiency, scouring, and economics. Each end condition may serve to meet some of these purposes, but none can satisfy all of these concerns. The designer must use good judgment to arrive at a compromise as to which end treatment is most appropriate for a specific site.

A number of different types of end treatments will be discussed in this section. The type of end treatment chosen for a culvert should be specified in the contract plans for each installation.

Projecting Ends

A projecting end is a treatment where the culvert is simply allowed to protrude out of the embankment (see Figure 5-5). The primary advantage of this type of end treatment is that it is the simplest and most economical of all treatments. Projecting ends also provide excellent strength characteristics because the pipe consists of a complete ring structure out to the culvert end.

There are several disadvantages to projecting ends. For metal, the thin wall thickness does not provide flow transition into or out of the culvert, significantly increasing head losses (the opposite is true for concrete -- the thicker wall provides a more efficient transition). From an aesthetic standpoint, projecting ends may not be desirable in areas exposed to public view. They should only be used when the culvert is located in the bottom of a ravine or in rural areas. Roadway safety considerations require that no projecting ends be allowed in the designated clear zone.

Projecting ends are also susceptible to flotation when the inlet is submerged during high flows. Flotation occurs when an air pocket forms near the projecting end, creating a buoyant force that lifts the end of the culvert out of alignment. The air pocket can form when debris plugs the culvert inlet or when significant turbulence occurs at the inlet as flow enters the culvert. Flotation tends to become a problem when the diameter exceeds 6 ft. for metal pipe and 2 ft. for thermoplastic pipe. It is recommended that pipes which exceed those diameters be installed with a beveled end and a concrete headwall or slope collar. Concrete pipe will not experience buoyancy problems and can be projected in any diameter. However, because concrete pipe is fabricated in relatively short 6-foot to 12-foot sections, the sections are susceptible to erosion and corresponding separation at the joint.

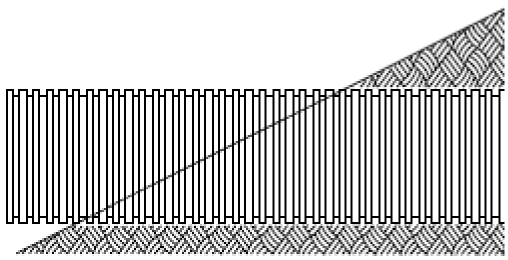


Figure 5-5: Projecting End

Beveled End Sections

A beveled end treatment consists of cutting the end of the culvert at an angle to match the embankment slope surrounding the culvert. A beveled end provides a more hydraulically efficient opening than a projecting end, is relatively cost-effective, and is generally considered to be aesthetically acceptable. Beveled ends should be considered for culverts approximately 6 ft. in diameter and less. If culverts larger than approximately 6 ft. in diameter are beveled but not reinforced with a headwall or slope collar, the structural integrity of the culvert can be compromised, and failure can occur. The standard beveled end section should not be used on culverts placed on a skew of more than 30 degrees from perpendicular to the centerline of the highway. Cutting the ends of a corrugated metal culvert structure to an extreme skew or bevel to conform to the embankment slope destroys the ability of the end portion of the structure to act as a ring in compression. Headwalls, riprap slopes, slope paving, or stiffening of the pipe may be required to stabilize these ends. In these cases, special end treatments should be provided, if needed.

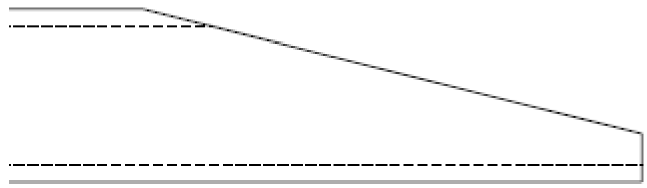


Figure 5-6: Beveled End Section

Flared End Sections

A metal flared end section is a manufactured culvert end that provides a simple transition from culvert to streambed. Flared end sections allow flow to smoothly constrict into a culvert entrance and then spread out at the culvert exit as flow is discharged into the natural stream or watercourse. Flared ends are generally considered aesthetically acceptable because they serve to blend the culvert end into the finished embankment slope.

Flared end sections are typically used only on circular pipe or pipe arches. Flared ends are generally constructed out of steel and aluminum and should match the existing culvert material, if possible. However, either type of end section can be attached to concrete or thermoplastic pipe, and the contractor should be given the option of furnishing either steel or aluminum flared end sections for those materials.

A flared end section is usually the most feasible option in smaller pipe sizes and should be considered for use on culverts up to 48 in. in diameter. For diameters larger than 48 in., end treatments such as concrete headwalls tend to become more economically viable than the flared end sections.

The undesirable safety properties of flared end sections generally prohibit their use in the clear zone for all but the smallest diameters. A flared end section is made of light gage metal, and because of the overall width of the structure, it is not possible to modify it with safety bars. When the culvert end is within the clear zone and safety is a consideration, the designer must use a tapered end section with safety bars. The tapered end section is designed to match the embankment slope and allow an errant vehicle to negotiate the culvert opening in a safe manner.

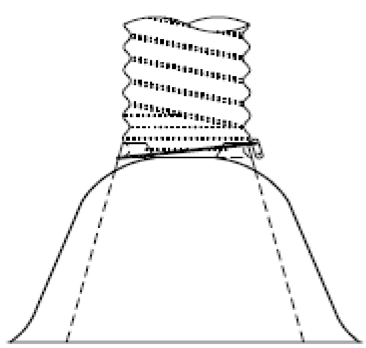


Figure 5-7: Flared End Section

Slope Collars

A slope collar is a concrete frame poured around a beveled culvert end. It provides structural support to the culvert and eliminates the tendency for buoyancy. A slope collar is generally considered to be an economically feasible end treatment for metal culverts that range in size from 6 to 10 ft. Generally, metal culverts smaller than 6 ft. do not need the structural support provided by a slope collar. Slope collars should be used on thermoplastic culverts larger than 2 ft. When the culvert is within the clear zone, the collar design can be modified by adding safety bars. The designer is cautioned not to use safety bars on a culvert where debris may cause plugging of the culvert entrance, even though the safety bars may have been designed to be removed for cleaning purposes. When the stream is known to carry debris, the designer should provide an alternate solution to safety bars, such as increasing the culvert size or providing guardrail protection around the culvert end.

Slope collars for culverts larger than 10 ft. tend to lose cost-effectiveness due to the large volume of material and forming cost required for this type of end treatment. Instead, a headwall is recommended for culverts larger than 10 ft.

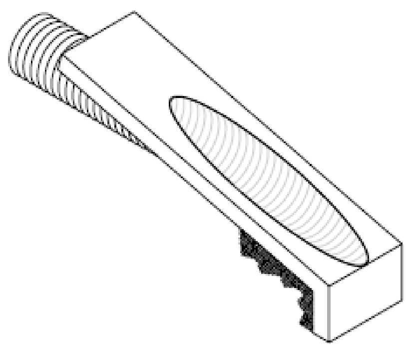


Figure 5-8: Slope Collar

Headwalls, Wingwalls, and Aprons

Headwalls with or without wingwalls and aprons are intended for use where site constraints restrict the fill slope and fill retention is needed, or where flow transitions are needed to avoid erosion of the channel slopes, and for box culverts. Their purpose is to retain and protect the embankment and provide a smooth transition between the culvert and the channel. Normally, they will consist of vertical headwall, flared vertical wingwalls, a full or partial apron, and bottom and side cutoff walls (to prevent piping and undercutting). The wingwall and apron will provide a smooth transition for the flow as it spreads to the natural channel. Headwalls may be precast or cast-in-place reinforced concrete structures, designed to be stable for the soil loadings particular to the site.

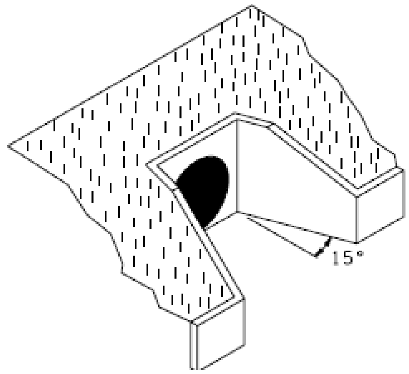


Figure 5-9: Headwall with Wingwalls for Circular Pipe

Improved Inlets

In conditions of inlet control, techniques available to balance the inlet capacity include beveled inlet edges, the side tapering of inlet, and the slope-tapering of inlet. When the head losses in a culvert are critical, the designer may consider using a hydraulically-improved inlet. These inlets provide side transitions as well as top and bottom transitions that have been carefully designed to maximize the culvert capacity with the minimum amount of headwater; however, the design and form construction costs can become quite high for hydraulically-improved inlets. For this reason, their use is not encouraged in routine culvert design. It is usually less expensive to simply increase the culvert diameter by one or two sizes to achieve the same or greater benefit.

Inlet Bevel

Beveled edges are usually a standard component of the inlet ends of box culverts and headwall structures. A bevel is similar to a chamfer, except that a chamfer is smaller and is generally used to prevent damage to sharp concrete edges during construction. The entrance loss coefficient can be reduced from 0.7 for a square edge to 0.2 for beveled edges. It should be noted that the socket end of concrete pipe is comparable to a bevel in reducing the entrance loss coefficient and thus increasing the inlet capacity.

Side-Tapered Inlet

Side-tapered inlets provide an enlarged culvert entrance with transitions to original barrel dimensions. The inlet face has the same height as the barrel, and its top and bottom are extensions of the top and bottom of the barrel. The intersection of the side wall tapers and barrel is called the throat section. The use of a side-tapered improvement is maximized by designing it so that the capacity is controlled by the throat.

Slope-Tapered Inlets

Slope-tapered inlets provide a steeper slope at the entrance than occurs throughout the remaining length of a culvert. Providing this steeper slope allows the head on the throat section to be increased to make additional fall available. Depending upon the fall, inlet capacities can be increased 100 percent or greater above conventional culverts with square edges.

5.6.8 CONSTRUCTION AND MAINTENANCE CONSIDERATION

The design of a culvert should be consistent with standard construction and specifications. If special provisions are warranted in order to properly construct or maintain the proposed facility, this information should be specified in the design documentation. The designer must also consider maintenance of traffic requirements because cost and disruption of the installation may be the major concern for some locations.

In all cases, the culverts should be designed to have self-cleaning velocities, and both ends should have some type of erosion protection. The material selected should have a 50-year or longer life span estimate, because most roads can be resurfaced a number of times to increase their life without the reconstruction of subgrade.

The use of multiple culvert openings is discouraged except in situations where very little vertical distance is available from the roadway to the culvert invert. Alternatives to multiple culvert installations are low-profile arches and three-sided box structures that provide significant horizontal span lengths while minimizing the vertical rise.

Where possible, maintenance access should be provided at the upstream end of cross culverts. For shallow culverts, this can be a widened shoulder pull-out on which to park a vehicle. For culverts in deeper fills, provide a separate maintenance access road from off the embankment. Access roads should be a minimum of 12 ft. wide and should not exceed a 15 percent slope. The maintenance road should be paved to match the anticipated maintenance vehicle loadings, but should never be less than a 6-in. thick layer of crushed gravel over a geotextile filter fabric.

Safety fencing should be provided along the tops of all culvert headwalls with a vertical face of 6 ft. or more.

5.6.9 ENERGY DISSIPATERS

When the outlet velocities of a culvert are excessive for the site conditions, the designer must consider erosion protection. The protection can be fairly simple inlet and outlet channel stabilization methods, such as riprap slope and bottom protection, splash pads, and vegetated slope protection measures. Or it may require the installation of energy dissipaters. Dissipaters are hydraulic control structures to reduce velocities to within tolerable limits. Culvert erosion protection and energy dissipaters should be designed in accordance with FHWA publication *HEC 14, Hydraulic Design of Energy Dissipaters for Culverts and Channels*, *No. FHWA-NHI-06-086, July 2006*. Typical protected outlets and energy dissipaters include:

Riprap Protected Outlets

A common mitigation measure for small culverts is to provide at least minimum protection using riprap aprons. The initial protection against channel erosion should be sufficient to provide some assurance that extensive damage could not result from one runoff event. These aprons do not dissipate significant energy except through increased roughness for a short distance. However, they do serve to spread the flow helping to transition to the natural drainage way or to sheet flow where no natural drainage way exists. The configuration and riprap sizing is defined in Section 10.2 of *HEC 14*.

For larger culverts, the designer should consider estimating the size and riprapping the scour hole using the procedures in Chapter 5 of *HEC 14*, or using a riprap basin in accordance with Section 10.1 of *HEC 14*.

Where suitably-sized riprap rock is unavailable, gabion baskets and mattresses are alternatives to using loose rock. The gabions are wire mesh baskets that are filled with smaller-sized rock. They can provide the same level of erosion protection using smaller-sized rock, usually easier to handle and more readily available than riprap materials. See Chapter 6 of FHWA publication *HEC 11, Design of Riprap Revetment, No. FHWA-IP-89-016, March 1989* for guidelines pertaining to design of wire-encased rock.

Splash Pads

Concrete splash pads are constructed in the field at the outlet end of smaller culverts and storm drain discharges to prevent erosion. Splash pads should be a minimum of three times the diameter in width and four times the diameter in length, as shown in Figure 5-10.

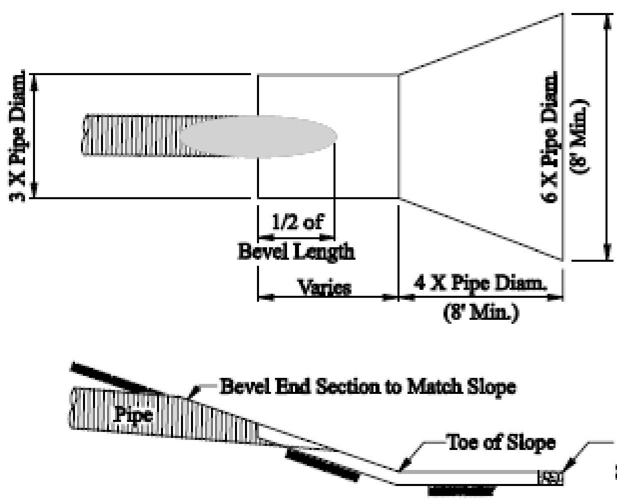


Figure 5-10: Splash Pad Details

Other Energy Dissipating Structures

Other structures include impact basins, stilling basins/wells, and drop structures. These structures may consist of baffles, posts, or other means of creating roughness and hydraulic jumps to dissipate excessive velocity. See FHWA publication *HEC 14* for the selection and design criteria.

Energy dissipaters have a reputation for collecting debris on the baffles, so the designer should consider this possibility when choosing a dissipater design. In areas of high debris, the dissipater should be a self-clearing type and easily accessible to maintenance crews.

5.6.10 CULVERT DEBRIS

Debris problems can cause even an adequately-designed culvert to experience hydraulic capacity problems. Debris may consist of anything from limbs and sticks, or orchard pruning, to logs and trees. Silt, sand, gravel, and boulders can also be classified as debris. The culvert site is a natural place for these materials to settle and accumulate. No method is available for accurately predicting debris problems. Examining the maintenance history of each site is the most reliable way of determining potential problems. Sometimes, upsizing a culvert is necessary to enable it to pass debris more effectively. Upsizing may also allow a culvert to be more easily cleaned.

Methods to counter debris at culverts are discussed in Section 5.2 of FHWA publication *HEC 9, Debris Control Structures, Evaluation and Countermeasures, Third Edition, No. FHWA-IF-04-016, October 2005*. In all cases, culverts should be designed to have maintenance access for debris removal at the inlets.

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6 PERMANENT BEST MANAGEMENT PRACTICES

6.1 INTRODUCTION

This chapter provides designers with specific guidelines for the selection, design, and application of permanent stormwater Best Management Practices (BMPs).

Stormwater BMPs are the physical, structural, and managerial practices that, when used alone or in combination, prevent or reduce the detrimental impacts of stormwater, such as the pollution of water, degradation of channels, damage to structures, and flooding.

The BMP principles adopted in this Transportation Stormwater Drainage Manual (TSDM) are widely-accepted nationwide. However, the BMPs presented have been selected as being more applicable to the linear nature of transportation projects, with details modified to better fit with roadway features and limited right-of-ways.

For each BMP, this chapter presents a selection process along with design considerations. This chapter also presents ways to combine or enhance the different types of facilities to maximize their efficiency or to better fit within the project site.

The BMP descriptions include general recommendations regarding the conditions under which a BMP applies, as well as the advantages and disadvantages of that BMP. It is recommended that designers take an iterative approach to selecting BMPs based on site-specific criteria. This entails being flexible and somewhat creative when determining a final stormwater management solution that works best in each situation. It is essential that care be taken in the selection and site application of the various BMPs, such that maximum benefit is obtained.

6.2 TYPES AND FUNCTIONS OF BMPs

Permanent BMPs are generally categorized by design pollution prevention, runoff treatment, and flow control as shown in Table 6-1. The BMP selection process, design applications, and details are described in the following sections.

BMP	Description
Design Pollution Prevention BMPs	Consideration of downstream effects related to potentially increased flow velocities; preservation of existing vegetation; concentrated flow conveyance systems; and slope/surface protection systems.
Quality Treatment BMPs	Permanent runoff quality treatment devices and facilities for the removal of pollutants prior to discharge back to the natural or existing watercourse.

BMP	Description
Flow Control BMPs	Detention or infiltration type facilities for purposes of minimizing downstream channel erosion and overbank flooding, and/or for groundwater recharge.

Table 6-1: Permanent BMP Categories

The stormwater management methods in this chapter have been categorized in order of preferred use and grouped according to similar composition and function. Each BMP has an associated number to distinguish it from other BMPs with similar names. The numbering convention represents the following classifications:

RT.XX –	Runoff Treatment BMPs
FC.XX –	Flow Control BMPs
IN.XX –	Infiltration BMPs

Table 6-2: Permanent BMP Numbering Conventions

6.2.1 DESIGN POLLUTION PREVENTION BMPS

A main consideration in project design should be the prevention of pollutants from entering stormwater by eliminating the source of pollution or by preventing the contact of pollutants with rainfall and runoff. The three design objectives are:

1. Maximize vegetated surfaces: Vegetated surfaces prevent erosion, help the pollutant removal process, and promote infiltration, which reduces runoff.
2. Prevent downstream erosion: Apply designs to minimize impacts from any downstream increases in velocity.
3. Stabilize soil areas: Areas prone to erosion will be stabilized through the use of flow control and grading/cover improvements.

These design objectives should be applied to the entire project, both existing and new project areas. The typical design pollution prevention BMPs that accomplish this are:

- Preservation of vegetation
  - Design of permanent facilities to minimize ground disturbance areas
  - Construction staging to avoid stands of trees and shrubs
- Consideration of downstream effects related to potentially increased flow velocities
  - Making modifications to channel lining materials (both natural and man-made), including vegetation, geotextile mats, rock, and riprap

  - Using energy-dissipation devices at culvert outlets
  - Smoothing the transition between culvert outlets, headwalls, wingwalls, and channels to reduce turbulence and scour
  - Incorporating detention and infiltration into designs to reduce peak discharge rates
- Concentrated flow conveyance systems to avoid gullying and erosion
  - Ditches, berms, dikes, and swales
  - Oversize drains
  - Flared-end culvert sections
  - Protective outlet treatments
- Slope/surface protection systems
  - Vegetated surfacing
  - Surface roughening, terracing, stepping, or rounding
  - Hard surfacing

6.2.2 QUALITY TREATMENT BMPS

Runoff treatment BMPs that remove pollutants from runoff use a variety of mechanisms including sedimentation, filtration, plant uptake, ion exchange, adsorption, precipitation, and bacterial decomposition. The following overview provides information on the most commonly used runoff treatment BMPs:

- Infiltration BMPs: Infiltration BMPs are the preferred method for both runoff treatment and flow control. Infiltration treatment has the highest pollutant removal efficiency of the listed BMPs. Treatment is achieved through settling, biological action, and filtration. The advantage of this type of BMP is that it also provides recharge of the ground water. It is a primary BMP for quality treatment in the northern Guam area, where the goal is to infiltrate as much of the project runoff as possible. All infiltration facilities must be preceded by a presettling basin for removing most of the sediment particles that would otherwise reduce the infiltrative capacity of the facility. The infiltration BMPs include:

IN.01 - Bioinfiltration Pond	IN.02 - Infiltration Pond	IN.03- Infiltration Trench
IN.04 - Infiltration Vault	IN.05 -Drywell	IN.06- Permeable Pavements

- Dispersion BMPs: Perhaps the single most promising and effective approach to mitigating the effects of highway runoff is to look for opportunities to use the existing natural areas for pollutant removal. Natural dispersion requires that runoff sheet flows off of the pavement where it flows through the natural vegetation without being channelized. Pollutant removal typically occurs through a combined process of vegetative filtration and shallow surface infiltration.

  A good portion of the existing roadway runoff in Guam is already treated by natural dispersion. If this condition can be maintained within the project limits for new projects, natural dispersion can be very cost effective while helping to preserve the natural environmental functions, including flow attenuation. Engineered dispersion techniques use the same removal processes as natural dispersion, but use a constructed conveyance system to direct runoff to the sheet flow dispersion area. Dispersion BMPs are:

RT.01 - Natural Dispersion	RT.02 - Engineered Dispersion

- Biofiltration BMPs: Runoff treatment to remove pollutants can be best accomplished before concentrating the flow. Biofiltration functions slow the runoff velocities, filter out sediment and other pollutants, and provide some infiltration into the underlying soils. Although limited to fairly flat terrain, vegetated filter strips, continuous inflow biofiltration swales, and media filter drains provide direct treatment of the sheet flow off of the pavement. Biofiltration swale is similar in function, but able to treat concentrated runoff flows.

  All of the following BMPs are a cost-effective treatment option, suitable for use within the typical limited width right-of-way.

RT.03 -Vegetated Filter Strip	RT.05 - Wet Biofiltration Swale
RT.04 - Biofiltration Swale	RT.06 - Continuous Inflow Biofiltration Swale
RT.07 -Media Filter Drain	

- Wet Pool BMPs: Wet ponds are constructed basins containing a permanent pool of water throughout the wet season. Wet ponds function by settling suspended solids, where the biological action of plants and bacteria provides some additional treatment. Wet ponds are usually constructed using multiple cells, where coarser sediments become trapped in the first cell or forebay.

  Wet pond designs can also provide flow control by adding detention volume (live storage) above the dead storage. Wet ponds can be designed for the treatment of conventional pollutants, as well as enhanced pollutant removal using constructed stormwater treatment wetlands for removal of nutrients and dissolved metals. Designers of constructed stormwater treatment wetlands should consider the landscape context as groundwater, soils, and surrounding vegetation must be compatible for long-term maintenance of the wetland plants. Applicable wet pool BMPs are:

RT.08 - Wet Pond	RT.10 - Constructed Stormwater Treatment Wetland
RT.09 – Combined Wet/Detention Pond	RT.11 - Combined Stormwater Treatment Wetland/Detention Pond

- Phosphorous Control BMPs: Where runoff discharge is to a Guam Environmental Protection Agency (GEPA)-designated resource protection area, enhanced phosphorous removal may be required. BMPs that are applicable to this requirement are listed below. The wet pond BMP size is increased 1.5 times the basic wet pond treatment volume for phosphorous control.

RT.08 - Wet Pond (Large)	RT.07 - Media Filter Drain

- There are additional BMPs that are generally accepted for stormwater quality treatment; however they have high maintenance requirements. Some of these are listed below. The use of any of the following BMPs will require pre-approval by the Department of Public Works (DPW):

Sand Filters	Underground Wet Vaults and Sedimentation Chambers
Proprietary Sediment Concentrators and Pollutant-Removal Systems	Proprietary Filtration Systems
Coalescing Plate Oil/Water Separators	

6.2.3 FLOW CONTROL BMPS

Stormwater flow control BMPs are designed to control the flow rate or the amount of runoff leaving a site after development. The primary mechanisms used to manage flow control include dispersion, infiltration, and detention. Increased flow rates can cause downstream damage due to flooding, erosion, and scour, as well as degradation of water quality and in-stream habitat because of channel and stream bank erosion. The following provides an overview of the most commonly used flow control BMPs for transportation type applications:

- Infiltration BMPs: Infiltration is the preferred BMP for both stormwater treatment and flow control. Infiltration BMPs will be almost exclusively required for use in the northern Guam area due to aquifer recharge requirements. However, infiltration systems are practicable only in areas where groundwater tables are sufficiently below the bottom of the facility and in highly permeable soil conditions. Also, all infiltration systems require some type of pre-treatment measures, such as a swale or sediment basin to protect the infiltration facility from sedimentation clogging.

  Subsurface infiltration systems should be considered only when room is inadequate to construct an infiltration basin. Underground systems are difficult to maintain and verify whether they are functioning properly.

IN.01 - Bioinfiltration Pond	IN.02 - Infiltration Pond	IN.03 - Infiltration Trench
IN.04 - Infiltration Vault	IN.05 - Drywell	

- Dispersion BMPs: See Section 6.2.2 above for an overview of dispersion BMPs.

RT.01 - Natural Dispersion	RT.02 - Engineered Dispersion

- Detention BMPs: Detention facilities generally take the form of either a pond or an underground vault or tank. They operate by providing a volume of live storage with an outlet control structure designed to release flow at a reduced rate over time. Ponds can be configured as dry ponds to control flow only, or combined with a wet pond or created wetland to also provide runoff treatment within the same footprint.

FC.01 – Detention Pond	RT.09 – Combined Wet/Detention Pond
RT.11 - Combined Stormwater Treatment Wetland/Detention Pond	

6.2.4 BMP SELECTION PROCESS

The appropriate selection of BMPs requires designers to have an understanding of the process used to identify water quality requirements and pollutants of concern for specific water bodies.

The term “permanent BMP” refers to permanent physical controls that control, prevent, remove, or reduce pollution, and minimize potential impacts on receiving waters.

Accordingly, the BMPs are usually selected during the design phase and will be operational post-construction.

Selection of the BMP that best fits a specific application should be generally approached using the following main steps.

Step 1. Determine the applicable Minimum Requirements.

Review the procedures in Chapter 3 of this TSDM. Even if no quality treatment or flow control BMPs are required, the designer should still proceed with Step 2.

Step 2. Select design pollution prevention BMPs.

See Figure 6-1 for the selection of design pollution prevention BMPs.

Step 2 a. Select flow control BMPs.

Based on the Minimum Requirements in Step 1, use Figure 6-2 for selection of flow control BMPs.

Step 3. Select runoff treatment BMPs.

Based on the Minimum Requirements in Step 1, use Figure 6-3 for selection of runoff treatment BMPs.

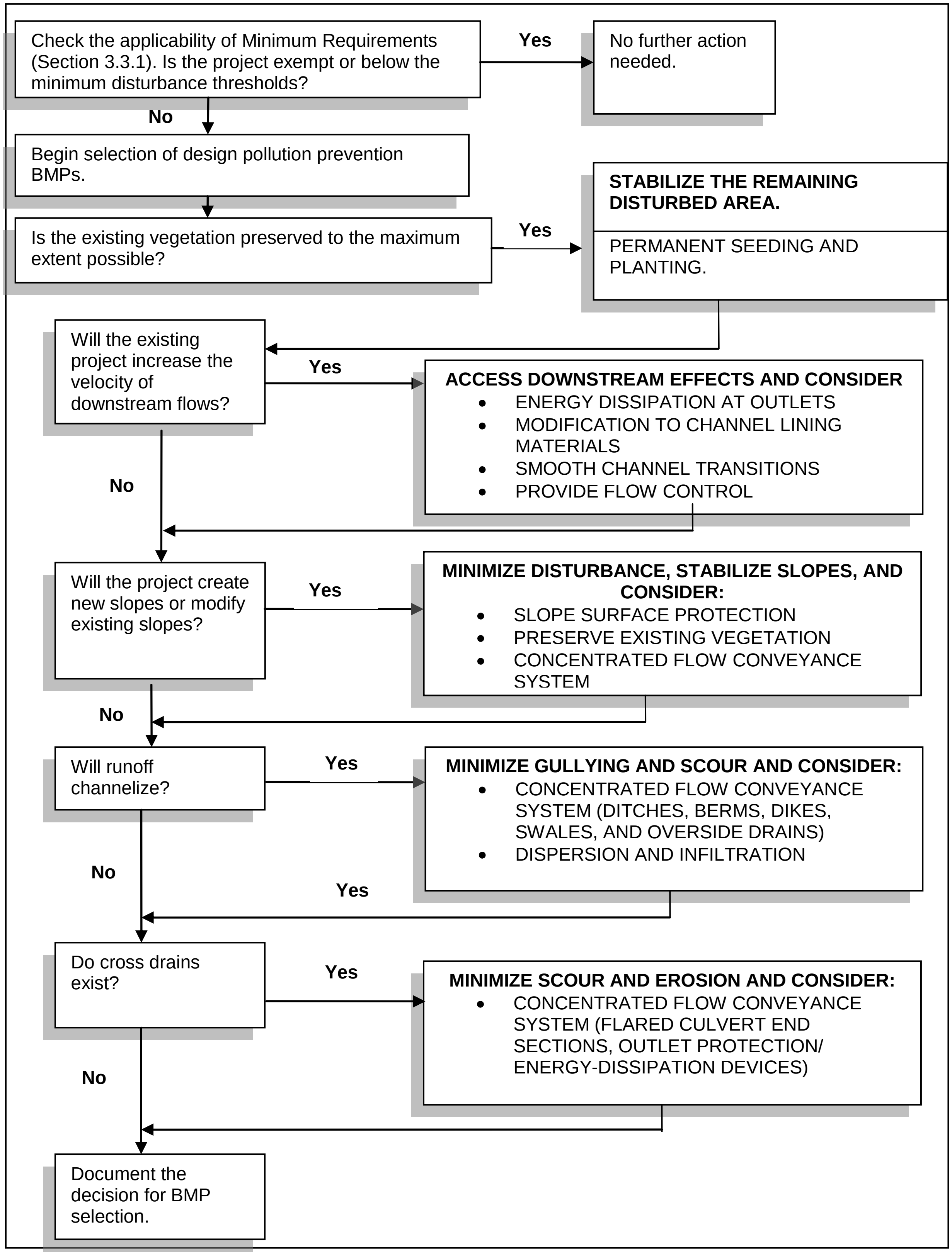


Figure 6-1: Flow Chart – Selection of Design Pollution Prevention BMP

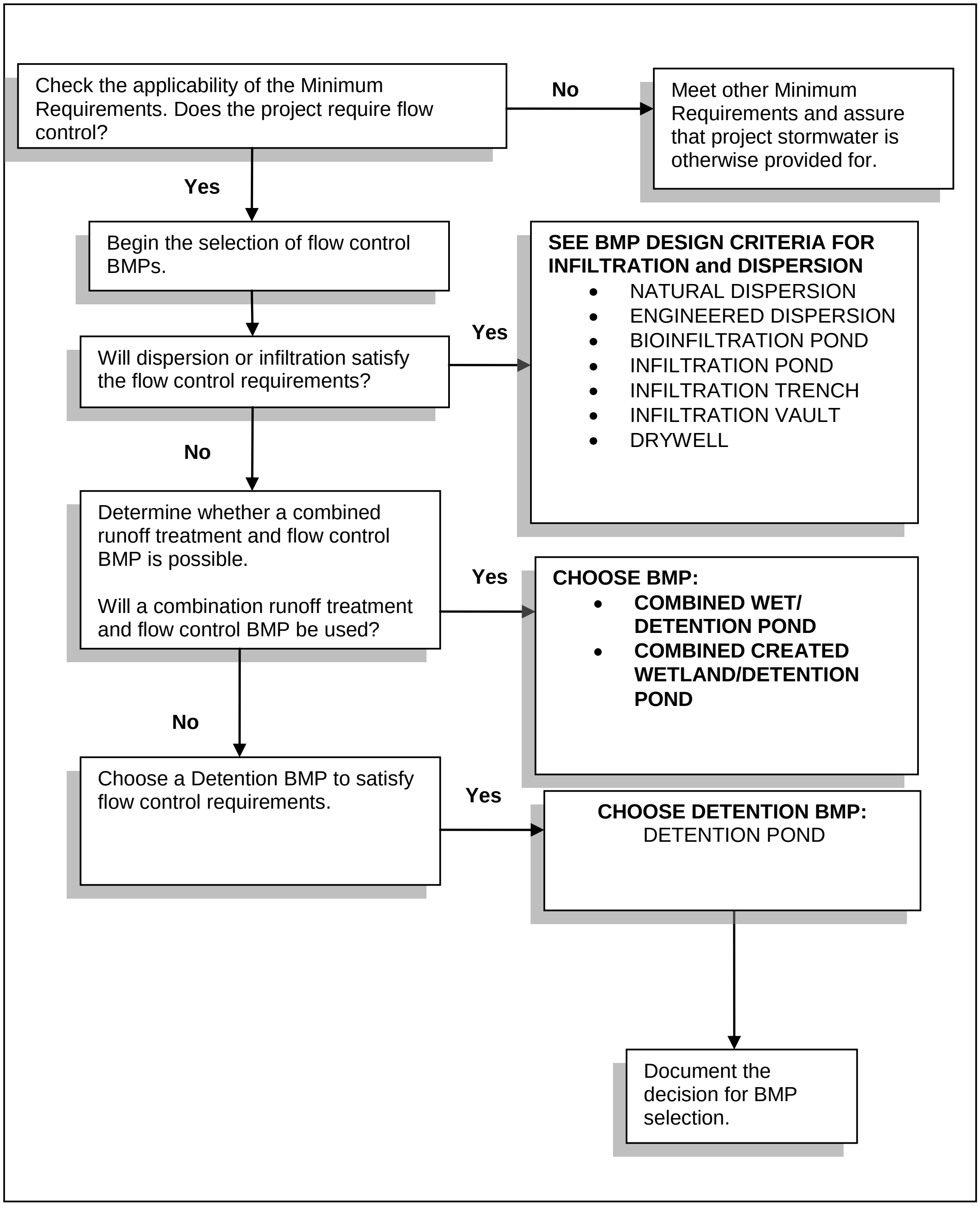


Figure 6-2: Flow Chart - Selection of Flow Control BMP

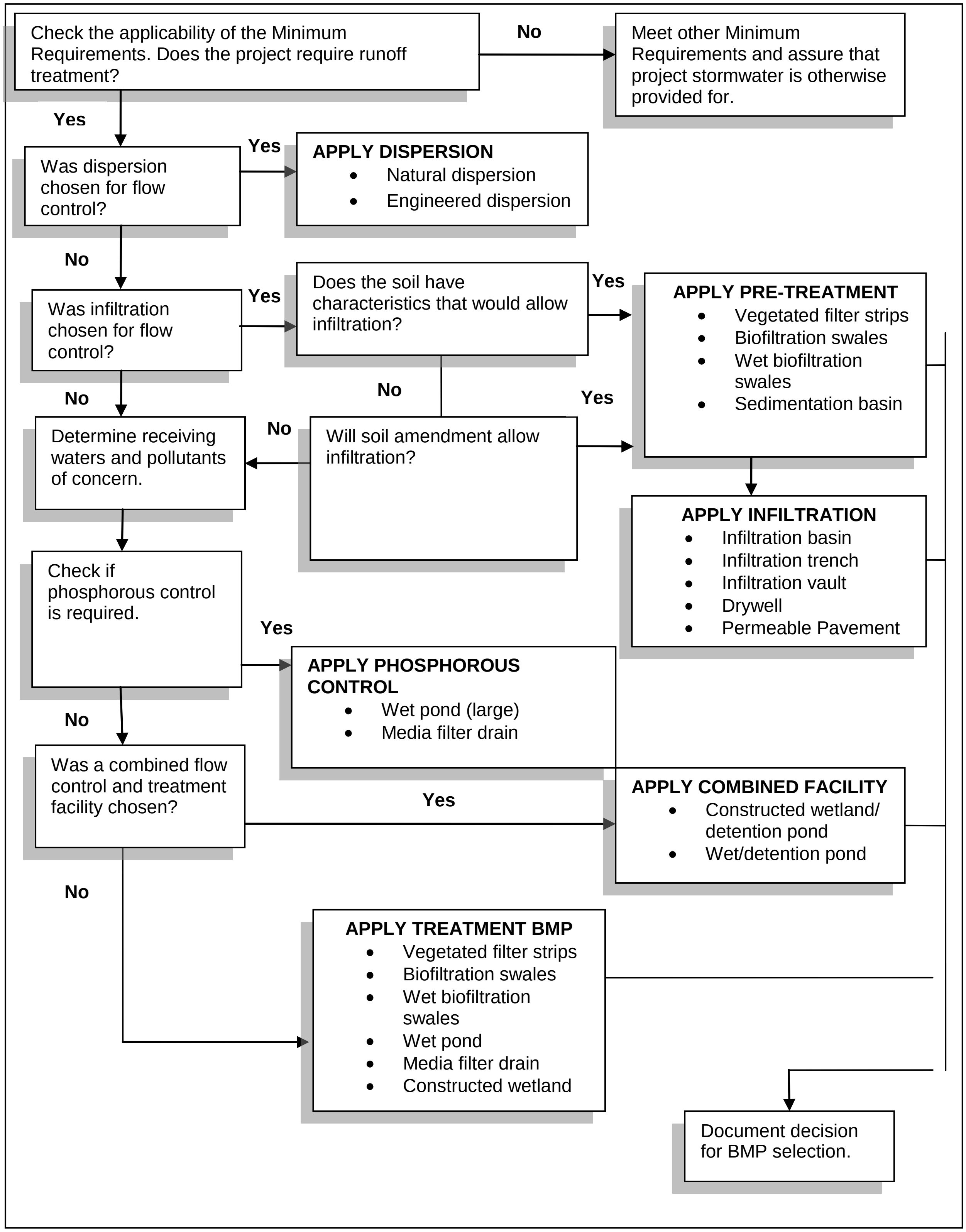


Figure 6-3: Flow Chart – Selection of Runoff Treatment BMP

6.3 DESIGN POLLUTION PREVENTION BMPs

6.3.1 CONSIDERATION OF DOWNSTREAM EFFECTS RELATED TO POTENTIALLY INCREASED FLOW VELOCITIES

Changes in the velocity or volume of runoff, the sediment load, or other hydraulic changes from stream encroachments, crossings, or realignment may affect downstream channel stability.

The designer will evaluate the effects on downstream channel stability and the applicability of the mitigation measures described under the implementation for this BMP.

Appropriate Applications

During the design of both new and reconstructed facilities, the designer may include new road surfaces or additional surface paving to enhance the operational safety and functionality of the facility. The designer must also consider the effect of collecting and concentrating flows in roadside ditches and storm drain systems or the effect of re-directing flows to treatment BMPs.

Diversions or overflows from large storm events in these instances may create concentrated discharges in areas that have not historically received these flows.

Implementation

If these changes result in an increased potential for downstream effects in channels, the designer should consider the following:

- Making modifications to channel lining materials (both natural and man-made), including vegetation, geotextile mats, rock, and riprap. The primary goal will be to use vegetative stabilization techniques whenever the conditions allow, such as use of “tree stakes” along toes and sides of channel banks, and/or provide vegetation plantings to stabilize stream banks and overflow areas.
- Using energy-dissipation devices at outlets. This includes such items as rock pads, gabion pads, and constructed structures at outlets of ditches and pipes. More natural alternatives include the discharge to spreader swales or spreader ditches that sheet flow over the bank to the stream channel.
- Smoothing the transition between culvert and ditch outlets to the natural waterway using headwalls, wingwalls, and riprap/gabion protection to reduce turbulence and scour.
- Modifying the existing waterway to a more stable hydraulic design.
- Incorporating detention and infiltration into designs to reduce peak discharge rates. Typical applications are the inclusion of low areas in the terrain into the conveyance system, over-sizing of conveyance system components, or providing

specific detention ponds. The effectiveness of these features should be determined by using a hydraulic routing computer model of the overall conveyance system and matching the conveyance discharge hydrograph with the stream hydrograph. A downstream analysis may be needed if the stream flows are increased. Refer to Section 3.2.6.1 for more details.

The designer should implement the appropriate measures to ensure that runoff from stormwater facilities will not increase downstream erosion.

6.3.2 PRESERVATION OF EXISTING VEGETATION

Description

The preservation of existing vegetation involves the identification and protection of desirable vegetation. In particular, identification and protection of those locations which provide specific runoff filtration and soil stabilization benefits.

Appropriate Applications

The designer should preserve existing vegetation at areas on a site where no construction activity is planned or where it will occur at a later date.

Implementation

The following general steps should be taken to preserve existing vegetation:

- Designers should review and include vegetation types/features on the topographic surveys. Use the topographic surveys to prepare designs that help to minimize the specific runoff benefit of vegetation removal.
- Designers should identify and delineate in the contract documents all vegetation to be retained.
- The contractor should delineate the areas to be preserved in the field prior to the start of soil-disturbing activities.
- The contractor should minimize disturbed areas by locating temporary construction access, work areas, and staging areas to avoid stands of trees and shrubs, and follow existing contours to reduce cutting and filling.
- When removing vegetation, the designer and contractor should consider impacts (increased exposure or wind damage) to the adjacent vegetation that will be preserved.

6.3.3 CONCENTRATED FLOW CONVEYANCE SYSTEMS

Concentrated flow conveyance systems consist of permanent design measures that are used alone or in combination to intercept and divert surface flows, and to convey and discharge concentrated flows with minimum soil erosion.

Ditches, Berms, Dikes, and Swales

Description

These are permanent devices typically used to intercept and direct surface runoff to an over-side (or slope) drain or stabilized watercourse.

Appropriate Applications

Ditches, berms, dikes, and swales are typically implemented:

- At the top of slopes to divert run-on from adjacent slopes and areas
- At bottom and mid-slope locations to intercept sheet flow and convey concentrated flows
- At other locations to convey runoff to over-side drains, stabilized watercourses, and stormwater drainage system inlets (catch basins), pipes, and channels
- To intercept runoff from paved surfaces
- Along roadways and facilities subject to flooding

Implementation

The hydraulic designs must be in accordance with Chapter 5 of this TSDM. Select design storm frequencies based on the risk evaluation of erosion, overtopping, and flow backups. Conveyances must be lined when velocities exceed allowable limits for bare soil (see Chapter 5). Liners can consist of vegetative types, rock riprap, gabion mats, and engineering erosion control fabric.

Consider outlet protection where localized scour is anticipated. Examine the site for run-on from off-site sources and try to divert the flows around the work area. Review the order-of-work provisions to install and use permanent dikes, swales, and ditches early in the construction process.

Over-side Drains

Description

Over-side drains are conveyance systems used to protect slopes against erosion. Over-side drains are usually piped drains, flumes, or paved spillways that protect slopes against erosion by collecting surface runoff from the roadbed, the tops of cuts, and benches (in cut or fill slopes), conveying it down the slope to a stabilized outlet.

Appropriate Applications

Over-side drains are typically used at sites where slopes may be eroded by gully flow action.

Implementation

- The hydraulic design must be in accordance with Chapter 5 of this TSDM.
- Pipe drains are storm sewer pipes adaptable to any slope. They are recommended where side slopes are 1:4 (V:H) or steeper. Design and installation will require additional energy dissipation and pipe stability measures for high-velocity situations.

  Pipe and flume down drains are surface-mounted pipes or cut pipe sections. They are best adapted for low flow rates on slopes that are 1:2 (V:H) or flatter. Pipe and flume down drains should only be used for temporary applications, and must be securely anchored to the slope.
- Paved spillways are recommended on side slopes flatter than 1:4 (V:H). On steeper slopes, pipe drains should be used.
- Provide over-side drains every 300 ft. to 500 ft. from benches in cut-and-fill slopes.

Flared Culvert End Sections

Description

These are devices typically placed at inlets and outlets of pipes and channels to improve the hydraulic operation, retain the embankment near pipe conveyances, and help prevent scour and minimize erosion at these inlets and outlets.

Appropriate Applications

Use flared culvert end sections at outlets of storm drains, for over-side drains, and on both the inlet and outlet of culverts.

Implementation

The design must be in accordance with Chapter 5 of this TSDM. Alternatives to manufactured flared end sections are riprap pads, concrete slope collars, and headwalls.

Outlet Protection/Velocity Dissipation Devices

Description

These devices are typically placed at pipe outlets to prevent scour and reduce the outlet velocity and/or energy of exiting stormwater flows. They function to transition from the ditch or pipe flow section to the existing waterway section. The purpose is to protect the existing soil from erosion, while helping to dissipate flow energy and transitioning the flow to a wider, flatter, and less velocity condition. Depending on the flow energy, the outlet protection can consist of spreader swales or ditches, rock pads, riprap sections, flared-end sections, concrete collars, concrete pads, headwalls, headwalls with wingwalls and aprons, and energy dissipater structures.

Appropriate Applications

These devices are typically used at the outlets of ditches, pipes, drains, culverts, slope drains, diversion ditches, swales, conduits, or channels where localized scouring is anticipated.

Implementation

- The hydraulic design must be in accordance with Chapter 5 of this TSDM
- Install riprap, grouted riprap, slope collars, headwalls, gabion mats, or energy dissipater structures at the selected outlet
- Designs are usually related to outlet flow rate and tailwater level
- For the proper operation of aprons and rock pads, align the apron with the receiving stream and keep it straight throughout its length

6.3.4 SLOPE PROTECTION SYSTEMS

Surface protection consists of permanent design measures that are used alone or in combination to minimize erosion from sloped ground surfaces. Vegetated surface protection is preferred as it offers advantages such as infiltration with lower runoff rates, slower flow velocities, longer times of concentration, and lesser costs. However, where site- or slope-specific conditions would prevent adequate establishment and maintenance of a vegetative cover, hard surfacing should be considered.

Vegetated Surfaces

Description

A vegetated surface is a permanent perennial vegetative cover on all project pervious areas. The purpose of a vegetated surface (from a water quality perspective) is to prevent surface soil erosion, allow infiltration, and help to filter out pollutants from surface flows.

Appropriate Applications

Vegetated surfaces should be established on areas of disturbed soil after construction is completed and in areas where existing vegetation is not suitable as a stabilization measure. Vegetated surfaces should only be considered for areas that can support the selected vegetation long term. The vegetation type and application should be selected in accordance with the guidance and recommendations of the Guam Division of Aquatic and Wildlife Resources (DAWR). Another resource for vegetation type and application guidelines is the USDA, National Resources Conservation Service (NRCS).

Implementation

The following steps are typically implemented by the designer:

- Evaluate the site. The site evaluation should consider soil type, site topography, and availability of equipment access.
- Prepare grading plans as required to provide more efficient stabilization and bed preparation for the plantings. Vegetated surfaces should be designed to sheet flow conditions, and maximize contact time between water and vegetated surfaces. This will enhance infiltration and pollutant removal opportunities.
- Select vegetation species to match site conditions and seasonal restraints in accordance with NRCS's or DAWR's recommendations. Provide vegetation application and seed bed preparation specifications and details. Require a one-year maintenance guarantee from the contractor. Include temporary irrigation, mulching and planting methods as may be necessary to match site conditions and seasonal variations.
- Site preparation may include removal and stockpiling of topsoil for later replacement over the finished site grading.

Slope Roughening/Terracing/Rounding/Stepping

Roughening and terracing are techniques for creating furrows, terraces, serrations, stair-steps, or track marks on the soil surface to increase the effectiveness of temporary and permanent soil stabilization practices. Slope rounding is a design technique to minimize the formation of concentrated flows.

Use vegetated surfaces on embankment or cut slopes prior to the application of temporary soil stabilization or permanent seeding.

Hard Surfaces

Description

Hard surfaces consist of placing concrete, rock, or rock and mortar slope protection. The designer should consider the effects of increased runoff from impervious areas.

Appropriate Applications

Apply hard surfaces on soil areas where vegetation would not provide adequate erosion protection. Hard surfaces are also considered where it is difficult to maintain vegetation.

Implementation

Rock Slope Protection:

Consists of riprap rock revetment courses along water courses. Angular rocks of specified sizes are placed over filter fabric and/or gravel and used as riprap to armor slopes, stream banks, etc.

Remove loose, sharp, or extraneous material from the slope to be treated.

Place underlayment fabric loosely over the surface so that the fabric conforms to the surface without damage. Protect the fabric from puncture with a sand/gravel overlay prior to placing the rock. Equipment or vehicles should not be driven directly on the fabric.

Revetments along streams/rivers with potential for high velocities and/or stream bed degradation should have an excavated toe trench with additional rock fill to anchor the upper-rocked slope.

Alternatives to rock slope protection are rock-filled gabion baskets, gabion mats, and vegetative stabilization. Vegetative-type slope protection measures are the more preferred if conditions warrant. Vegetative measures can be combined with rock and gabion slope protection measures.

Concreted Rock Slope Protection (Grouted Riprap):

Angular rocks of specified sizes are placed over engineering filter fabric protected by a layer of sand/gravel mixture.

Lean concrete is placed into the rock interstices. Rock should be wetted immediately prior to placement. Use of vibrators helps to work the concrete down into the rock volume.

Grouted riprap is used where flow velocities exceed the loose riprap resistance, or where larger riprap size and density suitable for the flow energy conditions is not available.

Rock Blanket:

A rock blanket consists of round cobble rock placed as a landscape feature in areas often inundated with water. The rock should be placed over a graded sand/gravel filter layer and/or filter fabric.

Sacked Concrete Slope Protection:

Bags are filled with concrete mix and stacked against the slope to cure. Rebar can be driven into the wet mix and bags.

Sacked concrete slope protection is aesthetically less desirable and is often times used as an emergency measure to protect a higher-value structure.

Slope Paving:

Slope paving is used almost exclusively below bridge decks at abutments. It provides erosion control and soil stabilization in areas too dark for vegetation to establish. It may be constructed of finish poured Portland Cement Concrete (PCC), shotcrete, or masonry paving units.

Gabions:

Gabions are wire cages filled with rock. These units are then constructed into structures of various configurations. They are an excellent alternative to riprap-type rock, where riprap rock of suitable density and size is not available. They also allow for vegetative plantings using tree stakes and/or with a layer of soil for seeding. They can be installed in locations of limited access by heavy machinery using hand labor.

6.4 QUALITY TREATMENT BMPs

6.4.1 INFILTRATION BMPS

Infiltration BMPs for runoff treatment include the following:

- IN.01 Bioinfiltration Pond
- IN.02 Infiltration Pond
- IN.03 Infiltration Trench
- IN.04 Infiltration Vault
- IN.05 Drywell

In addition to being the preferred method for flow control, infiltration is a preferred method for runoff treatment, offering the highest level of pollutant removal. Treatment is achieved through settling, biological action, and filtration. One important advantage to using infiltration is that it recharges the groundwater, thereby helping to maintain dry season base flows for streams. Infiltration also produces a natural reduction in stream temperature, which is an important factor in maintaining a healthy habitat. Infiltration will be the primary stormwater quality treatment BMP in the northern area of Guam, due to the aquifer recharge requirements.

Infiltration facilities must be preceded by a pre-settling basin for removing most of the sediment particles that would otherwise reduce the infiltrative capacity of the soil.

6.4.1.1 IN.01: BIOINFILTRATION POND

General Description

Bioinfiltration ponds, also known as bioinfiltration swales, combine filtration, soil absorption, and uptake by vegetative root zones to remove stormwater pollutants by percolation into the ground.

Overflows are typically routed through an appropriate conveyance system to a higher permeability infiltration BMP, such as a drywell or infiltration pond, or to a surface water discharge point with flow control, as necessary.

Appropriate Applications

This BMP meets the runoff treatment objectives for all treated pollution-generating impervious surfaces. Treatment is provided by a combination of the plant filtration and root uptake of nutrients and the infiltration through soil. The infiltration capacity of these facilities is usually insufficient to provide flow control to meet the criteria of Minimum Requirement 6 as defined in Chapter 3 of this TSDM. Unless a very large area is available for the shallow water depth required of a bioinfiltration pond, flow control must be implemented using a different facility. Bioinfiltration ponds require moderately permeable soil for proper function. In general, the site-suitability criteria are similar to that of an infiltration pond.

Implementation

Pre-settling/Pre-Treatment

Pre-treatment for removal of suspended solids, trash, and oils is required to prevent the bioinfiltration pond treatment soil from clogging. Pre-treatment BMPs can be bioswales, wet bioswales, wet ponds, and sedimentation ponds.

Flows To Be Treated

Bioinfiltration ponds are designed as volume-based infiltration treatment facilities. The runoff volume to be treated should be calculated using the guidelines in Chapter 4 of this TSDM.

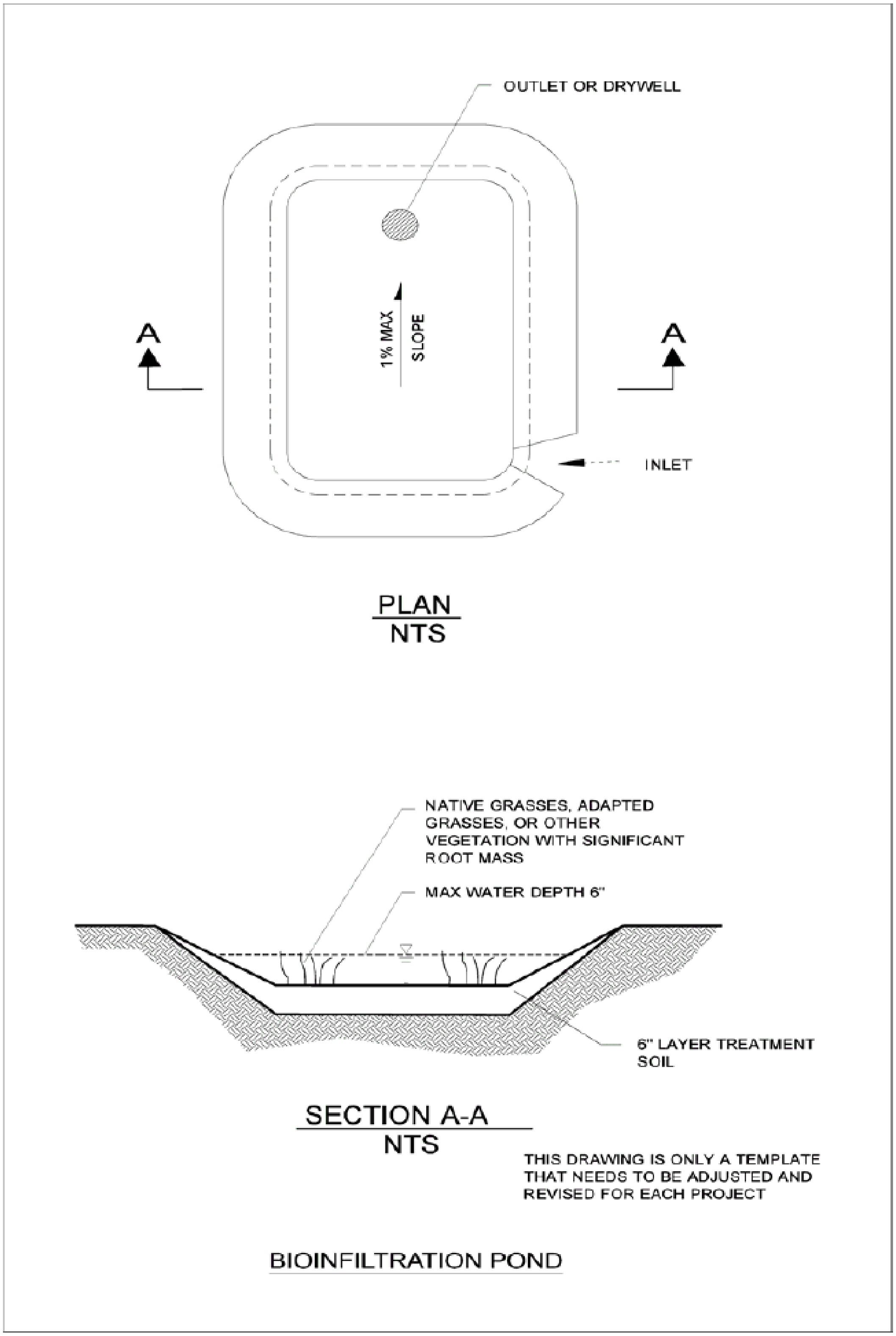


Figure 6-4: Bioinfiltration Pond

Geometry

Sizing methods for bioinfiltration ponds are the same as those for infiltration ponds designed for runoff treatment, except for the following:

- Drawdown time for the maximum ponded volume is 72 hours following the design storm event.
- The maximum ponded level is 6 in. prior to overflow to a drywell or other infiltrative or overflow facility.
- The swale bottom should be flat with a longitudinal slope less than 1 percent.
- A concrete or riprap apron should be provided at the inlet to spread the flow and keep vegetation from blocking the inlet.
- The treatment zone depth of 6 in. or more should contain sufficient organics and texture to ensure good vegetation growth. The average infiltration rate of the 6-in. thick layer of treatment soil should not exceed 1 in. per hour for a system relying on the root zone to enhance pollutant removal. Furthermore, a maximum infiltration rate of 2.4 in. per hour is applicable.
- Native grasses, adapted grasses, or other vegetation with significant root mass should be used.
- Pre-treatment may be used to prevent clogging of the treatment soil and vegetation by debris, Total Suspended Solids (TSS), and oil and grease.

Site Design Elements

Initial excavation should be conducted to within 1 ft. of the final elevation of the floor of the bioinfiltration pond. Defer final excavation to the finished grade until all disturbed areas in the up-gradient drainage area have been stabilized or protected. The final phase of excavation should remove all accumulated sediment. After construction is completed, prevent sediment from entering the bioinfiltration pond by first conveying the runoff water through an appropriate pre-treatment system, such as a pre-settling basin.

Bioinfiltration ponds, as with all types of infiltration facilities, should generally not be used as temporary sediment traps during construction. If a bioinfiltration pond is to be used as a sediment trap, do not excavate to final grade until after the up-gradient drainage area has been stabilized. Remove any accumulation of silt in the swale before putting the swale into service.

Relatively light-tracked equipment is recommended for excavation to avoid compacting the floor of the bioinfiltration pond. Consider the use of draglines and track hoes. The bioinfiltration pond area should be flagged or marked to keep equipment away.

Setback Requirements

Setback requirements for bioinfiltration ponds are the same as those for infiltration ponds.

Right-of-Way

Right-of-way requirements for bioinfiltration ponds are the same as those for detention ponds.

Landscaping (Planting Considerations)

Use native or adapted grass species for the entire area of the bioinfiltration pond.

Maintenance Access Roads (Access Requirements)

Access requirements for bioinfiltration ponds are the same as those for infiltration ponds.

6.4.1.2 IN.02: INFILTRATION POND

General Description

Infiltration ponds for stormwater quality treatment are earthen impoundments used for the collection, temporary storage, and infiltration of incoming stormwater runoff to groundwater. Infiltration ponds can also be designed as combination detention/infiltration ponds for flow control where soil conditions limit full infiltration of the runoff.

Appropriate Applications:

Infiltration of runoff is the preferred method of stormwater quality treatment and flow control. Runoff in excess of the infiltration capacity must be detained and released in compliance with the flow control requirement described as part of Minimum Requirement 6 in Chapter 3 of this TSDM.

Site-Suitability Criteria

Infiltration ponds require permeable soil conditions for proper function. For a site to be considered suitable for an infiltration pond, the design infiltration rate must be at least 0.5 in. per hour. Infiltration can still be considered in the design if the infiltration rate is less, but infiltration would be considered a secondary function in this case.

The infiltration rate to use for design should be established by site testing. Site infiltration should be determined in-situ by a method that accurately estimates the infiltration rate of the soil layer at the bottom of pond elevation. One such method is the ASTM D3385-Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer. At least three tests should be taken over each infiltration site. The design infiltration rate will be the average value of the tests divided by a Safety Factor (SF). The SF varies depending on the regular maintenance of the facility and the designer's estimate of sedimentation loads that could plug and seal off the infiltration facility. For example, the SF will vary from a minimum of two for a facility with good maintenance access serving a village street with curb and gutter inlets having relatively clean inflows, to a SF of four for difficult to access sites with off-site inflows subject to higher sedimentation and organic debris.

The base of all infiltration ponds should typically be 5 ft. above the seasonal high-water mark, bedrock (or hardpan), or other low-permeability layer. This vertical distance may be reduced to a minimum of 2 ft. if the following apply:

- The groundwater mounding analysis, volumetric receptor capacity, and design of the overflow or bypass structures are judged by the designer to be adequate to prevent overtopping.
- For the northern Guam aquifer recharge area, the bottom of the infiltration pond must be at least 2 ft. above the top of the limestone bedrock (permeable aquifer layer) to provide suitable soil filtration treatment prior to inflow to the aquifer. If the infiltration pond bottom is less than 2 ft. above the limestone bedrock, then another stormwater water quality treatment BMP must be incorporated prior to flow to the infiltration pond.
- The facility meets all other criteria listed in this BMP description.

Pre-settling/Pre-treatment

Infiltration ponds should follow a runoff treatment or pre-treatment facility to prevent sediment build-up and clogging of the infiltrative soils. A pre-settling sedimentation cell can be included in the infiltration pond design, as shown in Figure 6-5. If an infiltration pond cannot meet the site-suitability criteria for treatment, a quality treatment BMP must be provided prior to infiltration.

Design Flow Elements

Flows To Be Infiltrated

Site runoff should be infiltrated to the extent required in Minimum Requirement 5, as described in Chapter 3 of this TSDM. Runoff in excess of the infiltration capacity must be detained and released in compliance with the flow control requirement described as part of Minimum Requirement 6.

For a site to be considered suitable for an infiltration pond, the design infiltration rate must be at least 0.5 in. per hour. Infiltration can still be considered in flow control facility design if the infiltration rate is less than this, but infiltration must be considered a secondary function in that case. A pond should be designed to a desirable depth of 3 ft. and a maximum depth of 6 ft., with a minimum freeboard of 1 ft. above the design water level.

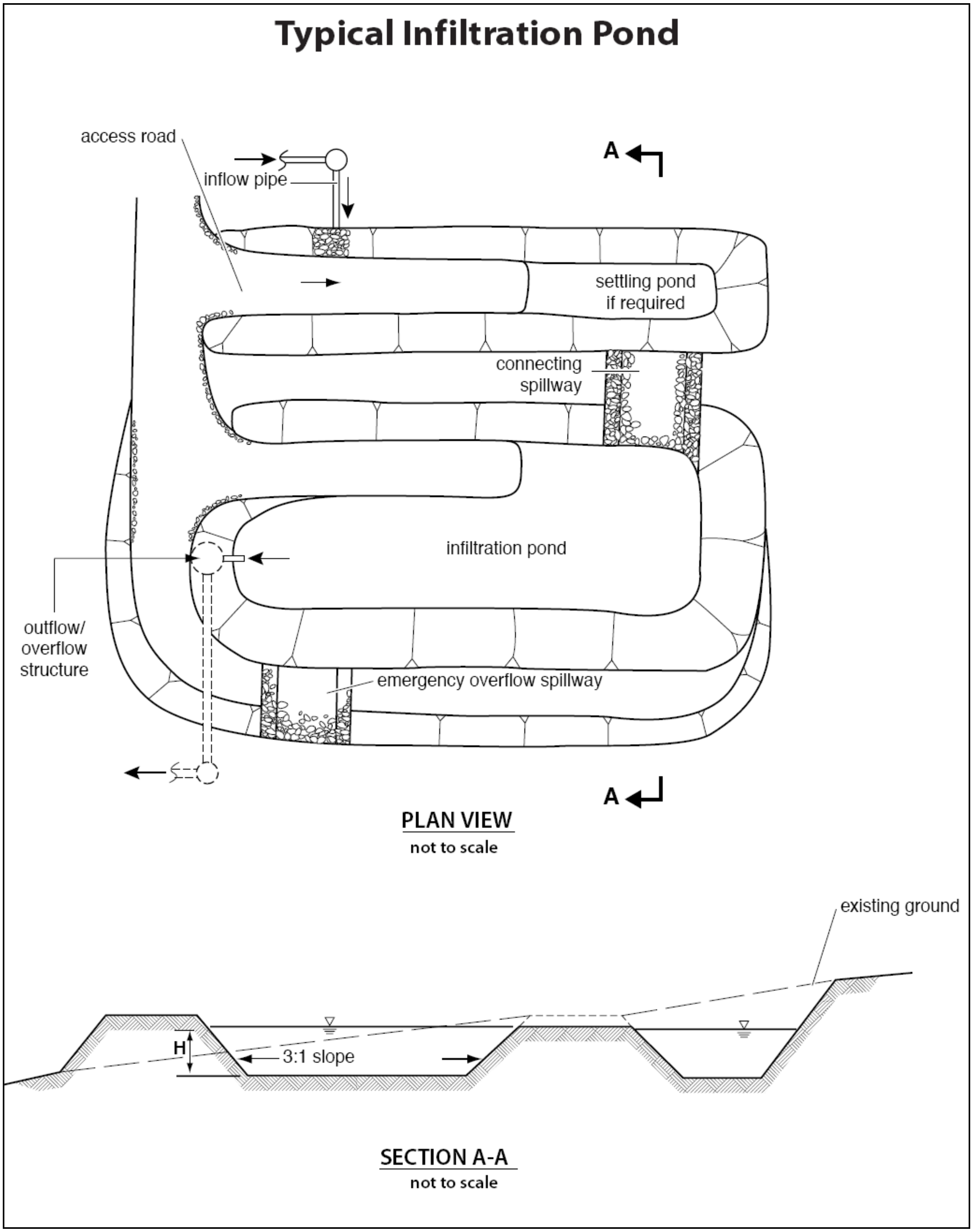
An infiltration pond must be designed using a single-event hydrograph model to infiltrate the stormwater quality treatment volume out of the pond within 72 hours.

An infiltration pond must be designed using a single-event hydrograph model to detain and infiltrate the design frequency storm with an overflow for the higher events. For locations without suitable overflow outlets, the 100-year frequency storm should be detained and fully-infiltrated.

Outlet Control Structure

Runoff in excess of the infiltration capacity must be detained and released in compliance with the flow control requirement described as part of Minimum Requirement 6 as defined in Chapter 3 of this TSDM.

Refer to BMP FC.01 – Detention Pond for design of the outlet control structure.



1
2 **Figure 6-5: Infiltration Pond**

Site Design Elements

Setback Requirements

For infiltration facilities, the designer should evaluate the geotechnical report. The report should address the adequacy of pond locations and recommend the necessary setbacks from any steep slopes and building foundations.

Infiltration facilities should be set back at least 1000 ft. from drinking water wells, and at least 100 ft. from septic tank drain field systems.

Infiltration facilities must be located at least 20 ft. downslope and 100 ft. upslope from building foundations, and must be 5 ft. from any property line.

Flow Splitters

When designed to serve only as a runoff treatment facility, the pond may be located offline. The facility must be designed to infiltrate all water quality volume directed to it. All bypassed flow must be conveyed to a flow control facility, unless it is directly discharged to an exempt water body. Note: Infiltration ponds designed for flow control must be located on-line.

Emergency Overflow Spillway

An emergency overflow-type, non-erodible outlet or spillway must be constructed to discharge flow in excess of the design flows to the downstream conveyance system, as described in BMP FC.01-Detention Pond. Ponding depth, drawdown time, and storage volume are calculated from the overflow elevation.

Structural Design Considerations

Geometry

The slope of the floor of an infiltration pond must not exceed 3 percent in any direction.

Embankments

Requirements for infiltration pond embankments are the same as those for BMP FC.01-Detention Pond. In addition to the testing for establishing the design soil infiltration rate, the geotechnical investigation must include the following:

- Stability analysis of side slopes for ponds
- Seepage analysis of any berms or dams

Liners

The floor of infiltration ponds can be covered with a 6-in. to 12-in. layer of filter material such as coarse sand. Over time, incoming organic materials and fine soil particles will seal the surface of the pond, lowering the infiltration rate. This filter layer can be readily replaced or cleaned as it becomes clogged.

Site Design Elements

Initial excavation should be conducted to within 1 ft. of the final elevation of the infiltration pond floor. Final excavation to the finished grade should be deferred until all disturbed areas in the up-gradient drainage area have been stabilized or protected. The final phase of excavation should remove all accumulated sediment.

Infiltration ponds, as with all types of infiltration facilities, should generally not be used as temporary sediment traps during construction. If an infiltration pond is to be used as a sediment trap, it must not be excavated to final grade until after the upstream drainage area has been stabilized. Any accumulation of silt in the pond must be removed before the pond is put into service.

Low-ground-pressure equipment is recommended for excavation to avoid compacting the floor of the infiltration pond. The use of draglines and track hoes should be considered. The infiltration area should be flagged or marked to keep equipment away.

Landscaping (Planting Considerations)

The interior of the infiltration pond, as well as surrounding berms, spoil areas, borrow areas, and other disturbed areas, should be stabilized and planted, preferably with suitable type grass. Without healthy vegetation, the surface soil pores quickly plug. Vegetative planting mixes should use seed mix suitable for the site and seasonal conditions. The actual seed mix, fertilizer, and planting methods should be performed in accordance with NRCS or DAWR recommendations.

Fencing

Fencing requirements for an infiltration pond are identical to those required for BMP FC.01-Detention Pond.

Signage

Signage requirements for an infiltration pond are identical to those required for BMP FC.01-Detention Pond

Maintenance Access Roads (Access Requirements)

Vehicle access must be provided for removal of sediment from the pre-treatment sedimentation cell (or forebay), and for maintenance of the outfall structure. Access roads and ramps should meet the minimum requirements listed for BMP FC.01-Detention Pond.

Operation and Maintenance

Infiltration ponds, as with all BMPs, must have routine inspection and maintenance designed into the life performance of the facility. They should be inspected regularly during the wet season to ensure that the inlet and overflow devices are not plugged and working correctly. They should also be checked immediately after any large storm event and any damage should be repaired immediately. The sedimentation cell should be checked annually for sediment buildup and the accumulated sediment should be removed if it exceeds 18 in. of depth. As part of the sediment removal process, the disturbed soil areas and any other eroded spots should be re-graded to the original grade and re-seeded. Infiltration facilities should also be checked at least on an annual basis during the wet season for infiltration capacity. This can be accomplished by observing that the time to empty after a storm event is within the basic design requirements.

6.4.1.3 IN.03: INFILTRATION TRENCH

General Description

Infiltration trenches are long, narrow, stone-filled trenches used for the collection, temporary storage, and infiltration of stormwater runoff to groundwater. They can be a useful alternative for sites with constraints that make siting an infiltration pond difficult. Infiltration trenches may be placed beneath parking areas, along the site periphery, or in other suitable linear areas. For infiltration trench concept details, see Figures 6-6 through 6-11.

Appropriate Applications

The infiltration of runoff is the preferred method of runoff quality treatment and flow control. Runoff in excess of the infiltration capacity must be otherwise detained and released in compliance with the flow control requirement described as part of Minimum Requirement 6 in Chapter 3 of this TSDM.

Site-Suitability Criteria

Site-suitability criteria are the same as those for BMP IN-01 Infiltration Ponds.

Pre-settling/Pre-treatment

Infiltration trenches should follow a runoff treatment or sedimentation (pre-treatment) facility to limit sediment build-up and clogging of the trench. Where surface runoff is routed directly to the infiltration trench, it should pass as sheet flow over a grassed slope or through a biofiltration swale to help remove as much of the coarser sediments as possible.

Design Flow Elements

Flows To Be Infiltrated

The flows to be treated by an infiltration trench are identical to those for an infiltration pond.

Overflow or Bypass

Because infiltration trenches are generally used for small drainage areas, an emergency spillway is not necessary. However, a non-erosive overflow system leading to a stabilized watercourse should be provided. If a suitable overflow site is not available, then all the volume from the 100-year storm event should be detained and infiltrated.

Outlet Control Structure

Outlet control structure requirements for an infiltration trench are identical to those for an infiltration pond.

Flow Splitters

Flow splitter requirements for an infiltration trench are identical to those for an infiltration pond.

Structural Design Considerations

Geometry

Infiltration trench-sizing methods use the volume of the voids of the rock, any storage area above the rock, and additional volume within a pipe in the trench, as appropriate, to detain the stormwater quality treatment and/or flow control volume designed by routing the design storm inflow against the infiltration outflow. The design method is essentially the same as that for BMP IN.02-Infiltration Pond, where the design is based on in-situ infiltration testing. Note that in the Guam limestone aquifer recharge area, the bottom of the infiltration volume must be at least 2 ft. above the limestone bedrock surface. If less than 2 ft. of soil exists, then the flows to the infiltration trench must be pretreated by another stormwater quality treatment BMP.

Materials

Backfill Material

The backfill material for the infiltration trench should consist of clean aggregate with a maximum diameter of 3 in. and a minimum diameter of 1.5 in. Void space for the aggregate should be in the range of 30 percent to 40 percent.

Geotextile Filter Fabric

An engineering geotextile material, which can be a sand/gravel mixture or natural grassed soil condition, must encase all of the aggregate fill material under the top 6 in. to 12 in. of trench. Geotextile fabric with acceptable properties must be carefully selected to avoid plugging.

Additional guidelines on geotextile filter fabric design and installation can be found in FHWA publication NHI Course No. 13213, Geosynthetic Design and Construction Guidelines, No. FHWA HI-95-038, April 1998.

Observation Well

An observation well should be installed at the lower end of the infiltration trench to check water levels, draw-down time, and sediment accumulation, and to allow for water-quality monitoring. The well should consist of a perforated PVC pipe 4 in. to 6 in. in diameter, with the top constructed flush with the ground elevation. For larger trenches, a 12-in. diameter to 36-in. diameter well can be installed to facilitate maintenance operations, such as pumping out trapped sediment. The top of the well should be capped to discourage vandalism and tampering. See Figure 6-11 for typical details.

Groundwater Issues

Groundwater issues for an infiltration trench are identical to those for an infiltration pond.

Site Design Elements

Setback Requirements

Setback requirements for an infiltration trench are identical to those for an infiltration pond.

Landscaping (Planting Considerations)

All disturbed earth surfaces and slopes should be vegetated with an erosion protection type grass seed mix. The seed mix should be suitable for the site and seasonal conditions. The actual seed mix, fertilizer, and planting methods should be specified in accordance with NRCS or DAWR recommendations.

Maintenance Access Roads (Access Requirements)

Similar to all other hydraulic systems, the inlet/outlet structures that are more susceptible to sedimentation and clogging by debris should be accessible for maintenance by suction/rodding-type maintenance trucks. The observation well should include a lockable cap or cover and be located for easy access by maintenance personnel.

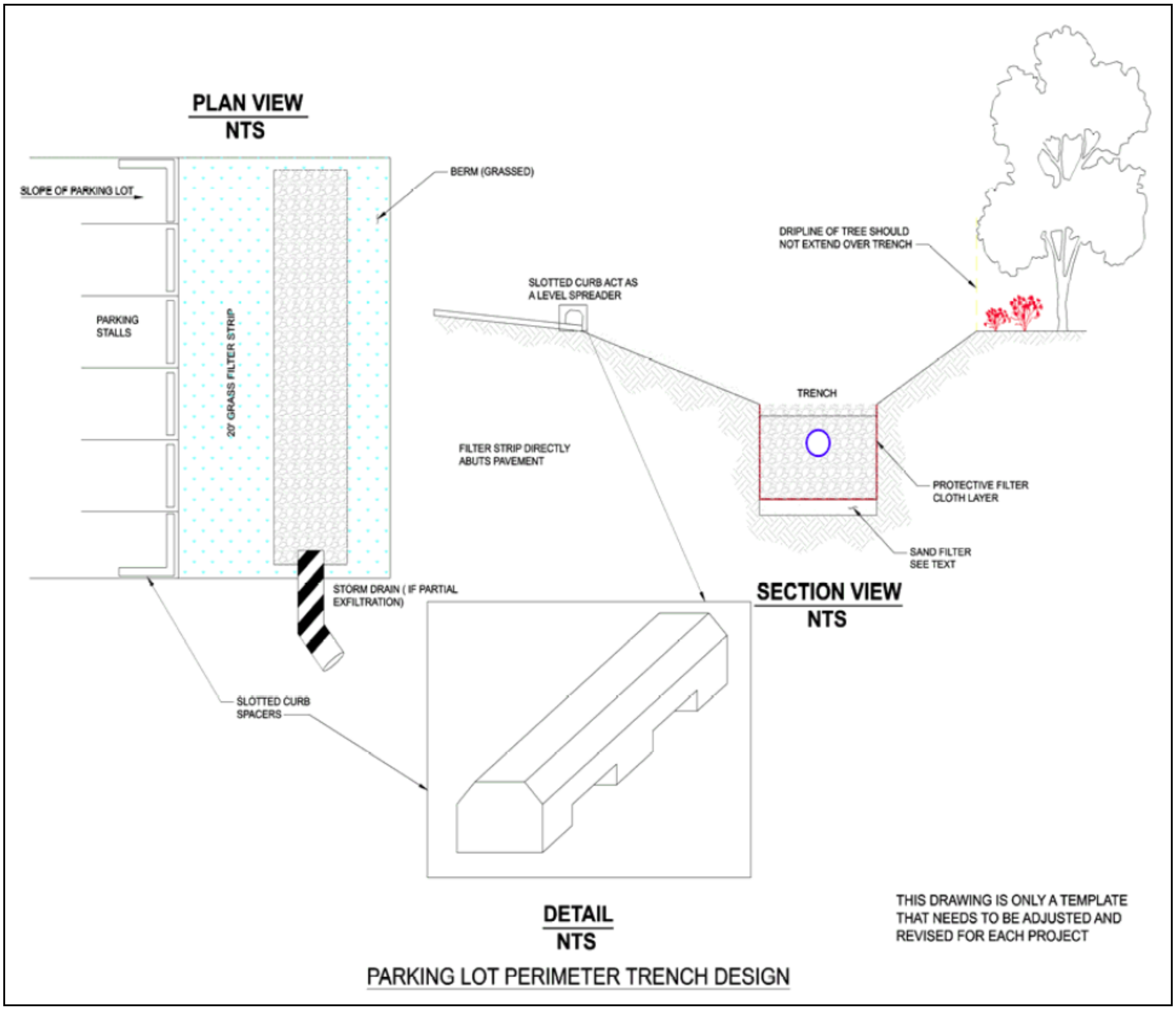


Figure 6-6: Parking Lot Perimeter Trench Design

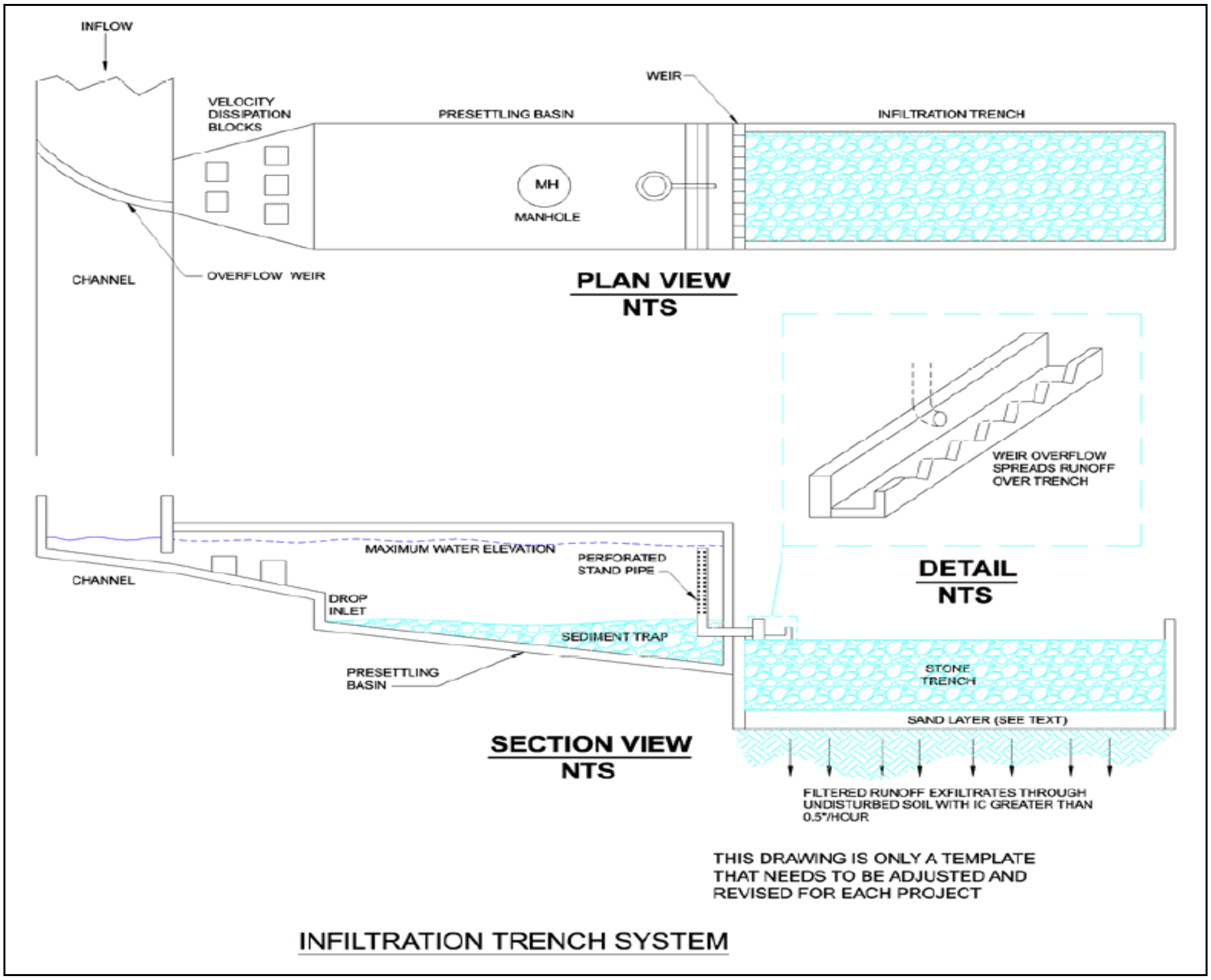


Figure 6-7: Infiltration Trench System

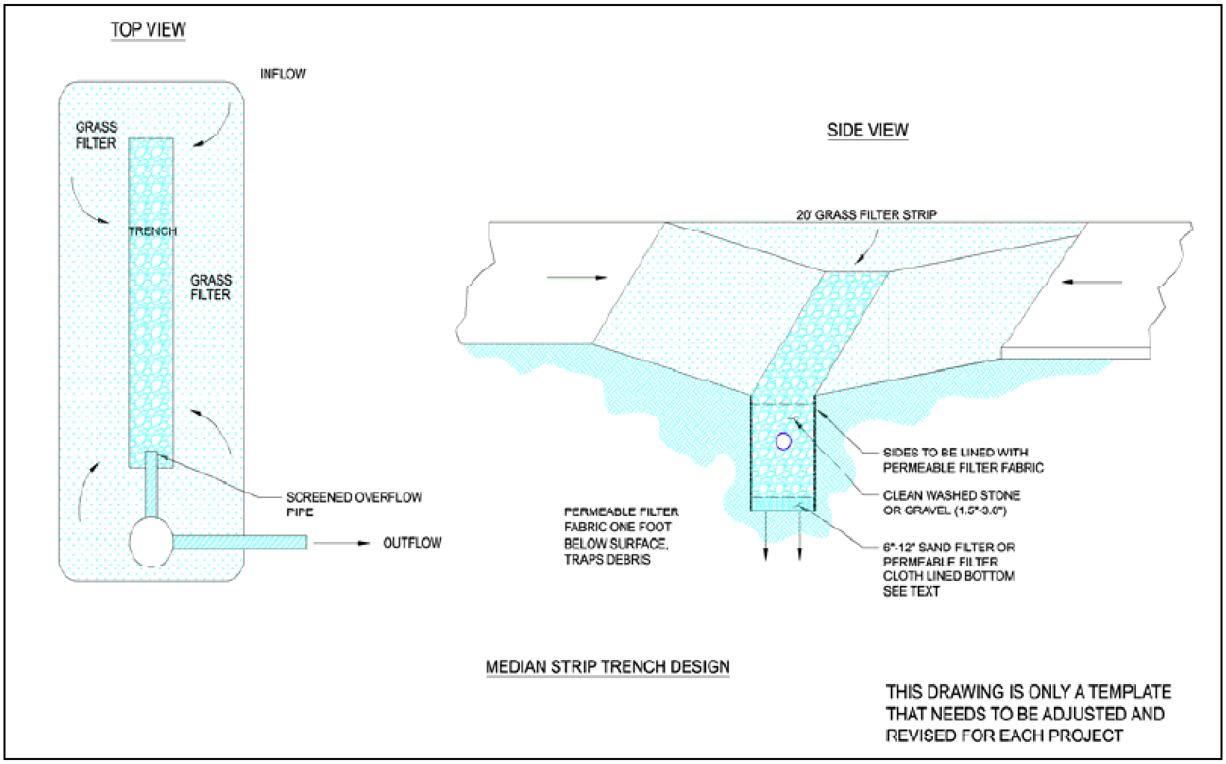


Figure 6-8: Median Strip Trench Design

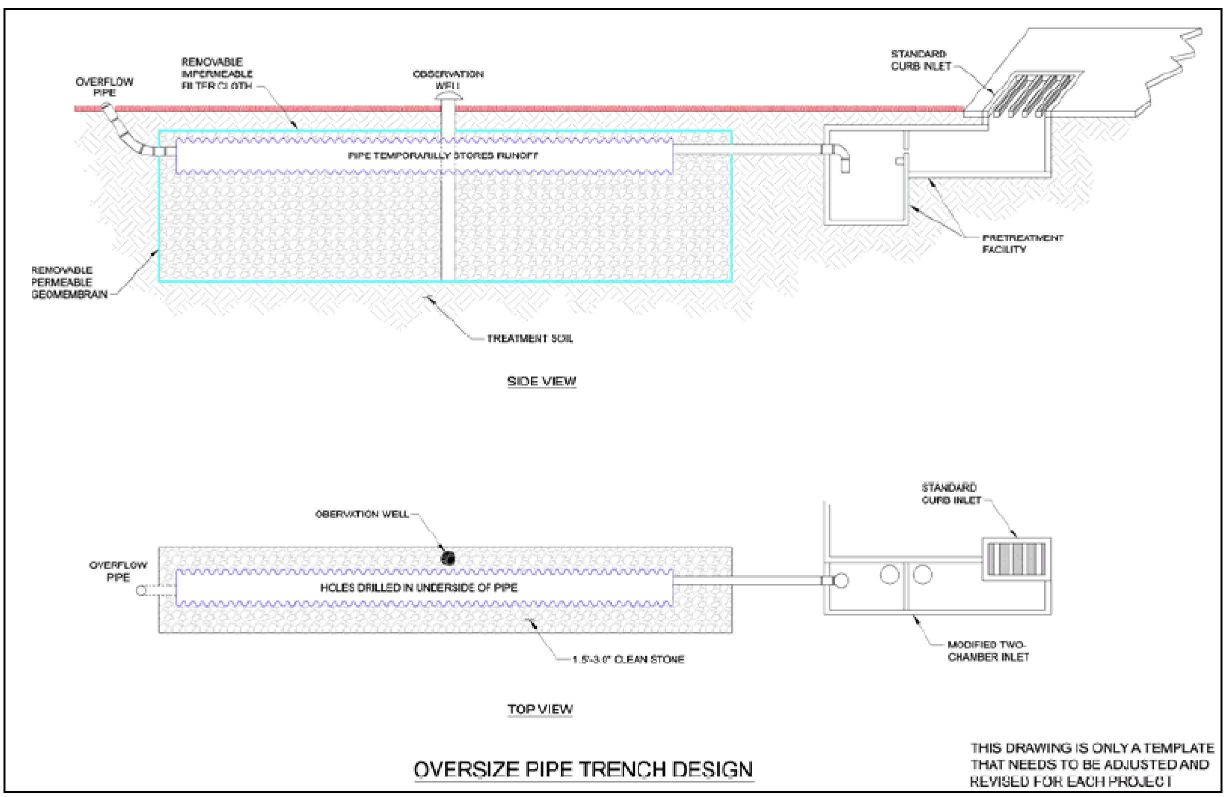


Figure 6-9: Oversize Pipe Trench Design

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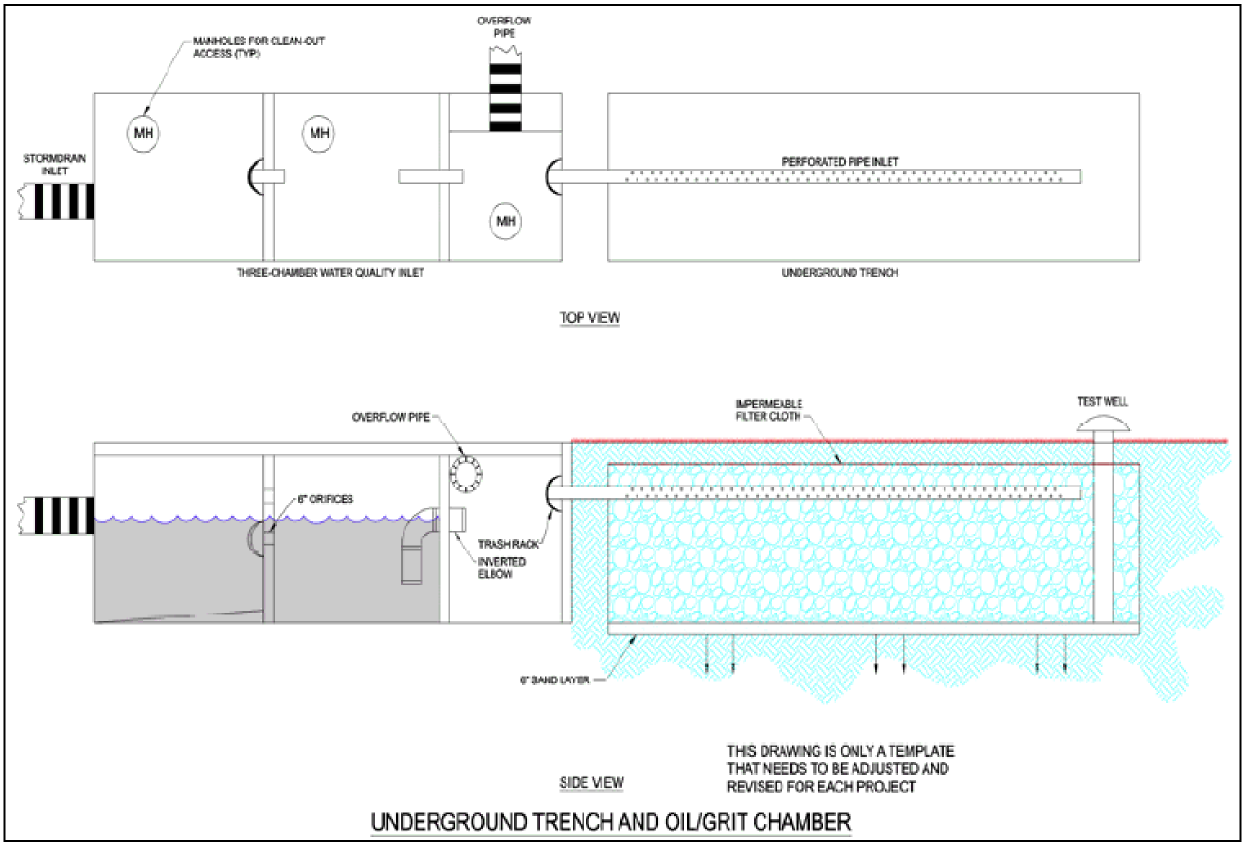

2 **Figure 6-10: Underground Trench and Grit Chamber**

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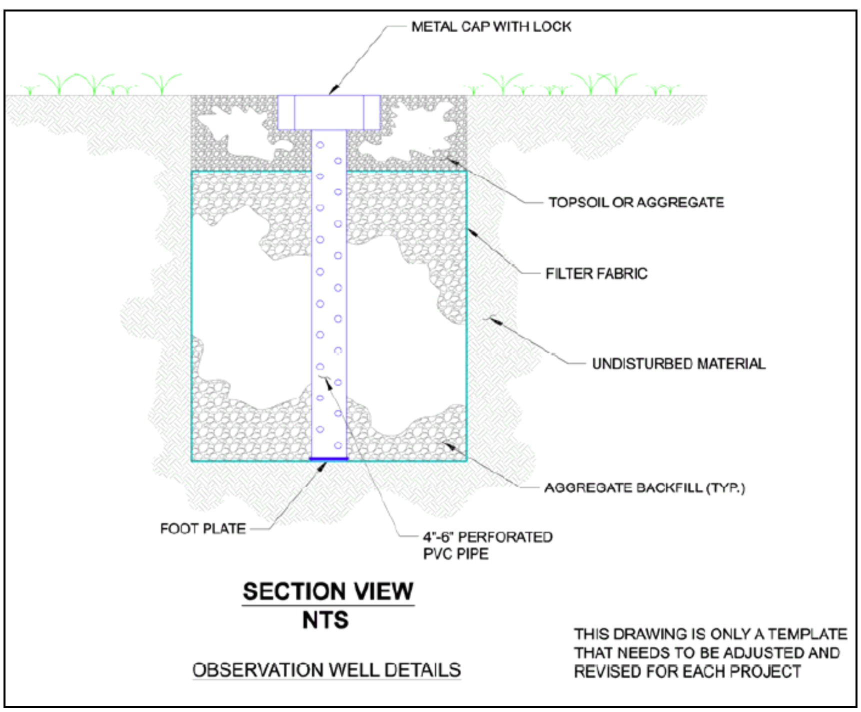

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5 **Figure 6-11: Observation Wells**

Implementation

Trench Preparation

Excavated materials must be placed away from the trench sides to enhance trench wall stability. Care should be taken to keep this material away from slopes, neighboring property, sidewalks, and streets. It is recommended that this material be covered with plastic.

Stone Aggregate Placement and Compaction

The stone aggregate should be placed in lifts and compacted using plate compactors. As a rule of thumb, a maximum loose-lift thickness of 12 in. is recommended. The compaction process ensures geotextile conformity to the excavation sides, thereby reducing potential piping and geotextile clogging as well as settlement problems.

Separation of Aggregate from Surrounding Soil

Natural or fill soils must not intermix with the stone aggregate. If the stone aggregate becomes mixed with the soil, the stone aggregate must be removed and replaced with uncontaminated stone aggregate.

Overlapping and Covering

The stone aggregate should be wrapped in a geotextile filter fabric. The fabric is draped in the trench prior to the stone placement. Following stone aggregate placement and compaction, the geotextile is then folded over the stone aggregate to form a 12-in. minimum longitudinal overlap. When overlaps are required between rolls, the upstream roll should overlap a minimum of 2 ft. over the downstream roll to provide a shingled effect.

Voids Behind Geotextile

Voids between the geotextile and excavation sides must be avoided. The space left by boulders or other obstacles removed from the trench walls is one source of such voids. Natural soils should be placed in these voids at the most convenient time during construction to ensure geotextile conformity to the excavation sides. Soil piping, geotextile clogging, and possible surface subsidence can be avoided by this remedial process.

Unstable Excavation Sites

Vertically excavated walls may be difficult to maintain in areas where the soil moisture is high or where soft or cohesionless soils predominate. Trapezoidal rather than rectangular cross sections may be needed.

Initial excavation should be conducted to within 1 ft. of the final elevation of the infiltration pond floor. Final excavation to the finished grade should be deferred until all disturbed areas in the up-gradient drainage area have been stabilized or protected. The final phase of excavation should remove all accumulated sediment.

Infiltration trenches, as with all types of infiltration facilities, should generally not be used as temporary sediment traps during construction. If an infiltration trench is to be used as a sediment trap, it must not be excavated to final grade until after the up-gradient drainage area has been stabilized. Any accumulation of silt in the trench must be removed before the trench is put into service.

Operation and Maintenance

Infiltration trenches, as with all BMPs, must have routine inspection and maintenance designed into the life performance of the facility.

6.4.1.4 IN.04: INFILTRATION VAULT

General Description

Infiltration vaults are typically large diameter, perforated pipe (tanks); pre-cast or cast-in-place reinforced concrete box structures; or bottomless reinforced concrete structures used for temporary storage and the infiltration of stormwater runoff to groundwater. These types of underground infiltration facilities can be a useful alternative for sites with constraints that make locating an infiltration pond difficult.

Appropriate Applications

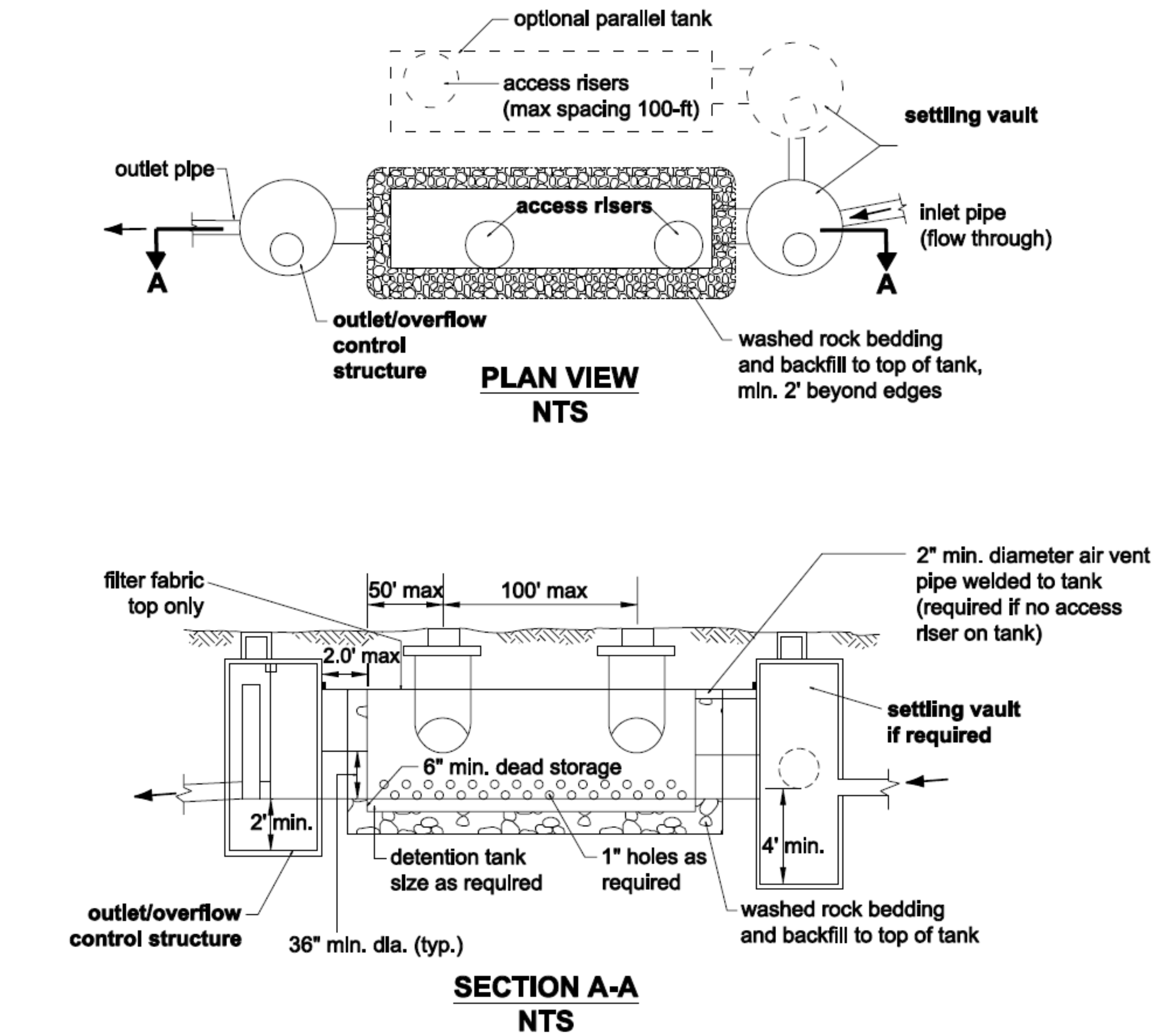
The infiltration of runoff is the preferred method of stormwater quality treatment and flow control. Runoff in excess of the infiltration capacity must be detained and released in compliance with the flow control requirement described as part of Minimum Requirement 6 as defined in Chapter 3 of this TSDM.

Site-Suitability Criteria

The site-suitability criteria for an infiltration vault are the same as for infiltration ponds. Infiltration vaults should not be constructed on slopes greater than 25 percent (4H:1V). On slopes more than 15 percent, near tops of steep slopes or in landslide hazard areas, a geotechnical investigation should be performed.

Pre-settling/Pre-Treatment

Infiltration vaults should follow a runoff treatment or sedimentation facility to prevent sediment accumulation and clogging of the basin.



NOTES:
- All metal parts corrosion resistant. Steel parts galvanized and asphalt coated.
- Filter fabric to be placed over washed rock backfill.

Figure 6-12: BMP IN.04 - Infiltration Vault

Design Flow Elements

Flows To Be Infiltrated

The flows to be disposed to groundwater by infiltration vaults are the same as those for BMP IN.02-Infiltration Ponds.

Overflow or Bypass

For on-line vaults, a primary overflow must be provided to bypass flows larger than the design storm event to the infiltration vault. See BMP FC.01-Detention Pond for overflow structure types. For off-line facilities, a flow splitter may be used to direct the stormwater quality treatment volume to the vault, while bypassing larger frequency storms.

Outlet Control Structure

Outlet control structure requirements for infiltration vaults are the same as those for BMP IN.02-Infiltration Pond.

Flow Splitters

Flow splitter requirements for infiltration vaults are the same as those for BMP IN.02-Infiltration Pond

Structural Design Considerations

Geometry

Infiltration vault geometric design requirements are similar to those for BMP IN.02-Infiltration Pond. Where used only for stormwater quality treatment, the storage volume sizing is based on a routing of the treatment volume inflow rate with regard to the design infiltration outflow rate. For combination quality treatment and flow control, the storage volume is based on the detention requirements between the pre-development and post-development land cover conditions for the design frequency storm. The infiltration rate is included as part of the discharge flow rate for the detention sizing calculations.

Materials

All vaults (both perforated pipe and reinforced concrete) must meet structural requirements for overburden support. Vaults located under roadways must meet the live load requirements of the FHWA *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects* (Standard Specification FP-03). Structural designs should be prepared by a Licensed Structural Engineer. Bottomless vaults must be provided with footings placed on stable, well-consolidated native material and sized in consideration of overburden support, traffic loading (assume maintenance traffic if vault is placed outside of right-of-way), and lateral soil pressures when the vault is dry. Infiltration vaults should not be constructed in fill slopes unless a geotechnical analysis determines fill stability.

Large diameter perforated pipe, bedding, and backfill should consist of washed, drain rock extending at least 1 ft. below the bottom of the structure, at least 2 ft. beyond the sides, and up to the top of the structure. The drain rock must be wrapped with geotextile filter fabric for separation from the native soil. If the drain rock becomes mixed with soil, the effected rock material must be removed and replaced with washed, drain rock to provide maximum infiltration effectiveness.

The perforations (holes) in the bottom half of the pipe should be 1 in. in diameter and start at an elevation of 6 in. above the invert. The non-perforated portion of the pipe in the lower 6 in. is intended for sediment storage to protect clogging of the native soil beneath the structure. The number and spacing of the perforations should be sufficient to allow complete infiltration of the soils with a safety factor of 2.0, without jeopardizing the structural integrity of the pipe.

The design must take into account the serviceability and design life of the materials, as well as the structural stability, buoyancy, maintenance access, access roads, and right-of-way.

Groundwater Issues

Groundwater issues for infiltration vaults are the same as those for BMP IN.02-Infiltration Pond.

Implementation

Initial excavation should be conducted to within 1 ft. of the final elevation of the infiltration vault base. Final excavation to the finished grade should be deferred until all disturbed areas in the up-gradient drainage area have been stabilized or protected. The final phase of excavation should remove all accumulated sediment.

Infiltration vaults, as with all types of infiltration facilities, should generally not be used as temporary sediment traps during construction. If an infiltration vault is to be used as a sediment trap, it must not be excavated to the final grade until after the up-gradient drainage area has been stabilized. Any accumulation of silt in the vault must be removed before the vault is put into service.

Relatively light-tracked equipment is recommended for excavation to avoid compacting the soil beneath the base of the infiltration vault. The use of draglines and track hoes should be considered. The infiltration area should be flagged or marked to keep equipment away.

Operation and Maintenance

Infiltration vaults, as with all BMPs, must have routine inspection and maintenance designed into the life performance of the facility. Access is required suitable for suction/rodding-type maintenance trucks for removal of sediments, and for maintenance personnel for routine inspections.

6.4.1.5 IN.05: DRYWELL

General Description

Drywells are sub-surface concrete structures, typically pre-cast, that convey stormwater runoff into the soil matrix. They can be used as stand-alone structures or as part of a larger drainage system (for example, the overflow for a bioinfiltration pond).

Appropriate Applications

Drywells may be used for both stormwater quality treatment and flow control. Flow splitters or overflow devices must be used for flows greater than the runoff treatment design storm, and for flows greater than the design infiltration rate.

Drywells may be used for the same applications as BMP IN.02-Infiltration Ponds and BMP IN.03-Infiltration Trench.

Pre-settling/Pre-Treatment

Drywells should follow a runoff treatment or sedimentation (pre-treatment) facility to limit sediment build-up and clogging of the infiltration media. Where surface runoff is routed directly to the drywell, it should pass as sheet flow over a grassed slope or through a biofiltration swale to help remove as much of the coarser sediments as possible.

Implementation

Inflow to infiltration facilities is calculated according to the methods described in Chapter 4 of this TSDM. Storage volume should be provided within and above the drywell as required for the necessary detention to contain the treatment volume and/or flow control volume as required for infiltration of the design flows. The infiltration rate is used in conjunction with the size of the storage area to design the facility. To prevent the onset of anaerobic conditions, the infiltration facility must be designed to completely drain 72 hours after the end of the design storm.

In general, an infiltration facility should have two discharge modes. The primary mode of discharge is infiltration into the ground. However, when the infiltration capacity of the facility is reached, a secondary overflow system is required to safely pass the flow from storms larger than the design frequency. Overflows from an infiltration facility must comply with Minimum Requirement 6 as defined in Chapter 3 of this TSDM.

Flows To Be Infiltrated

The flows to be disposed to groundwater by drywells are the same as those for BMP IN.02-Infiltration Pond.

Overflow or Bypass

On-line systems should have an overflow provision to safely pass storm flows larger than the design frequency. Drywells used off-line for stormwater quality treatment should use a flow splitter, so that flows larger than the treatment volume bypass the inlet to the drywell.

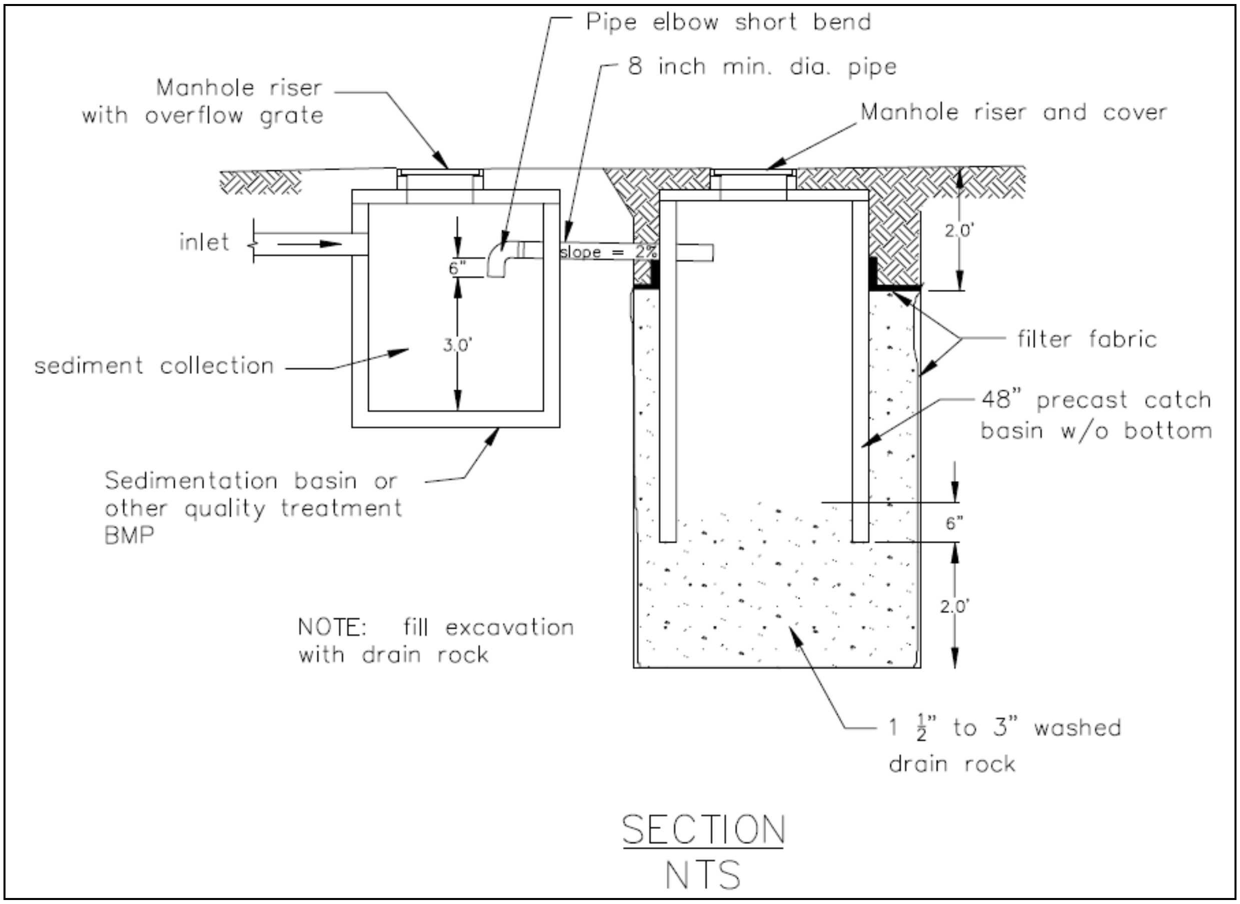


Figure 6-13: BMP IN.05 - Drywell

Structural Design Considerations

Geometry

- Typically, drywells are a minimum of 48 in. in diameter and are approximately 5 ft. to 10 ft. or more deep
- Filter fabric (geotextile) may need to be placed on top of the drain rock and on trench or drywell sides before the drywell is backfilled to prevent the migration of fines into the drain rock, depending on local soil conditions
- Drywells should be spaced no closer than 30 ft. center-to-center or twice the structure depth in free-flowing soils, whichever is greater
- Drywells should not be built on slopes greater than 25 percent (4H: 1V)

- Drywells should not be placed on or above a landslide hazard area or slopes greater than 15 percent without a geotechnical evaluation

Groundwater Issues

Drywell bottoms should be a minimum of 5 ft. above the seasonal high- groundwater level or impermeable soil layers. In northern Guam, this requirement is waived if located above the limestone aquifer recharge area. However, if the discharge infiltration level is less than 2 ft. above the limestone bedrock, the inflows must be pre-treated through another stormwater quality treatment BMP.

Site Design Elements

Setback Requirements

The setback requirements for drywells are the same as those for BMP IN.02-Infiltration Ponds.

Signage

The requirements for signs are the same as those for BMP IN.02-Infiltration Ponds.

6.4.1.6 IN.05: PERMEABLE PAVEMENT

General Description

Permeable (porous or pervious) surfaces can be applied to non-pollution-generating surfaces such as pedestrian/bike paths, raised traffic islands, and sidewalks. Permeable surfaces with a media filtration sub-layer (such as sand or an amended soil) could be applied to pollution generating surfaces (such as parking lots) for calculating runoff treatment. Permeable surfaces allow stormwater to pass through and infiltrate the soil below, thereby reducing the rate and volume of runoff associated with conventional surfacing and fostering groundwater recharge.

The permeable concrete or asphalt pavement surface is an open-graded mix placed in a manner that results in a high degree of interstitial spaces or voids within the cemented aggregate. This technique demonstrates a high degree of absorption or storage within the voids and infiltration to sub-soils. The pavement may be permeable concrete, permeable asphalt, or manufactured systems such as interlocking brick or a combination of sand and brick lattice. Geo-cell with geotextile and aggregate material may also be considered for limited applications.

Appropriate Applications

Possible areas for use of these permeable surface materials include the following:

- Sidewalks, bicycle trails, community trail/pedestrian path systems, or any pedestrian-accessible paved areas (such as traffic islands)

- Vehicle access areas, including emergency stopping lanes, maintenance/enforcement areas on divided highways, and facility maintenance access roads
- Public and municipal parking lots, including perimeter and overflow parking areas

Permeable surface systems function as stormwater infiltration areas and temporary stormwater retention areas that can accommodate pedestrians and light- to medium-load parking areas. They are applicable to both residential and commercial applications, with the exception of heavy truck traffic. This combination of functions offers the following benefits:

- Captures and retains precipitation on-site
- Mimics natural soils filtration throughout the pavement depth, underlying sub-base reservoir, and native soils for improved groundwater quality
- Eliminates surface runoff, depending on existing soil conditions
- Greatly reduces or eliminates the need for an on-site stormwater management system
- Reduces drainage water runoff temperatures
- Increases recharge of groundwater
- Provides runoff treatment with a media filtration layer

Handling and placement practices for permeable surfaces are different from conventional pavement placement. Unlike conventional pavement construction, it is important that the underlying native or sub-grade soils be nominally consolidated to prevent settling and minimize the effect of intentional or inadvertent heavy compaction due to heavy equipment operation during construction. Consolidation can be accomplished using static dual-wheel small mechanical rollers or plate vibration machines. If heavy compaction does occur, then tilling may be necessary to a depth of 2 ft. below the material placement. This would occur prior to subsequent application of the separation and base layers.

Permeable surfaces are vulnerable to clogging from sediment in runoff. The following techniques will reduce this potential:

- Surface runoff. Permeable surfaces should not be located where turbid runoff from adjacent areas can introduce sediments onto the permeable surface. Designs should slope impervious runoff away from permeable pavement installations to the maximum extent possible.
- Diversion. French drains, or other diversion structures, may be designed into the system to avoid unintended off-site runoff. Permeable systems

can be separated using edge drain systems, turnpikes, and 0.15-foot-high tapered bumps.

- Slopes. Off-site drainage slopes immediately adjacent to the permeable surface should be less than 5 percent to reduce the chance of soil loss that would cause clogging.

Limitations

Suitable grades, subsoil drainage characteristics, and groundwater table conditions require good multidisciplinary analysis and design. Proper construction techniques and diligent field inspection during the placement of permeable surfaces are also essential to a successful installation.

- Installation works best with level, adjacent slopes — 1 percent to 2 percent — and on upland soils. Permeable surface installations are not appropriate when adjacent draining slopes are 5 percent or greater.
- An extended period of saturation of the base material underlying the surface is undesirable. Therefore, the subsurface reservoir layer should fully drain in a period of less than 36 hours.
- The minimum depth from the bottom of the base course to bedrock and seasonally high water table should be 3 feet, unless it is possible to engineer a groundwater bypass into the system.

Examples of situations where the use of permeable surfaces is not currently recommended include the following:

- Roadway lanes because of a number of considerations (such as dynamic loading, safety, clogging, and heavy loads). More study and experience are needed before using permeable surfaces in these situations. Use of any type of shoulder application whereby the retained moisture drains away from the main line requires coordinated approval from materials, roadway design, hydraulics, and maintenance support staff.
- Areas where the permeable surface will be routinely exposed to heavy sediment loading.
- Areas such as maintenance yards that are subject, or potentially subject, to higher pollutant loadings, spills, and piles of bulk materials (such as sand or salt) should not incorporate permeable pavements.
- Areas where the risk of groundwater contamination from organic compounds is high (e.g., fueling stations, commercial truck parking areas, and maintenance and storage yards).

- Within 100 feet of a drinking water well and within areas designated as sole source aquifers.
- Areas with a high water table or impermeable soil layer.
- Within 100 feet up-gradient or 10 feet down-gradient from building foundations. Closer up-gradient distances may be considered where the minimum seasonal depth to groundwater lies below the foundation or where it can be demonstrated that infiltrating water from the permeable surface will not affect the foundation.

General Design Considerations

All projects considering the use of permeable surfaces should be further explored in coordination with the Design, Materials Lab, Hydraulics, and Maintenance offices.

- As long as runoff is not directed to the permeable asphalt from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.1 inch/hour. Soils with lower infiltration rates should have underdrains to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section.
- For initial planning purposes, permeable surface systems will work well on Hydrologic Soil Groups A and B and can be considered for Group C soils.
- Standard three-layer placement sections for Group D soils may not be applicable.
- For projects constructed on Group C and D soils, a minimum of three soil gradation analyses or three infiltration tests should be conducted to establish on-site soil permeability. Otherwise, a minimum of one such test should be conducted for Group A and B soils to verify adequate permeability.
- Ideally, the base layer should be designed with sufficient depth to meet flow control requirements (taking into account infiltration). If the infiltration rate and base layer’s recharge bed storage does not meet flow control requirements, an underdrain system may be required. The underdrain could be discharged to a bioretention area, dispersion system, or stormwater detention facility.
- Turbid runoff to the permeable surface from off-site areas is not allowed. Designs may incorporate infiltration trenches or other options to ensure long-term infiltration through the permeable surface.

- Any necessary boreholes must be installed to a depth of 10 feet below the base of the reservoir layer, and the water table must be monitored at least monthly for a year.
- Infiltration systems perform best on upland soils.

On-site soils should be tested for porosity, permeability, organic content, and potential for cation exchange. These properties should be reviewed when designing the recharge bed of pervious surfaces.

Once a permeable surface site is identified, a geotechnical investigation should be performed to determine the quantity and depth of borings/test pits required and any groundwater monitoring needed to characterize the soil.

For on-site locations where subgrade materials are marginal, the use of a heavy-duty geogrid placed directly on subgrade may be necessary. A sand layer is placed above the heavy geogrid, followed by geotextile for drainage.

Design Flow Elements

For sizing purposes, use the following guidelines:

- The bottom area of an "infiltration basin" will typically be equivalent to the area below the surrounding grade underlying the permeable surface. Adjust the depth of this "infiltration basin" so that it is sufficient to store the required design volume.
- Multiply this depth by a factor of five. This will determine the depth of the gravel base underlying the permeable surface. This assumes a void ratio of 0.20 — a conservative assumption. When a base material that has a different porosity will be used, that value may be substituted to determine the depth of the base. The minimum base depth is 6 inches, which allows for adequate structural support of the permeable surface.
- For a large, contiguous area of permeable surface, such as a parking lot, the area may be designed with a level surface grade and a sloped subgrade to prevent water buildup on the surface, except under extreme conditions. Rare instances of shallow ponding in a parking lot are normally acceptable.
- For projects where ponding is unacceptable under any condition, the surface of the parking lot may be graded at a 1 percent slope leading to a shallow swale, which would function to ensure emergency drainage (similar to an emergency overflow from a conventional infiltration pond). However, the design depth of the base material must be maintained at all locations.

Maintenance Considerations

Permeable surfaces require more maintenance than conventional pavement installations. The primary concern in maintaining the continued effectiveness of a permeable surface system is to prevent the surface from clogging with fine sediments and debris.

Materials

Permeable surfaces consist of a number of components — the surface pavement, an underlying base layer, a separation layer, and the native soil or subgrade soil. An overflow or underdrain system may need to be considered as part of the pavement's overall design.

Surface Layer

The surface layer is the first component of a permeable system's design that creates the ability for water to infiltrate through the surface. Permeable paving systems allow infiltration of storm flows; however, the wearing course should not be allowed to become saturated from excessive water volume stored in the aggregate base layer.

Portland Cement-Based Pervious Pavement Materials

The surface layer consists of specially formulated mixtures of Portland cement, uniform open-graded coarse aggregate, and potable water. The depth of the surface layer may increase from a minimum of 4 inches, depending on the required bearing strength and pavement design requirements. The gradation required to obtain a pervious concrete pavement is of the open-graded or coarse type (AASHTO Grading No. 67, ¾ inch and lower).

Due to the relatively low water content of the concrete mix, an agent may be added to retard concrete setup time. When properly handled and installed, pervious pavement has a higher percentage of void space than conventional pavement (approximately 12 percent to 21 percent), which allows rapid percolation of stormwater through the pavement. The initial permeability can commonly exceed 200 inches per hour

Asphalt-Based Pervious Pavement Materials

The surface asphalt layer consists of an open-graded asphalt mixture. The depth of the surface layer may increase from a minimum of 4 inches, depending on the required bearing strength and pavement design requirements.

Pervious asphalt pavement consists of an open-graded coarse aggregate. The pervious asphalt creates a surface layer with interconnected voids that provide a high rate of permeability.

Paving and Lattice Stones

Paving and lattice stones consist of a high-compressive-strength stone that may increase from a minimum depth of 4 inches, depending on the required bearing strength and pavement design requirements. When placed together, these paving stones create a reinforced surface layer. An open-graded fine aggregate fills the voids, which creates a system that provides infiltration into a permeable base layer. This system can be used in parking lots, bike paths, or areas that receive common local traffic.

Geo-Cell (PVC Containment Cell)

A Geo-Cell surface stabilization system consists of a high-strength, UV-resistant, PVC-celled panel that is 4 inches thick. The celled panels can be filled with soil and covered with turf by installing sod. Base gravel may also be used to fill the celled panels. Both applications create a surface layer.

The Geo-Cell creates an interlock layer with interconnected voids that provide a high rate of permeability of water to an infiltrative base layer. The common applications for this system are on slopes and pedestrian/bike paths and in parking and low-traffic areas.

Base Layer

The underlying base material is the second component of a permeable surface's design. The base material is a crushed aggregate and provides the following:

- A stable base for the pavement.
- A high degree of permeability to disperse water downward through the underlying layer to the separation layer.
- A temporary reservoir that slows the migration of water prior to infiltration into the underlying soil.
- Base material is often composed of larger aggregate (1.5 to 2.5 inches) with smaller stone (leveling or choker course) between the larger stone and the wearing course. Typical void space in base layers ranges from 20 percent to 40 percent.
- Depending on the target flow control standard and physical setting, retention or detention requirements can be partially or entirely met in the aggregate base.
- Aggregate base depths of 18 to 36 inches are common depending on storage needs, and they provide the additional benefit of increasing the strength of the wearing course by isolating underlying soil movement and imperfections that may be transmitted to the wearing course.

Separation Layer

The third component of permeable systems is the separation layer. This layer consists of a non-woven geotextile fabric and possibly a treatment media base material. A geotextile fabric layer is placed between the base material and the native soil to prevent migration of fine soil particles into the base material, followed by a runoff treatment media layer if required.

- For geotextile, see Standard Specifications.
- For separation base material, see the FHWA manual “Construction of Pavement Subsurface Drainage Systems” (2002) for aggregate gradation separation base guidance.
- A treatment media layer is not required where subgrade soil is determined to have a long-term infiltration rate less than 2.4 inches per hour and a CEC of the subgrade soil that is at least 5 milliequivalents/100 grams of dry soil or greater.
- If a treatment media layer is used, it must be distributed below the geotextile layer and above the subgrade soil. The media can consist of a sand filter layer or amended soil. Engineered amended soil layers should be a minimum of 18 inches and incorporate compost, sphagnum peat moss, or other organic material to provide a cation exchange capacity of greater than or equal to 5 milliequivalents/100 grams of dry soil. Gradations of the treatment media should follow base sizing.

Subgrade Soil

The underlying subgrade soil is the fourth component of pervious pavement. Runoff infiltrates into the soil and moves to the local interflow or groundwater layer. Compaction of the subgrade must be kept to an absolute minimum to ensure the soil maintains a high rate of permeability while maintaining the structural integrity of the pavement.

Liners

The primary purpose of a permeable pavement system is to promote infiltration. An impervious liner will discontinue infiltration; therefore, a flow control credit is not allowed and the surface is modeled as impervious.

6.4.2 DISPERSION: BMPS

Perhaps the single most promising and effective approach to mitigating the effects of highway runoff in non-urbanized areas is to look for opportunities to use the existing natural area capacity to remove pollutants. Natural dispersion requires that runoff cannot become concentrated in any way as it flows into a preserved, naturally vegetated area.

The preserved, naturally vegetated area must have topographic, soil, and vegetation characteristics that provide for the removal of pollutants. Pollutant removal typically occurs through a combined process of vegetative filtration and shallow surface infiltration. Dispersion BMPs include:

- RT.01 – Natural Dispersion
- RT.02 – Engineered Dispersion

6.4.2.1 RT.01: NATURAL DISPERSION

General Description

Natural dispersion is the simplest method of flow control and stormwater quality runoff treatment. This BMP can be used for impervious and pervious surfaces that are graded so that runoff occurs by sheet flow. Natural dispersion uses the existing vegetation, soils, and topography to effectively provide flow control and runoff treatment. It generally requires little or no construction activity. Site selection is very important to the success of this BMP. The pollutant-removal processes include infiltration into the existing soils and through vegetation root zones, evaporation, and uptake and transpiration by the vegetation.

The key to natural dispersion is that flows from the impervious area enter the natural dispersion area as sheet flow. Because stormwater enters the dispersion area as sheet flow, it only needs to traverse a narrow band of contiguous vegetation for effective attenuation and treatment. The goal is to have the flows dispersed into the surrounding landscape so that there is a low probability that any surface runoff will reach a flowing body of water.

When modeling the hydrology of the project site and the threshold discharge area, the designer should treat natural dispersion areas and their tributary drainage areas as disconnected from the project site because they do not contribute flow to other flow control or runoff treatment BMPs.

Applications and Limitations

Applications

- Natural dispersion is ideal for highways and linear roadway projects
- Natural dispersion helps maintain the temperature norms of stormwater because it promotes infiltration, evaporation, and transpiration, and should not have a surface discharge to a lake or a stream
- Natural dispersion areas meet runoff treatment criteria set forth in Minimum Requirement 5 as defined in Chapter 3 of this TSDM
- Natural dispersion areas meet flow control criteria set forth in Minimum Requirement 6 as defined in Chapter 3 of this TSDM

Limitations

- The effectiveness of natural dispersion relies on maintaining sheet flow to the dispersion area, which maximizes soil and vegetation contact and prevents short-circuiting due to channelized flow. If sheet flow cannot be maintained, natural dispersion will not be effective.
- Natural dispersion areas must be within the project right-of-way limits. Natural dispersion areas must be protected from future development. DPW may ultimately have to purchase right-of-way or easements to satisfy the criteria for natural dispersion areas, but this should be the last option a designer should choose.
- Natural dispersion areas initially may cost as much as other constructed BMPs (ponds or vaults) because right-of-way or easements often need to be purchased, but long-term maintenance costs are lower. These natural areas will also contribute to the preservation of native habitat and provide visual buffering of the roadway.
- Floodplains are not suitable areas for natural dispersion.

Site Design Elements

Siting Criteria

The key to natural dispersion is having vegetative land cover with an established root zone, where the roots, organic matter, and soil macro-organisms provide macro-pores to reduce surface compaction and prevent soil pore sealing. The vegetative cover also provides filtration and maintains sheet flow, reducing the chance for erosion. The following public agency owned areas are considered appropriate candidates for natural dispersion because they are likely to retain these vegetative conditions over the long term:

- Within DPWs right-of-ways
- Village or Territorial-protected beautification areas
- Parks
- Other Government-owned lands
- Where outside of the DPW right-of-way, the dispersion area will require permanent easements to restrict any other use or development by the other public agency.

Design Flow Elements

Flows To Be Dispersed

The size of the natural dispersion area depends on the flow-contributing area and the predicted rates of water loss through the dispersion system. The designer should ensure the dispersion area is sufficient to dispose the runoff through infiltration, evaporation, transpiration, and soil absorption.

Sheet Flow

The sheet flow dispersion criteria for natural dispersion areas are as follows:

- The sheet flow path leading to the natural dispersion area should not be longer than 150 ft. The sheet flow path is measured in the direction of the flow and generally represents the width of the pavement area.
- Pervious shoulders and side slopes are not counted in determining the sheet flow path.
- The longitudinal length of the dispersion area should be equivalent to the longitudinal length of roadway that is contributing sheet flow.
- The longitudinal pavement slope contributing flow to a dispersion area should be less than 5 percent. The lateral pavement slope should be less than 8 percent.
- Roadway side slopes leading to natural dispersion areas should be 25 percent (4H:1V) or flatter. Slopes steeper than 25 percent are allowed if the existing side slopes are well-vegetated and show no signs of erosion problems.
- For any existing slope that will lead to a natural dispersion area, if evidence of channelized flows (rills or gullies) is present, a flow spreading device should be used before those flows are allowed to enter the dispersion area.

Sizing Criteria

Based on Soil Characteristics

The following criteria are specific to sheet flow dispersion on all NRCS Type A and some Type B soils, depending on the saturated hydraulic conductivity rates:

- For saturated hydraulic conductivity rates of 4 in. per hour or greater, and for the first 20 ft. along the sheet flow path of impervious surface that drains to the dispersion area, there must be 10 lateral ft. of dispersion area width. For each additional foot of impervious surface along the sheet flow path that drains to the dispersion area, 0.25 lateral ft. of dispersion area should be provided.

- For dispersion areas that receive sheet flow from only disturbed pervious areas (bare soil and non-native landscaping), for every 6 ft. along the sheet flow path of disturbed pervious area, 1 lateral ft. width of dispersion area is required.

Criteria for sheet flow dispersion on all NRCS Type C and Type D soils and some Type B soils with saturated hydraulic conductivity rates of 4 in. per hour or less:

- For every 1 ft. of contributing pavement width, a dispersion area width of 6.5 ft. is needed.

Figure 6-14 illustrates the configuration of a typical natural dispersion area relative to the roadway

Structural Design Considerations

Geometry

- Be well vegetated with established root zones
- Have an average longitudinal slope of 6H:1V or flatter
- Have an average lateral slope of 6H:1V or flatter for both the roadway side slope and the natural area to be part of the natural dispersion area
- Have infiltrative soil properties that are verified by geotechnical evaluation

Natural dispersion areas should have a separation of at least 2 ft. between the existing ground elevation and the average annual maximum groundwater elevation. This separation depth requirement applies to the entire limits of the dispersion area. There should be no discernible continuous flow paths through the dispersion area.

Setback Requirements

Natural dispersion areas can extend beyond DPW's right-of-ways, provided that the documentation on right-of-way plans ensures (through easements) that the dispersion area is not developed in the future. Off-site dispersion areas will normally be limited to other public agency lands.

Natural dispersion areas should be set back at least 1,000 ft. from drinking water wells and 100 ft. from septic tank drain field systems.

The project must not drain onto adjacent off-site properties. Otherwise, a drainage easement will be required or additional right-of-way purchased.

Signage

The limits of the natural dispersion area should be physically marked in the field, both during and after construction.

Signage helps ensure the natural dispersion area is not cleared or disturbed after the construction project.

Construction Considerations

For the installation of dispersal BMPs and conveyance systems near dispersion areas, the area that needs to be cleared or grubbed should be minimized. Maintaining plant root systems is important for dispersion areas.

The area around dispersion areas should not be compacted.

To the maximum extent practicable, low-ground-pressure vehicles and equipment should be used during construction.

Maintenance Considerations

Maintenance pullout areas should be considered to promote successful maintenance practices at dispersion areas. Pullout areas should be large enough to accommodate a typical maintenance vehicle.

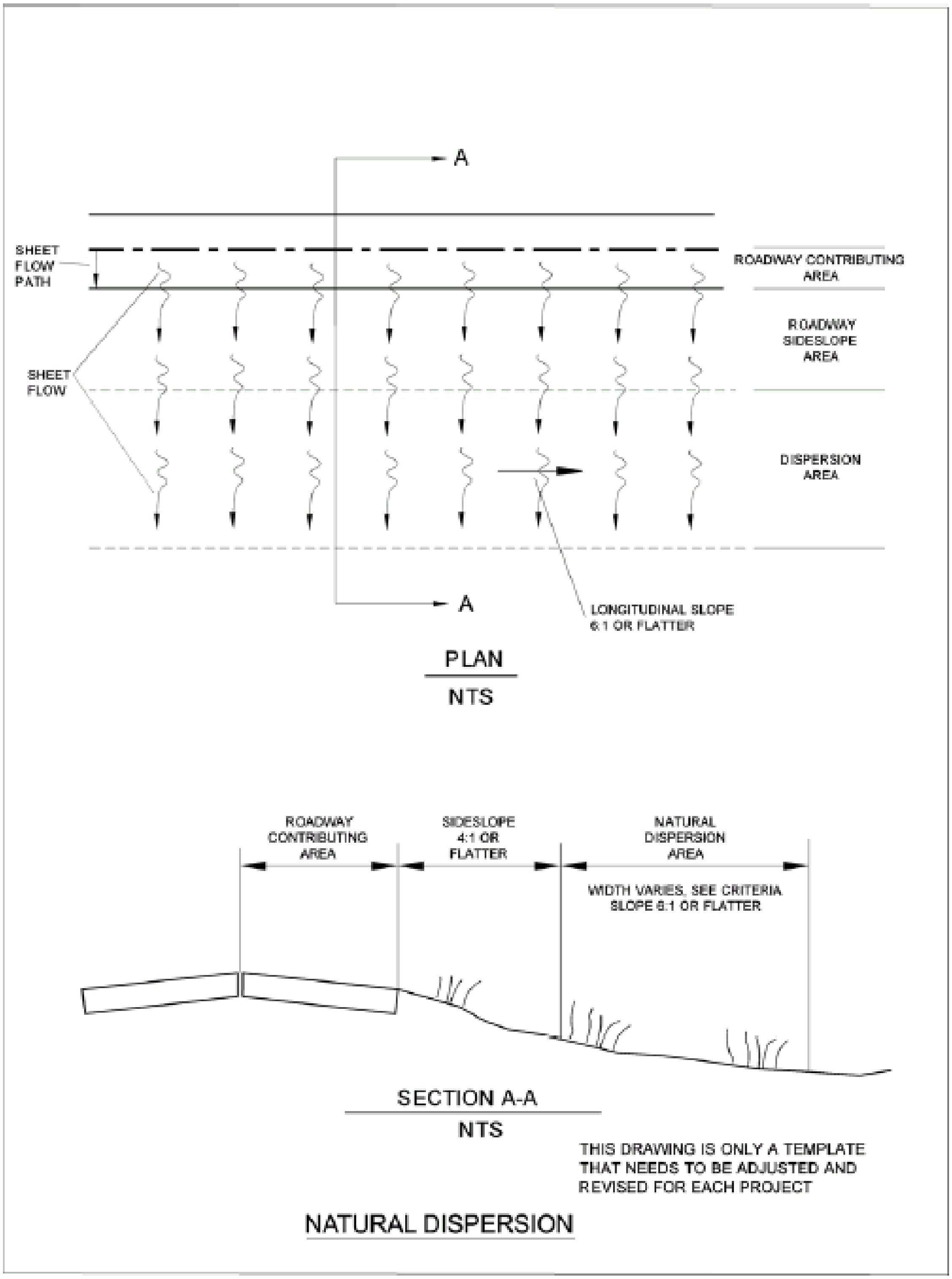


Figure 6-14: BMP RT.01 - Natural Dispersion

6.4.2.2 RT.02: ENGINEERED DISPERSION

General Description

Engineered dispersion is similar to natural dispersion. This BMP can be used for stormwater quality treatment and flow control at end of conveyance ditch or pipe locations. The stormwater conveyance discharges by sheet flow through level-flow spreaders across engineered dispersion areas. Engineered dispersion uses the existing vegetation or landscaped areas, existing soils or engineered compost-amended soils, and topography to effectively provide flow control and runoff treatment. Site selection is very important to the success of this BMP. The pollutant-removal processes include infiltration to the existing or engineered soils and through vegetation root zones, evaporation, and uptake and transpiration by the existing vegetation or landscaped areas.

Applications and Limitations

Applications

- Engineered dispersion is ideal for highways and linear roadway projects that collect and convey stormwater to discrete discharge points along the project
- Engineered dispersion maintains the temperature norms of stormwater because it promotes infiltration, evaporation, and transpiration, and should not have a surface discharge to a lake or stream
- Engineered dispersion areas meet the basic and enhanced runoff treatment criteria set forth in Minimum Requirement 5 as defined in Chapter 3 of this TSDM
- Engineered dispersion areas meet flow control criteria set forth in Minimum Requirement 6 as defined in Chapter 3 of this TSDM

Limitations

The effectiveness of engineered dispersion relies on maintaining sheet flow to the dispersion area, which maximizes soil and vegetated contact and prevents short-circuiting due to channelized flow. If sheet flow cannot be maintained, engineered dispersion will not be effective.

The project must ensure that the engineered dispersion area is not developed in the future. This requires that the engineered dispersion be constructed within the project right-of-way. Alternately, the dispersion could be placed on other suitable public agency property, although an easement or agreement will be needed. Otherwise, additional right-of-way acquisition may be necessary.

Engineered dispersion areas may cost as much as other BMPs (ponds or vaults) because right-of-way and easements may need to be purchased and compost-amended soils may need to be added.

Floodplains are not suitable areas for engineered dispersion.

Design Flow Elements

Flows To Be Dispersed

The required size of the engineered dispersion area depends on the area contributing flow and the predicted rates of water loss through the dispersion system. The design flow is the stormwater quality treatment volume and/or the flow control design storm frequency.

Structural Design Considerations

Geometry

- The average longitudinal slope of the dispersion area should not exceed 6H:1V
- The average lateral slope of the dispersion area should not exceed 6H:1V
- There should be no discernible flow paths through the dispersion area
- There should be no surface water discharge from the dispersion area to a conveyance system

Materials

Compost-amended soils should be generously applied to the dispersion areas. The final organic content of the soil in the dispersion areas should be 10 percent.

Site Design Elements

Siting Criteria

The following areas are appropriate engineered dispersion areas because they are likely to remain in their existing condition over the long term:

- DPW right-of-way
- Protected beautification areas
- Agricultural areas
- Parks
- Other Government-owned forestlands
- Rural areas with zoned densities of less than one dwelling unit per 5 acres

Engineered dispersion areas should have infiltrative soil properties that are verified by a geotechnical evaluation, and should not be sited above slopes greater than 20 percent.

Engineered dispersion areas should have a separation of at least 2 ft. between the existing ground elevation and the average annual maximum groundwater elevation.

Sizing Criteria

Figure 6-15 illustrates a typical engineered dispersion area relative to the adjacent roadway.

Concentrated runoff from the roadway and adjacent upstream areas (e.g., in a ditch or cut slope) must be incrementally discharged from the conveyance system, such as a ditch, gutter, or storm sewer, through cross culverts or at the ends of cut sections. These incremental discharges of newly-concentrated flows should not exceed 0.5 cfs for a single discharge point from the conveyance system for the 100-year runoff event. Where flows exceed this limit, the design of the associated discharge point and associated flow spreader should be carefully designed to avoid any erosion or surface gullying for the 100-yr storm.

Discharge points with up to 0.5 cfs discharge for the peak 100-year flow may use rock pads or level flow spreaders (spreader swales or trenches) to disperse flows. Discharge points with 0.5 cfs and larger discharge for the 100-year peak flow must use level flow spreaders or swales to disperse flows.

Level flow spreaders must be designed to accept surface flows (free discharge) from a pipe, culvert, or ditch end. They must be aligned perpendicular to the flow path (see Section 6.6.3 for level flow spreader design guidelines). Sheet flow over the level spreader berm or control weir should not exceed 4 in. in depth. Level flow spreaders must have a minimum spacing of 50 ft.

Flow paths from adjacent discharge points must not intersect within the required flow path lengths, and dispersed flow from a discharge point must not be intercepted by another discharge point.

Engineered dispersion areas should be selected so that there is no chance for any surface flow (flow not otherwise infiltrated) entering a stream, wetland, or other waterbody.

The width of the dispersion area should be at least three times the width required to infiltrate the flow depth over the weir from the flow spreader trench or swale. The infiltration width should be conservatively calculated using Mannings Equation for sheet flow over a natural grass ground cover (see design guidelines for the bioswale and vegetated filter strip BMPs) to obtain the flow velocity. Use the flow depth at the overflow weir crest for the calculations. The infiltration width corresponds to the time needed to infiltrate that depth of water times the sheet flow velocity. The required dispersion area width is at least three times the calculated infiltration width. Infiltration rates used for the calculations can be either determined by infiltration site testing by a qualified Geotechnical Engineer, or using the lower end of the ranges for infiltration rates as determined by the NRCS soil surveys for the particular soil types, by ground cover, slopes, and hydrologic soil group.

Pipe or Ditch Conveyance System

Flows collected in a pipe or ditch conveyance system require energy dissipation and dispersal at the end of the conveyance system before entering the dispersion area.

Setback Requirements

Engineered dispersion areas can extend beyond DPW's right-of-way, provided that documentation on the right-of-way plans ensures (through easement or agreement) that the dispersion area is not developed in the future.

Engineered dispersion areas should be set back at least 1,000 ft. from drinking water wells and 100 ft. from septic tank drain fields.

If the project significantly increases flows to off-site properties, a drainage easement may be required or right-of-way purchased.

Signage

The limits of the engineered dispersion area should be marked as a stormwater management facility and should also be physically marked in the field (during and after construction).

Signage helps ensure that the engineered dispersion area is not cleared or disturbed after the construction project.

Construction Considerations

For the installation of dispersal BMPs and conveyance systems near dispersion areas, the area that needs to be cleared or grubbed should be minimized. Maintaining plant root systems is important for dispersion areas.

The area around dispersion areas should not be compacted.

To the maximum extent practicable, low-ground-pressure vehicles and equipment should be used during construction.

Maintenance Considerations

Allow for off-road parking for maintenance vehicles/personnel. Pullout areas should be large enough to accommodate a typical maintenance vehicle.

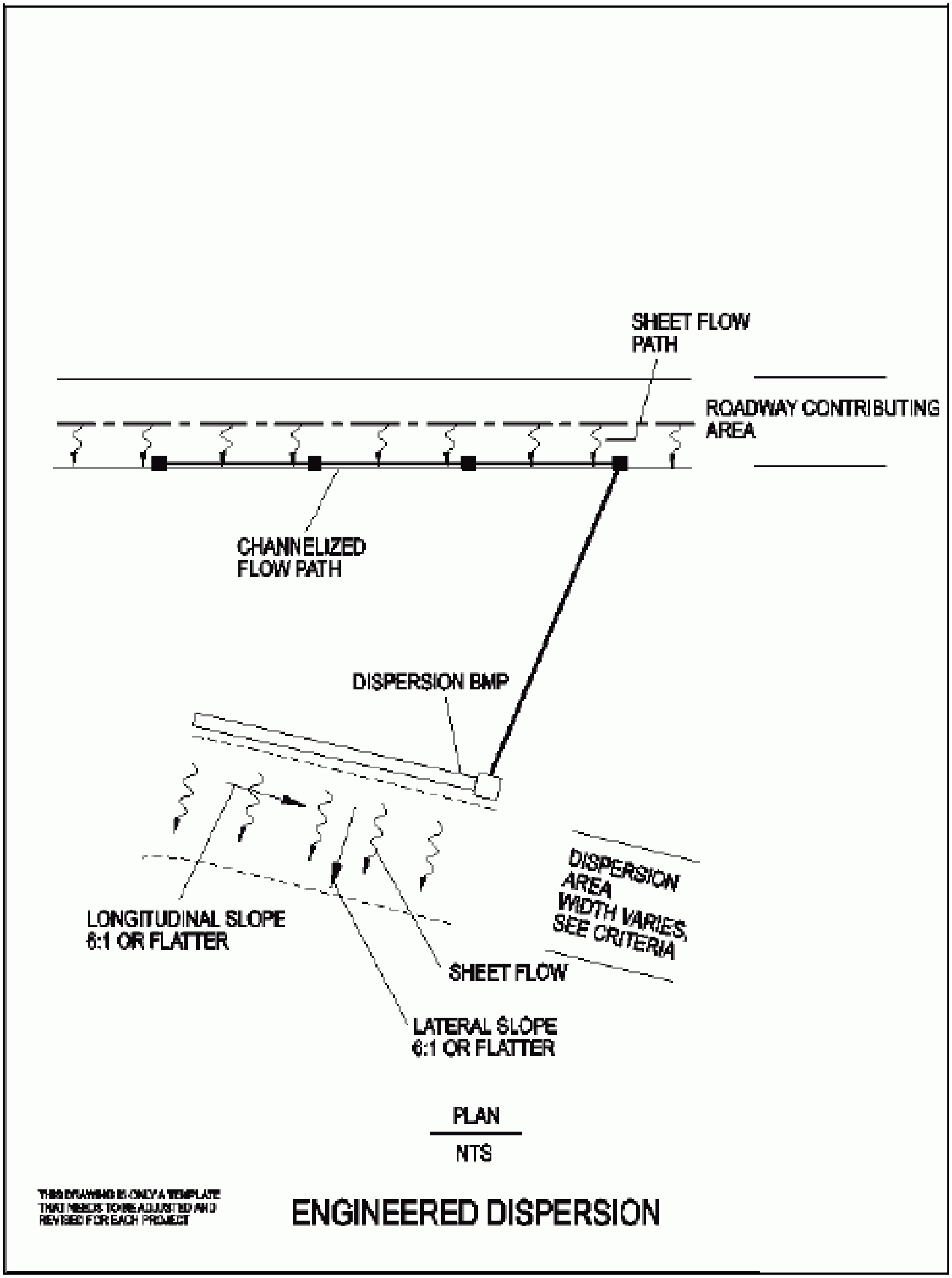


Figure 6-15: BMP RT.02 - Engineered Dispersion Area

6.4.3 DESIGN CRITERIA: BIOFILTRATION BMPS

Biofiltration BMPs are discussed in this chapter and include the following:

RT.03 – Vegetated Filter Strip (basic, narrow area, and compost-amended)

RT.04 –Biofiltration Swale

RT.05 –Wet Biofiltration Swale

RT.06 – Continuous Inflow Biofiltration Swale

RT.07 – Media Filter Drain

6.4.3.1 RT.03: VEGETATED FILTER STRIP

Vegetated filter strips are land areas of planted vegetation and amended soils situated between the pavement surface and a surface water collection system, pond, wetland, stream, or river. The term buffer strip is sometimes used interchangeably with vegetated filter strip, but in this TSDM, buffer strip refers to an area of natural indigenous vegetation that can be enhanced or preserved as part of a riparian buffer or stormwater dispersion system.

Runoff treatment to remove pollutants can be best accomplished before concentrating the flow. A vegetated filter strip provides a very efficient and cost-effective runoff treatment option. Vegetated filter strips function by slowing runoff velocities and filtering out sediment and other pollutants, and by providing some infiltration into underlying soils.

Vegetated filter strips consist of gradually sloping areas that run adjacent to the roadway. As highway runoff sheets off the roadway surface, it flows through the grass filter. The flow can then be intercepted by a ditch or other conveyance system and routed to a flow control BMP or outfall.

One challenge associated with vegetated filter strips is that sheet flow can sometimes be difficult to maintain. Consequently, vegetated filter strips can be short-circuited by concentrated flows, which create eroded rills or flow channels across the strips. This results in little or no treatment of stormwater runoff.

The design approach for vegetated filter strips involves site design techniques to maintain prescribed maximum sheet flow distances as well as to ensure adequate temporary storage so that the design storm runoff is treated. There is limited ponding or storage associated with vegetated filter strips unless soil amendments and sub-surface storage are incorporated into the design to reduce runoff volumes and peak discharges.

Vegetated filter strips can also be used as a pre-treatment BMP in conjunction with infiltration BMPs. The sediment and particulate pollutant load that could reach the primary BMP is reduced by the pre-treatment, which in turn reduces maintenance costs and enhances the pollutant-removal capabilities of the primary BMP.

There are three methods described in this section for designing vegetated filter strips: basic vegetated filter strips, Compost-Amended Vegetated Filter Strips (CAVFS), and narrow-area vegetated filter strips. The narrow-area vegetated filter strip is the simplest method to design; however, its use is limited to impervious flow paths less than 30 ft. If space is available to use the basic vegetated filter strip design or the CAVFS, either of the two designs should be used in preference to the narrow-area vegetated filter strip. For flow paths greater than 30 ft., designers should follow the design method for the basic vegetated filter strip or the CAVFS.

The basic vegetated filter strip is a compacted roadside embankment that is subsequently hydroseeded. The CAVFS is a variation of the basic vegetated filter strip that adds soil amendments to the roadside embankment. The soil amendments improve infiltration characteristics, increase surface roughness, and improve plant sustainability.

The CAVFS design incorporates compost into the native soils. The CAVFS bed should have a final organic content of 10 percent. Once permanent vegetation is established, the advantages of the CAVFS are higher surface roughness, greater retention and infiltration capacity, improved removal of soluble cationic contaminants through sorption, improved overall vegetative health, and a reduction of invasive weeds.

Compost-amended systems have somewhat higher construction costs due to more expensive materials, but require less land area for runoff treatment, which can reduce overall costs.

Applications and Limitations

Vegetated filter strips (narrow area, CAVFS, and basic) can be used to meet runoff quality treatment objectives or as part of a treatment train to provide pre-treatment for removal of sediments.

Applications

Vegetated filter strips can be effective in reducing sediments and the pollutants associated with sediments such as phosphorus, pesticides, or insoluble metallic salts.

Because they do not pond water on the surface for long periods, vegetated filter strips help maintain the temperature norms of the water and deter the creation of habitat for disease vectors, such as mosquitoes.

In less urbanized areas, vegetated filter strips can generally be located on existing roadside embankments, reducing the need for additional right-of-way acquisitions.

Designs can be modified to reduce runoff volumes and peak flows when needed or desired to reduce right-of-way acquisitions.

Limitations

- If sheet flow cannot be maintained, vegetated filter strips will not be effective
- Vegetated filter strips are generally not suitable for steep slopes or large impervious areas that can generate high-velocity runoff
- The use of vegetated filter strips can be impracticable in watersheds where open land is scarce or expensive
- For most project applications where less than 10 ft. of roadside embankment is available for water quality treatment, the Media Filter Drain (MFD) (see BMP RT.07), is a more suitable BMP option
- Improper grading can render this BMP ineffective

Design Flow Elements

Flows To Be Treated

Vegetated filter strips must be designed to treat the runoff treatment flow rate discussed as part of Minimum Requirement 5 as defined in Chapter 3 of this TSDM, and the guidelines and criteria provided in this section.

Design Criteria and Specifications

Drainage Area Limitations

Vegetated filter strips are used to treat small drainage areas. Flow must enter the vegetated filter strip as sheet flow, spread out over the length (long dimension perpendicular to flow) of the strip, generally no deeper than 1 in. For basic vegetated filter strips and CAVFS, the greatest flow path from the contributing area delivering sheet flow to the vegetated filter strip should not exceed 150 ft. For the narrow-area vegetated filter strip, the maximum contributing flow path should not exceed 30 ft.

The longitudinal slope of the contributing drainage area parallel to the edge of pavement should be 2 percent or less. The lateral slope of the contributing drainage area perpendicular to the pavement edge should be 5 percent or less.

Vegetated filter strips should be fully integrated within site designs, and should be constructed outside of the natural stream buffer area, whenever possible, to maintain a more natural buffer along the streambank.

Vegetated Filter Strip Geometry

Vegetated filter strips must provide a minimum residence time of nine minutes for full water-quality treatment.

Vegetated filter strips can be used for pre-treatment to another water quality BMP. Wherever a basic vegetated filter strip or CAVFS system cannot fit within the available space, a narrow area vegetated filter strip system can be used solely as a pre-treatment device. A narrow area design should have a minimum width of 4 ft., and should take advantage of all available space.

Basic vegetated filter strips should be designed for lateral slopes (along the direction of flow) between 2 percent and 15 percent. Steeper slopes encourage the development of concentrated flow; flatter slopes encourage standing water. Vegetated filter strips should not be used on soils that cannot sustain a dense grass cover with high flow retardance. In areas where lateral grades are between 15 percent and 25 percent, designers should consider using a CAVFS or an MFD (see BMP RT.07). The MFD will usually require less treatment area to achieve the water quality treatment objectives.

The minimum width of the vegetated filter strip generally is dictated by the design method.

Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.

The Manning's n to be used in the vegetated filter strip design calculations depends on the type of soil amendment and vegetation conditions used in construction of the vegetated filter strip (see Table 6-3).

When the runoff treatment peak flow rate Q_{WQ} has been established, the design flow velocity can be estimated using Manning's Equation to calculate the width of the vegetated filter strip parallel to the direction of flow.

Water Depth and Velocity

The maximum depth of sheet flow through a vegetated filter strip for the runoff treatment design flow rate is 1.0 in. The maximum flow velocity for the runoff treatment design flow velocity is 0.5 ft. per second.

Maintain Sheet Flow Conditions

Sheet flow conditions from the pavement into the vegetated filter strip should be maintained. A no-vegetation zone may help establish and maintain this condition.

In areas where it may be difficult to maintain sheet flow conditions, consider using aggregate as a flow spreader. Aggregate should be placed between the pavement surface and the vegetated filter strip. The aggregate should meet the specifications for crushed base course listed in the Standard Specifications or other aggregate should be used that provides the equivalent functionality.

If there are concerns that water percolated within the aggregate flow spreader may exfiltrate into the highway prism, impervious geotextiles can be used to line the bottom of the aggregate layer.

Option	Soil and Vegetation Conditions	Manning's n
1	Fully-compacted and hydroseeded	0.20
2	Compaction minimized and soils amended, hydroseeded	0.35
3	Compaction minimized; soils amended to a minimum 10% organic content, hydroseeded, grass maintained at 95% density and 4 in. in length through mowing, periodic re-seeding, and possible landscaping with herbaceous shrubs	0.40
4	Compost-amended vegetated filter strip: compaction minimized, soils amended to a minimum 10% organic content, and vegetated filter strip top dressed with ≥3 in. vegetated compost or compost/mulch (seeded or landscaped)	0.55

Table 6-3: Manning's n for BMP RT.03 - Vegetated Filter Strips

Design Method

1. Determine the runoff treatment design flow (Q_{WQ}).
2. Calculate the design flow depth at Q_{vfs}. The design flow depth is calculated based on the length of the vegetated filter strip (same as the length of the pavement edge contributing runoff to the vegetated filter strip) and the lateral slope of the vegetated filter strip parallel to the direction of flow. Design flow depth is calculated using a form of Manning's equation:

$$Q_{vfs} = \frac{1.49}{n} L\, y^{\frac{5}{3}} S^{0.5}$$

Equation 6-1

Where:

Q_{vfs} = Vegetated filter strip design flow rate in cfs.

n = Manning's roughness coefficient. Manning's n can be adjusted by specifying soil and vegetation conditions at the project site, as specified in Table 6-3.

y = Design flow depth in ft., also assumed to be the hydraulic radius = 1.0 in., maximum = 0.083 ft.

L = Length of vegetated filter strip parallel to pavement edge in ft.

s = Slope of vegetated filter strip parallel to direction of flow in ft./ft. Vegetated filter strip slopes should be greater than 2 percent and less than 15 percent. Vegetated filter strip slopes should be made as shallow as is feasible by site constraints. Gently sloping vegetated filter strips can produce the required residence time for runoff treatment using less space than steeper vegetated filter strips.

Rearranging Equation 6-1 to solve for y yields:

$$y = \left(\frac{nQ_{vfs}}{1.49\,L\,S^{0.5}}\right)^{\frac{3}{5}}$$

Equation 6-2

If the calculated depth y is greater than 1 in., either adjust the vegetated filter strip geometry or use other runoff treatment BMPs.

3. Calculate the design flow velocity passing through the vegetated filter strip at the vegetated filter strip design flow rate. The design flow velocity (V_{WQ}) is based on the vegetated filter strip design flow rate, the length of the vegetated filter strip, and the calculated design flow depth from Step 2:

$$V_{WQ} = \frac{Q_{vfs}}{Ly}$$

Equation 6-3

Where:

V_{WQ} = Design flow velocity in ft./s

y = Design flow depth in ft.

4. Calculate the vegetated filter strip width. The width of the vegetated filter strip is determined by the residence time of the flow through the vegetated filter strip. A nine-minute (540-second) residence time is used to calculate vegetated filter strip width:

$$W = TV_{WQ} = 540\,V_{WQ}$$

Where:

W = Vegetated filter strip width in ft.

T = Time in s

V_{WQ} = Design flow velocity in ft./s

A minimum width of 8 ft. is recommended in order to ensure the long-term effectiveness of the vegetated filter strip.

Narrow Area Vegetated Filter Strip

As previously discussed, narrow-area vegetated filter strips are limited to impervious flow paths less than 30 ft. For flow paths greater than 30 ft., designers should follow the basic vegetated filter strip guidelines. The sizing of a narrow-area vegetated filter strip is based on the width of the roadway surface parallel to the flow path of the vegetated filter strip and the lateral slope of the vegetated filter strip.

1. ***Determine the width of the roadway surface parallel to the flow path draining to the vegetated filter strip.*** Determine the width of the roadway surface parallel to the flow path from the upstream to the downstream edge of the impervious area draining to the vegetated filter strip. This is the same as the width of the paved area.
2. **Determine the average lateral slope of the vegetated filter strip.** Calculate the lateral slope of the vegetated filter strip (parallel to the flow path), averaged over the total length of the vegetated filter strip. If the slope is less than 2 percent, use 2 percent for sizing purposes. The maximum lateral slope allowed is 15 percent.
3. **Determine the required width of the vegetated filter strip.** Use Figure 6-16 to size the vegetated filter strip. Locate the width of the impervious surface parallel with the flow path on one of the curves; interpolate between curves as necessary. Next, move along the curve to the point where the design lateral slope of the vegetated filter strip is directly below. Read the vegetated filter strip width to the left on the y axis. The vegetated filter strip must be designed to provide this minimum width, W, along the entire stretch of pavement draining to it.

Materials

Vegetation

Vegetated filter strips should be planted with grass that can withstand relatively high-velocity flows as well as wet and dry periods. Filter strips may also incorporate native vegetation such as small herbaceous shrubs to make the system more effective in treating runoff and providing root penetration into subsoils, thereby enhancing infiltration. Use NRCS or DAWR recommendations for a mix of grasses and plants suitable for the project site.

Site Design Elements

Maintenance Access Roads (Access Requirements)

Access should be provided at the upper edge of all vegetated filter strips to enable maintenance of the gravel flow spreader and permit lawnmower entry to the vegetated filter strip.

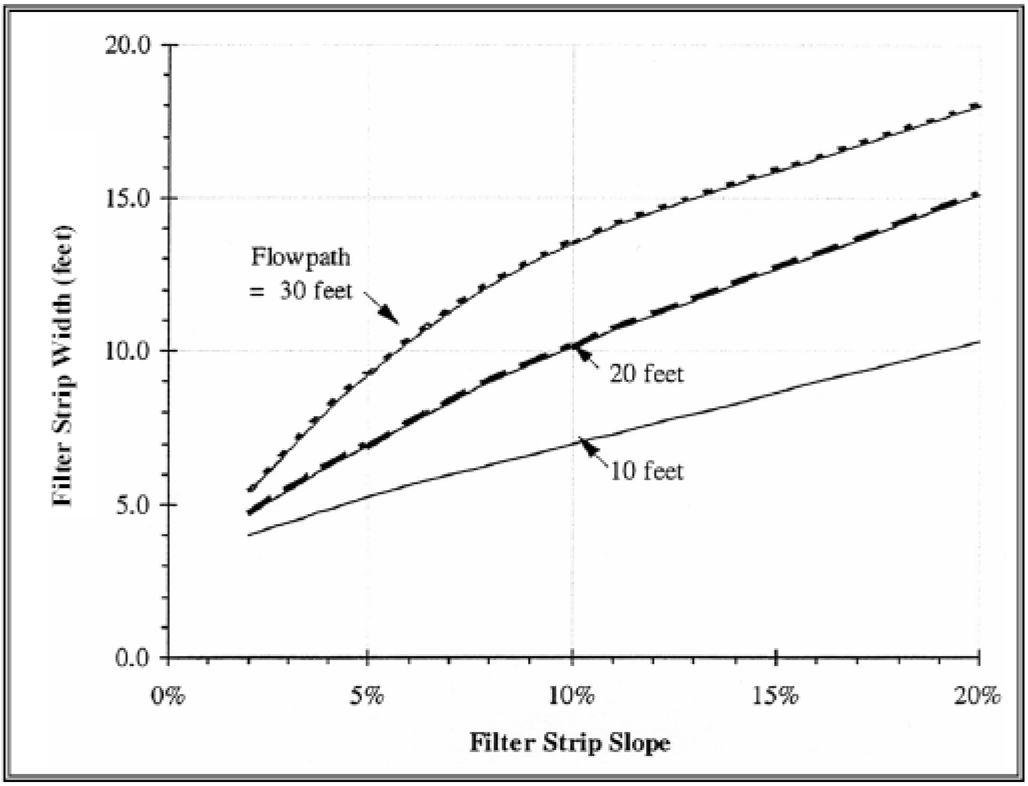


Figure 6-16: Narrow-Area Vegetated Filter Strip Design

6.4.3.2 RT.04 : BIOFILTRATION SWALE

General Description

Biofiltration swales are vegetation-lined channels designed to remove suspended solids from stormwater. The shallow, concentrated flow within these systems allows for the filtration of stormwater by plant stems and leaves. Biological uptake, biotransformation, absorption, and ion exchange are potential secondary pollutant-removal processes. The design procedure is described below.

Design Flow Elements

Flows To Be Treated

Biofiltration swales should be designed for the stormwater quality treatment design flow rate, Q_{WQ}.

Structural Design Considerations

Sizing Procedure

Preliminary Steps

1. Determine the stormwater quality treatment design flow rate (Q_{WQ}). See Chapter 4 of this TSDM.

2. Select a suitable site location having suitable grade and topographic characteristics.

3. Establish the longitudinal slope of the proposed biofiltration swale (see Table 6-5 for criteria).

4. Select a soil and vegetation cover suitable for the biofiltration swale. The grass seed mix and planting requirements should be selected based on NRCS or DAWR recommendations per site and seasonal conditions.

Design Steps

5. Select a trial depth of flow, Y (see Table 6-5).

6. Select a trial swale cross-sectional width.

7. Use Manning's Equation (Equation 6-5) to make an initial approximation relating hydraulic radius and dimensions for the selected swale shape. Use trial and error for various values of 'Y' and 'b' until $Q_{biofl} = Q_{WQ}$:

$$Q_{biofl} = \frac{1.49}{n} A R^{\frac{2}{3}} S^{0.5}$$

Equation 6-4

Where:

Q_{biofil} = Swale flow rate in cfs

A = Wetted area in $ft.^2$

R = A/P = Hydraulic radius in ft.

P = Wetted perimeter in ft.

s = Longitudinal slope of swale in ft./ft.

n = Manning's coefficient (see Table 6-4)

Y = Swale flow depth in ft.

b = Swale bottom width in ft.

8. Compute the flow velocity at $Q_{\mathbf{biofil}}$:

$$V_{biofl} = \frac{Q_{biofl}}{A}$$

Equation 6-5

Where:

V_{biofil} = Flow velocity at Q_{biofil} in ft./s

If $V_{\mathbf{biofil}}$ > 1.0 ft./s, increase width (b) or investigate ways to reduce Q_{wq}, and then repeat steps 3, 4, and 5 until $V_{\mathbf{biofil}} \le$ 1.0 ft./s. A velocity greater than 1.0 ft./s will flatten grasses, thus reducing filtration.

9. Compute the swale length, L in ft.:

$$L = V_{biofil}\ t\ \text{(60 s/min.)}$$

Equation 6-6

Where:

t = Hydraulic residence time (a minimum of nine minutes. for basic biofiltration swales)

10. If there is not sufficient space for the biofiltration swale, consider the following solutions:
    - Divide the site drainage to flow to multiple biofiltration swales
    - Use infiltration or dispersion to provide lower Q_{WQ}
    - Alter the design depth of flow if possible (see Table 6-5)
    - Reduce the developed surface area to gain space for the biofiltration swale
    - Reduce the longitudinal slope by meandering the biofiltration swale
    - Nest the biofiltration swale within or around another stormwater BMP

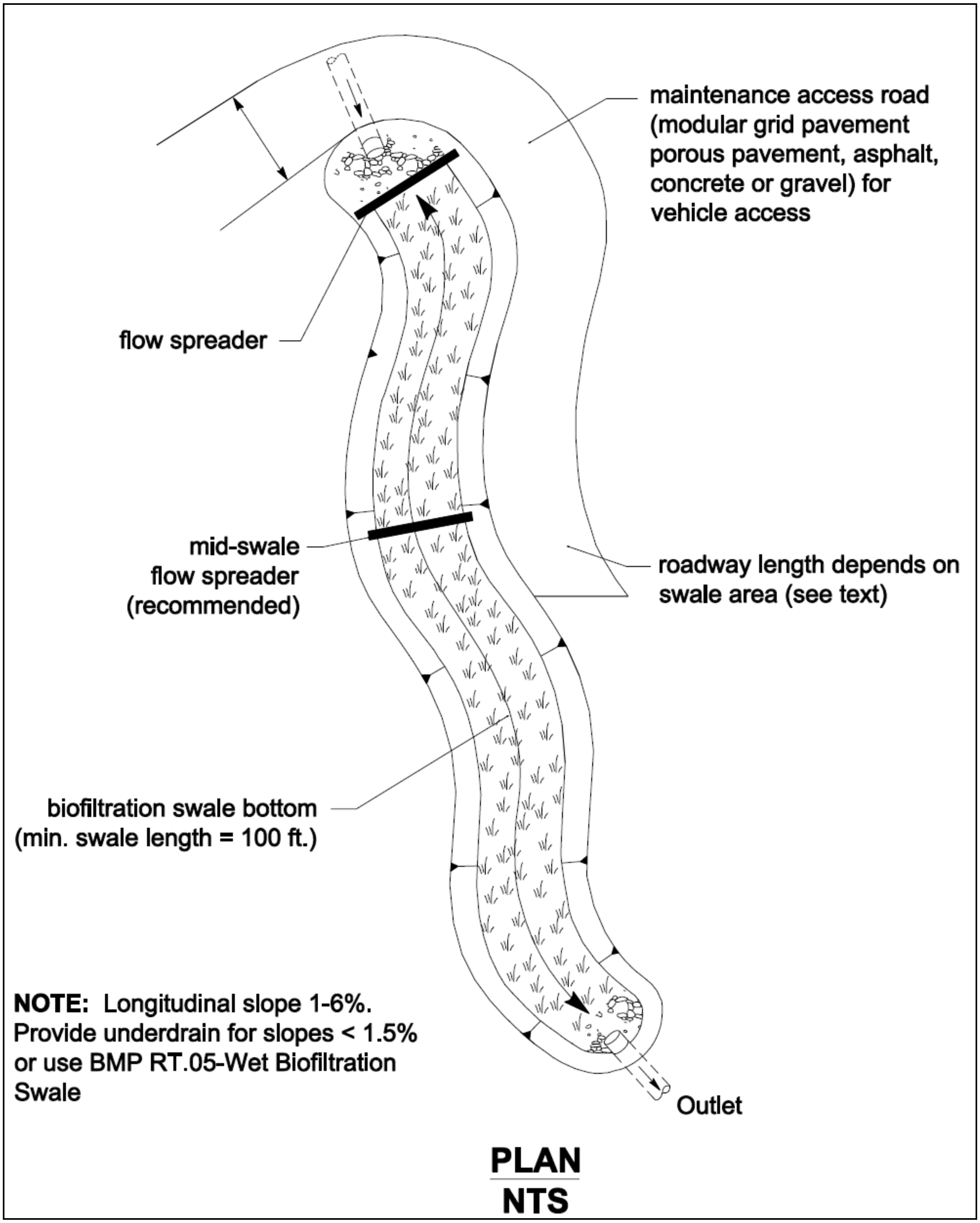


Figure 6-17: BMP RT.04 - Biofiltration Swale Plan

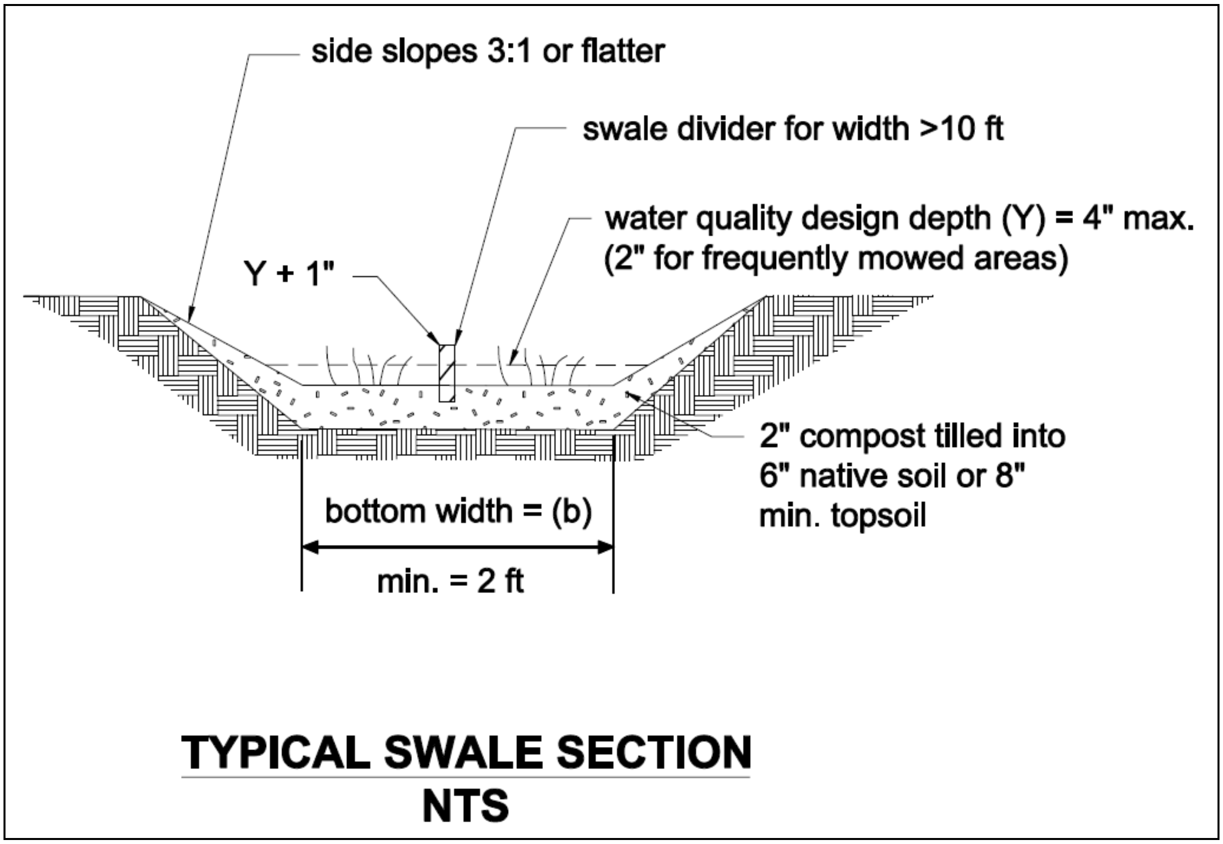


Figure 6-18: BMP RT.04 - Biofiltration Swale Section

Soil and Cover	Manning's Coefficient
Grass-legume mix on compacted native soil	0.20
Grass-legume mix on lightly compacted, compost-amended soil	0.22
Grass-legume mix on lightly compacted, compost-amended soil with surface roughness features	0.35

Table 6-4: Manning's Coefficient in Basic, Wet, and Continuous Bioinfiltration Swales

Design Parameters	Basic Biofiltration Swale	Wet Biofiltration Swale	Continuous Inflow Bioinfiltration Swale
Longitudinal slope	0.010–0.060 [1] ft./ft.	0.015 ft. or less per ft.	Same as basic swale
Maximum velocity	1 ft./s at Q_{biofil}	Same as basic swale	Same as basic swale

Design Parameters	**Basic Biofiltration Swale**	**Wet Biofiltration Swale**	**Continuous Inflow Bioinfiltration Swale**
Maximum water depth at Q_{biofil}, 'Y'	2 in. if swale mowed frequently; 4 in. if mowed infrequently or inconsistently. For dry land grasses, set depth to 3 in.	4 in.	Same as basic swale
Manning coefficient, 'n', at Q_{biofil}	See Table 6-4	Same as basic swale	Same as basic swale
Bed width, 'b'	2ft.[2] - 10 ft.[2]	2 ft. - 25 ft.	Same as basic swale
Freeboard height	1 ft. for the peak conveyance flow rate (Q_{convey})[3]	Same as basic swale	Same as basic swale
Minimum length, 'L'	100 ft.	Same as basic swale	Same as basic swale
Maximum side slope (for trapezoidal cross section)	3H:1V	Same as basic swale	Same as basic swale

Table 6-5: Bioinfiltration Swale Sizing Criteria

1. For basic biofiltration swale on slopes less than 1.5 percent, install an underdrain system (see Figure 6-19)

Backfill should be covered by at least 4 in. of amended soil or topsoil. Install the low-flow drain 6 in. deep in the soil (see Figure 6-19). Underdrains can be made of 6-in. Schedule 40 PVC perforated pipe with 6 in. of drain gravel on the pipe. The gravel and pipe must be enclosed by geotextile fabric. The pipe outlet should be protected from erosion.

2. Multiple parallel swales can be constructed when the calculated swale bottom width exceeds 10 ft. using a divider berm or concrete curb.

3. Q_{convey} should be based on the peak capacity of the incoming conveyance system to the biofiltration swale. For off-line bioswales, this will be the design Q_{WQ}. For on-line bioswales this should be the maximum capacity of the conveyance system, but not less than $Q_{25\text{-}yr}$.

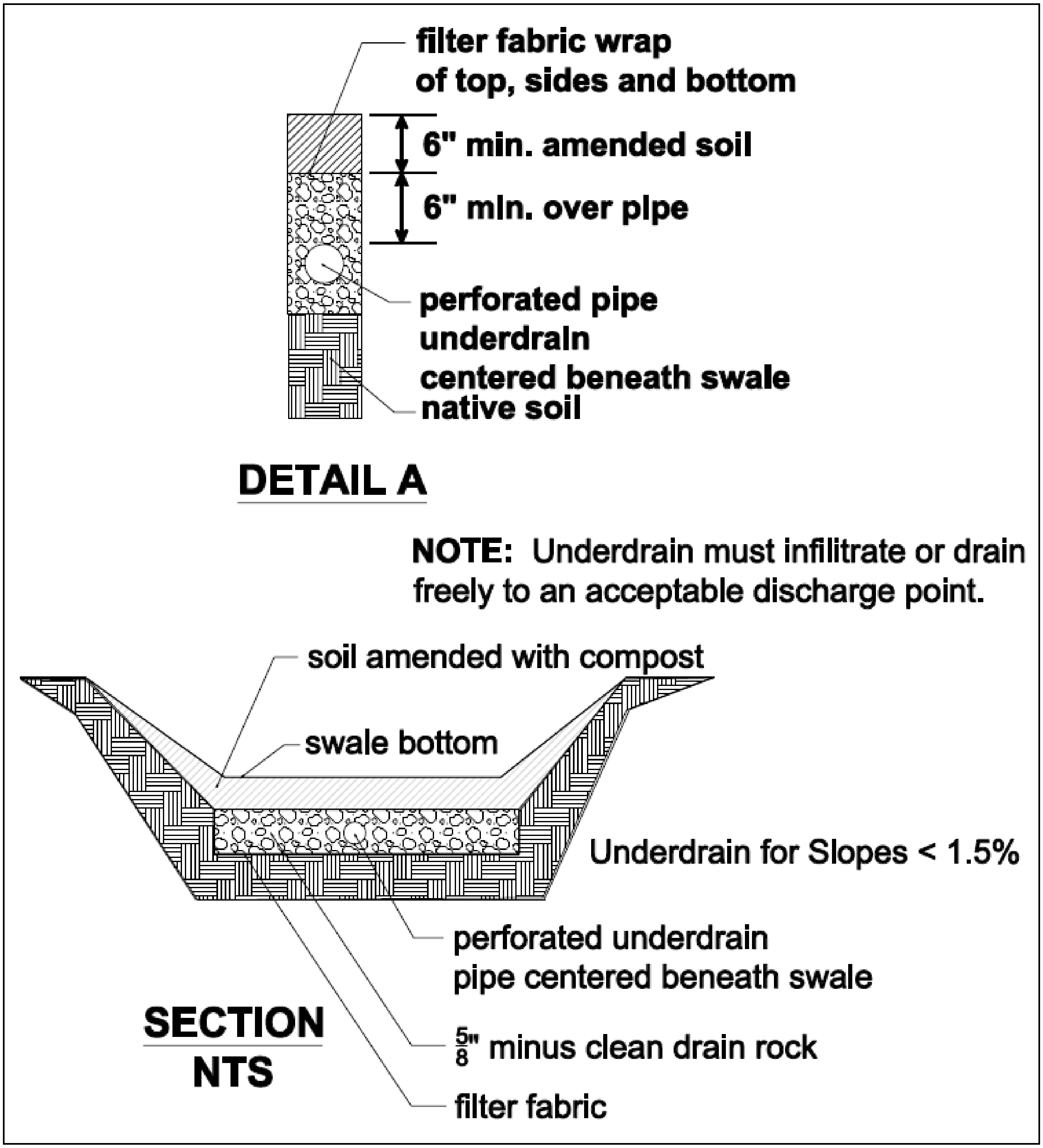


Figure 6-19: Bioinfiltration Swale Underdrain Detail

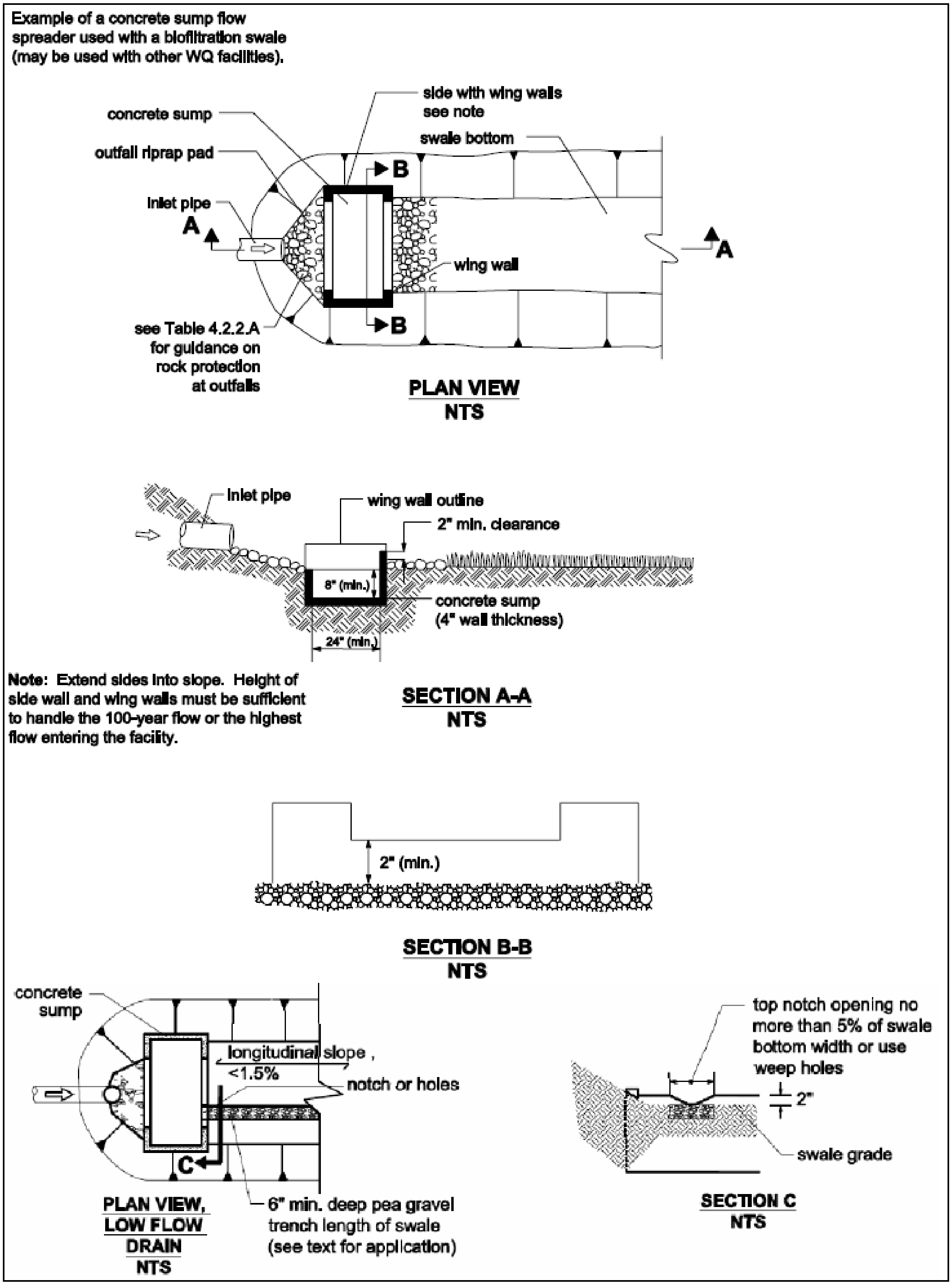


Figure 6-20: Bioinfiltration Swale Details

Freeboard Check (FC)

A Freeboard Check (FC) must be performed for the combination of highest expected flow and least vegetation coverage and height. The FC is not necessary for biofiltration swales that are located off-line from the primary conveyance and detention system (that is, when flows in excess of Q_{WQ} bypass the biofiltration swale). Off-line is the preferred configuration of biofiltration swales. Ensure swale depth exceeds flow depth at Q_{convey} by a minimum of 1 ft. (1-ft. minimum freeboard).

Site Design Elements

Install level spreaders at the head of the biofiltration swale in swales that are 6 ft. or greater in bottom width. Include sediment cleanouts at the head of the swale as needed. It is recommended that swales with a bottom width in excess of 6 ft. or greater have a level spreader for every 50 ft. of swale length.

Use energy dissipaters for swales on longitudinal slopes exceeding 2.5 percent.

Specify that topsoil extends to at least an 8-in. depth, unless an underdrain system is needed (see Table 6-5).

To improve infiltration on longitudinal slopes less than 1.5 percent, ensure the swale bed material contains a sand percentage greater than 70 percent (greater than 70 percent by weight retained on the No. 40 sieve) before organic amendments are added.

Provide an access road for maintenance vehicles. The width of access should normally be 20 ft., but in no case should it be less than 12 ft. The access road should be surfaced with a permeable surface suitable for heavier vehicular loadings such as crushed gravel, vegetative paver blocks, or permeable pavement. The access road should provide access for cleaning the inlet structures and extend along one side of the swale. The length of the access road should be at least one-half of the length of the swale to accommodate removal of accumulated sediments in the upper area.

Landscaping (Planting Considerations)

- Select grasses suitable for the site conditions in accordance with DAWR's recommendations
- Select fine, turf-forming grasses where moisture is appropriate for growth
- Plant wet-tolerant species for wet site locations
- Stabilize soil areas upslope of the biofiltration swale to prevent erosion and excessive sediment deposition
- Apply seed using a hydroseeder or broadcaster

Construction Criteria

- Do not put the biofiltration swale into operation until areas of exposed soil in the contributing drainage catchment have been sufficiently stabilized
- Keep effective erosion and sediment control measures in place until the swale vegetation is established
- Avoid over-compaction during construction
- Grade biofiltration swales to attain uniform longitudinal and lateral slopes

6.4.3.3 RT.05: WET BIOFILTRATION SWALE

General Description

A wet biofiltration swale is a variation of a basic biofiltration swale for use where the longitudinal slope is slight, water tables are high, or continuous base flow is likely to result in saturated soil conditions. Where saturation exceeds about two continuous weeks, typical grasses die; so vegetation specifically adapted to saturated soil conditions is needed. This type of vegetation, in turn, requires modification of several of the design parameters for the basic biofiltration swale to remove low concentrations of pollutants, such as sediments, heavy metals, nutrients, and petroleum hydrocarbons.

Applications and Limitations

Wet biofiltration swales are applied where a basic biofiltration swale is desired but not allowed or advisable because of one or more of the following conditions:

- The swale is on thin soils with low permeability on flat slopes
- The swale is downstream of a detention pond providing flow control
- Saturated soil conditions are likely because of seeps, high groundwater, or base flows on the site
- Longitudinal slopes are slight (generally less than 1.5 percent), and ponding is likely

Design Flow Elements

Flows To Be Treated

Wet biofiltration swales should be designed to treat the runoff treatment flow rate discussed as part of Minimum Requirement 5 as defined in Chapter 3 of this TSDM.

Overflow or Bypass

To accommodate flows exceeding the stormwater quality treatment flow rate, the following two design options are available:

1. A high-flow bypass can be installed for flows greater than the runoff treatment design flow to protect wetland vegetation from damage. Unlike grass, wetland vegetation does not quickly regain an upright attitude after being flattened by high flows. New growth, usually from the base of the plant and often taking several weeks, is required for the grass to regain its upright form. The bypass may be a flow-splitter structure for a storm drain system, or an overflow type open channel parallel to the wet biofiltration swale.
2. Alternatively, swale bottom width may be tripled to accommodate high flows. The following features must be included:
    - An energy dissipater and level spreader must be set at the head of the swale to ensure the equal distribution of influent and reduce the potential for scour. Gravel filter berms must be placed every 30 ft. across the full width of the swale. The minimum required swale length should not include the length occupied by gravel filter berms.
    - If the calculated width to convey high flows exceeds 25 ft., then a high flow channel with a bed elevation 0.5 ft. above the swale depth can be constructed. The high-flow channel can be either planted or rock-lined.

Structural Design Considerations

Geometry

Use the same design approach as for basic biofiltration swales, except add the following:

Extended wet season flow adjustment. If the swale is downstream of a detention pond providing flow control, multiply the treatment area (bottom width times length) of the swale by two and readjust the swale length or width to provide an equivalent area. Maintain a 5:1 length-to-width ratio.

Intent: The treatment area of swales following detention ponds needs to be increased because of the differences in vegetation established in a constant flow environment. Flows following detention are much more prolonged. These prolonged flows result in more stream-like conditions than are typical for other wet biofiltration situations. Because vegetation growing in streams is often less dense, an increase in treatment area is needed to ensure equivalent pollutant removal is achieved in extended flow situations.

Swale geometry. Use the same geometry specified for basic biofiltration swales (see Table 6-5), except for the following modifications:

- The bottom width may be increased to 25 ft. maximum, but a length-to width ratio of 5:1 must be maintained. No longitudinal dividing berm is needed. Note: The minimum swale length is 100 ft.

- If longitudinal slopes are greater than 1.5 percent, the wet swale must be stepped so that the slope within the stepped sections averages 1.5 percent or less. Steps may be made of concrete or block walls, short riprap sections, or similar structures. Steps must be designed to prevent scour or undermining on the downstream side of the step. No underdrain or low-flow drain is required.

Water depth and base flow. Use the same criteria specified for basic biofiltration swales, except that the design water depth must be 4 in. for all wetland vegetation selections, and no underdrains or low-flow drains are required.

Flow velocity, energy dissipation, and flow spreading. Use the same criteria specified for basic biofiltration swales.

Site Design Elements

Landscaping (Planting Considerations)

Use the same design considerations specified for basic biofiltration swales, except for the following modifications:

- In general, it is best to plant several species to increase the likelihood that at least some of the selected species will find growing conditions favorable.
- A wetland seed mix may be applied by hydroseeding, but if coverage is poor, planting rootstock or nursery stock is required. Poor coverage is considered to be more than 30 percent bare area through the upper two-thirds of the swale after four weeks.
- Use plant species suitable for a wetland environment in accordance with NRCS or DAWR recommendations.

Construction Considerations

Use the same construction considerations specified for basic biofiltration swales.

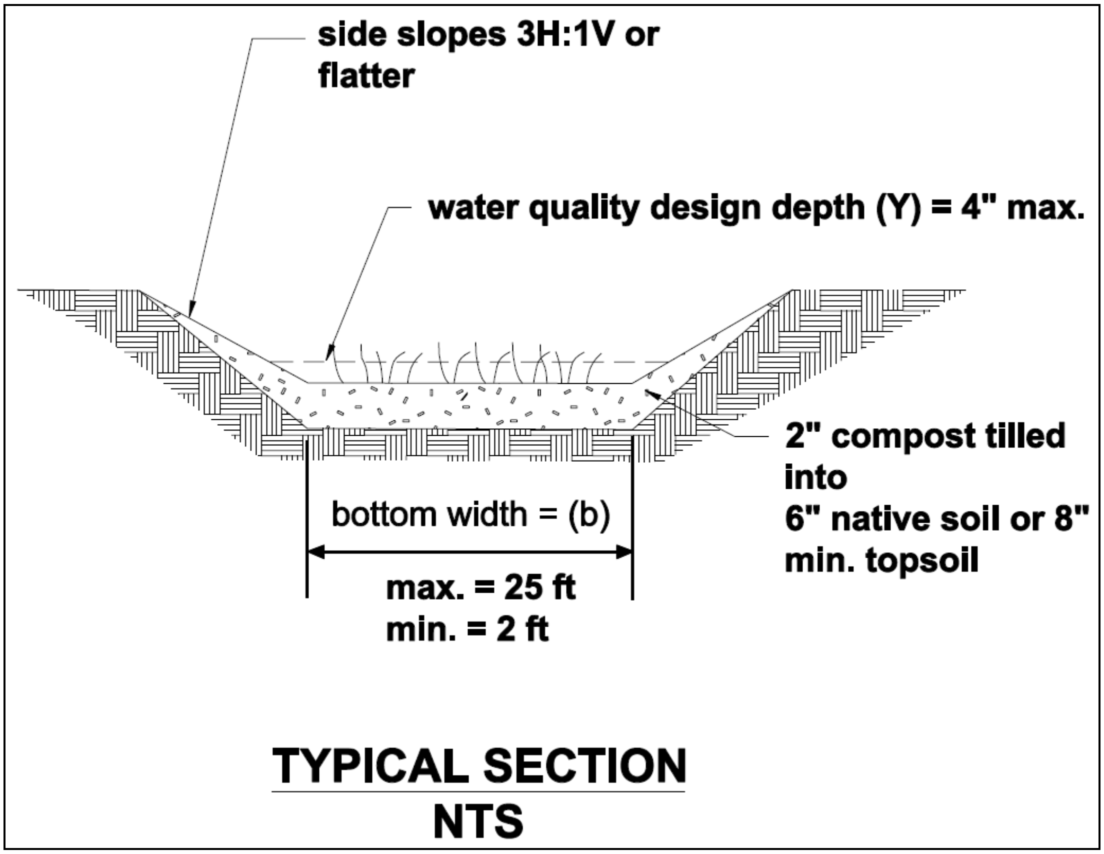


Figure 6-21: BMP RT.05 - Wet Biofiltration Swale

6.4.3.4 RT.06: CONTINUOUS INFLOW BIOFILTRATION SWALE

General Description

In situations where water enters a biofiltration swale continuously along the side slope rather than discreetly at the head, a different design approach — the continuous inflow biofiltration swale — is needed. The basic swale design is modified by increasing swale length to achieve an equivalent average hydraulic residence time.

Applications and Limitations

A continuous inflow biofiltration swale is used when inflows are not concentrated, such as locations along the shoulder of a road without curbs. This design may also be used where frequent, small-point flows enter a swale, such as through curb inlet ports spaced at intervals along a road or from a parking lot with frequent curb cuts. In general, no inlet port should carry more than approximately 10 percent of the flow.

A continuous inflow swale is not appropriate where significant lateral flows enter a swale at some point downstream from the head of the swale. In this situation, the swale width and length must be recalculated from the point of confluence to the discharge point, in order to provide adequate treatment for the increased flows.

Design Considerations

Use the same considerations specified for BMP RT.04–Biofiltration Swale (see Table 6-5), except for the following:

- For the design flow, include runoff from the pervious side slopes draining to the swale along the entire swale length.
- If only a single design flow is used, use the flow rate at the outlet. The goal is to achieve an average residence time through the swale of nine minutes. Assuming an even distribution of inflow into the side of the swale, double the hydraulic residence time to a minimum of 18 minutes.
- For continuous inflow biofiltration swales, plant interior side slopes above the runoff treatment design elevation in grass. Landscape plants or groundcovers other than grass generally should not be used between the runoff inflow elevation and the bottom of the swale.

Intent: The use of grass on interior side slopes reduces the chance of soil erosion and transfer of pollutants from landscape areas to the biofiltration treatment area.

After the cross-sectional size of the biofiltration swale is determined using Q_{biofil}, complete the following steps. This is to account for the hydraulic residence time of flow moving through the vegetated side slopes (3H:1V or shallower and slope length >5 ft.) at various points along the length of the swale.

1. Break the drainage basin of the swale into areas so that no area contributes more than 20 percent of the flow. Include only those areas that discharge sheet flow to the vegetated side slopes and biofiltration swale.
2. Determine the velocity of flows through each vegetated side slope, $V_{n,ss}$ (feet per second), for each of the contributing areas by completing steps 1 through 3 of the vegetated filter strip design methodology.
3. Determine the hydraulic residence time within each vegetated side slope, t_{ss} (second), for each area using:

$$L_{n,ss}/V_{n,ss} = t_{n,ss}$$

Where:

$L_{n,ss}$ = Length of vegetated side slope of the nth swale sub-basin in ft.

4. Determine the weighted mean hydraulic residence time, $t_{mean,ss}$, for all flows passing through vegetated side slopes using:

$$[Q_1(t_{ss,1})+Q2(t_{ss,2})+\ldots+Q_n(t_{ss,n})]/Q_{total,ss}= t_{mean,ss}$$

Where:

Q_n = Flow rate for nth contributing area in cfs

$Q_{total,ss}$ = Total flow that passes through all of the vegetated side slopes in cfs

5. Multiply $t_{mean,ss}$ by R

Where:

$t_{mean,ss} \times R = t_{adj}$

$R = Q_{total,ss} / Q_{biofil}$

$Q_{biofil} = Q_{WQ}$ (for the properly-sized swale section)

6. If the head of the swale is located downstream of the last contributing vegetated side slope section, subtract t_{adj} from 540 seconds (= nine minutes) to determine the t_{design}. If the swale is located along the entire toe of the contributing vegetated side slope, subtract t_{adj} from 1,080 seconds (=18 minutes) to determine t_{design}. Note: In the latter case, the swale must be at least as long as the contributing vegetated side slopes.

7. Using the downstream flow rate (Q_{biofil}), determine the velocity through the swale, and use t_{design}, calculated in Step 6, to determine the total swale length required. Make any necessary adjustments to ensure the criteria in Table 6-5 are met.

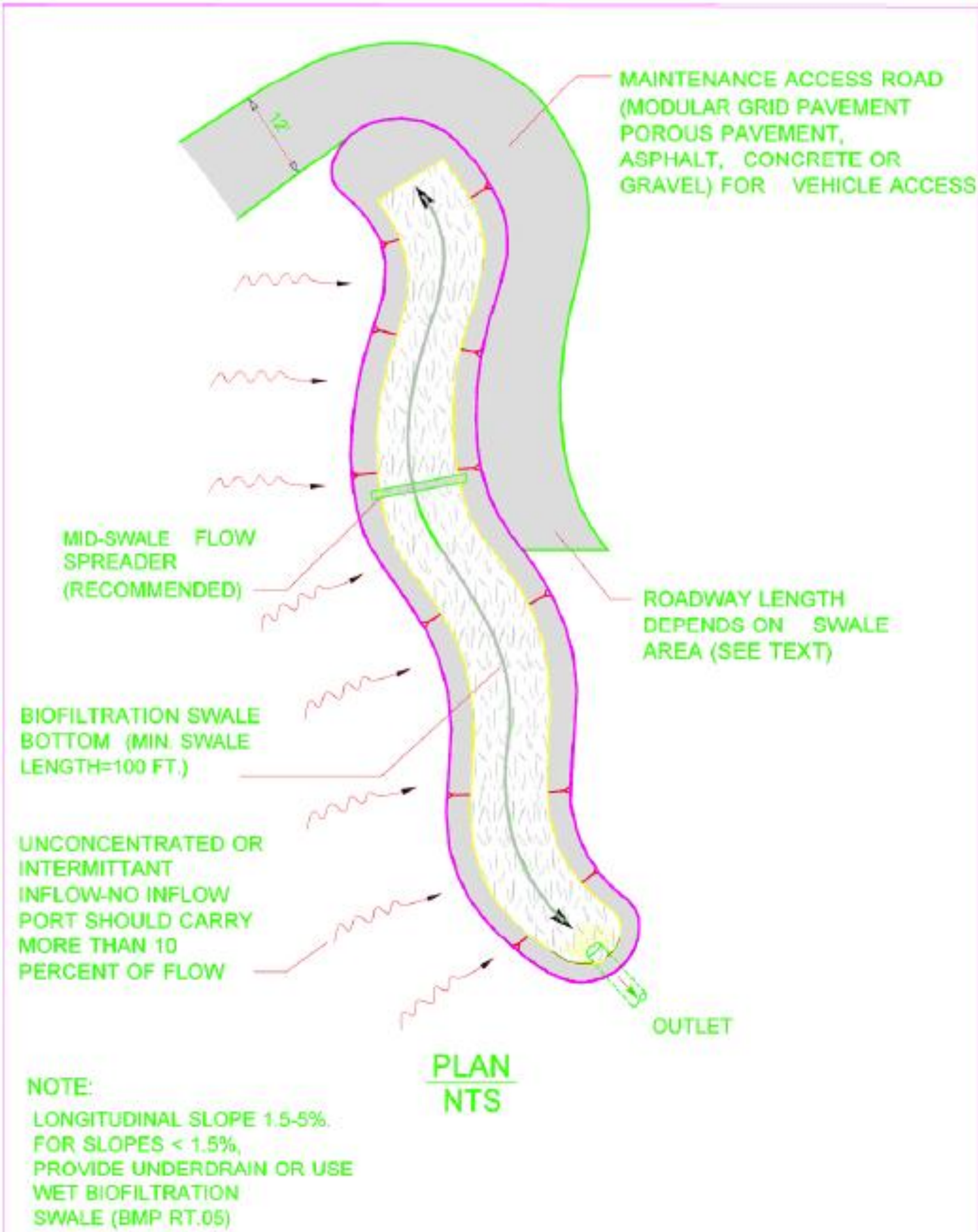


Figure 6-22: BMP RT.06 - Continuous Inflow Bioinfiltration Swale

6.4.3.5 RT.07: MEDIA FILTER DRAIN

General Description

The Media Filter Drain (MFD) is a linear flow-through stormwater runoff treatment device that can be sited along highway side slopes (conventional design), borrow ditches, or other linear depressions. The MFD can be used where available right-of-way is limited, sheet flow from the highway surface is feasible, and lateral gradients are generally less than 25 percent (4H:1V). The MFD is also suitable as a phosphorus removal treatment BMP, where discharge is to an Environmental Protection Agency (EPA)-designated phosphorus protected water body.

MFDs have four basic components: a gravel no-vegetation zone, a grass filter strip, the MFD mix bed, and a conveyance system for flows leaving the MFD mix. This conveyance system usually consists of a gravel-filled underdrain trench or an underlying layer of crushed gravel for free-side slope discharge. This layer of gravel must be porous enough to allow treated flows to freely drain away from the MFD mix. Typical MFD configurations are shown in Figures 6-23 through 6-26.

Functional Description

The MFD removes suspended solids, phosphorus, and metals from highway runoff through physical straining, ion exchange, carbonate precipitation, and biofiltration.

Stormwater runoff is conveyed to the MFD through sheet flow over a vegetation-free gravel zone to ensure sheet dispersion and provide some heavier particle pollutant trapping. Next, a grass filter strip (planted in topsoil amended with compost) is incorporated into the top of the fill slope to provide pre-treatment, further enhancing filtration and extending the life of the system. The runoff is then filtered through a bed of porous, alkalinity-generating granular medium — the MFD mix. MFD mix is a fill material composed of crushed rock (sized by screening), dolomite, gypsum, and perlite. The dolomite and gypsum additives serve to buffer acidic pH conditions and exchange light metals for heavy metals. Perlite is incorporated to improve moisture retention, which is critical for the formation of biomass epilithic biofilm to assist in the removal of solids, metals, and nutrients. Treated water drains from the MFD mix bed into the conveyance system (underlying free draining crushed gravel, with under drain as applicable) below the MFD mix. Geotextile filter fabric is placed between to separate the underside of the MFD mix bed from the underlying gravel material.

The underdrain trench is an option for hydraulic conveyance of treated stormwater to a desired location, such as a downstream flow control facility or stormwater outfall.

It is critical to note that water must sheet flow across the MFD.

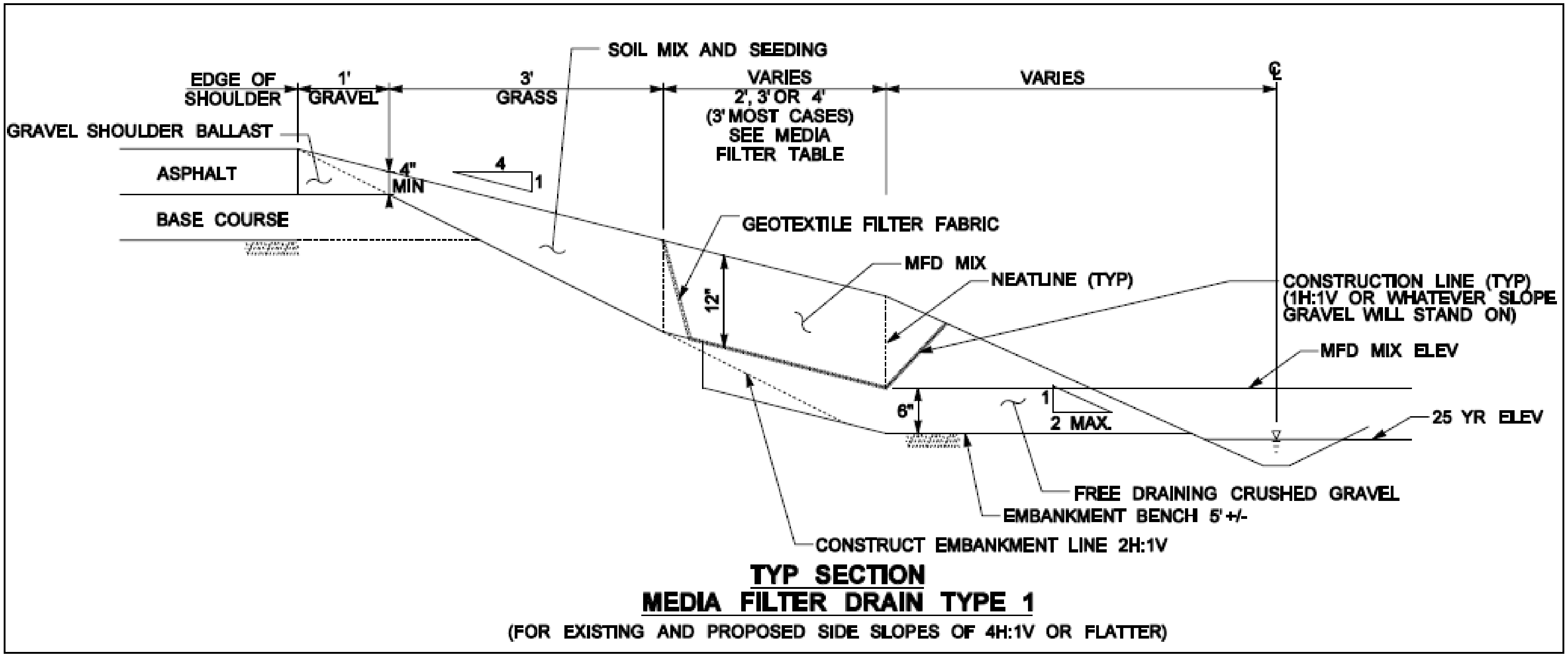


Figure 6-23: BMP RT.07 - Media Filter Drain Type 1

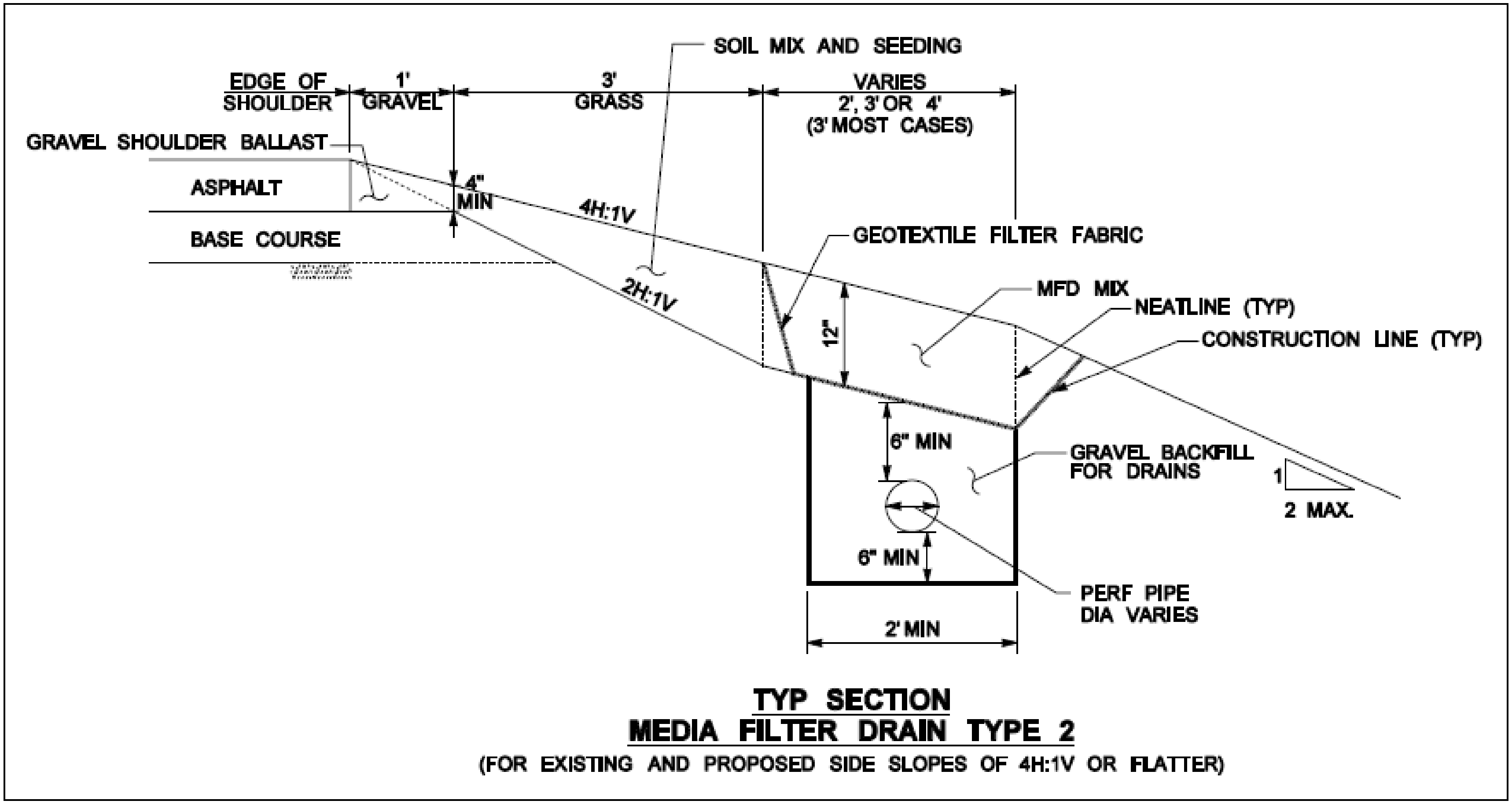
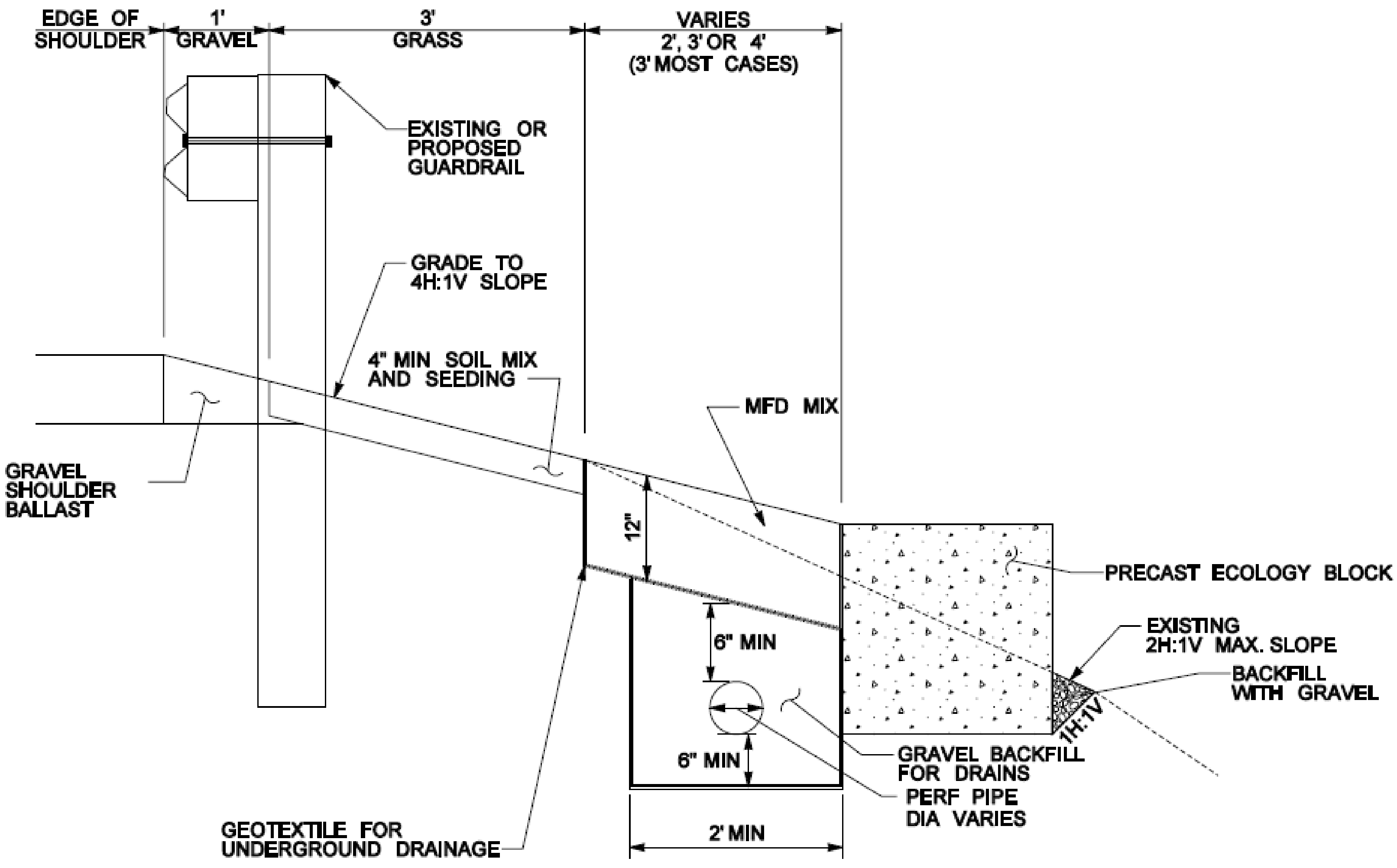


Figure 6-24: BMP RT.07 - Media Filter Drain Type 2



TYP SECTION
MEDIA FILTER DRAIN TYPE 3

(FOR EXISTING SIDE SLOPE THAT VARIES FROM 4H:1V)

Figure 6-25: BMP RT.07 - Media Filter Drain Type 3

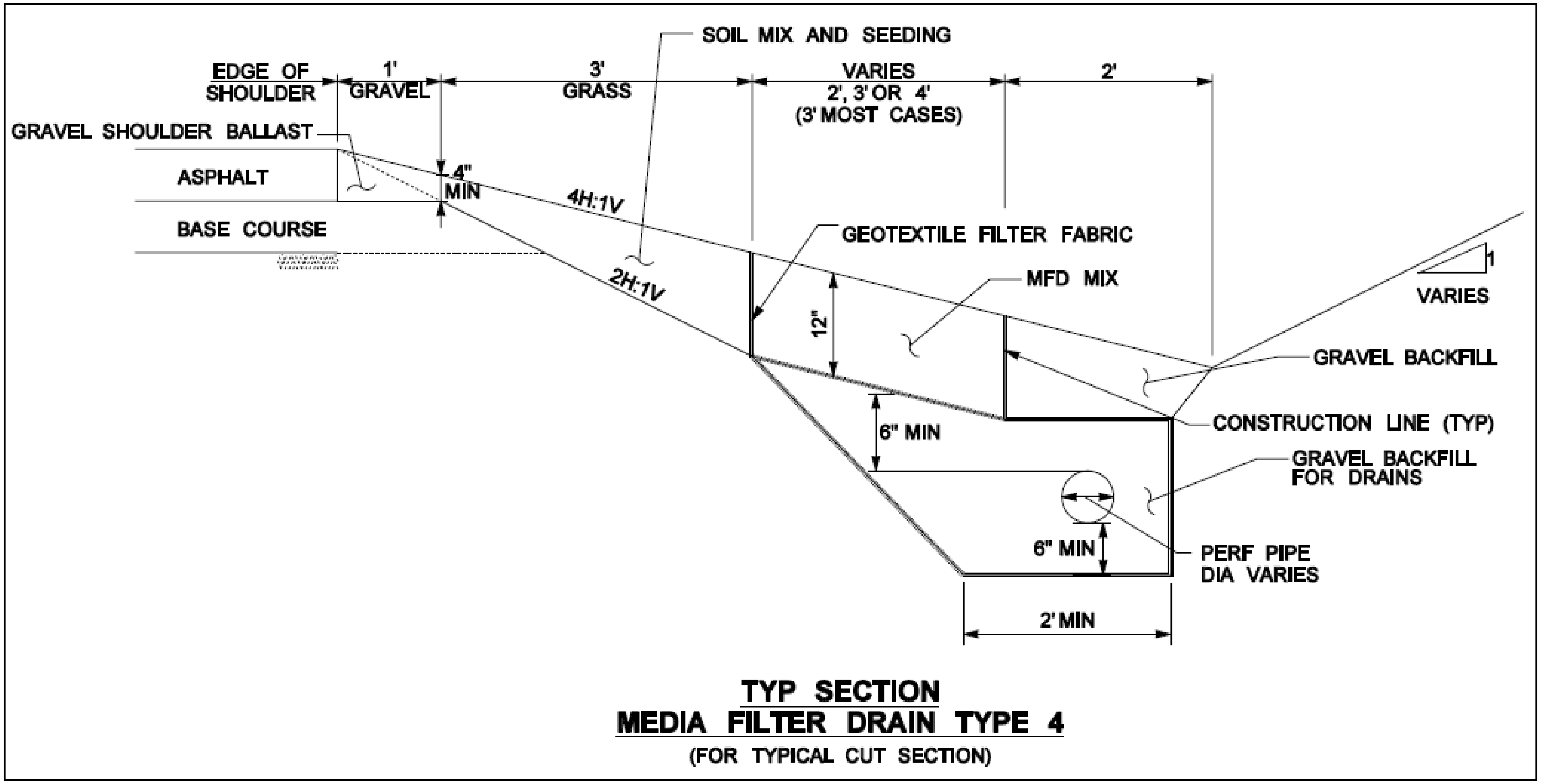


Figure 6-26: BMP RT.07 - Media Filter Drain Type 4

Applications and Limitations

Applications

Media Filter Drains

The MFD can achieve basic, phosphorus, and enhanced water quality treatment. Because maintaining sheet flow across the MFD is required for its proper function, the ideal locations for MFDs in highway settings are highway side slopes or other long, linear grades with lateral side slopes less than 4H:1V and longitudinal slopes no steeper than 5 percent. As side slopes approach 3H:1V, without design modifications, sloughing may become a problem due to friction limitations between the separation geotextile and underlying soils. The longest flow path from the contributing area delivering sheet flow to the MFD should not exceed 150 ft.

Four typical applications are shown in Figures 6-23 through 6-26. Figure 6-23 (Type 1) shows the typical installation for roadways that have a roadside ditch for stormwater conveyance. The design stormwater level in the ditch should be below the media filter mix; otherwise, erosion of the mix and flushing of the trapped contaminates may occur.

Figure 6-24 (Type 2) shows the typical application where flow from the media filter mix needs to be collected and transported by perforated pipe to a separate storm drain, outfall, or detention facility.

Figure 6-25 (Type 3) is where a MFD needs to be installed on an existing side slope that is less than 4H:1V. Figure 6-26 (Type 4) is the typical situation for a roadway in a cut slope condition, where there is no room for a conventional edge of road drainage ditch. For this condition, the underdrain must be sized for not only the roadway runoff, but the back slope and any off-site runoff as well.

Note that the underdrain section can be sized to act as an infiltration trench for the Types 2, 3 and 4 media filter drains. The underlying infiltration trench would be sized to detain the design stormwater volume until it infiltrates into the underlying soil or limestone bedrock strata. Where infiltration capacity is not sufficient to fully infiltrate the design volume, the perforated underdrain pipe can be utilized as a conveyance to a separate overflow type discharge or detention location.

Limitations

Media Filter Drains

Steep slopes. Avoid construction on longitudinal slopes steeper than 5 percent. Avoid construction on steeper than 3H:1V lateral slopes, and preferably use 4H:1V slopes or less. In areas where lateral slopes exceed 4H:1V, it may be possible to construct terraces to create 4H:1V slopes or to otherwise stabilize up to 3H:1V slopes. (For details, see "Geometry, Components, and Sizing Criteria, Cross Section in the Structural Design Considerations" section, below).

Wetlands. Do not construct in wetlands and wetland buffers. In many cases, an MFD (due to its small lateral footprint) can fit within the highway fill slopes adjacent to a wetland buffer. In those situations where the highway fill prism is located adjacent to wetlands, an interception trench/underdrain will need to be incorporated as a design element in the MFD.

Shallow groundwater. Mean high-water table levels at the project site need to be determined to ensure the MFD mix bed and the underdrain, if needed, will not become saturated by shallow groundwater.

Unstable slopes. In areas where slope stability may be problematic, consult a Geotechnical Engineer.

Design Flow Elements

Flows To Be Treated

The basic design concept behind the MFD is to fully filter all the roadway runoff through the MFD mix. Therefore, the infiltration capacity of the medium and drainage below needs to match or exceed the design frequency storm hydraulic loading rate.

Where the MFD underdrain is acting as the roadway collection conveyance, then the infiltration and underdrain capacity must meet the appropriate design storm frequency (see Chapter 5).

Structural Design Considerations

Geometry

No-Vegetation Zone

The no-vegetation zone (vegetation-free zone) is a shallow, gravel trench located directly adjacent to the highway pavement. The no-vegetation zone is a crucial element in a properly-functioning MFD or other BMPs that use sheet flow to convey runoff from the highway surface to the BMP. The no-vegetation zone functions as a level spreader to promote sheet flow and as a deposition area for coarse sediments. The no-vegetation zone should be between 1 ft. and 3 ft. wide. Depth will be a function of how the roadway section is built from sub-grade to finished grade; the resultant cross section will typically be triangular to trapezoidal.

Grass Strip

The width of the grass strip is dependent on the availability of space within the highway side slope. The baseline design criterion for the grass strip within the

MFD is a 3-ft. minimum width, but wider grass strips are recommended if additional space is available. The designer should bring in a suitable topsoil or native soil with at least 2 in. of compost tilled in. The designer may consider adding aggregate to the soil mix to help minimize rutting problems from errant vehicles. The soil mix should ensure grass growth for the design life of the MFD. The grass seed mix should be a seed mix as recommended by the NRCS or DAWR for the site location and the seasonal conditions at the time of planting.

Media Filter Drain Mix Bed

The MFD mix is a mixture of crushed rock (screened to 3/8 in. to #10 sieve), dolomite, gypsum, and perlite (see Table 6-6). The crushed rock provides the support matrix of the medium; the dolomite and gypsum add alkalinity and ion exchange capacity to promote the precipitation and exchange of heavy metals; and the perlite improves moisture retention to promote the formation of biomass within the MFD mix. The combination of physical filtering, precipitation, ion exchange, and biofiltration enhances the water treatment capacity of the mix. The MFD mix has an estimated initial filtration rate of 50 in./hour and a long-term filtration rate of 28 in./hour, due to siltation. With an additional safety factor, the rate used to size the length of the MFD should be 10 in./hour.

<table>
<tr><th>Media Filter Drain Materials</th><th>Quantity</th></tr>
<tr><td>

Mineral Aggregate: Crushed screenings 3/8-in. to #10 sieve

Crushed screenings should be manufactured from ledge rock, talus, or gravel in accordance with Section 3-01 of the *Standard Specifications for Road, Bridge, and Municipal Construction* (2002), which meets the following test requirements:
Los Angeles Wear, 500 Revolutions 35% max.
Degradation Factor 30 min.

Crushed screenings should conform to the following requirements for grading and quality:

Sieve	Size Percent Passing (by weight)
1/2 in. square	100
3/8 in. square	90-100
U.S. No. 4	30-56
U.S. No. 10	0-10
U.S. No. 200	0-1.5
% fracture, by weight, min.	75
Static stripping test	Pass

The fracture requirement should be at least one fractured face and will apply to material retained on the U.S. No. 10 if that sieve retains more than 5% of the total sample.

The finished product should be clean; uniform in quality; and free from wood, bark, roots, and other deleterious materials.

Crushed screenings should be substantially free from adherent coatings. The presence of a thin, firmly adhering film of weathered rock should not be considered as coating unless it exists on more than 50 percent of the surface area of any size between successive laboratory sieves.

</td><td>3 cubic yards</td></tr>
<tr><td>

Perlite:

Horticultural grade, free of any toxic materials

0-30% passing U.S. No. 18 Sieve

0-10% passing U.S. No. 30 Sieve

</td><td>1 cubic yard per 3 cubic yards of mineral aggregate</td></tr>
<tr><td>

Dolomite: CaMg(CO3)2 (calcium magnesium carbonate)

Agricultural grade, free of any toxic materials

100% passing U.S. No. 8 Sieve

</td><td>10 pounds per cubic yard of perlite</td></tr>
</table>

Media Filter Drain Materials	Quantity
0% passing U.S. No. 16 Sieve	
Gypsum: Non-calcined, agricultural gypsum $CaSO_4 \cdot 2H_2O$ (hydrated calcium sulfate) Agricultural grade, free of any toxic materials 100% passing U.S. No. 8 Sieve 0% passing U.S. No. 16 Sieve	1.5 pounds per cubic yard of perlite

Table 6-6: Media Filter Drain Mix

Conveyance System Below Media Filter Drain Mix

The gravel under-layer and/or underdrain trench provides hydraulic conveyance. The underdrain is used when treated runoff needs to be conveyed to a desired location, such as a downstream flow control facility or stormwater outfall. The underdrain trench should be a minimum of 2 ft. wide. In the limestone bedrock areas of northern Guam, the underdrain should be designed as an infiltration trench sized to detain and infiltrate the design storm event. In the case where there is no overtopping discharge location, then the under drain infiltration trench should be sized to detain and infiltrate the 100-year storm.

The gravel underdrain trench may be eliminated if there is evidence to support that flows can be conveyed laterally to an adjacent ditch or onto a fill slope that is properly vegetated to protect against erosion. The MFD mix should be kept free to drain, or un-submerged above the 25-year storm event water surface elevations in the downstream ditch.

Sizing Criteria

Width

The width of the MFD mix bed is determined by the amount of contributing pavement routed to the embankment. The surface area of the MFD mix bed needs to be sufficiently large to fully infiltrate the runoff treatment design flow rate using the long-term filtration rate of the MFD mix. For design purposes, a 50 percent safety factor is incorporated into the long-term MFD mix filtration rate to accommodate variations in slope, resulting in a design filtration rate of 10 in. per hour. The MFD mix bed should have a bottom width of at least 2 ft. in contact with the conveyance system below the MFD mix.

Length

In general, the length of an MFD is the same as the contributing pavement. Any length is acceptable as long as the surface area MFD mix bed is sufficient to fully infiltrate the stormwater quality treatment design flow rate.

Cross-Section

In profile, the surface of the MFD should preferably have a lateral slope less than 4H:1V (<25 percent). On steeper terrain, it may be possible to construct terraces to create a 4H:1V slope, or other engineering may be employed to ensure a slope stability up to 3H:1V. If sloughing is a concern on steeper slopes, consideration should be given to incorporating permeable soil reinforcements such as geotextiles, open-graded/permeable pavements, or commercially-available ring and grid reinforcement structures, as top layer components to the MFD mix bed. Consultation with a Geotechnical Engineer is required.

Inflow

Runoff is conveyed to an MFD using sheet flow from the pavement area. The longitudinal pavement slope contributing flow to an MFD should be less than 5 percent. Although there is no lateral pavement slope restriction for flows going to an MFD, the designer should ensure flows remain as sheet flow.

Media Filter Drain Mix Bed Sizing Procedure

The MFD mix should be a minimum of 12 in. deep, including the section on top of the underdrain trench.

For runoff treatment, sizing the MFD mix bed is based on the requirement that the runoff treatment flow rate from the pavement area, $Q_{Highway}$, cannot exceed the long-term infiltration capacity of the MFD, $Q_{Infiltration}$:

$$Q_{Highway} \leq Q_{Infiltration}$$

Calculations should be based on a long-term infiltration capacity of 10 in. per hour. From a practical standpoint, it has been found that the media filter drain should have the minimum widths shown in Table 6-7.

Pavement width that contributes runoff to the media filter drain	Minimum media filter drain width*
$\leq$ 20 ft.	2 ft.
> 20 and $\leq$ 35 ft.	3 ft.
> 35 ft.	4 ft.

Table 6-7: Media Filter Drain Widths

*Width does not include the required 1-ft. to 3-ft. gravel vegetation-free zone or the 3-ft. filter strip width.

Materials

Media Filter Drain Mix

The MFD mix used in the construction of MFDs consists of the material proportions listed in Table 6-6. Mixing and transportation must occur in a manner that ensures the materials are thoroughly mixed prior to placement, and that separation does not occur during transportation or construction operations.

Site Design Elements

Planting Considerations

Planting of the grassed filter strip is the same as for biofiltration swales.

Operations and Maintenance

Maintenance will consist of routine roadside management. While herbicides will not be applied directly over the MFD, it may be necessary to periodically control noxious weeds with herbicides in areas around the MFD.

The design life of the MFD is expected to be approximately 20 years. At that time, the MFD mix should be removed and replaced with new filter mix. The mix replacement should normally be part of any adjacent pavement rehabilitation or resurfacing project.

Signing

Non-reflective guideposts should delineate the MFD. This practice allows DPW's personnel to identify where the system is installed and to make appropriate repairs should damage occur to the system.

6.4.4 WET POOL: BMPS

Wet pool BMPs include the following:

RT.08 – Wet Pond

RT.10 – Constructed Stormwater Treatment Wetland

RT.09 – Combined Wet/Detention Pond

RT.11 – Combined Stormwater Treatment Wetland/Detention Pond

Wet pool BMPs are constructed basins containing a permanent pool of water. Wet ponds function by settling suspended solids. The biological action of plants and bacteria provides some additional treatment. Not only can wet ponds be designed for the treatment of conventional pollutants, but they can also be modified (such as a created wetland) to enhance the removal of nutrients or dissolved metals. Wet ponds are usually more effective and efficient when constructed using multiple cells (a series of individual smaller basins), where coarser sediments become trapped in the first cell, or forebay.

Wet pond designs can also provide flow control by adding detention volume (live storage) above the dead storage.

A wet pool BMP can be either an on- or off-line facility receiving the stormwater quality treatment volume.

Constructed stormwater quality treatment wetlands offer a suitable alternative to wet ponds or biofiltration swales and can also provide treatment for dissolved metals. However, designers must consider the availability of water and the water needs of plants used in the stormwater wetland. The landscape context for stormwater wetland placement must be appropriate for the creation of an artificial wetland (groundwater, soils, and surrounding vegetation). Natural wetlands cannot be used for stormwater treatment purposes.

6.4.4.1 RT.08: WET POND

General Description

A wet pond is a constructed stormwater pond that retains a permanent pool of water (wet pool), at least during the wet season. The volume of the wet pool is related to the effectiveness of the pond in settling particulate pollutants. As an option, a shallow marsh area can be created within the permanent pool volume to provide additional treatment for nutrient removal. The BMP RT.09 Combined Wet/Detention Pond is the wet pond provided with live storage area above the permanent pool for detention flow control. Figures 6-27 and 6-28 illustrate a typical wet pond BMP.

Applications and Limitations

Wet ponds can be designed in two sizes -- basic and large. A basic wet pond is the stormwater quality treatment BMP for the usual case. Large wet ponds are designed for higher levels of pollutant removal and are an appropriate treatment BMP for phosphorus removal. In areas of higher soil permeability, wet ponds should be lined with impermeable membranes.

Refer to RT.09-Combined Wet/Detention Pond if the pond is to be used for flow control in addition to runoff treatment.

Design Flow Elements

Flows To Be Treated

Basic wet ponds are designed to treat the runoff treatment volume described as part of Minimum Requirement 5 as defined in Chapter 3 of this TSDM. Large wet ponds are designed to treat a volume 1.5 times greater than the water quality treatment volume.

Overflow or Bypass

The overflow criteria for single-purpose (treatment only, not combined with flow control) wet ponds are as follows:

- An open-top, standpipe riser in the control structure satisfies the requirement for primary overflow design.
- The top of the riser should be set at the water quality design water surface elevation.
- If it is an on-line pond, the primary overflow should be sized to pass the 100-year flow. If the pond is off-line (upstream flow splitter to bypass the flows in excess of the design stormwater quality treatment flow), the primary overflow should be sized to pass the upstream conveyance capacity.

Emergency Overflow Spillway

An emergency spillway or structure must be provided and designed according to the requirements for BMP FC.01-Detention Pond. The control surface of the emergency overflow spillway must be set at the design water surface elevation.

Structural Design Considerations

Geometry

Design Criteria

The wet pond is divided into a minimum of two cells, separated by a baffle or berm. The first cell must contain between 25 percent and 35 percent of the total wet pond volume. The baffle or berm volume does not count as part of the total wet pond volume. The term baffle means a vertical divider placed across the entire width of the pond, stopping short of the bottom. A berm is a vertical divider typically built up from the bottom; in a wet vault, it connects all the way to the bottom.

Intent: The full-length berm or baffle promotes plug flow and enhances quiescence and laminar flow through as much of the entire water volume as possible. Alternative methods to the full-length berm or baffle that provide equivalent flow characteristics may be approved on a case-by-case basis by DPW.

Sediment storage is provided in the first cell. The minimum depth of the sediment storage must be 1 ft. A fixed sediment depth monitor should be installed in the first cell to gauge sediment accumulation, or an alternative gauging method should be used.

The minimum depth of the first cell must be 4 ft., exclusive of sediment storage requirements. The depth of the first cell may be greater than the depth of the second cell.

The maximum depth of each cell must not exceed 8 ft. (exclusive of sediment storage in the first cell). Pool depths of 3 ft. or shallower (second cell) must be planted with emergent wetland vegetation (see "Landscaping" later in this section).

Inlets and outlets must be placed to maximize the flow path through the facility. The ratio of flow path length to width from the inlet to the outlet must be at least 2:1. The flow path length is defined as the distance from the inlet to the outlet, as measured at mid-depth. The width at mid-depth is calculated as follows: width = (average top width + average bottom width)/2.

Wet ponds with wet pool volumes less than or equal to 4,000 cu. ft. may be single-celled (no baffle or berm is required). However, it is especially important that the flow path length be maximized in single-celled wet ponds. The ratio of flow path length to width must be greater than 4:1 in single-celled wet ponds.

All inlets must enter the first cell. If there are multiple inlets, the length-to-width ratio is based on the average flow path length for all inlets.

Sizing Procedure

Design Steps (D)

D-1 Identify the required wet pool volume (Vol_{wq}). For large wet ponds, the wet pool volume is 1.5 times the water quality volume.

D-2 Estimate wet pool dimensions satisfying the following design criterion:

$$Vol_{wq} = [h_1(A_{t1} + A_{b1}) / 2] + [h_2(A_{t2} + A_{b2}) / 2] + \ldots\ldots + [h_n(A_{tn} + A_{bn}) / 2]$$

Where:

A_{tn} = Top area of wet pool surface in cell n in $ft.^2$

A_{bn} = Bottom area of wet pool surface in cell n in $ft.^2$

h_n = Depth of wet pool in cell n (above top of sediment storage) in ft.

D-3 Design pond outlet pipe and determine primary overflow water surface

Inlet and Outlet

For details on the following requirements, see Figures 6-27 and 6-28.

The inlet to the wet pond must be submerged, with the inlet pipe invert a minimum of 2 ft. from the pond bottom (not including the 1-ft. minimum sediment storage). The top of the inlet pipe should be submerged at least 1 ft. below the runoff treatment design water surface, if possible. The designer should compute the Hydraulic Grade Line (HGL) of the inlet pipe to verify that backwater conditions are acceptable.

Intent: The inlet is submerged to dissipate the energy of the incoming flow. The distance from the bottom is set to minimize the re-suspension of settled sediments. Alternative inlet designs that accomplish these objectives are acceptable.

An outlet structure must be provided. No sump is required in the outlet structure for wet ponds not providing detention storage. The outlet structure receives flow from the pond outlet pipe. The birdcage opening provides an overflow route should the pond outlet pipe become clogged.

The pond outlet pipe (from the pond into the outlet structure) must be back-sloped, or have a turn-down elbow, and extend 1 ft. below the runoff treatment design water surface. A floating outlet, set to draw water from 1 ft. below the water surface, is also acceptable if vandalism concerns are adequately addressed.

Intent: The inverted outlet pipe traps oils and floatables in the wet pond.

The pond outlet pipe must be sized, at a minimum, to pass the runoff treatment design flow. Note: The highest invert of the outlet pipe sets the runoff treatment design water surface elevation.

Materials

All metal parts must be corrosion-resistant. Galvanized materials should not be used unless unavoidable.

Intent: Galvanized metal contributes zinc to stormwater, sometimes in very high concentrations.

Berms, Baffles, and Slopes

A berm or baffle must extend across the full width of the wet pool and tie into the wet pond side slopes. If the berm embankments are greater than 4 ft. high, the berm must be constructed by excavating a key trench equal to 50 percent of the embankment cross-sectional height and width. A Geotechnical Engineer may waive this requirement for specific site conditions. A geotechnical analysis must address situations in which one of the two cells is empty while the other remains full of water.

The top of the berm should be submerged 1 ft. below this surface. Earthen berms should have a minimum top width of 5 ft.

Intent: The submerged berm of 1 ft. provides a surface skimming effect to improve the sedimentation settlement efficiency.

If good vegetation cover is not established on the berm, erosion control measures should be used to prevent erosion of the berm back-slope when the pond is initially filled.

Instead of an interior berm, a structural type retaining wall may be used.

The criteria for wet pond side slopes are as follows:

- Interior side slopes should be no steeper than 2H:1V. However, slopes of 3H:1V or flatter are preferred. If using 2H:1V slopes, the pond must be fenced for safety reasons.
- Exterior side slopes must be no steeper than 2H:1V.
- Slopes should be no steeper than 4H:1V if they are to be mowed.
- Pond sides may be retaining walls, provided that a fence is situated along the top of the wall and at least 25 percent of the pond perimeter is a vegetated side slope no steeper than 3H: 1V.
- The toe of the exterior slope must be no closer than 5 ft. from the right-of-way line.

Embankments

The berm embankment must be constructed of material consisting of a minimum of 30 percent clay, a maximum of 60 percent sand, a maximum of 60 percent silt, and negligible gravel and cobble.

To prevent undermining, installation of a perimeter cutoff trench underneath or near embankments should be considered.

Anti-seepage collars must be placed on outflow pipes in berm embankments impounding water deeper than 8 ft. at the runoff treatment design water surface. Anti-seepage collars may also be necessary in other situations.

Ponds having storage impoundments of 10 ac-ft. or greater, must have DPW's pre-approval, where the design of the pond should meet federal or typical industry large dam safety guidelines in regards to the hydrology, geotechnical, structural, and hydraulic considerations.

Site Design Elements

Setback Requirements

Wet ponds must be a minimum of 5 ft. from any property line or vegetative buffer, and must be 100 ft. from any septic tank or drain field.

The designer should request a geotechnical report for the project that evaluates any potential structural site instability due to extended sub-grade saturation or head-loading of the permeable layer. This includes the potential impacts to down-gradient properties, especially on hills with known side-hill seeps. The report should address the adequacy of the proposed wet pond locations and recommend the necessary setbacks from any steep slopes and building foundations.

Landscaping (Planting Considerations)

Planting requirements for detention ponds also apply to wet ponds.

The cells in large wet ponds intended for phosphorus control should not be planted because the plants release phosphorus in the winter when they die off.

If the second cell of a basic wet pond is 3 ft. or shallower, the bottom area must be planted with emergent wetland vegetation. This results in habitat for natural predators of mosquitoes such as dragonflies, birds, fish, and frogs.

Intent: The planting of shallow pond areas helps to stabilize settled sediment and prevent re-suspension.

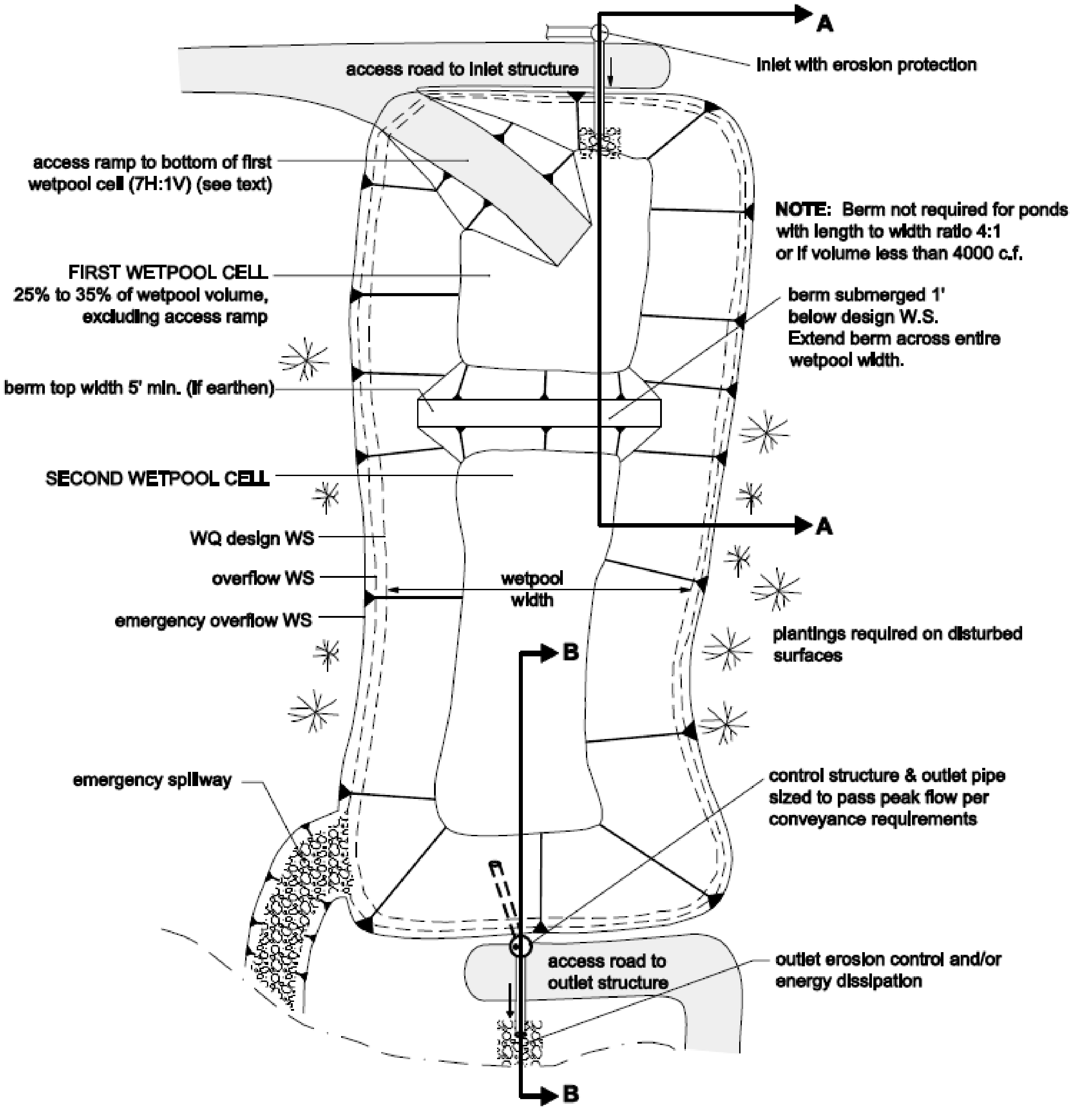
Vegetation that forms floating mats should not be planted because the mats protect mosquito larvae.

A variety of plant species should be planted to encourage a diversity of mosquito predators. This variety can also make the overall predator population more robust to withstand environmental changes to the facility.

If the wet pond discharges to a phosphorus-sensitive lake or wetland, shrubs that form a dense cover should be planted on slopes above the runoff treatment design water surface on at least three sides. For banks that are berms, no planting is allowed if the berm is regulated by dam safety requirements. The purpose of planting is to provide shading.

Fencing

Pond walls may be retaining walls as long as a fence is provided along the top of the wall and at least 25 percent of the pond perimeter will have a slope of 3H:1V or flatter. For safety reasons, the pond must be fenced if the slopes are steeper than 3H:1V.



PLAN VIEW
NTS

Figure 6-27: BMP RT.08 - Wet Pond

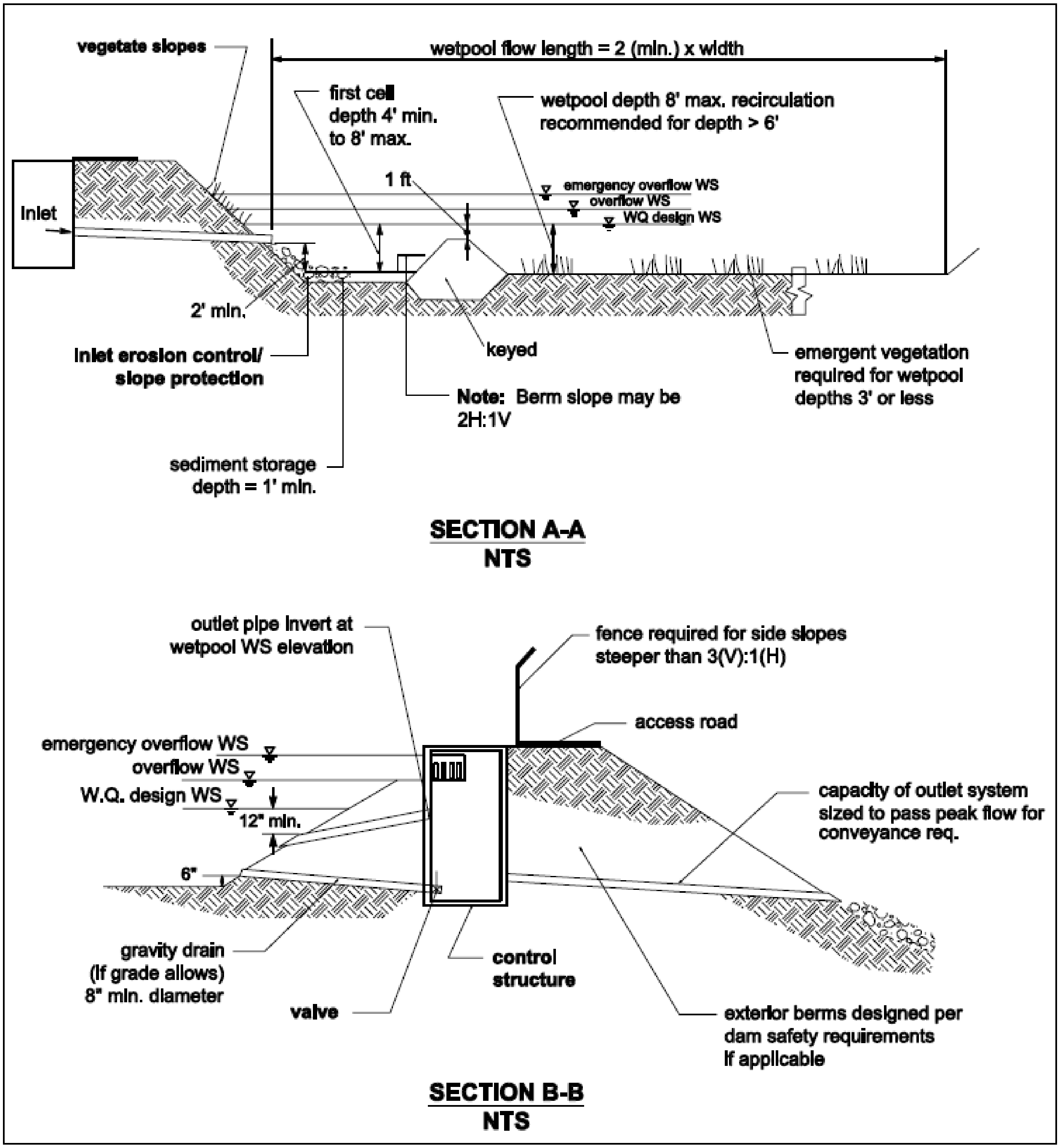


Figure 6-28: Wet Pond Cross Sections

Recommended Design Features

The following design features should be incorporated into the wet pond design where site conditions allow:

For wet pool depths in excess of 6 ft., it is recommended that some form of recirculation be provided. A fountain or aerator may be used to prevent stagnation and low-dissolved oxygen conditions. Alternatively, a small amount of base flow could be directed to the pond to maintain circulation and reduce the potential for low-oxygen conditions.

Trees should be planted along the west and south sides of ponds to reduce thermal heating, except that no trees or shrubs may be planted on compacted fill berms. Trees should be set back so that the branches will not extend over the pond.

The number of inlets to the facility should be limited; ideally, there should be only one inlet. Regardless of the number of inlets, the flow path length between the inlet and outlet should be maximized.

Where possible, the following design features should be incorporated to enhance aesthetics:

- Provide side slopes that are sufficiently gentle (3H:1V or flatter) to avoid the need for fencing. Gentler slopes typically allow a facility to better blend into its surroundings.
- Use sinuous or irregularly-shaped ponds to create a more naturalistic landscape.
- Provide visual enhancement with clusters of trees and shrubs. On most pond sites, it is important to amend the soil before planting because ponds are typically placed well below the native soil horizon in very poor soils. Make sure that dam safety restrictions against planting do not apply.
- Orient the pond length along the direction of prevailing summer winds to enhance wind mixing.
- Impermeable liners may be necessary to maintain the wet pool volume in permeable soils.

Construction Criteria

If the pond has been used for temporary sedimentation purposes during construction, the accumulated sediment must be cleaned out at the end of construction.

6.4.4.2 RT.10: COMBINED WET/DETENTION POND

General Description

A combined detention and runoff treatment wet pond facility has the appearance of a detention facility but contains a permanent pool of water as well. The following design procedures, requirements, and recommendations cover differences in the design of the stand-alone runoff treatment facility when combined with detention storage.

There are two sizes of the combined wet pond -- basic and large. The facility sizes (basic and large) are related to the pollutant-removal goals.

Applications and Limitations

Combined detention and runoff treatment facilities are very efficient for sites that also have flow control requirements, but are not conducive to dispersion or infiltration. The runoff treatment BMP may often be placed beneath detention storage without increasing the overall facility surface area. However, the fluctuating water surface of the live storage creates unique challenges for plant growth and aesthetics.

The basis for pollutant removal in combined facilities is the same as that for stand-alone runoff treatment facilities. However, in the combined facility, the detention function creates fluctuating water levels and added turbulence. For simplicity, the positive effect of the extra live storage volume and the negative effect of increased turbulence are assumed to balance, and are thus ignored when the wet pool volume is sized. For the combined detention/stormwater wetland, criteria that limit the extent of water level fluctuation are specified to better ensure survival of the wetland plants.

Unlike the wet pool volume, the live storage component of the facility must be provided above the seasonal high-water table. It is recommended that all stormwater quality treatment BMPs that use permanent wet pools use facility liners.

Typical design details and concepts for a combined detention and wet pond are shown in Figures 6-29 and 6-30. The detention portion of the facility must meet the design criteria and sizing procedures set forth in the flow control BMP FC.01 - Detention Pond.

Design Flow Elements

Flows To Be Treated

Basic combined wet/detention ponds are designed to treat the runoff treatment volume and detain flows according to the criteria described as part of Minimum Requirements 5 and 6, respectively, as defined in Chapter 3 of this TSDM. Large combined wet/detention ponds are designed to treat 1.5 times the runoff treatment volume.

Structural Design Considerations

Geometry

The geometry criteria for wet ponds (see BMP RT.08) apply, with the following modifications and clarifications:

The permanent pool may be made shallower to take up most of the pond bottom, or it may be deeper and positioned to take up only a limited portion of the bottom. Wet pond criteria governing water depth, however, must still be met. (See Figure 6-31 for alternate possibilities for wet pool cell placement.)

Intent: This flexibility in positioning cells allows for multiple-use options in live storage areas during the drier months.

The minimum sediment storage depth in the first cell is 1 ft. The 6 in. of sediment storage required for a detention pond does not need to be added to this, but 6 in. of sediment storage must be added to the second cell to comply with the detention sediment storage requirement.

The wet pool and sediment storage volumes are not included in the required detention volume.

Sizing Procedure

The sizing procedure for combined detention and wet ponds is identical to that outlined for wet ponds (see BMP RT.08) and detention ponds (see BMP FC.01).

Inlet and Outlet

The inlet and outlet criteria for wet ponds (see BMP RT.08) apply, with the following modifications:

- A sump must be provided in the outlet control structure of combined ponds
- The detention flow restrictor and its outlet pipe must be designed according to the requirements for detention ponds (see BMP FC.01)

Berms, Baffles, and Slopes

The criteria are the same as for wet ponds (see BMP RT.08).

Groundwater Issues

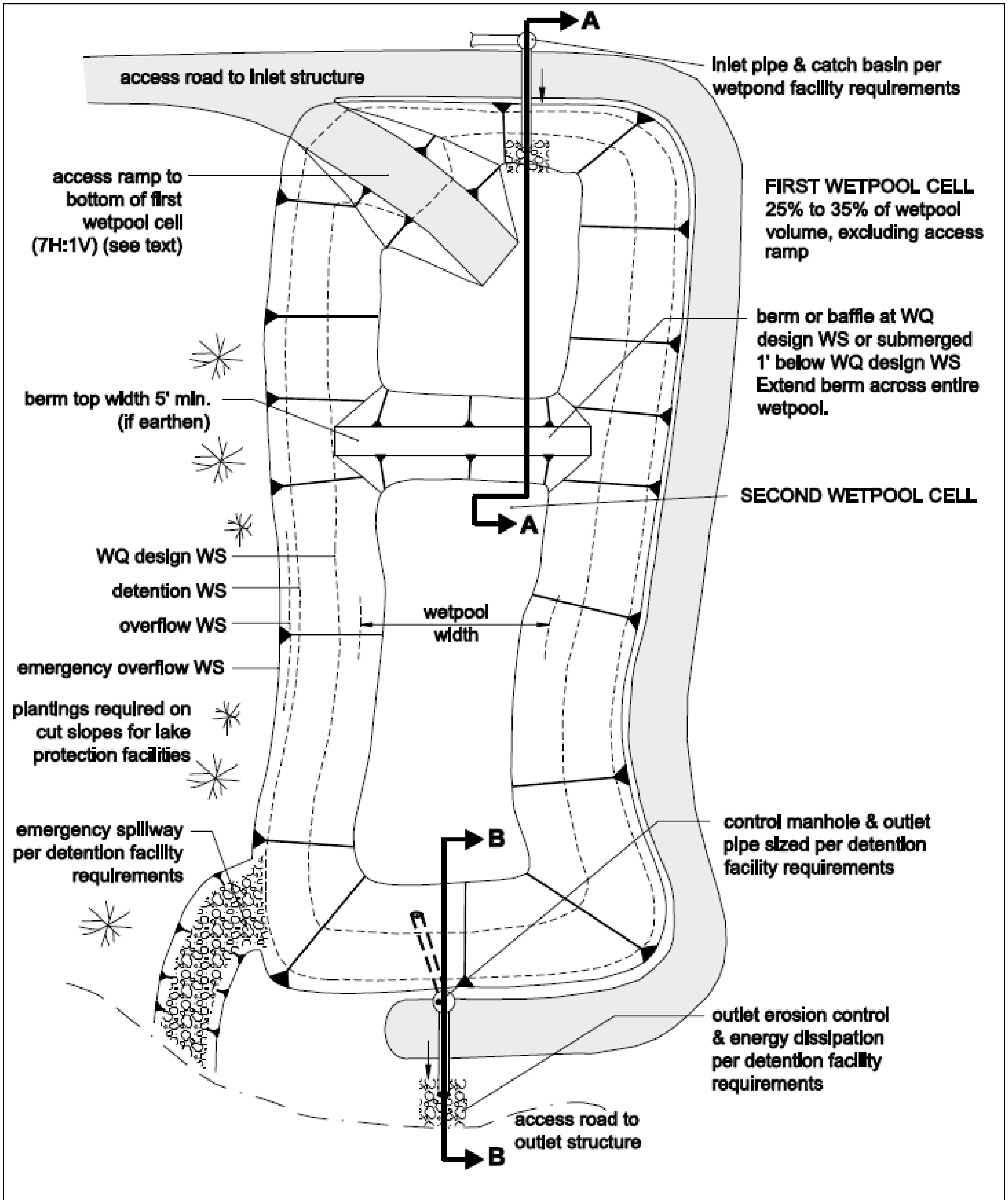
Live storage requirements are the same as for detention ponds (see BMP FC.01). This does not apply to the wet pond dead storage component.

Site Design Elements

General maintenance requirements and setback criteria are the same as for wet ponds (see BMP RT.08).

Planting Requirements

The criteria are the same as for wet ponds (see BMP RT.08).



PLAN VIEW
NTS

Figure 6-29: BMP RT.10 - Combined Detention and Wet Pond – Plan View

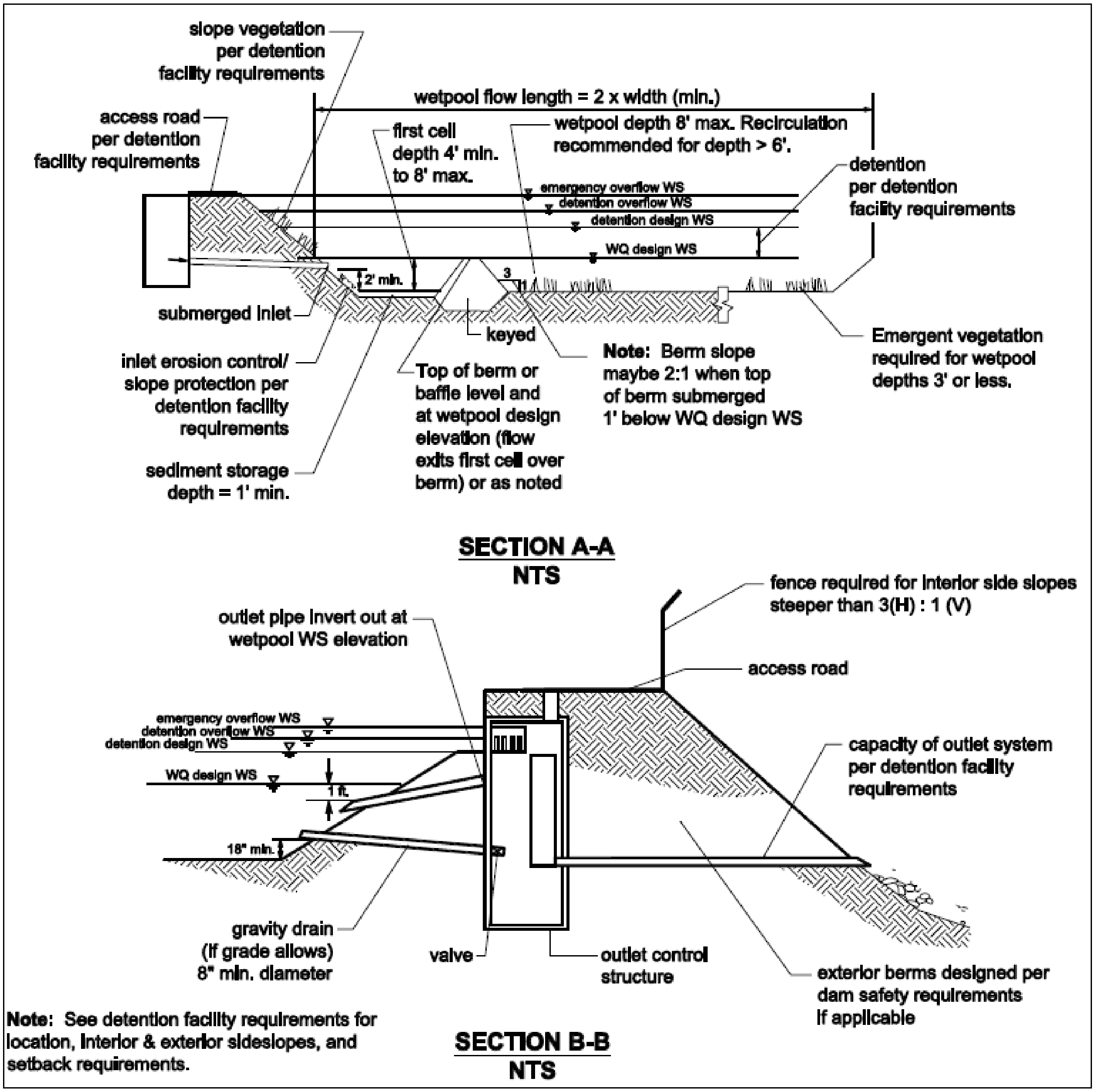


Figure 6-30: Combined Detention and Wet Pond – Cross Sections

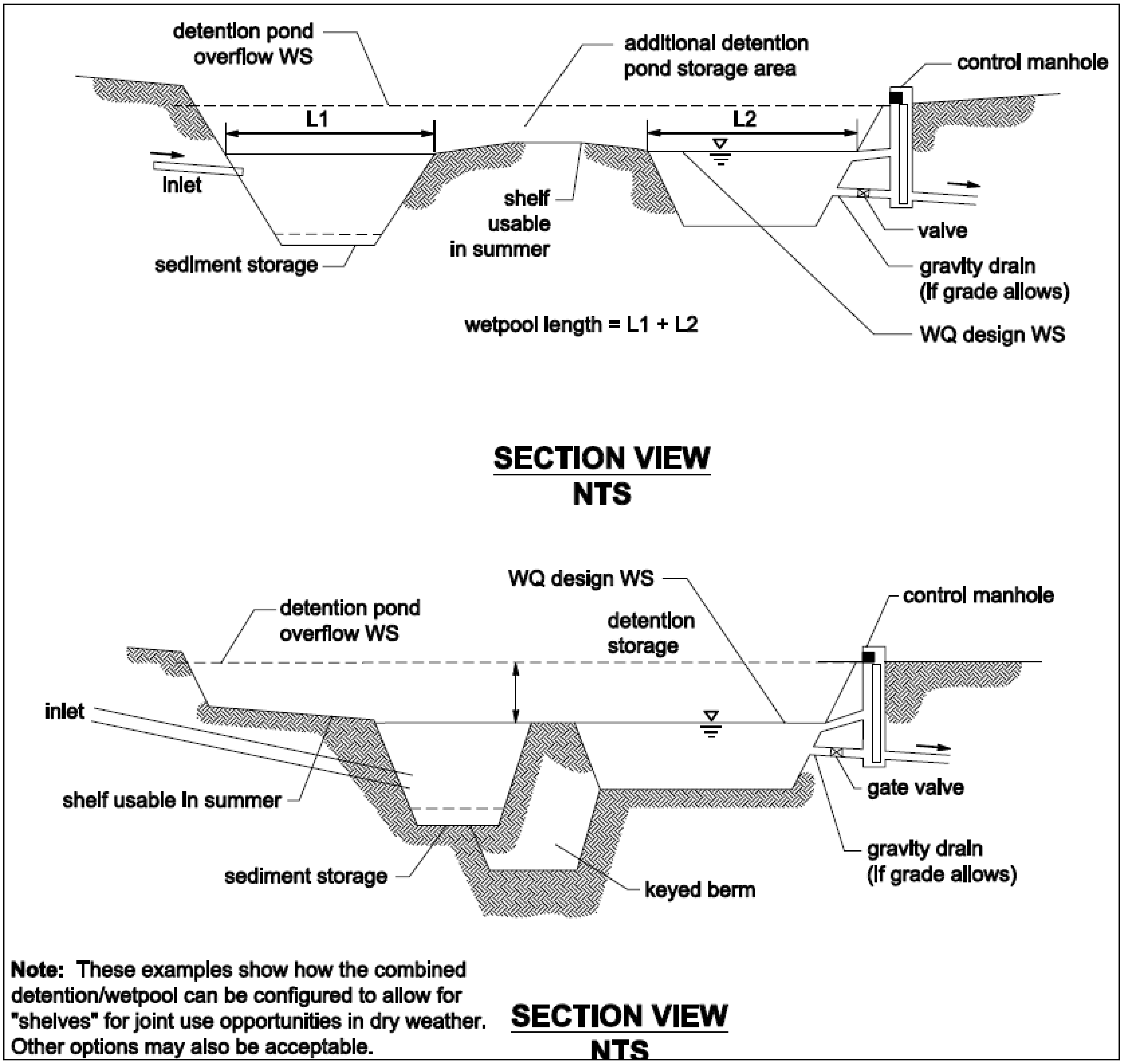


Figure 6-31: Alternative Configuration of Detention and Wet Pond

6.4.4.3 RT.09: CONSTRUCTED STORMWATER TREATMENT WETLAND

General Description

Stormwater treatment wetlands are shallow constructed wetlands designed to treat stormwater through settling, filtering, and the biological processes associated with emergent aquatic plants. Stormwater treatment wetlands, like wet ponds, are used to capture and transform pollutants. Over time, these pollutants concentrate in the sediment.

Instead of treating stormwater runoff, some wetlands are constructed to replace or mitigate impacts when natural wetlands are filled or impacted by development (mitigation wetlands). Natural wetlands and mitigation wetlands cannot be used to treat stormwater.

Applications and Limitations

As an enhanced treatment BMP, stormwater wetlands can be considered for roadways where metal removal is a concern. Stormwater wetlands occupy roughly the same surface area as wet ponds, but they have the potential to be better aesthetically integrated into a site because of the abundance of emergent aquatic vegetation. The most critical factor for a successful design is an adequate supply of water for most of the year. Careful planning is needed to ensure sufficient water is retained to sustain good wetland plant growth. Because water depths in stormwater wetlands are shallower than in wet ponds, water loss by evaporation is an important concern. Stormwater wetlands are a good runoff treatment facility choice in areas where groundwater levels are high in the wet season. It is recommended that all runoff treatment BMPs that use permanent wet pools use facility liners.

Design Flow Elements

Flows To Be Treated

Constructed stormwater treatment wetlands are designed for the stormwater quality treatment volume (Vol_{WQ}) described as part of Minimum Requirement 5 as defined in Chapter 3 of this TSDM.

Overflow or Bypass

The overflow criteria for single-purpose wetlands (treatment only, not combined with flow control) follow the same criteria for wet ponds (see BMP RT.08).

Emergency Overflow Spillway

An emergency spillway must be provided and designed according to the requirements for detention ponds (see BMP FC.01). In addition, a bypass or shutoff valve to enable the wetland to be taken off-line for maintenance purposes should be provided, if possible.

Bioengineered stabilization measures should be provided at the end of the outlet pipe and spillway to minimize the need for riprap and to increase aesthetics.

Structural Design Considerations

Geometry

Design Criteria

1. Stormwater wetlands must consist of two cells -- a pre-settling cell and a wetland cell.

2. The pre-settling cell must contain approximately 33 percent of the wet pool volume.
3. The depth of the pre-settling cell must be between 4 ft. (minimum) and 8 ft. (maximum), excluding sediment storage.
4. The pre-settling cell must provide 1 ft. of sediment storage.
5. The wetland cell must have an average water depth of approximately 1.5 ft. (plus or minus 3 in.).

Sizing Procedure

Step 1. Specify the depth of the pre-settling cell (D_{pc} ft.). See Criterion 3 in “Design Criteria,” listed above.

Step 2. Determine the volume of the pre-settling cell (V_{pc} ft.^{3}) by using Criterion 2 in “Design Criteria,” listed above.

Step 3. Determine the surface area of the pre-settling cell (A_{pc} ft.^{2}) of the stormwater wetland using the pre-settling cell volume and depth. $A_{pc} = V_{pc} / D_{pc}$.

Step 4. Calculate the surface area of the stormwater wetland. The surface area of the entire wetland (A_{total} ft.^{2}) must be the same as the top area of a wet pond sized for the same site conditions. The surface area of the entire stormwater wetland is the runoff treatment wet pool volume divided by the wet pool water depth (use 3 ft.).

$$A_{total} = V_{total} / 3 \text{ ft.}$$

Step 5. Determine the surface area of the wetland cell (A_{wc} ft.^{2}). Subtract the surface area of the pre-settling cell from the total wetland surface area.

$$(A_{total}).\ A_{wc} = A_{total} – A_{pc.}$$

Step 6. Determine water depth distributions in the wetland cell. Decide whether the top of the dividing berm is at the surface or submerged (designer's choice). Adjust the distribution of water depths in the wetland cell according to the surface area of the wetland cell (A_{wc}) and the discussion below. Note: This results in a facility that holds less volume than the runoff treatment volume; which is acceptable.

Intent: The surface area of the stormwater wetland is set to be roughly equivalent to that of a wet pond (with an average depth of the wetland cell of 1.5 ft.) designed for the same site so as not to discourage use of this option.

Two examples for grading the bottom of the wetland cell are shown in Figures 6-32 and 6-33. Option A is a shallow, evenly-graded slope from the upstream to the downstream edge of the wetland cell. The second example, Option B, is a naturalistic alternative with the specified range of depths intermixed throughout the second cell. A distribution of depths must be provided in the wetland cell depending on whether the dividing berm is at the water surface or submerged (see Table 6-8). The maximum depth is 2.5 ft. in either configuration.

Dividing Berm at Runoff Treatment Design Water Surface		**Dividing Berm Submerged 1 Foot**	
Depth Range (feet)	**Percent**	**Depth Range (feet)**	**Percent**
0.1 to 1	25	1 to 1.5	40
1 to 2	55	1.5 to 2	40
2 to 2.5	20	2 to 2.5	20

Table 6-8: Distribution of Depths in Wetland Cell

Inlet

The inlet to the pre-settling cell of the wetland must be submerged, with the inlet pipe invert a minimum of 2 ft. from the wetland bottom, not including sediment storage. The top of the inlet pipe should be submerged at least 1 ft., if possible. The designer should compute the HGL of the inlet pipe to verify whether backwater conditions are acceptable.

Intent: The inlet is submerged to dissipate the energy of the incoming flow. The distance from the bottom is set to minimize the re-suspension of settled sediments. Alternative inlet designs that accomplish these objectives are acceptable.

Outlet

An outlet structure must be provided. No sump is required in the outlet structure for wetlands not providing detention storage. The outlet structure receives flow from the wetland outlet pipe. The birdcage opening provides an overflow route should the wetland outlet pipe become clogged. The following overflow criteria specify the sizing and position of the grate opening:

- The wetland outlet pipe (from the wetland into the control structure) must be back-sloped or have a turn-down elbow and extend 1 ft. below the runoff treatment design water surface.

  Intent: The inverted outlet pipe traps oils and floatables in the wetland.

- At a minimum, the wetland outlet pipe must be sized to pass the runoff treatment design flow for off-line wetlands. For on-line wetlands, the outlet pipe must be able to pass the maximum possible inlet conveyance flow. Note: The highest invert of the outlet pipe sets the runoff treatment design water surface elevation.

- Alternative methods to dissipate energy at the end of the outlet pipe, such as a dissipater tee, should be considered to reduce the need for extensive riprap.

Berms, Baffles, and Slopes

The berm separating the two cells must be shaped so that its downstream side gradually slopes to form the second shallow wetland cell (see the section view in Figure 6-31). Alternately, the second cell may be graded naturalistically from the top of the dividing berm (see “Sizing Procedure,” Step 6, above).

The top of the berm must be either at the runoff treatment design water surface or submerged 1 ft. below this surface, as for wet ponds.

Correspondingly, the side slopes of the berm must meet the following criteria:

- If the top of the berm is at the runoff treatment design water surface, then for safety reasons, the berm should not be greater than 3H:1V, just as the wetland banks should not be greater than 3H:1V if the wetland is not fenced.
- If the top of the berm is submerged 1 ft., the upstream side slope may be up to 2H:1V. If submerged, the berm is not considered accessible, and the steeper slope is allowable.

Liners

If soil permeability allows for sufficient water retention, lining is not necessary. In infiltrative soils, both cells of the stormwater wetland must be lined with an impermeable membrane.

Site Design Elements

Setback Requirements

Stormwater treatment wetlands must be a minimum of 5 ft. from any property line or vegetative buffer.

Unlined stormwater treatment wetlands must be 100 ft. from any septic tank or drain field. Lined wetlands must be a minimum of 20 ft.

The designer should request a geotechnical report for the project that evaluates any potential structural site instability due to extended sub-grade saturation and/or head-loading of the permeable layer. This includes the potential impacts to down-gradient properties, especially on hills with known side-hill seeps. The report should address the adequacy of the proposed stormwater treatment wetland locations and recommend the necessary setbacks from any steep slopes and building foundations.

Landscaping (Planting Considerations)

When used for stormwater treatment, stormwater wetlands incorporate some of the same design features as wet ponds. However, instead of gravity settling being the dominant treatment process, pollutant removal mediated by aquatic vegetation (and the microbiological community associated with that vegetation) becomes the dominant treatment process. Thus, water volume is not the dominant design criterion for stormwater wetlands; rather, factors that affect plant vigor and biomass are the primary concerns. It is critical to involve a Wetland Scientist, Biologist, or Landscape Architect throughout the design process.

The wetland cells must be planted with emergent wetland plants following those of a Wetland Specialist, Biologist, or Landscape Architect.

Soil Amendments and Protection

The method of construction for soil/landscape systems can affect the natural selection of specific plant species. Consult a wetland specialist for site-specific soil amendment recommendations. The formulation should encourage desired species and discourage undesired species. Soils should be stabilized with permanent or temporary cover to prevent washout due to storm flows.

Soil Preparation

The incorrect control of soil moisture is the most frequent cause of failure to establish wetland plants. Inadequate water results in the desiccation of roots. Too much water results in oxygen depletion in the root zone; submergence and drowning or flotation of plants; and/or slow growth or plant death.

To maintain adequate soil moisture during plant establishment, a reliable and adequate supply of water for site irrigation is needed. When feasible, a water source for plant establishment is usually the stormwater treated in the wetland. However, if stormwater is not available, another irrigation source must be identified to maximize planting success. Adequate pumps, piping, and sprinklers or hoses must be provided to allow even flow distribution.

The recommended sequence for maintaining soil moisture for wetland planting starts with the initial saturation of soil by sprinkling or flood irrigation. For optimal plant growth, the soil should be fully or partially saturated with water immediately before planting and should not be allowed to completely dry out any time after planting. High soil moisture must be maintained after planting for the first few weeks without creating flooded conditions for more than a few hours. The best method of maintaining soil saturation without excessive flooding is to start planting at the down-gradient end of the wetland and continue planting up-gradient, while gradually raising water levels using the wetland outlet water level controls or gravity drain, if possible. When planting is complete, water levels can be dropped or raised as needed to maintain saturated soil conditions. Sprinklers can also be used to irrigate evenly over planted areas.

After an entire cell is planted, the water should be maintained at a level that ensures all areas of the cell continue to have saturated soil conditions between waterings. This can be achieved by flood-irrigating the entire cell with enough water to allow infiltration or evapotranspiration to eliminate the applied surface water within one or two days, or distributing water through the inlet distribution structures or down the embankment side slopes and allowing this water to re-saturate the wetland soils as it sheet flows across the wetland to the outlet. Weirs or outlet water control gates should be removed or left open during plant establishment to prevent flooding if rainfall is high or if a sprinkler or irrigator is accidentally left running. At no time should flood irrigation result in complete submergence of above-ground portions of installed plants. Permits may be required to use water from nearby natural aquatic water bodies for temporary irrigation purposes.

As the wetland plants grow, they have an increased ability to transport oxygen to the root zone from their leaves. Thus the plants are able to withstand longer periods of flooding. However, the best technique for establishing rapid plant cover is to maintain saturated soil conditions without surface flooding. The higher soil oxygen condition resulting from the absence of floodwaters allows maximum root metabolism, effective nutrient use, and rapid development of the plants within the wetland. This soil condition should, optimally, be maintained until plants achieve complete cover (100 percent) or at least the minimum cover required for system startup (about 60 percent to 80 percent).

Design and construction should allow the design water surface to be temporarily modified to enable plant installation and establishment before the system is brought on line. Strategies may be available depending on the project situation, schedule, and site conditions.

- If the system must go on-line the same year it is constructed, plant the constructed wetland cell early in the dry season and irrigate to maintain saturated soils without plant submergence or flotation, until plants are sufficiently developed to operate the system at the start of the wet season.
- If the system can remain off-line during the wet season, plant the constructed wetland cell at the start of the wet season and monitor water conditions, maintaining saturated soils without plant submergence or flotation by irrigating or draining as necessary, until plants are sufficiently developed to allow operation of the system the following year.

Several methods could be used to temporarily control water levels during plant establishment, depending on project conditions.

- Build the treatment wetland before the project is started, so that wetland plants are established before flows are introduced
- Keep the treatment wetland off-line until wetland plants become established by bypassing the treatment wetland
- Temporarily operate the drain of the treatment wetland as the outlet to maintain water surface elevations below the design water surface level

- Plant during the dry season when water surface elevations are naturally lower
- Pump out water to lower the wetland cell for planting and establishment

A wetland treatment system can typically begin operation when plant cover is at least 60 percent to 80 percent, which may require at least three to four months of active growth. If this coverage is achieved during the first growing season after planting, the wetland system can begin operating during the ensuing wet season.

Planting

Seed embankment areas above the runoff treatment design water surface and below the emergency overflow water level. Areas with permanent pools that are protected from erosion do not need to be seeded.

Consider planting trees along the west and south sides of wetlands to reduce thermal heating, except that no trees or shrubs may be planted on berms meeting the criteria of dams regulated for safety. Trees should be set back so that the branches will not extend over the wetland.

Include trees and shrubs on slopes and on top of banks to increase aesthetics. If the treatment wetland discharges to a phosphorus-sensitive lake or natural wetland, shrubs that form a dense cover should be planted on slopes above the runoff treatment design water surface on at least three sides. For banks that are berms, no planting is allowed if the berm is regulated by dam safety requirements. The purpose of planting is to provide shading.

General Maintenance Requirements

A drain in the wetland cell (or cells) may also be necessary to avoid surface flooding during wetland plant installation and establishment.

Recommended Design Features

Where possible, the following design features should be incorporated to enhance aesthetics:

- Provide maintenance access to shallow pool areas enhanced with emergent wetland vegetation. This allows the wetland to be accessible for vegetation maintenance without incurring safety risks.
- Provide side slopes that are sufficiently gentle to avoid the need for fencing (3H:1V or flatter). Ponds with submerged slopes steeper than 3H:1V must be fenced.
- Provide visual enhancement with clusters of trees and shrubs. On most wetland sites, it is important to amend the soil before planting because wetlands are typically placed well below the native soil horizon in very poor soils. Make sure that dam safety restrictions against planting do not apply.

- Consider extending the access and maintenance road along the full length of the treatment wetland. The maintenance road should have a permeable surface.
- Where right-of-way allows, orient the wetland length along the direction of prevailing winds to enhance wind mixing.

Construction

Construction and maintenance considerations are the same as those for wet ponds (see BMP RT.08).

The naturalistic grading alternative (see Figure 6-33) can be constructed by first excavating the entire area to the 1.5-foot average depth. Soil subsequently excavated to form deeper areas can then be deposited to raise other areas until the distribution of design depths is achieved.

Ideally, a period of approximately one year is desirable to establish plants before the system goes on-line.

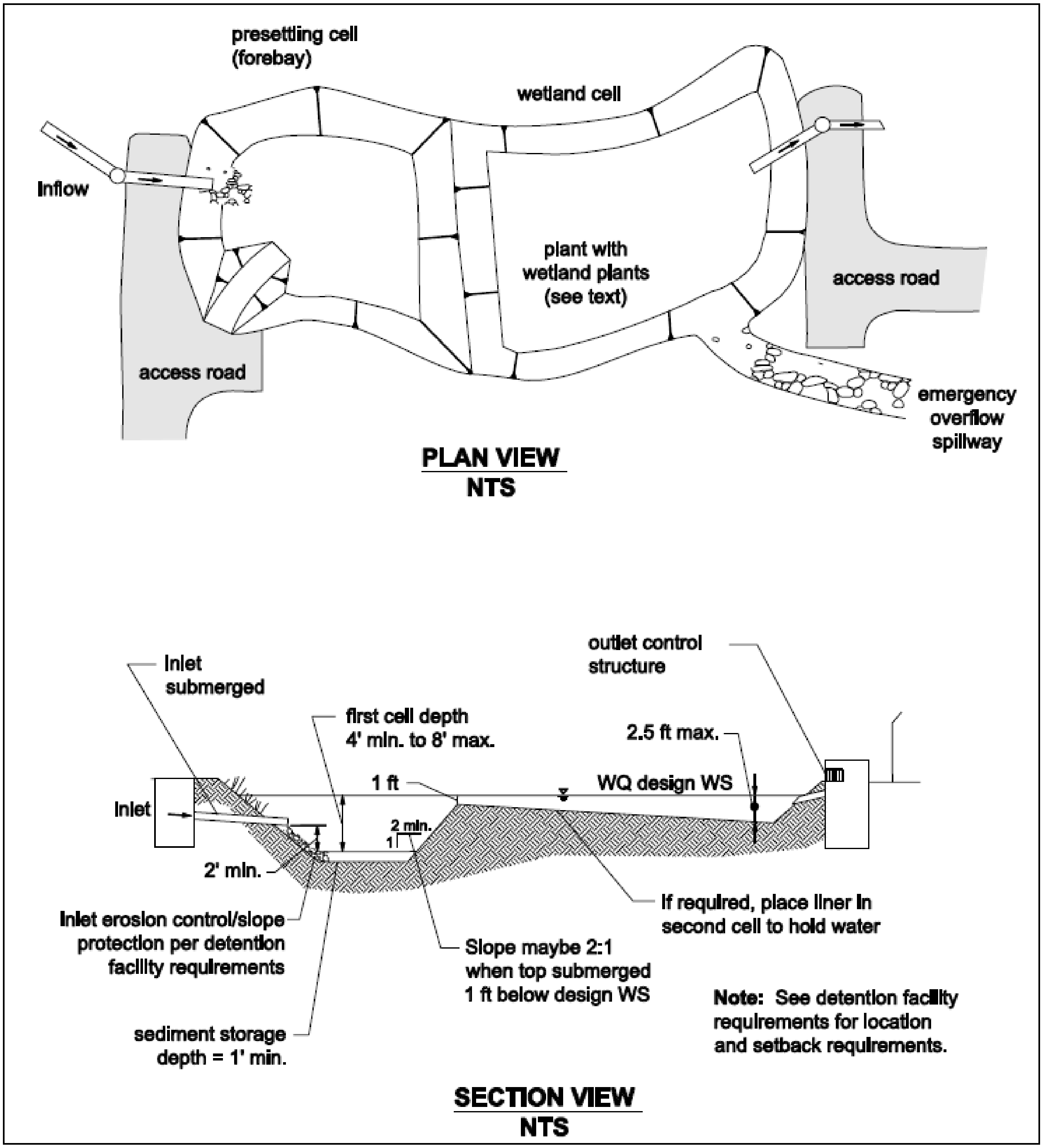


Figure 6-32: BMP RT.09 - Constructed Wetland, Option A

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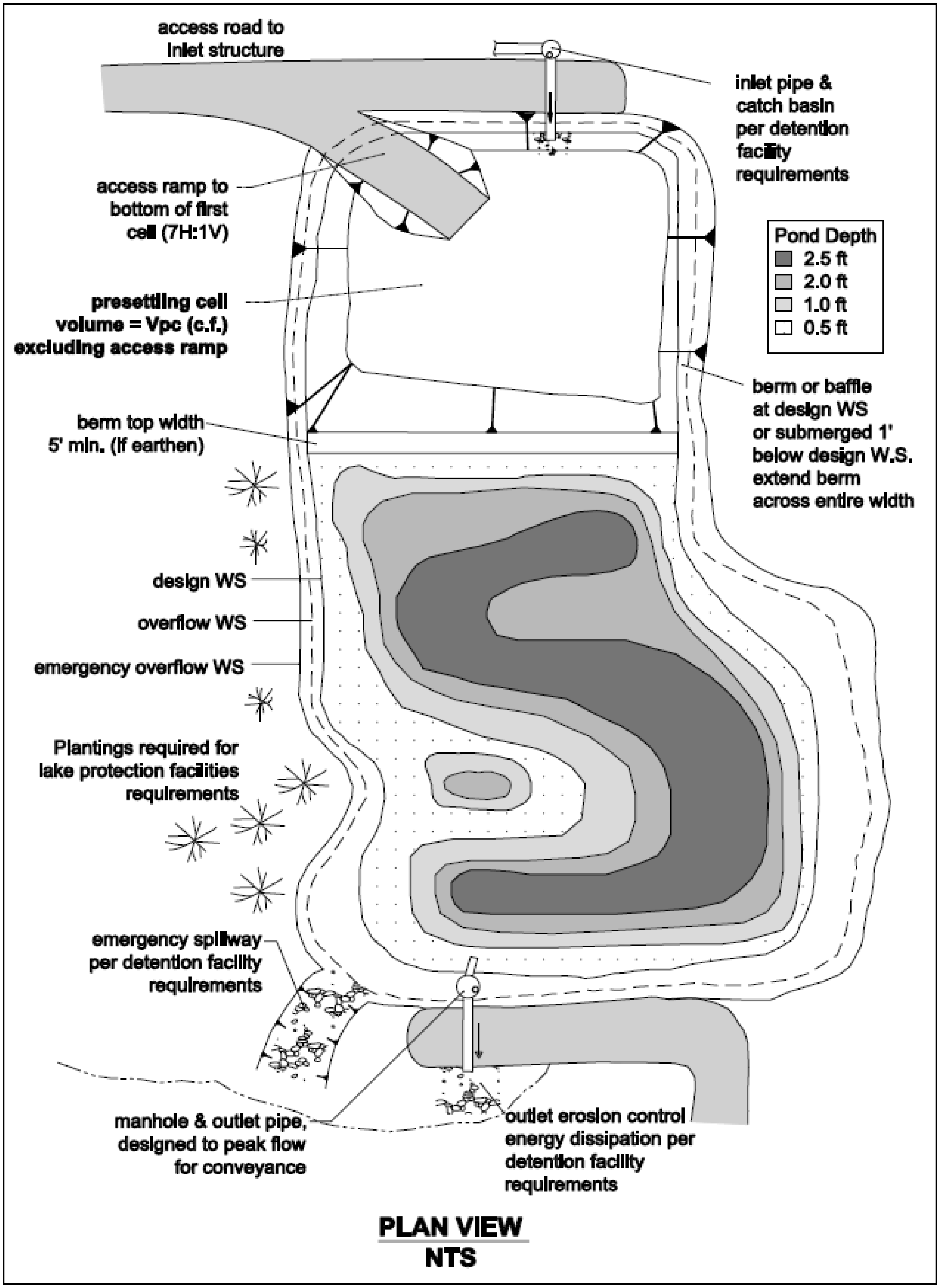


2 **Figure 6-33: BMP RT.09 - Constructed Wetland, Option B**

6.4.4.4 RT.11: COMBINED STORMWATER TREATMENT WETLAND/DETENTION POND

General Description

The combined stormwater treatment wetland/detention pond is best described as a wetland system that provides for the extended detention of runoff during and following storm events. This BMP is useful in areas with limited right-of-way, where separate runoff treatment and flow control facilities are not feasible. It is recommended that all BMPs that use permanent wet pools also use facility liners.

Design Flow Elements

Flows To Be Treated

The sizing procedure for the combined stormwater treatment wetland and detention pond is identical to that outlined for stormwater wetlands (see BMP RT.09) and for combined wet/detention ponds (see BMP RT.10). Follow the procedures outlined in those sections to determine the stormwater wetland size.

Structural Design Considerations

Geometry

The design criteria for detention ponds (see BMP FC.01) and constructed stormwater treatment wetlands (see BMP RT.09) must both be met, except for the following modification:

- The minimum sediment storage depth in the first cell is 1 ft. The 6 in. of sediment storage required for detention ponds and the 6 in. of sediment storage in the second cell of detention ponds does not need to be added to this.

  Intent: Because emergent plants are limited to shallower water depths, the deeper water created before sediments accumulate is considered detrimental to robust emergent growth. Therefore, sediment storage is confined to the first cell, which functions as a pre-settling cell.

The inlet and outlet criteria for constructed stormwater treatment wetlands (see BMP RT.09) apply, with the following modifications:

- A sump must be provided in the outlet control structure of combined facilities.
- The detention flow restrictor and its outlet pipe must be designed according to the requirements for detention ponds (see BMP FC.01).

Groundwater Issues

Live storage requirements are the same as the requirements for detention ponds (see BMP FC.01). This does not apply to the dead storage component of the constructed stormwater treatment wetlands. The maximum live storage depth over the permanent pool water surface should not exceed 3 ft.

Landscaping (Planting)

Check with a Wetlands Scientist; although usually, landscaping requirements for constructed stormwater treatment wetlands should suffice.

6.5 FLOW CONTROL BMPs

Flow control BMPs include the following:

FC.01 – Detention Pond

General Description

Flow control or detention ponds are open basins that provide live storage volume to enable the reduction of stormwater runoff flow rates discharged from a project site (see Figure 6-34). Detention ponds are commonly used for flow control in locations where space is available for an above-ground stormwater facility, but where infiltration of runoff is not feasible. Detention ponds are designed to drain within 72 hours after a storm event, so that the live storage volume is available for the next event.

Detention pond requirements discussed in this TSDM generally relate to ponds having impoundment volumes less than 10 ac-ft. Larger ponds will usually require more stringent geotechnical, hydraulic, and safety designs meeting federal dam guidelines. Larger pond designs should be pre-approved by DPW.

Applications and Limitations

Runoff infiltration is the preferred method of flow control following appropriate runoff treatment. However, in areas where infiltration is not feasible, runoff detention should be implemented.

Detention ponds can be combined with wet pool stormwater quality treatment BMPs to make more effective use of available land area (see BMP RT.10, Combined Wet/Detention Pond, and BMP RT.11, Combined Stormwater Treatment Wetland/Detention Pond).

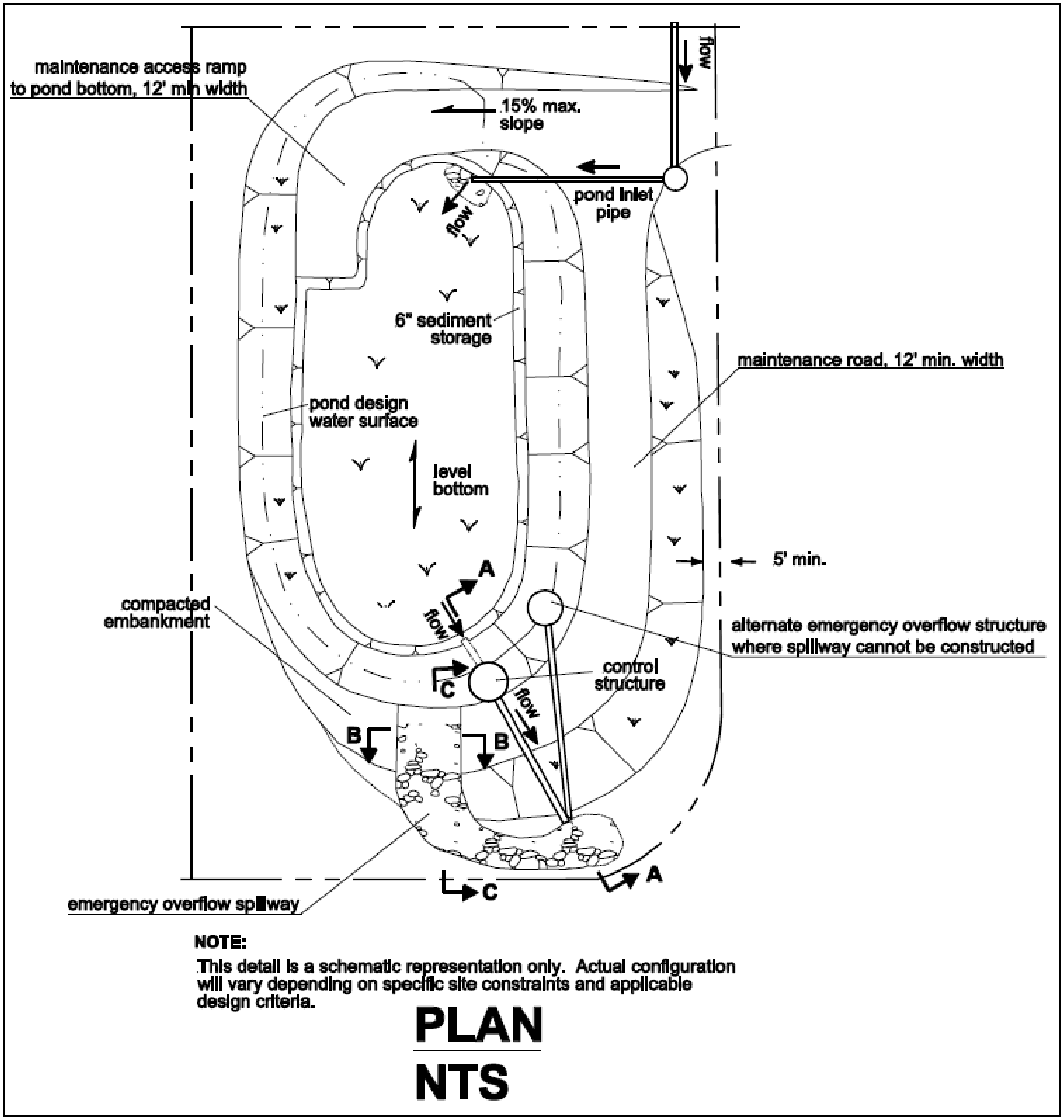
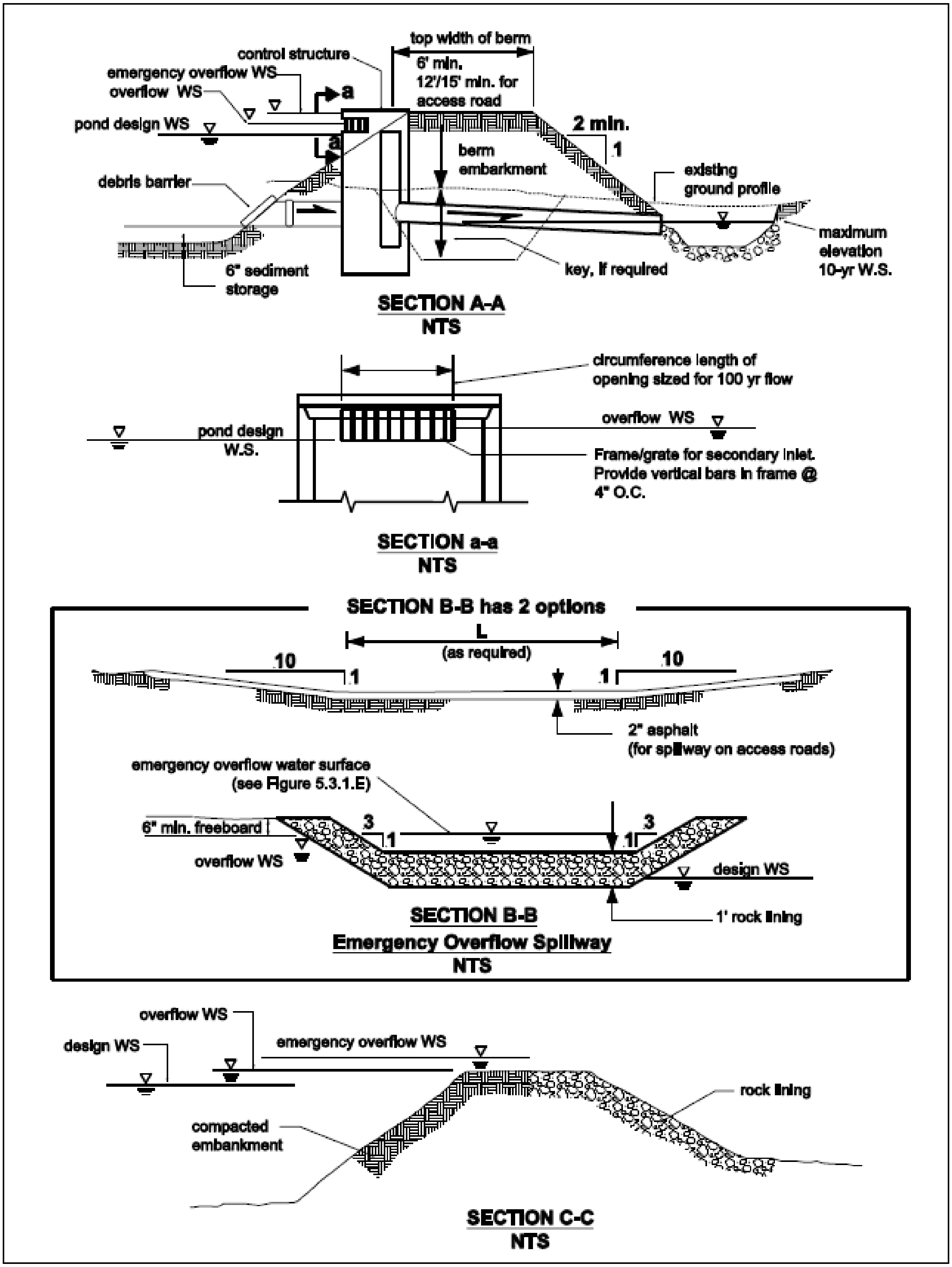


Figure 6-34: BMP FC.01 - Detention Pond



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2 **Figure 6-35: Detention Pond – Cross Sections**

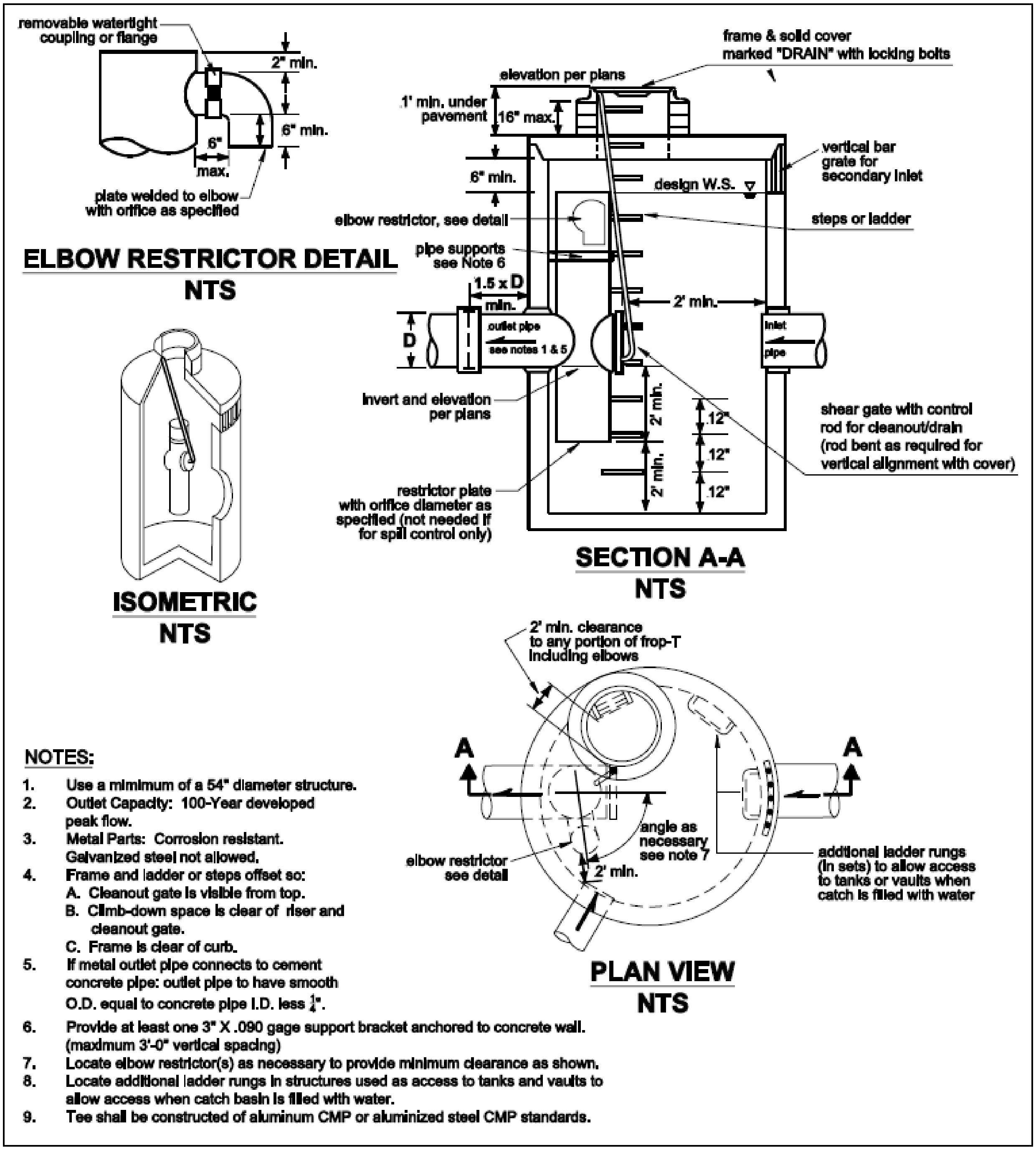


Figure 6-36: Outlet Control Structure, Option A

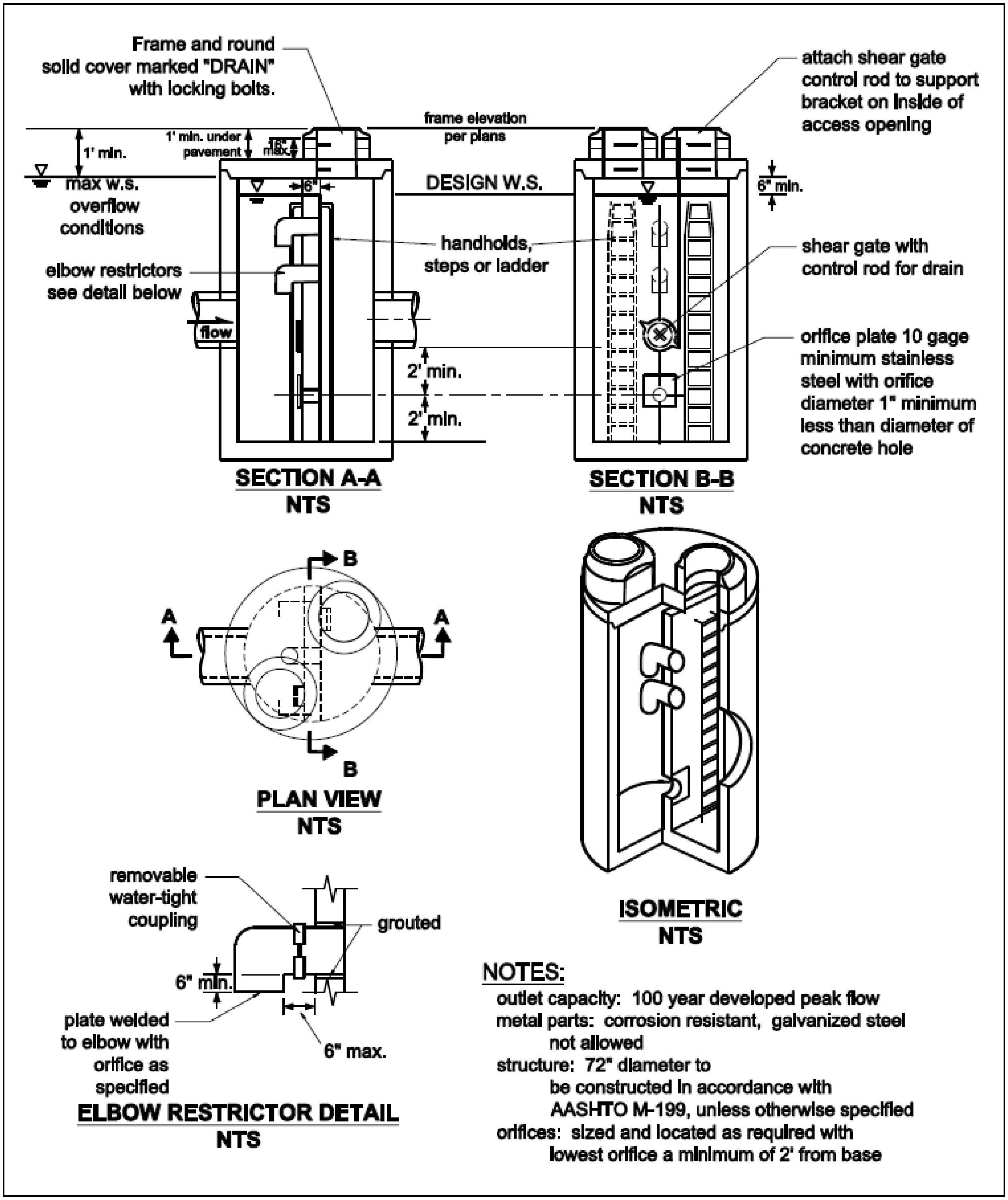
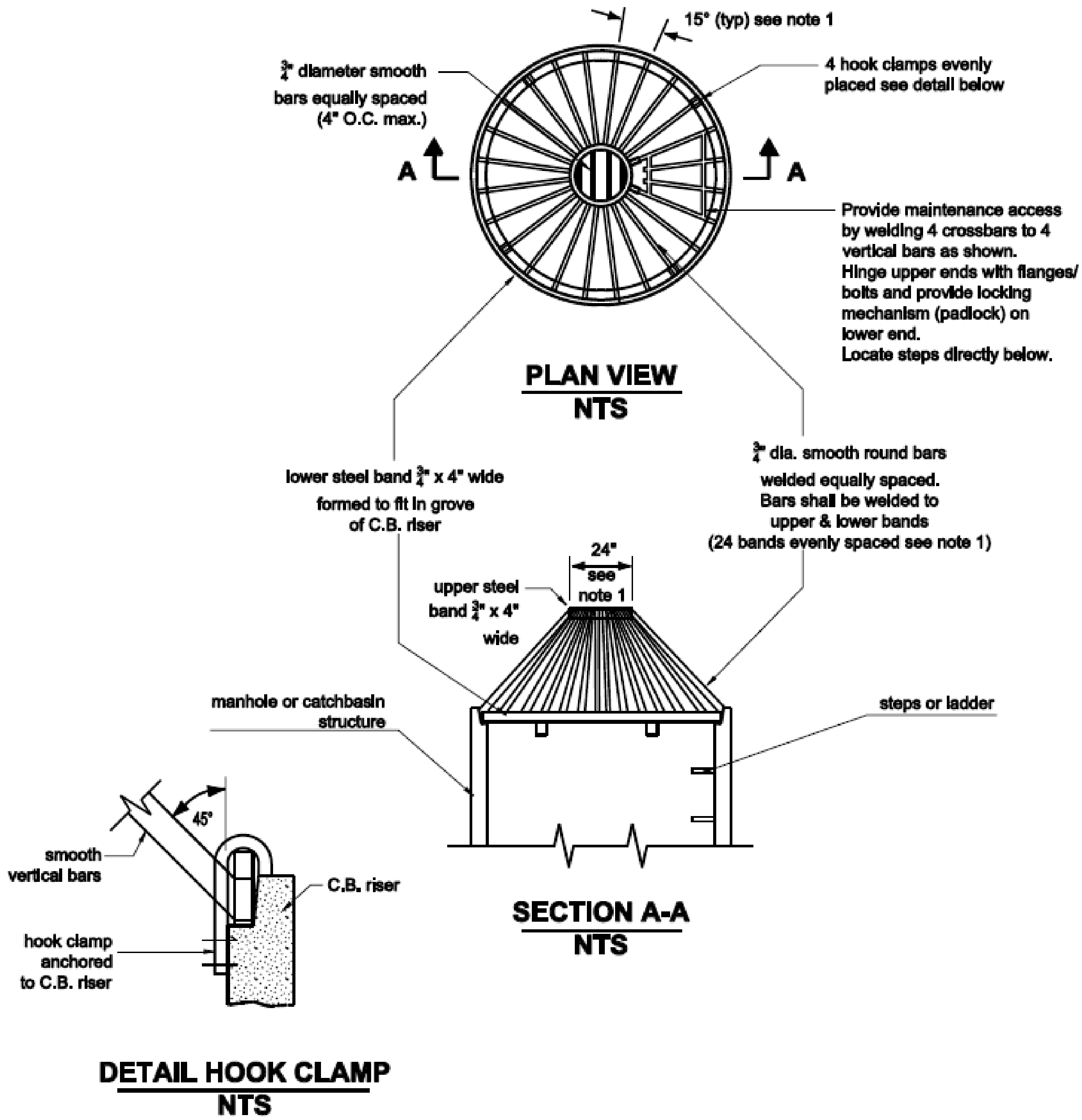


Figure 6-37: Outlet Control Structure, Option B



NOTES:

1. Dimensions are for illustration on 54" diameter CB. For different diameter CB's adjust to maintain 45° angle on "vertical" bars and 7" o.c. maximum spacing of bars around lower steel band.
2. Metal parts must be corrosion resistant; Do not use galvanized steel.
3. This debris barrier is also recommended for use on the inlet to roadway cross-culverts with high potential for debris collection.

Figure 6-38: Alternate Overflow Structure and Trash Rack (Birdcage)

Design Flow Elements

Flows To Be Detained

The volume and outflow design for detention ponds with a minimum 1-ft. freeboard above the design water surface elevation must be determined in accordance with the flow control criteria presented as part of Minimum Requirement 6 as defined in Chapter 3 of this TSDM. The design water surface elevation is the highest water surface elevation that is projected in order to satisfy the flow control requirements. Note: If the inlet pipe is submerged below the design water surface elevation, the designer should then compute the HGL of the inlet pipe to verify that backwater conditions are acceptable.

Detention Ponds in Infiltrative Soils

Detention ponds may occasionally be sited on soils that are sufficiently permeable for a properly-functioning infiltration system. These detention ponds have both a surface discharge and a sub-surface discharge. If infiltration is accounted for in the detention pond sizing calculations, the pond design process and corresponding site conditions must meet all of the requirements for infiltration ponds (see BMP IN.02), including a soils report, soil infiltration testing, groundwater monitoring, pre-settling, and construction techniques.

Overflow or Bypass

A primary overflow (usually a riser pipe within the outlet control structure) must be provided for the detention pond system to bypass the 100-year, post-developed peak flow over or around the flow restrictor system. Overflow can occur when the facility is full of water due to plugging of the outlet control structure or high inflows; the primary overflow is intended to protect against breaching of the pond embankment (or overflows of the upstream conveyance system). The design must provide controlled discharge of pond overflows directly into the downstream conveyance system or another acceptable discharge point.

A secondary inlet to the pond discharge control structure should be provided as additional protection against overflows due to plugging of the primary inlet pipe to the control structure. One option for the secondary inlet is a grated opening, called a jailhouse window, (see Section a-a, Figure 6-35) in the control structure that functions as a weir when used as a secondary inlet. The maximum circumferential length of a jailhouse window weir opening must not exceed one-half the control structure circumference.

Another common option for a secondary inlet is to allow flow to spill over the top of the discharge control structure or another structure linked to the discharge control structure that is fitted with a debris cage, called a birdcage (see Figure 6-38).

Outlet Control Structure

Control structures are catch basins or manholes with a restrictor device for controlling outflow from a facility to meet the desired performance. Riser-type restrictor devices also provide some incidental oil/water separation to temporarily detain oil or other floatable pollutants in runoff due to accidental spill or illegal dumping.

The restrictor device usually consists of two or more orifices or an orifice/weir section sized to meet performance requirements.

Discharge from the outlet pipe back to the existing or natural waterway should have positive erosion protection, and if necessary, an energy dissipater structure. See Section 6.6.4 for a discussion on outfalls.

Multiple Orifice Restrictor

In most cases, control structures need only two orifices -- one at the bottom and one near the top of the riser, although additional orifices may optimize the detention storage volume. Several orifices may be located at the same elevation if necessary to meet performance requirements.

The minimum circular orifice diameter is 0.5 in. and the minimum vertical rectangular orifice length is 0.25 in. Orifices may be constructed on a tee section.

In some cases, performance requirements may require the top orifice or elbow to be located too high on the riser to be physically constructed (e.g., a 13-in. diameter orifice cannot be positioned 6 in. from the top of the riser). In these cases, a notch weir in the riser pipe may be used to meet performance requirements.

Consideration must be given to the backwater effect of water surface elevations in the downstream conveyance system. High tailwater elevations may affect performance of the restrictor system and reduce live storage volumes.

Riser and Weir Restrictor

Properly-designed weirs may be used as flow restrictors; however, they must be designed to provide for primary overflow of the developed 100-year peak flow discharging to the detention facility.

The combined orifice and riser (or weir) overflow may be used to meet performance requirements; however, the design must still provide for primary overflow of the developed 100-year peak flow, assuming all orifices are plugged.

Emergency Overflow Spillway

In addition to the overflow provisions described above, detention ponds must have an emergency overflow spillway that is sized to pass the 100-year, post-developed, un-detained peak flow in the event of total control structure failure, such as blockage of the control structure outlet pipe, or extreme inflows. Emergency overflow spillways are intended to control the location where flows overtop the pond perimeter and direct overflows into the downstream conveyance system or other acceptable discharge point. The bottom of the emergency overflow spillway must be set at the design frequency water surface elevation.

As an option, emergency overflow may be provided by a manhole fitted with a birdcage, as shown in Figure 6-38. Where an emergency overflow spillway would discharge to a steep slope, consideration should be given to providing an emergency overflow structure in addition to the spillway.

The emergency overflow spillway must be armored with riprap that is sized in conformance with the guidelines in Chapter 4 of FHWA publication HEC-11. The spillway must be armored across its full width and also must be armored down the embankment, as shown in Figure 6-35.

Emergency overflow spillway designs as shown in Figure 6-35 must be analyzed as broad-crested trapezoidal weirs. The minimum bottom width of the weir should be 6 ft.

Emergency overflow spillway designs using a manhole fitted with a birdcage, as shown in Figure 6-38, should be analyzed as a sharp-crested weir with no end contractions to pass the 100-year, post-developed, un-detained peak flow.

Structural Design Considerations

Geometry

Pond inflows must enter through a conveyance system separate from the outlet control structure and outflow conveyance system. Maximizing the distance between the inlet and outlet is encouraged to promote sediment trapping.

Pond bottoms must be level and a minimum of 0.5 ft. below the outlet invert elevation to provide sediment storage.

Berms, Baffles, and Slopes

Interior side slopes up to the emergency overflow water surface should not be steeper than 3H:1V, unless a fence is provided (see “Fencing”, below).

Exterior side slopes must not be steeper than 2H:1V, unless they are analyzed for stability by a Geotechnical Engineer.

Pond walls may be vertical retaining walls subject to the following:

- Cast-in-place wall sections must be designed as retaining walls. A Licensed Civil Engineer with structural expertise must stamp structural designs for cast-in-place walls. All construction joints must be provided with water stops.

- Gravity type block walls (rockery or ecology block types) may be used to no more than 9 ft. vertical height. These gravity walls must be backfilled with a free-draining, structural backfill using either well-graded aggregate or a geotextile to act as a filter layer to protect soil fines from migrating through the block openings.
- Walls must be placed on stable, well-consolidated native material with suitable bedding. Walls must not be placed in fill slopes unless the slopes have been analyzed in a geotechnical report for stability and constructability.
- A fence is provided along the top of the wall.
- Although the entire pond perimeter may be retaining walls, it is recommended that at least 25 percent of the pond perimeter be a vegetated soil slope not steeper than 3H:1V.
- If the entire pond perimeter is to be retaining walls, ladders should be provided on the full height of the walls for safe access by maintenance staff.

Embankments

The minimum top width of berm embankments should be 5 ft. or as recommended by a Geotechnical Engineer. If used for maintenance access, the berm tops should be a minimum of 12 ft. wide.

Pond berm embankments are usually constructed on native consolidated soil (or adequately compacted and stable fill soils analyzed by a Geotechnical Engineer), and free of loose surface soil materials, roots, and other organic debris.

Pond berm embankments greater than 4 ft. high must be constructed by excavating a key trench equal to 50 percent of the berm embankment's cross-sectional height and width, unless otherwise specified by a Geotechnical Engineer.

Anti-seepage filter-drain diaphragms (pipe collars) must be placed on outflow pipes in berm embankments impounding water with depths greater than 8 ft. at the design water surface. The size of the pipe collars should be such to extend the seepage flow path at least 1.5 times the length of the buried pipe section.

Groundwater Issues

Identification and Avoidance

Flow control BMPs must be constructed above the seasonal high groundwater table. Storage capacity and proper flow attenuation are compromised if groundwater levels exceed the live storage elevations. The project should locate the pond so that there is a separation between the local groundwater table elevation and the bottom of the proposed BMP. In some cases, this may require that a much shallower pond be constructed in order to function properly.

The groundwater table elevation in and around the flow control facility needs to be determined early in the project. This can be done by installing piezometers at the BMP location and taking water table readings over at least one wet season.

Designers should look for opportunities to provide flow control to an equivalent area in the project that discharges to the same watershed.

Site Design Elements

Setback Requirements

Detention ponds must be a minimum of 5 ft. from any property line or vegetative buffer. This distance may need to be increased based on the permit requirements of the local jurisdiction.

Detention ponds must be 100 ft. from any septic tank or drain field.

The designer should request a geotechnical report for the project that evaluates any potential structural site instability due to extended sub-grade saturation or head loading of the permeable layer, including the potential impacts to down-gradient properties, especially on hills with known side-hill seeps. The report should address the adequacy of the proposed detention pond locations and recommend the minimum excavation and fill slopes, plus necessary setbacks from any steep slopes and building foundations.

Landscaping (Planting Considerations)

Earthen ponds should be vegetated with a good erosion control grass seed mix that is tolerant of being submerged for short periods of time. All disturbed soil surfaces should be covered with topsoil or mulch amended and seeded with an erosion control grass mix as recommended by NRCS or DAWR for the site and climate conditions.

Fencing

Ponds having submerged slopes steeper than 3H:1V must be fenced to restrict public access.

6.6 STORMWATER FACILITY COMPONENTS

6.6.1 PRE-SETTLING/SEDIMENTATION BASIN

General Description

A pre-settling basin provides pre-treatment of runoff to remove suspended solids that can impact other primary runoff treatment BMPs (see Figures 6-39 and 6-40).

Applications and Limitations

The most attractive aspect of a pre-settling basin is its isolation from the rest of the facility. Pre-settling basins allow sediment to fall out of suspension. However, they do not detain water long enough for the removal of most pollutants (such as some metals). Pre-settling basins are frequently used as pre-treatment for downstream infiltration facilities and to protect more sensitive facilities, such as constructed stormwater treatment wetlands, from excessive sediment loads. Runoff treated by a pre-settling basin may not be discharged directly to a receiving water body; it must be further treated by a stormwater quality treatment BMP.

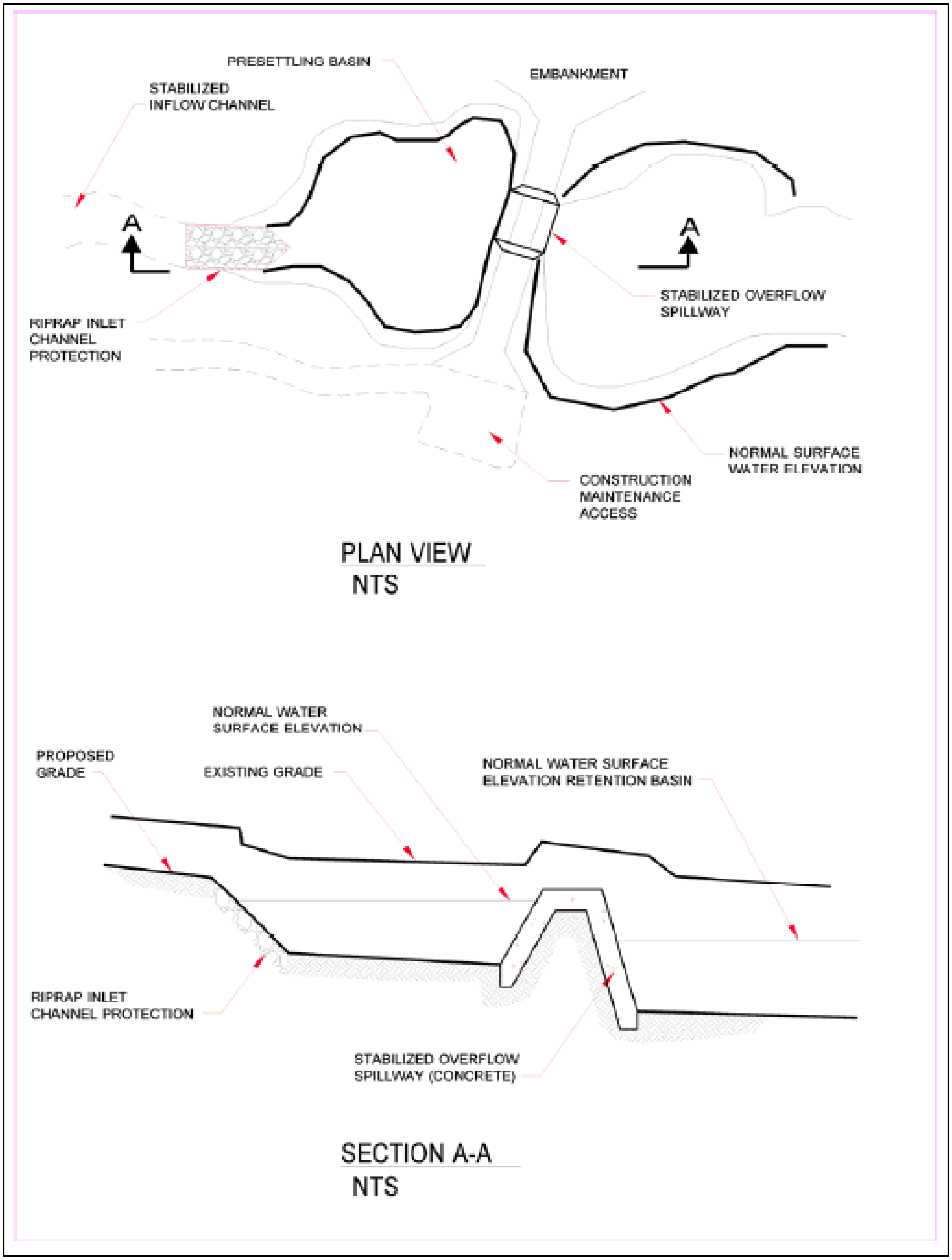


Figure 6-39: Typical Pre-settling/Sedimentation Basin

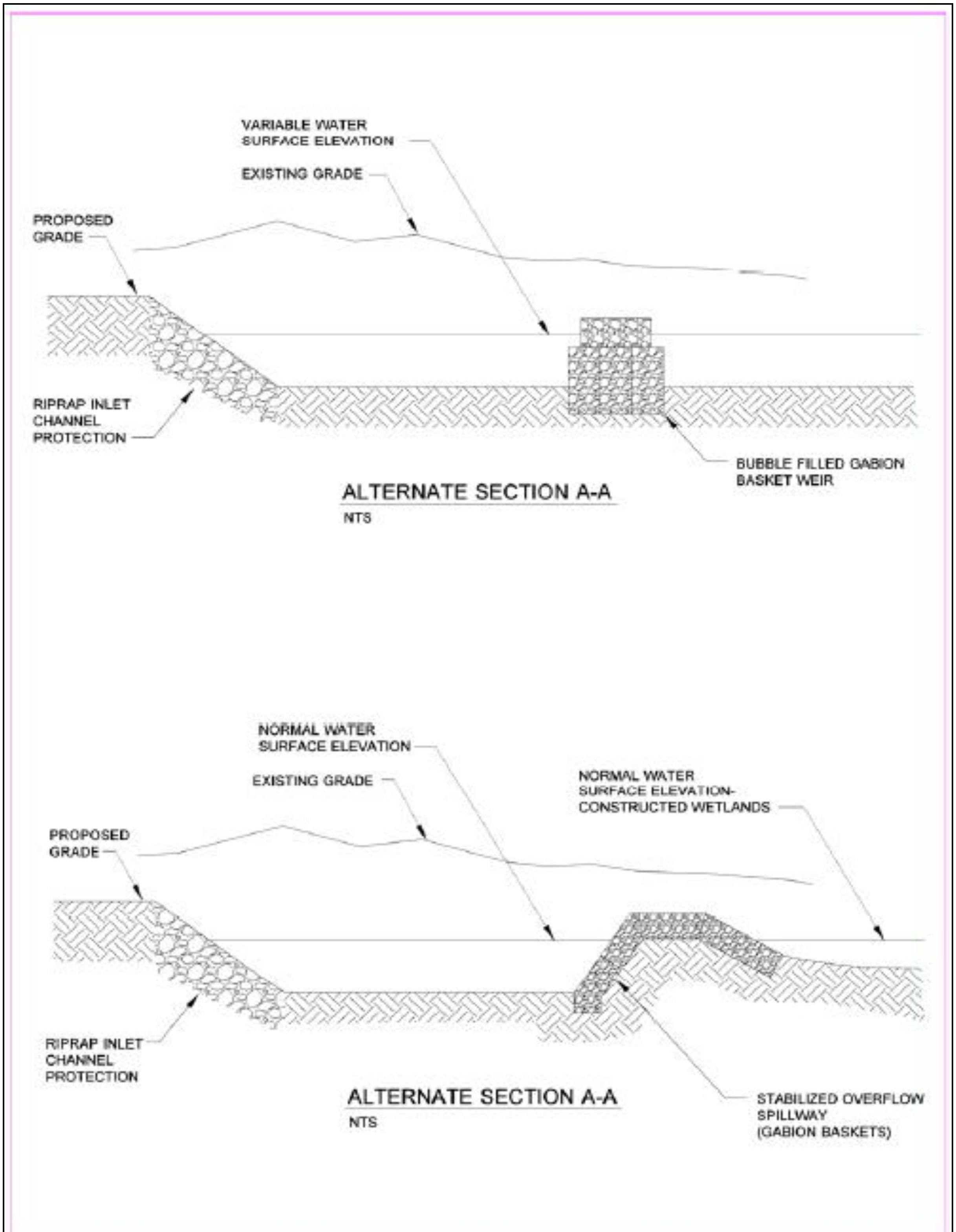


Figure 6-40: Pre-settling/Sedimentation Basin – Alternate Sections

Design Flow Elements

Flows To Be Treated

A pre-settling basin should be designed as a wet pool. The wet pool volume must be at least 30 percent of the total volume of runoff from the three-year frequency storm event. The wet pool volume should be allowed to dry out between rain storms, either by infiltration and evaporation, or by providing a pipe outlet with a perforated type riser to allow for low-flow percolation flows.

Overflow or Bypass

Pre-settling basin design must take into consideration the possibility of overflows. A designed overflow section should be constructed along the pre-settling basin embankment to allow flows to exit at a non-erosive velocity during the design frequency storm event. The overflow may be set at the permanent pool level. The use of an aquatic bench with emergent vegetation around the perimeter helps with water quality.

Any basin design must consider both a primary discharge and an emergency overflow discharge in accordance with the requirements of BMP FC.01. Overflow non-piped outlets can also function for the emergency case as long as they are sized for the maximum peak inlet conveyance flow (or the 100-year frequency storm with 1 ft. of freeboard).

Inlet Structure

The runoff treatment volume should be discharged uniformly and at a low velocity into the pre-settling basin to maintain near-quiescent conditions, which are necessary for effective treatment. It is desirable for the heavier-suspended material to drop out near the front of the basin. Energy-dissipation devices may be necessary to reduce inlet velocities that exceed 3 ft. per second.

Outlet Control Structure

The outlet structure conveys the runoff treatment volume from the pre-settling basin to the primary treatment BMP (e.g., an infiltration pond). The outlet control structure should skim the surface water. It can be a piped outlet structural overflow weir (see Figure 6-38), or it can be created as an earthen berm, gabion, concrete, or riprap wall along the separation embankment preceding the primary treatment BMP.

Structural Design Considerations

Geometry

A long, narrow basin is preferred because it is less prone to short-circuiting and tends to maximize the available treatment area. The length-to-width ratio should be at least 3:1, and preferably 5:1. The inlet and outlet should be at opposite ends of the basin.

Berms, Embankments, and Slopes

Berm embankments must be constructed on suitably-prepared native soil (or adequately-compacted and stable fill soils analyzed by a geotechnical report) and free of loose surface soil materials, roots, and other organic debris.

Exposed earth on the side slopes and bottom should be sodded or seeded with the appropriate seed mixture as soon as practicable. If necessary, geotextile or matting may be used to stabilize slopes until seeding or sodding become established.

If composed of a structural retaining wall, interior side slopes may be nearly vertical, as long as maintenance access is provided. Otherwise, they should be no steeper than 3H:1V. Exterior embankment slopes should be 2H:1V or less. The bottom of the basin should have a 2 percent slope to allow for complete drainage. The minimum depth must be 4 ft. and the maximum depth must be 6 ft.

Liners

Infiltration from the typical sediment basin is desirable, except where the bottom of the basin is less than 3 ft. above the limestone bedrock in the aquifer recharge areas of northern Guam. In that case, the pre-treatment pond must be lined with an impermeable membrane.

Site Design Elements

Setback Requirements

Pre-settling basins must be a minimum of 5 ft. from any property line or vegetative buffer. This distance may need to be increased based on the permit requirements of the local jurisdiction.

Pre-settling basins must be 100 ft. from any septic tank or drain field, except wet vaults, which must be a minimum of 20 ft. If lined with an impermeable membrane, the pre-settling basins may be within 20 ft. of a drain field.

The designer should request a geotechnical report for the project that evaluates any potential structural site instability due to extended sub-grade saturation or head-loading of the permeable layer, including the potential impacts to down-gradient properties (especially on hills with known side-hill seeps). The report should address the adequacy of the proposed pre-settling basin locations and recommend the necessary setbacks from any steep slopes and building foundations.

Safety, Signage, and Fencing

Basins that are readily-accessible to populated areas should incorporate all possible safety precautions. Dangerous outlet facilities should be protected by an enclosure.

Warning signs should be used wherever appropriate and placed so that at least one is clearly visible and legible from all adjacent streets, sidewalks, or paths.

Maintenance

The failure of large impoundment structures can cause significant property damage and even loss of life. Impoundment structures should be regularly inspected for signs of failure, such as seepage or cracks in the walls or berm.

Pre-settling basins are less likely than wet ponds to build up excessive levels of heavy metals from sediments washed off of impervious areas. Routine maintenance should remove and properly dispose of any significant sediment deposits. Sediment should be removed every three to five years or when 6 in. to 12 in. have accumulated, whichever comes first. More frequent removal of sediment from the pre-settling basin may be less costly over the same time period than a one-time cleaning of the entire basin.

6.6.2 FLOW SPLITTERS

Although volume-based (wet pool) runoff treatment BMPs must be designed as on-line facilities, many flow rate-based runoff treatment BMPs can be designed as either on-line or off-line. On-line systems allow flows above the runoff treatment design flow to pass through the facility at a lower pollutant-removal efficiency. However, it is sometimes desirable to restrict flows to an off-line runoff treatment facility and bypass the remaining higher flows around the BMP. This can be accomplished by splitting flows in excess of the runoff treatment design flow upstream of the facility, and diverting higher flows to a bypass pipe or channel. The bypass typically enters a detention pond or the downstream receiving drainage system, depending on flow control requirements. In most cases, it is the designer's choice whether runoff treatment facilities are designed as on- or off-line.

A crucial factor in designing flow splitters is ensuring that low flows are delivered to the treatment facility up to the runoff treatment design flow rate. Above this rate, additional flows are diverted to the bypass system, with minimal increase in head at the flow splitter structure, to avoid surcharging the runoff treatment facility under high flow conditions.

Flow splitters are typically manholes or vaults with concrete baffles. In place of baffles, the splitter mechanism may be a half-tee section with a solid top and an orifice in the bottom of the tee section. A full tee option may also be used, as described below in "General Design Criteria." One possible design for flow splitters is shown in Figure 6-41. Other equivalent designs that achieve the result of splitting low flows and diverting higher flows around the facility are also acceptable.

General Design Criteria

A flow splitter must be designed to deliver the stormwater quality treatment design flow rate to the runoff treatment facility. For the wet pond and created wetland, which are sized based on volume, use the stormwater quality treatment design flow rate to design the splitter.

The typical flow splitter is based on a weir design. The top of the weir must be located at the water surface for the design flow. Excess spillover flows enter the bypass line.

The maximum head must be minimized for flow in excess of the runoff treatment design flow. Specifically, flow to the runoff treatment facility in the 100-year event must not increase the runoff treatment design flow by more than 10 percent.

Special applications may require the use of a modified flow splitter. The baffle wall may be fitted with a notch and adjustable weir plate to proportion runoff volumes other than high flows.

Ladder or step-and-handhold access must be provided. If the weir wall is higher than 36 in., two ladders, one on either side of the wall, must be used.

Materials

The splitter baffle may be installed in a manhole or vault.

The baffle wall must be made of reinforced concrete or another suitable material resistant to corrosion and have a minimum 4-in. thickness. The minimum clearance between the top of the baffle wall and the bottom of the manhole cover must be 4 ft.; otherwise, dual access points should be provided.

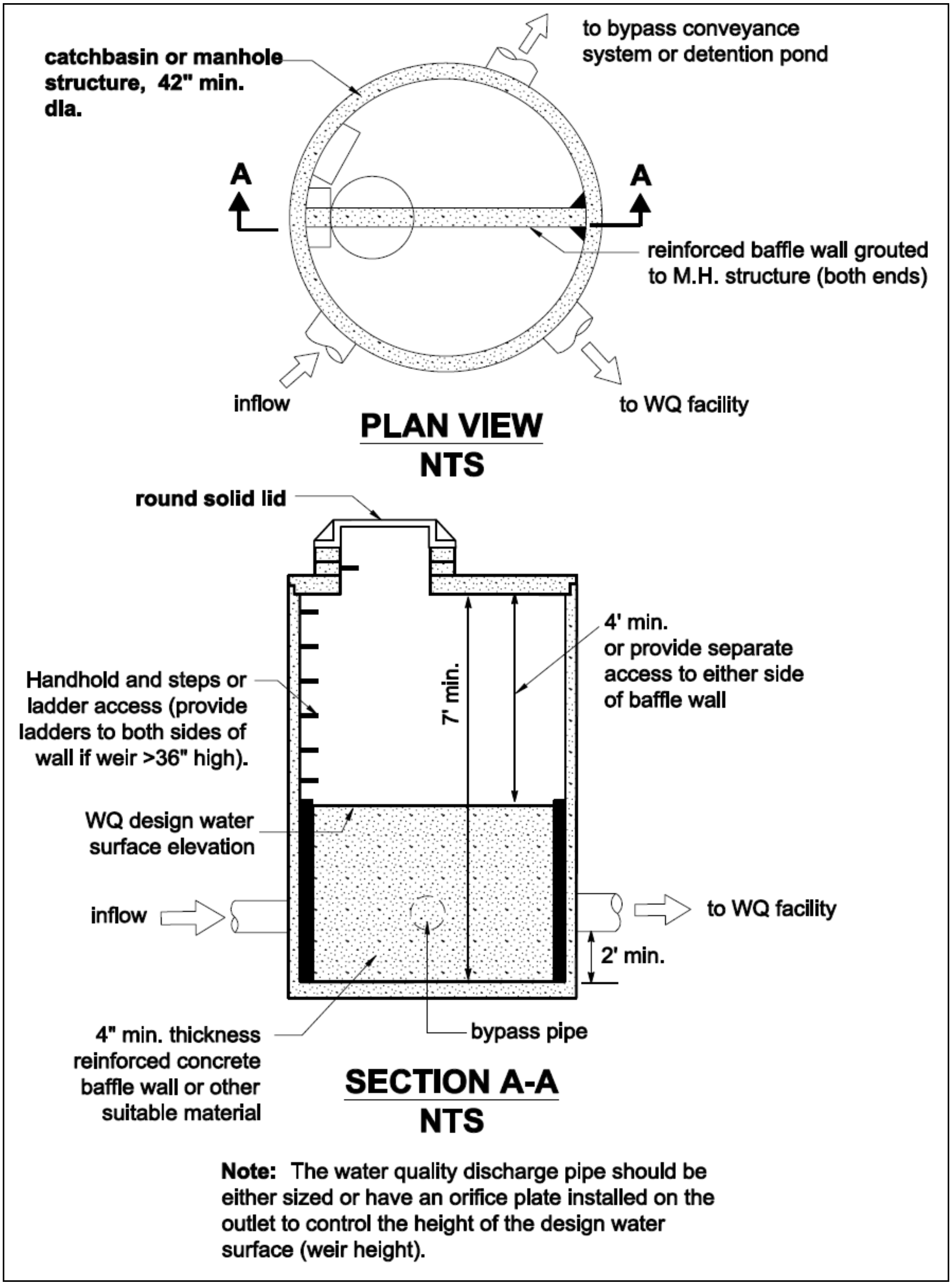


Figure 6-41: Flow Splitter

All metal parts must be corrosion-resistant. Examples of preferred materials include aluminum, stainless steel, and plastic. Avoid the use of zinc and galvanized materials because of their aquatic toxicity potential, when substitutes are available. Painting metal parts for corrosion resistance is not allowed because paint does not provide long-term protection.

6.6.3 FLOW-SPREADING OPTIONS

Flow spreaders function to uniformly spread flows across the inflow portion of runoff treatment facilities (such as a biofiltration swale, or a vegetated filter strip). Seven flow spreader options are presented in this section:

Option A – Anchored plate

Option B – Concrete sump box

Option C – Notched curb spreader

Option D – Through-curb ports

Option E – Interrupted curb

Option F – Flow Spreader Trench

Option G – Flow Spreader Swale

Options A through C, F, and G can be used for spreading flows that are concentrated. Any one of these options can be used when spreading is required by the facility design criteria. Options A through C, F, and G can also be used for un-concentrated flows; in some cases they must be used, such as to correct for moderate grade changes along a vegetated filter strip.

Options D and E are only for runoff that is already in a sheet flow condition and enters a vegetated filter strip, continuous inflow biofiltration swale, or infiltration trench.

General Design Criteria

Flows entering the spreader structure should be sub-critical non-erosive velocities. If required, energy dissipation should be provided by using rock or concrete pads or stilling structures (typically an inlet structure with flow overflowing the grated top into the spreader).

Option A – Anchored Plate

Anchor plates can be used wherever concentrated flows need to be spread for a uniform sheet flow condition such as at biofiltration swales and engineered dispersion BMPs. An anchored plate flow spreader (see Figure 6-42) must be preceded by a sump having a minimum depth of 8 in. and a minimum width of 24 in. If not otherwise stabilized, the sump area must be rock riprap protected to reduce erosion and dissipate energy.

The top surface of the flow spreader plate must be level, projecting a minimum of 2 in. above the ground surface of the runoff treatment facility, or V-notched with notches 6 in. to 10 in. on center, and 1 in. to 6 in. deep (use shallower notches with closer spacing). Alternative designs may also be used.

A flow spreader plate must extend horizontally beyond the bottom width of the facility to prevent water from eroding the side slope. The horizontal extent should protect the bank for all flows up to the 100-year flow or the maximum flow that enters the runoff treatment facility.

Flow spreader plates must be securely fixed in place, and may be made of wood, metal, fiberglass-reinforced plastic, or other durable material. If wood, pressure-treated 4-in. by 10-in. lumber/landscape timbers are acceptable.

Anchor posts must be 4-in. square concrete, tubular stainless steel, or other material resistant to decay.

Option B – Concrete Sump Box

The concrete sump box is used mainly as a spreader for biofiltration swale BMPs. The wall of the downstream side of a rectangular concrete sump box (see Figure 6-20) must extend a minimum of 2 in. above the treatment bed. This serves as a weir to spread the flows uniformly across the bed.

The downstream wall of a sump box must have wing walls at both ends. Sidewalls and returns must be slightly higher than the weir so that erosion of the side slope is minimized.

Concrete for a sump box can be either cast-in-place or pre-cast, Both types must be reinforced with rebar or wire mesh per standard structural design requirements.

Sump boxes must be placed over bases consisting of 4 in. of crushed rock, 5/8-in. minus, to help ensure the sump remains level.

Option C – Notched Curb Spreader

Notched curb spreader sections (see Figure 6-43) are usually made of extruded or pre-cast concrete laid side-by-side and level. Typically, five teeth per 4-ft. section provides good spacing. The space between adjacent teeth forms a V-notch.

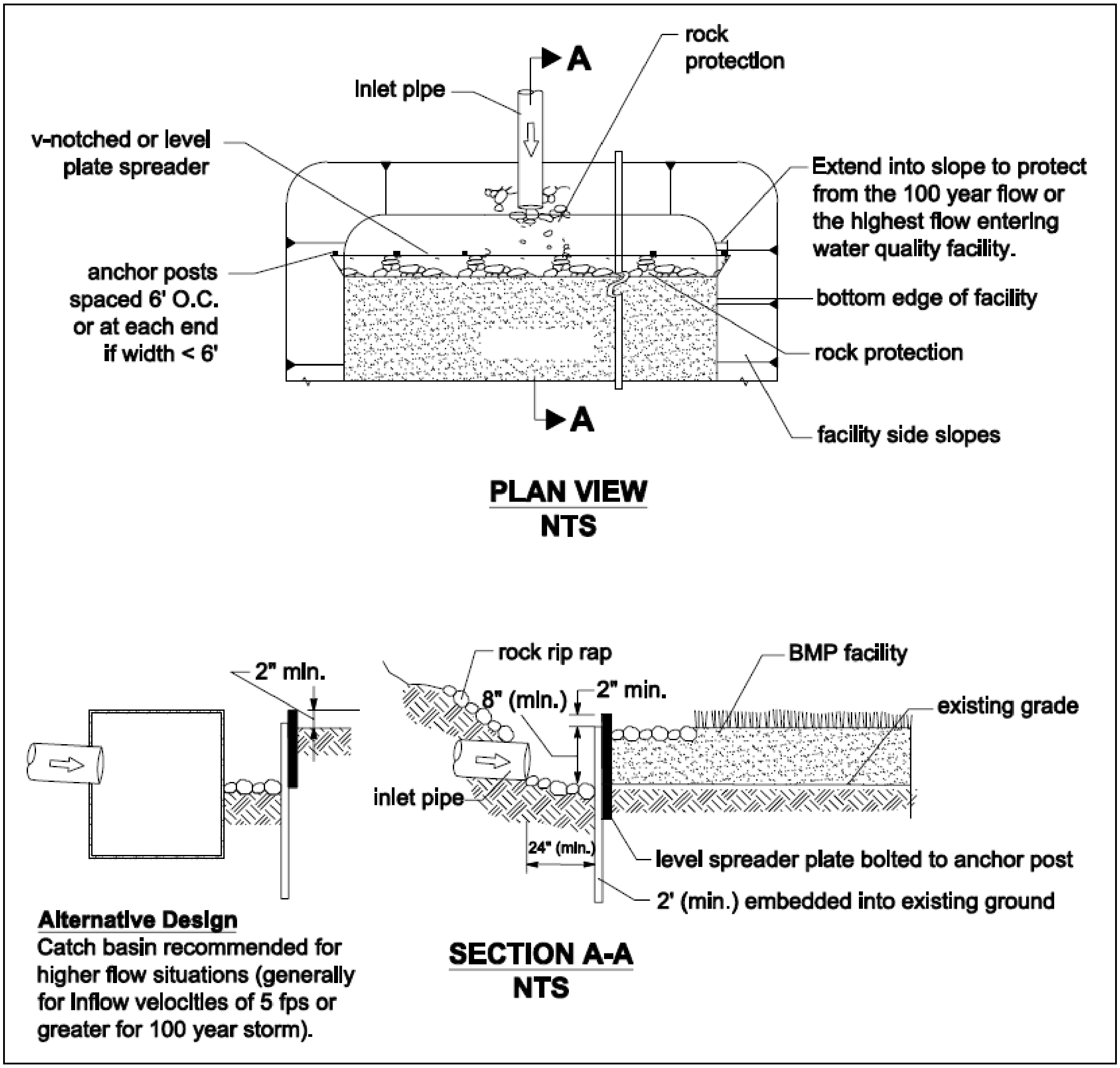


Figure 6-42: Flow Spreader – Anchor Plate

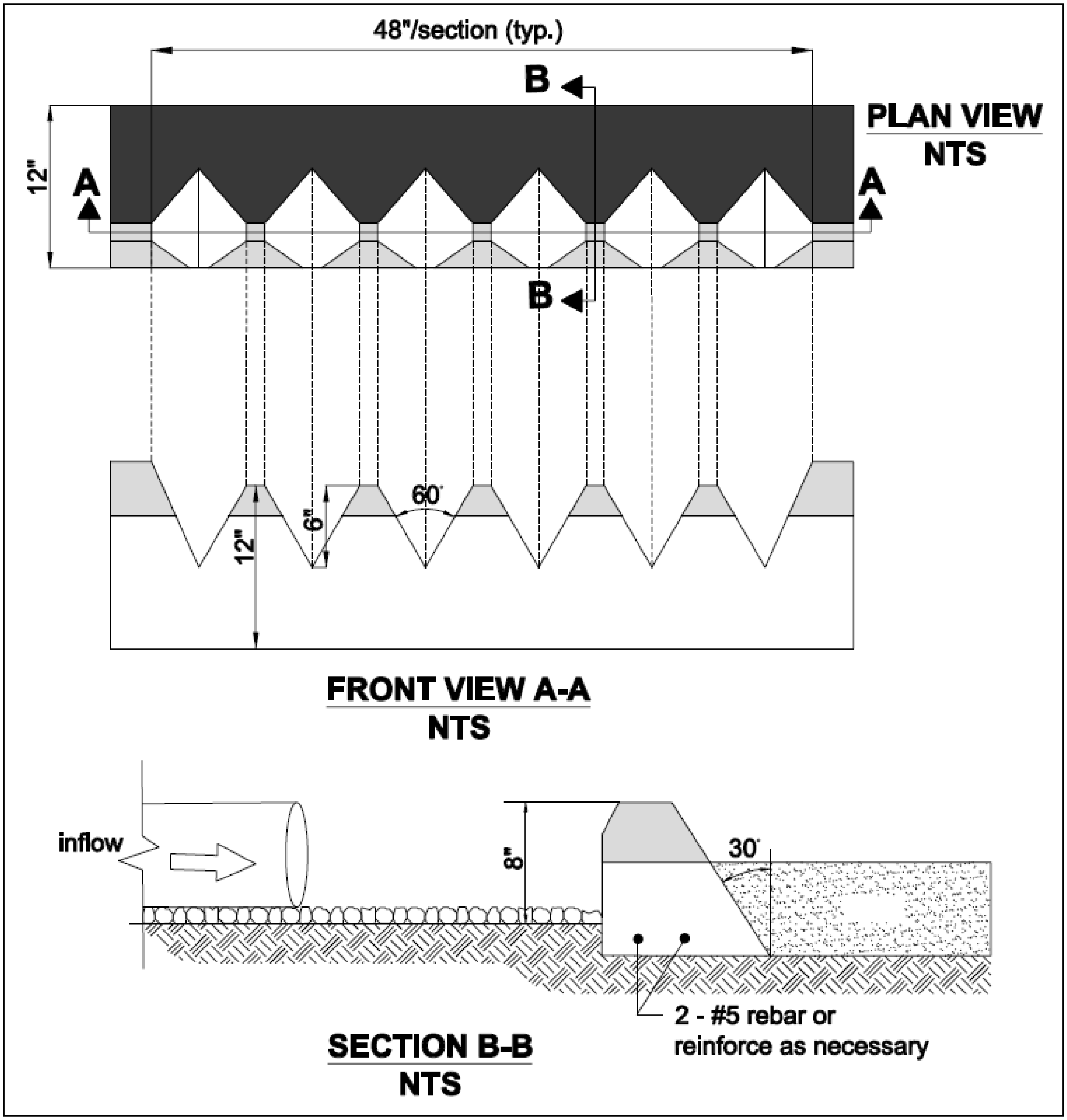


Figure 6-43: Flow Spreader – Notched Curb Spreader

Option D – Through-Curb Ports

Un-concentrated flows from paved areas entering vegetated filter strips or continuous inflow biofiltration swales can use curb ports (see Figure 6-44) or interrupted curbs (Option E) to allow flows to enter the strip or swale. Curb ports use fabricated openings that allow concrete curbing to be poured, pre-cast or extruded, with an opening through the base to admit water to the runoff treatment facility.

Openings in the curb must be at regular intervals — at least every 6 ft. (minimum). The width of each curb port opening must be a minimum of 11 in. Approximately 15 percent or more of the curb section length should be in open ports, and no port should discharge more than approximately 10 percent of the flow.

Option E – Interrupted Curb

Interrupted curbs are sections of curb placed to have gaps spaced at regular intervals along the total width (or length, depending on the facility) of the treatment area. At a minimum, gaps must be every 6 ft. to allow for the distribution of flows into the treatment facility before the flows become too concentrated. The opening must be a minimum of 11 in. As a general rule, no opening should discharge more than 10 percent of the overall flow entering the facility.

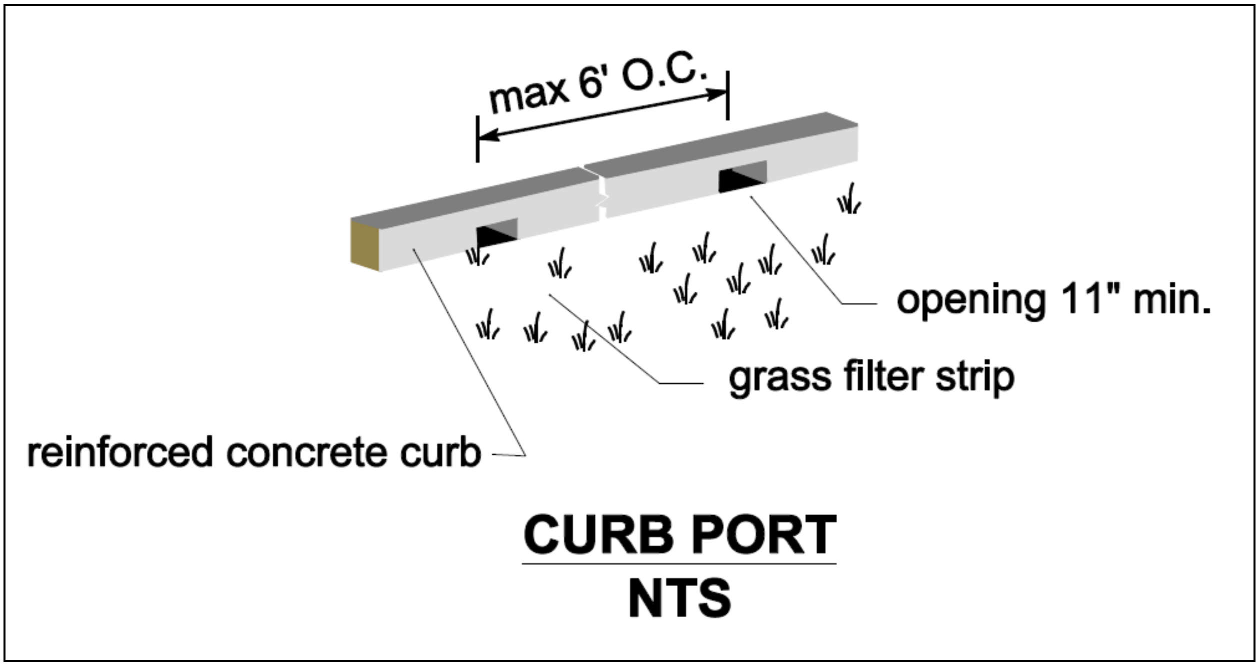


Figure 6-44: Flow Spreader – Through-Curb Port

Option F – Flow Spreader Trench

Flow spreader trenches are the preferred outlet type device for discharge of concentrated flows from stormwater quality treatment and detention facilities. They act as both infiltration trenches, and they allow sheet flow discharge over the top for flows in excess of the infiltration capacity. They provide a more natural type of discharge regime where placed parallel to streams and wetlands, a better alternative than direct pipe outfalls to water bodies.

Flow spreader trenches are also the usual flow spreader device where concentrated flows must be converted to sheet flow for distribution to engineered wetlands and vegetated filter strips. Two types of flow spreader trenches are shown in Figures 6-45 and 6-46.

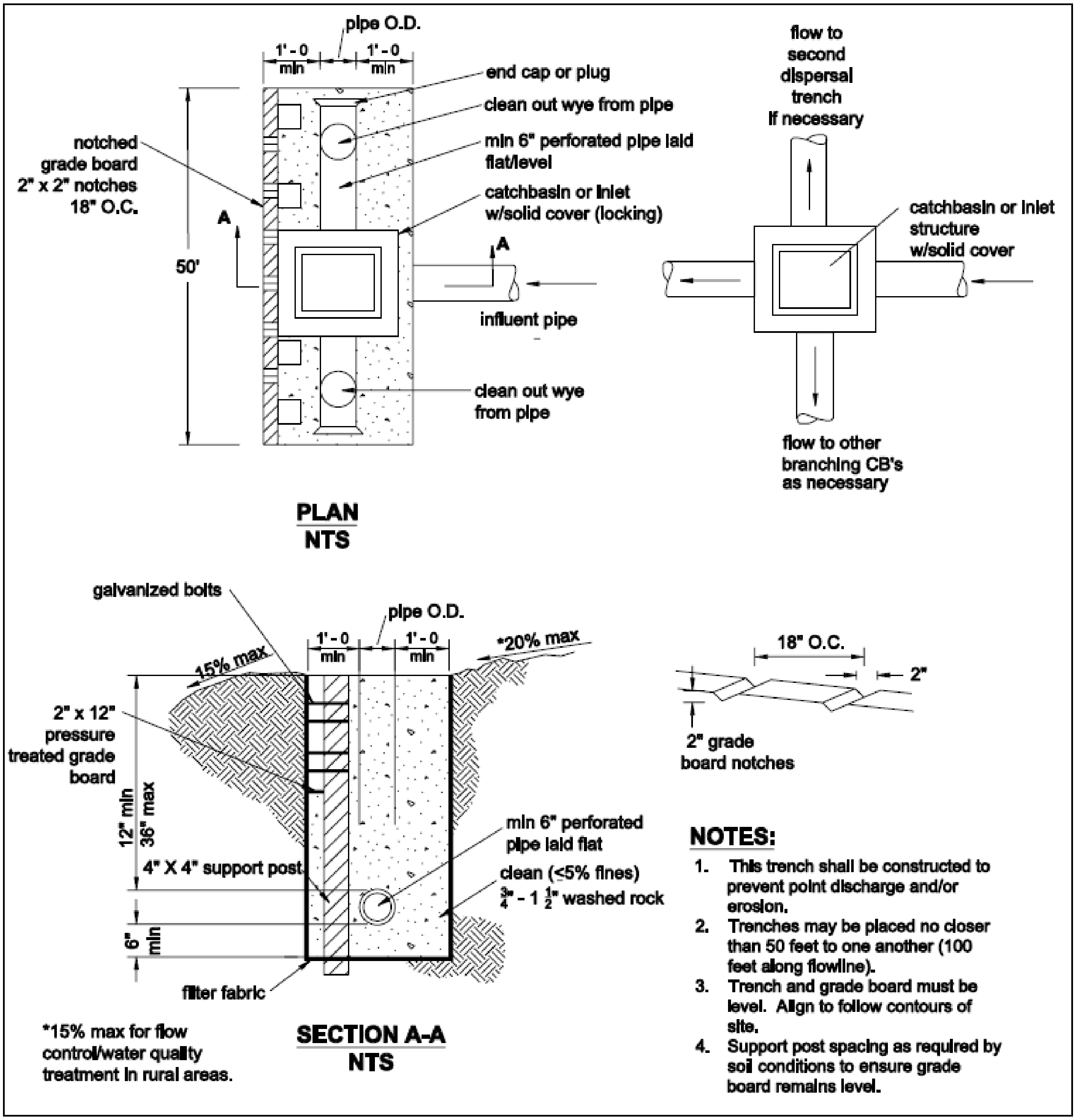


Figure 6-45: Flow Spreader Trench Type 1

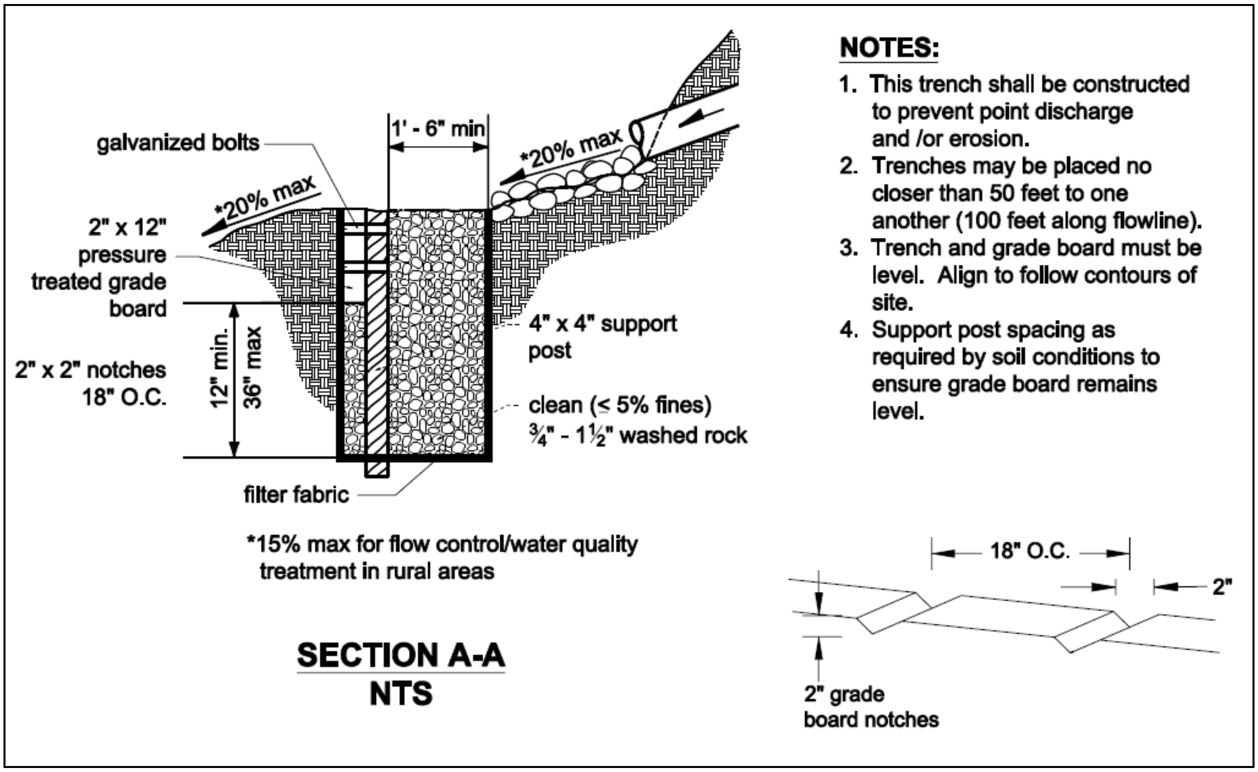


Figure 6-46: Flow Spreader Trench Type 2

The Type 1 trench works well for energy dissipation of higher velocity incoming flow. The pipe sizes and trench length are sized to accommodate the design flow rate while limiting the flow depth over the weir to 3 in. or 4 in. maximum. The maximum hydraulic capacity of these flow dispersal trenches are limited by the practical flow parameters, so that there is no possibility of dislodging the trench backfill material, and pipe flow velocities in the perforated pipe are no more than 5 fps to 6 fps.

Option G – Flow Spreader Swale

A flow spreader swale is simply a ditch with a level berm along the downhill side. The ditch should be sized for the design flow with a flow velocity limited to 2 ft. or 3 ft. per second with the outlet being the overtopping of the downhill level berm. The swale should be trapezoidal in shape with side slopes no steeper than 3H:1V for ease in maintenance mowing. The level berm should be at least 4 ft. in top width constructed of compacted soil and grassed with a heavy sod-forming type plant mix.

The berm overflow depth should not exceed 1 in. to 2 in. to protect against flow cutting and rutting. These level flow spreaders are most applicable for use with engineered dispersion BMPs and vegetated filter strips. The level berm should be protected with an erosion control type geotextile if placed into use prior to full development of the grass sod.

Level flow spreaders should have frequent maintenance checking for any signs of erosion or soil rutting. Any damaged areas on the level berm should be immediately repaired and reseeded. The level flow swales also require frequent mowing, and should not be used in areas inaccessible to this requirement.

6.6.4 OUTFALLS

Properly-designed outfalls are critical to reducing the chance of adverse impacts as the result of concentrated discharges from pipe systems and culverts, both on-site and downstream.

Outfall systems include rock splash pads, flow spreader trenches, gabion, or other energy pipe used to convey flows down a steep or sensitive slope with appropriate energy dissipation at the discharge end.

General Design Criteria

At a minimum, all outfalls must be provided with a rock splash pad (see Table 6-9 and Figure 6-47).

Where discharging from a stormwater quality treatment BMP to a natural stream or wetland, the preferred outfall is the flow spreader trench (see Figures 6-45 and 6-46). The flow spreader trench provides a combination infiltration/sheet flow discharge that is more natural and protective of the existing water body.

For outfalls with a design velocity greater than 8 ft. to 10 ft per second, an engineered energy dissipater may be required. There are many possible designs. One example for typical-sized storm drainage pipe outfalls with higher velocities is the gabion basket protection (see Figure 6-48). Note: The gabion outfall detail shown in Figure 6-48 is illustrative only. A design engineered to specific site conditions must be developed.

Tight-line systems may be needed to prevent aggravation or creation of a downstream erosion problem.

Outfalls to marine waters require specific engineering designs to account for the additional corrosion effects and energy of the receiving waters, and to minimize impacts to the ecology of the tidal zone. In marine waters, rock splash pads and gabion structures are not recommended. Rock splash pads can be destroyed by wave action, and gabion baskets will corrode in saltwater and, potentially, be dislocated by wave action.

If the discharge cannot be made above the mean high water in marine waters, tight line systems are used. The energy dissipation is performed within the submerged section of the outfall pipeline/structures. The outfall pipeline is normally trenched to discharge below extreme low water, often times using a ‘T’ diffuser on the end. The outfall must be protected by heavy riprap blankets from wave and tidal current action, and boat anchorage.

Where discharge flows exceed 10 ft. to 12 ft. per second with a Froud number above 1, engineered energy dissipaters should be used. They should be designed in accordance with FHWA publication HEC-14 guidelines. There are also public domain computer programs to assist with the selection and design of dissipater structures such as the FHWA's HY-8, the USDA's WinFlume32, and the Nebraska Department of Roads' BCAP (Broken-Back Culvert Analysis Program).

Discharge Velocity at Design Flow (ft./s)	**Required Protection Minimum Dimensions**				
	Type	**Thickness**	**Width**	**Length**	**Height**
0-5	Rock lining[1]	1 ft.	Diameter + 6 ft.	8 ft. or 4 x diameter, whichever is greater	Crown + 1 ft.
5-10	Riprap[2]	2 ft.	Diameter + 6 ft. or 3 x diameter, whichever is greater	12 ft. or 4 x diameter, whichever is greater	Crown + 1 ft.

Table 6-9: Rock Protection at Outfalls

1 Rock lining is quarry spalls (pit run) with gradation as follows:
- Passing 8-in.-square sieve: 100%
- Passing 3-in.-square sieve: 40% to 60% maximum
- Passing 3/4-in.-square sieve: 0% to 10% maximum

2 Riprap to be reasonably well-graded with gradation as follows:
- Maximum stone size: 24 in. (nominal diameter)
- Median stone size: 16 in.
- Minimum stone size: 4 in.

Note: Riprap sizing on an outlet channel is assumed to be governed by side slopes of approximately 3H:1V.

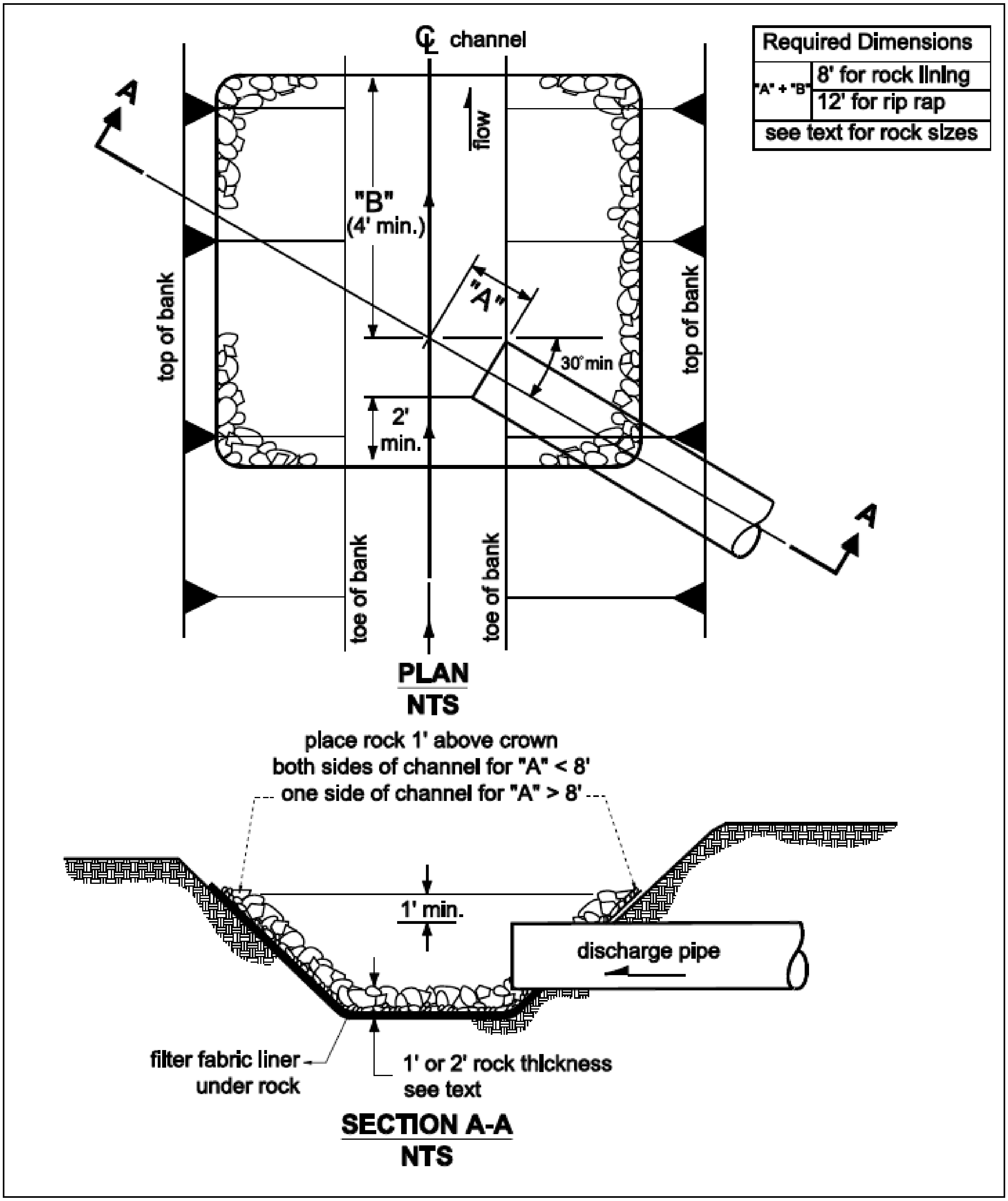


Figure 6-47: Pipe/Culvert Outlet Rock Protection

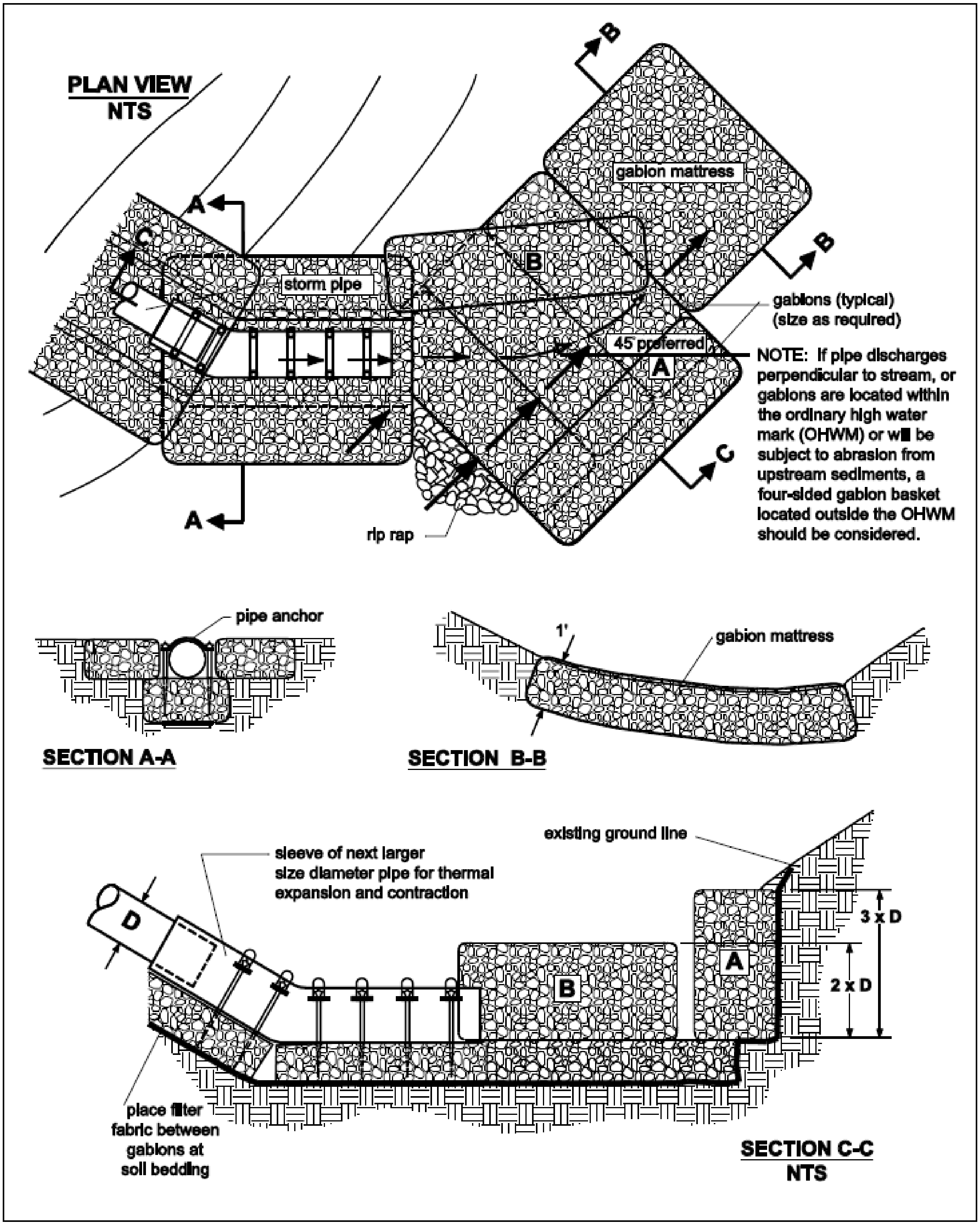


Figure 6-48: Gabion Outlet Protection

Tight-Line Systems

Mechanisms that reduce runoff velocity prior to discharge from an outfall are encouraged. Two of these mechanisms are drop manholes and the rapid expansion of pipe diameter.

Bank stabilization, bioengineering, and habitat features may be required for disturbed areas. Outfall structures should be located and configured to minimize impacts to the riparian habitat, and in particular, avoid impacts below the Ordinary High Water of natural water bodies.

6.6.5 SOIL AMENDMENTS

General Description

Soil amendments, including compost and other organic materials, help restore the health of the soil and increase environmental functions such as rainwater infiltration and natural detention, evapotranspiration, and plant health. Soil amendments can help prevent or minimize adverse stormwater impacts during construction and are used along with vegetation as a permanent runoff treatment BMP. Compost is a versatile material that can be used as a component in many other permanent and temporary stormwater BMPs.

Compost-amended soils can be modeled as pasture on native soil. The final organic content of these soils should be 10 percent for all areas, excluding turf areas, which are expected to receive a high amount of foot traffic. Turf (lawn) areas with high foot traffic must have a 5 percent final organic content.

Applications and Limitations

Soil amendments can be used in most unpaved areas within the project. If soil amendments are applied as a blanket, they perform erosion control functions immediately by providing a cover to bare soils. When incorporated into the soil, they increase infiltration and adsorption of metals and aid in the uptake of nutrients. They also enhance vegetation growth and plant establishment.

Compost provides an excellent growing medium for roadside vegetation. Traditional highway construction methods typically result in the excavation and removal of the area’s topsoil. Roadway embankments are then constructed from material that has few nutrients, is low in organic material, and is compacted to 95 percent maximum density. Adding compost to roadway slopes and ditches provides soil cover, improves soil fertility and texture, and greatly improves the vegetative growth and soil stability, thereby reducing erosion.

Organic soil amendments soak up water like a sponge and store it until it can be slowly infiltrated into the ground or taken up by plants. In some BMP applications, the volume of compost can be sized to absorb and hold the runoff treatment storm.

Compost is an excellent filtration medium, which provides treatment for highway runoff. Compost has a high cation exchange capacity (CEC) that chemically traps dissolved heavy metals and binds them to the compost material. Oils, grease, and floatables are also removed from stormwater as it is filtered through the compost.

Compost is very absorbent when dry, but when saturated it has a high infiltration rate. Therefore, greater storm events can pass through compost medium without hindering the infiltration rates of underlying soils or drain materials. Compost has also been shown to improve the infiltration rates of underlying soils, even till soils.

Placement of a compost blanket on bare soil helps stabilize the soil and prevent surface erosion by intercepting rainfall. This type of application changes the texture and workability of the soil, lengthens the acceptable seeding windows, and encourages plant growth.

Compost soil amendments can be used in the construction phase of projects as compost berms and compost socks in lieu of conventional geotextile silt fences for sediment control. While being an effective sediment trap during the construction phase, compost berms are advantageous in that they can be bladed out at the construction site, which avoids bid items for the haul and disposal of silt fences. If the permanent stormwater design involves use of compost-amended vegetated filter strips, a batch of compost can be used as sediment control in a berm, then the berm can be bladed out along a highway roadside, where it can be used as part of vegetated filter strip construction. Compost socks can be left in place and will deteriorate with time.

Maintenance

Compost, as with sand filters or other filter mediums, can become plugged with fines and sediment, which may require removal and replacement. Including vegetation with compost helps prevent the medium from becoming plugged with sediment by breaking up the sediment and creating root pathways for stormwater to penetrate into the compost. It is expected that soil amendments will have a removal and replacement cycle; however, this time frame has not yet been established.

6.7 OPERATION AND MAINTENANCE

Inadequate maintenance is a common cause of failure for stormwater control facilities. Proper maintenance requires regular inspection and prompt repair and cleaning of structures when needed. The designer should simplify this process by providing designs that promote easy access for maintenance inspections and regular maintenance work. The stormwater designer should follow these guidelines as a minimum:

- Review other stormwater BMP installations and observe those items that are ineffective, poorly-maintained, and/or working correctly for what should not be or what should be incorporated into the planned BMPs.
- Review all preliminary BMP designs with DPW's maintenance staff for their input on the maintainability.
- Provide safe, convenient access to the BMPs for ease of regular maintenance. This should include properly-designed traffic pull-out areas that allow for safe egress in and out of traffic, with surfaced parking and walking access. Working pads and access ramps should be suitable for the facility in regards to the equipment needed to maintain the facility, such as surfaced pads large enough to maneuver trucks for cleaning and loading, ramps surfaced on slopes suitable for the equipment, parking in front of gates for inspection vehicles, etc.
- Provide vehicle access for cleaning of all inlet and outlet control structures.
- Provide pullout locations for maintenance vehicles with trailers where mowing is required.
- Underground structures should have suitable work pads around the access opening for equipment, with access openings suitable for both inspection manhole access and larger sediment/trash removal equipment.
- Provide lighting and ventilation where regular access must be made in enclosed space locations such as underground sumps and pump chambers.
- For critical drainage and flood control facilities, provide emergency failure alarms based on high water levels or pump failure, with red flashing light and signs at the site plus a wireless signal to DPW's maintenance headquarters.

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7 CONSTRUCTION SITE BEST MANAGEMENT PRACTICES

This chapter of the Transportation Stormwater Drainage Manual (TSDM) provides designers with specific guidelines and criteria on the proper selection, design, and application of construction site stormwater management techniques. A selection process is presented, along with design considerations for each Best Management Practice (BMP).

Construction site BMPs are applied during construction activities to reduce the pollutants in stormwater discharges throughout construction. These construction site BMPs provide both temporary erosion and sediment control, as well as control for potential pollutants other than sediment. There are five categories of BMPs suitable for controlling potential pollutants on construction sites. They are:

- Soil stabilization practices
- Sediment control practices
- Wind erosion control
- Tracking control practices
- Non-stormwater controls

It is generally accepted that practices that perform well by themselves can be complemented by other BMPs to raise the collective effectiveness level for erosion control and sediment retention.

Effective erosion and sediment control planning relies on a system of BMPs such as mulches for source control, fiber rolls on slopes for reducing runoff velocities, and silt fences at the toe of slopes for capturing sediment, among others.

To meet regulatory requirements and protect the site resources, every project must include an effective combination of erosion and sediment control measures. These measures must be selected from all of the BMP categories presented in this section -- soil stabilization practices, sediment control practices, tracking control practices, and wind erosion control practices.

Additionally, the project plan must include non-stormwater controls, waste management, and material pollution controls.

Table 7-1 is a matrix of the construction site BMPs that are generally used during construction. Detailed descriptions and guidance regarding the implementation of these BMPs may be found in later sections of this chapter. The individual BMPs, designated by an “X” in Table 7-1 as being applicable to a particular, typical construction activity, is a guideline only, and the final selection of BMPs will depend on the actual site conditions and contractor’s work elements, staging, schedule, and site management philosophy.

The last section of this chapter discusses post construction source control BMPs, sometimes also known as “maintenance BMPs”. The objective of implementing maintenance BMPs is to provide preventative measures to ensure that maintenance activities are conducted in a manner that reduces the amount of pollutants discharged to surface waters through DPW’s stormwater drainage systems. DPW’s maintenance activities involve the use of a variety of products. Under normal, intended conditions of use, these materials are not considered “pollutants of concern.” However, if these products are used, stored, spilled, or disposed of in a way that may cause them to contact stormwater or enter stormwater drainage systems, they may become a concern for water quality.

	Demolish Pavement and Structures	Clear and Grub	Construct Access Roads	Grading (inc. cut and fill slopes)	Channel Excavation	Trenching and Underground Drainage	Utility Trenching	Utility Installation	Subgrade preparation	Base Paving	Paving	Saw Cutting	Joint Sealing	Grind/Groove	Structure Excavation	Erect Falsework	Bridge/Structure Construction	Remove Falsework	Striping	Misc. Concrete Work	Sound and Retaining Walls	Planting and Irrigation	Contractor Activities	Treatment BMP Construction
Construction Best Management Practices																								
Soil Stabilization Practices																								
Scheduling	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X
Preservation of Existing Vegetation		X	X	X		X	X								X	X		X			X			
Hydraulic Mulch	X	X		X	X												X					X		X
Hydroseeding	X	X		X	X												X					X		X
Soil Binders	X	X		X	X										X		X					X		X
Fiber Mulch	X	X	X	X	X	X	X		X						X		X					X		X
Geotextile, Plastic Covers, and Erosion Control Blankets/Mats	X	X	X	X	X	X	X		X						X		X					X		X
Temporary Concentrated Flow Conveyance Controls		X	X	X													X					X		
Streambank Stabilization		X	X	X	X	X											X					X		
Sediment Control Practices																								
Silt Fence	X	X	X	X	X	X	X		X						X		X				X	X	X	X
Sediment Basin		X		X	X												X					X		X
Sediment Traps	X	X	X	X	X	X	X		X						X		X				X	X	X	X
Check Dams	X	X	X	X	X	X	X		X						X		X				X	X	X	X
Fiber Rolls/Wattles	X	X	X	X	X	X	X		X						X		X				X	X	X	X
Gravel Bag Berm	X	X	X	X	X	X	X		X						X		X				X	X	X	X
Street Sweeping and Vacuuming	X	X	X	X	X	X	X		X						X		X				X	X	X	X
Storm Drain Inlet Protection	X	X	X	X	X	X	X		X						X		X				X	X	X	X
Streambank Sediment Control	X	X	X	X	X	X	X		X						X		X				X	X	X	X
Wind Erosion Control																								
Tracking Control Practices																								
Stabilized Construction Entrance/Exit		X	X	X																			X	
Stabilized Construction Roadway		X	X	X																			X	
Entrance/Outlet Tire Wash		X	X	X																		X	X	
Non-stormwater Controls																								
Water Conservation Practices	X	X	X	X	X	X	X		X			X	X	X	X		X			X		X	X	X
De-Watering Operation	X			X	X	X	X	X							X		X			X	X	X		X
Temporary Stream Crossing			X			X	X	X								X	X	X		X				
Clear Water Diversion	X		X		X											X	X	X		X				X
Potable Water/Irrigation																						X	X	X
Vehicle and Equipment Cleaning	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Vehicle and Equipment Fueling	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Vehicle and Equipment Maintenance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	Demolish Pavement and Structures	Clear and Grub	Construct Access Roads	Grading (inc. cut and fill slopes)	Channel Excavation	Trenching and Underground Drainage	Utility Trenching	Utility Installation	Subgrade preparation	Base Paving	Paving	Saw Cutting	Joint Sealing	Grind/Groove	Structure Excavation	Erect Falsework	Bridge/Structure Construction	Remove Falsework	Striping	Misc. Concrete Work	Sound and Retaining Walls	Planting and Irrigation	Contractor Activities	Treatment BMP Construction
Pile-Driving Operations															X	X	X	X		X	X			
Concrete Curing								X									X	X		X	X		X	
Material and Equipment Use Over Water	X		X		X	X	X	X							X	X	X	X	X	X	X			X
Concrete Finishing																	X			X	X			
Structure Demolition Over Or Adjacent To Water	X																X	X		X				

Table 7-1: Construction Site BMPs by Construction Activity

7.1 SOIL STABILIZATION PRACTICES

Temporary soil stabilization practices consist of preparing the soil surface and applying one of the BMPs shown in Table 7-2, or a combination thereof, to disturbed soil areas.

BMP Name
Scheduling
Preservation of Existing Vegetation
Hydraulic Mulch
Hydroseeding
Soil Binders
Fiber Mulch
Geotextiles, Plastic Covers, and Erosion Control Blankets/Mats
Temporary Concentrated Flow Conveyance Controls
Stream Bank Stabilization

Table 7-2: Temporary Soil Stabilization BMPs

7.1.1 SCHEDULING

Definition and Purpose

This BMP involves developing a schedule for every project that includes the sequencing of construction activities with the implementation of construction site BMPs such as temporary soil stabilization (erosion control) and temporary sediment control measures. The purpose is to reduce the amount and duration of soil exposed to erosion by wind, rain, runoff, and vehicle tracking, and to perform the construction activities and control practices in accordance with the planned schedule.

Appropriate Applications

Construction sequencing should be scheduled to minimize land disturbance for all projects during the rainy season. Appropriate BMPs should be implemented during both rainy and non-rainy seasons.

Limitations

None identified.

Standards and Specifications

- Developing a schedule and planning the project are the very first steps in an effective stormwater program. The schedule should clearly show how the rainy season relates to soil-disturbing and re-stabilization activities. The construction schedule should be incorporated into the Stormwater Pollution Prevention Plan (SWPPP).

- The schedule should include details on the rainy season implementation and deployment of:
  - Temporary soil stabilization BMPs
  - Temporary sediment control BMPs
  - Tracking control BMPs
  - Wind erosion control BMPs
  - Non-stormwater BMPs
  - Waste management and materials pollution control BMPs
- The schedule should also include dates for significant long-term operations or activities that may have planned non-stormwater discharges such as de-watering, saw-cutting, grinding, drilling, boring, crushing, blasting, painting, hydro-demolition, mortar mixing, bridge cleaning, etc.
- Schedule work to minimize soil-disturbing activities during the rainy season.
  - Develop the sequencing and timetable for the start and completion of each item, such as site clearing and grubbing, grading, excavation, paving, pouring foundations, installing utilities, etc., to minimize the active construction area during the rainy season.
  - Schedule major grading operations for the non-rainy season when practical.
  - Stabilize non-active areas within two days during wet season and seven days during dry season, or one day prior to the onset of precipitation, whichever occurs first.
  - Monitor the weather forecast for rainfall.
  - When rainfall is predicted, adjust the construction schedule to allow the implementation of soil stabilization and sediment controls and sediment treatment controls on all disturbed areas prior to the onset of rain.
- Be prepared year-round to deploy soil stabilization and sediment control practices. Erosion may be caused during dry seasons by unseasonal rainfall, wind, and vehicle tracking. Keep the site stabilized year round, and retain and maintain rainy-season sediment-trapping devices in operational condition.
- Sequence trenching activities so that most open portions are closed before new trenching begins.

- Incorporate staged seeding and the re-vegetation of graded slopes as work progresses.
- Consider scheduling when establishing permanent vegetation (appropriate planting time for specified vegetation).
- Apply permanent erosion control to areas deemed substantially complete during the project's defined seeding window.

Maintenance and Inspection

- Verify that work is progressing in accordance with the schedule. If progress deviates, take corrective actions.
- Amend the schedule when changes are warranted.
- The contractual specifications may require the annual submittal of a rainy season implementation schedule. Amend the schedule prior to the rainy season to show updated information on the deployment and implementation of construction site BMPs.

7.1.2 PRESERVATION OF EXISTING VEGETATION

Definition and Purpose

The preservation of existing vegetation is the identification and protection of desirable vegetation that provides erosion and sediment control benefits. The purpose of preserving natural vegetation is to reduce erosion wherever practicable. Limiting site disturbance is the single most effective method for reducing erosion.

Appropriate Applications

- Preserve existing vegetation at areas on a site where no construction activity is planned or where construction will occur at a later date. Specifications for the preservation of existing vegetation can be found in the *Federal Highway Administration (FHWA) Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, Section 201 (FP-03)* (Standard Specifications). On a year-round basis, temporary fencing should be placed around areas not to be disturbed prior to the commencement of clearing and grubbing operations or other soil-disturbing activities.
- Clearing and grubbing operations should be staged to preserve existing vegetation.

Limitations

The protection of existing vegetation requires planning and may limit the area available for construction activities.

Standards and Specifications

Timing

- The preservation and fencing-off of existing vegetation should be provided prior to the commencement of clearing and grubbing operations or other soil-disturbing activities in areas identified on the plans to be preserved, especially on areas designated as environmentally sensitive.
- The preservation of existing vegetation should conform to the approved project schedule.

Design and Layout

- Mark areas to be preserved with temporary fencing made of orange polypropylene that is stabilized against ultraviolet (UV) light. The temporary fencing should be at least 3.2 ft. tall and should have openings no larger than 2 in. by 2 in.
- At the contractor's discretion, fence posts should be either wood or metal, as appropriate for the intended purpose. The post spacing and depth should be adequate to completely support the fence in an upright position.
- Minimize the disturbed areas by locating temporary roadways to avoid stands of trees and shrubs and to follow existing contours to reduce cutting and filling.
- Consider the impact of grade changes to existing vegetation and the root zone.

Installation

- Construction materials, equipment storage, and parking areas should be located where they will not cause root compaction.
- Keep equipment away from trees to prevent trunk and root damage.
- Maintain existing irrigation systems.
- Employees and subcontractors should be instructed to honor protective devices.
- No heavy equipment, vehicular traffic, or storage piles of any construction materials should be permitted within the drip line of any tree to be retained.
- Removed trees should not be felled, pushed, or pulled into any retained trees.
- Fires should not be permitted within 100 ft. of the drip line of any retained trees. Any fires should be of limited size and should be kept under continual

surveillance. No toxic or construction materials (including paint, acid, nails, gypsum board, chemicals, fuels, and lubricants) should be stored within 50 ft. of the drip line of any retained trees, nor disposed of in any way that would injure vegetation.

Trenching and Tunneling

- Trenching should be as far away from tree trunks as possible, usually outside of the tree drip line or canopy. Curve trenches around trees to avoid large roots or root concentrations. If roots are encountered, consider tunneling under them. When trenching and/or tunneling near or under trees to be retained, tunnels should be at least 18 in. below the ground surface and not below the tree center, to minimize impact on the roots.
- Tree roots should not be left exposed to air; they should be covered with soil as soon as possible, protected, and kept moistened with wet burlap or peat moss until the tunnel and/or trench can be completed.
- The ends of damaged or cut roots should be cut off smoothly.
- Trenches and tunnels should be filled as soon as possible. Careful filling and tamping will eliminate air spaces in the soil, which can damage roots.
- Remove any trees intended for retention if those trees are damaged seriously enough to affect their survival. If replacement is desired or required, the new tree should be of a similar species, and at least 2 in. caliper, unless otherwise required by the contract documents.
- After all other work is complete, fences and barriers should be removed last. This is because protected trees may be destroyed by carelessness during final cleanup and landscaping.

Maintenance and Inspection

- During construction, the limits of disturbance should remain clearly marked at all times. Irrigation or maintenance of existing vegetation should conform to the requirements in the landscaping plan. If damage to protected trees occurs, the trees should be attended to by an arborist.

7.1.3 HYDRAULIC MULCH

Definition and Purpose

Hydraulic mulch consists of applying a mixture of shredded wood, plant, or pulp fiber, or another bonded fiber matrix and a stabilizing emulsion or tackifier with hydroseeding equipment, which temporarily protects exposed soil from erosion by raindrop impact or wind. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

- Hydraulic mulch is applied to disturbed areas requiring temporary protection until permanent vegetation is established or disturbed areas that must be re-disturbed, following an extended period of inactivity.

Limitations

Hydraulic mulches are generally short-lived (only last a part of a growing season) and need 24 hours to dry before rainfall occurs, to be effective. Avoid use in areas where the mulch would be incompatible with immediate future earthwork activities and would have to be removed.

Standards and Specifications

- Prior to application, roughen embankment and fill areas by rolling with a crimping or punching-type roller or by track walking. Track walking should only be used where other methods are impractical.
- Hydraulic matrices require 24 hours to dry before rainfall occurs to be effective.
- Avoid mulch overspray onto the traveled way, sidewalks, lined drainage channels, and existing vegetation.
- Hydraulic mulch should be applied in accordance with Standard Specification, Section 625.08 (b), Hydraulic Method.
- Materials for hydraulic mulches and hydraulic matrices should conform to Standard Specification, Section 713.05.

Hydraulic Mulch

- Wood fiber mulch is a component of hydraulic applications. It is typically applied at the rate of 2,000 pounds per acre to 4,000 pounds per acre, with 0 percent to 5 percent by weight of a stabilizing emulsion or tackifier, such as guar, psyllium, and acrylic copolymer, and applied as a slurry. This type of mulch is manufactured from wood or wood waste from lumber mills or from urban sources.
- A hydraulic matrix is a combination of fiber mulch and a tackifier applied as a slurry. It is typically applied at the rate of 1,500 pounds per acre, with 5 percent to 10 percent by weight of a stabilizing emulsion or tackifier such as guar, psyllium, and acrylic copolymer.
- Bonded Fiber Matrix (BFM) is a hydraulically-applied system of fibers and adhesives that, upon drying, forms an erosion-resistant blanket that promotes vegetation and prevents soil erosion. BFMs are typically applied at rates from 3,400 kilograms per hectare to 4,500 kilograms per hectare, based on the manufacturer's recommendation. The biodegradable BFM is composed of

materials that are 100 percent biodegradable. The binder in the BFM should also be biodegradable and should not dissolve or disperse upon re-wetting. Typically, biodegradable BFMs should not be applied immediately before, during, or after rainfall, if the soil is saturated. Depending on the product, BFMs require 12 hours to 24 hours to dry to become effective.

Maintenance and Inspections

- Maintain an unbroken, temporary mulched ground cover throughout the period of construction when the soils are not being reworked. Inspect the ground cover before expected rain storms, repair any damaged ground cover, and re-mulch the exposed areas of bare soil.
- After any rainfall event, the contractor is responsible for maintaining all slopes to prevent erosion.

7.1.4 HYDROSEEDING

Definition and Purpose

Hydroseeding typically consists of applying a mixture of wood, plant or pulp fiber, seed, fertilizer, and stabilizing emulsion with hydromulch equipment, which temporarily protects exposed soils from erosion by water and wind. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

Hydroseeding is applied on disturbed soil areas requiring temporary protection until permanent vegetation is established, or disturbed soil areas that must be re-disturbed following an extended period of inactivity.

Limitations

- Hydroseeding may be used alone only when there is sufficient time in the season to ensure adequate vegetation establishment and erosion control. Otherwise, hydroseeding must be used in conjunction with a soil binder or heavier layer of mulching such as wood, plant, or pulp fiber mulch.
- Steep slopes are difficult to protect with temporary seeding.
- Temporary seeding may not be appropriate in dry periods without supplemental irrigation.
- Temporary vegetation may have to be removed before permanent vegetation is applied.
- Temporary vegetation is not appropriate for short-term inactivity.

Standards and Specifications

To select appropriate hydroseeding mixtures, an evaluation of site conditions should be performed with respect to:

- Soil conditions
- Site topography
- Season and climate
- Vegetation types
- Maintenance requirements
- Sensitive adjacent areas
- Water availability
- Plans for permanent vegetation

The following steps should be followed for implementation:

- Seed mix should comply with the Standard Specifications, Section 713.04, and be of type to match the application and climate conditions in accordance with the guidance provided by the Guam Division of Aquatic and Wildlife Resources (DAWR) or the USDA, National Resources Conservation Service (NRCS).
- Hydroseeding should be performed in accordance with Standard Specifications 625.06 or 625.07.
- Prior to application, roughen the slope, fill area, or area to be seeded with the furrows trending along the contours. Rolling with a crimping or punching-type roller or track walking is required on all slopes prior to hydroseeding. Track walking should only be used where other methods are impractical.
- Apply a fiber mulch to keep seeds in place and to moderate soil moisture and temperature until the seeds germinate and grow. Refer to Standard Specification 625.08.
- Follow-up applications should be made as needed to cover weak spots and to maintain adequate soil protection.
- Avoid overspray onto the traveled way, sidewalks, lined drainage channels, and existing vegetation.

Maintenance and Inspection

- All seeded areas should be inspected for failures and re-seeded, fertilized, and mulched within the planting season, using not less than half the original application rates. Any temporary re-vegetation efforts that do not provide adequate cover must be reapplied.

- After any rainfall event, the contractor is responsible for maintaining all slopes to prevent erosion.

7.1.5 SOIL BINDERS

Definition and Purpose

Soil binders consist of applying and maintaining a soil stabilizer to exposed soil surfaces. Soil binders are materials applied to the soil surface to temporarily prevent water-induced erosion of exposed soils on construction sites. Soil binders also provide temporary dust, wind, and soil stabilization (erosion control) benefits. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

Soil binders are typically applied to disturbed areas requiring short-term temporary protection. Because soil binders can often be incorporated into the work, they may be a good choice for areas where grading activities will soon resume, and as an application on stockpiles to prevent water and wind erosion.

Limitations

- Soil binders are temporary in nature and may need reapplication.
- Soil binders require a minimum curing time until fully-effective, as prescribed by the manufacturer, which may be 24 hours or longer. Soil binders may need reapplication after a storm event.
- Soil binders will generally experience spot failures during heavy rainfall events. If runoff penetrates the soil at the top of a slope treated with a soil binder, it is likely that the runoff will undercut the stabilized soil layer and discharge at a point farther down slope.
- Soil binders do not hold up to pedestrian or vehicular traffic across treated areas.
- Soil binders may not penetrate soil surfaces made up primarily of silt and clay, particularly when compacted.
- Some soil binders may not perform well with low relative humidity. Under rainy conditions, some agents may become slippery or leach out of the soil.

Standards and Specifications

General Considerations

- Site-specific soil types will dictate the appropriate soil binders to be used. Refer to the soil binder supplier's literature for proper soil types and application.

- A soil binder must be environmentally benign (non-toxic to plant and animal life), easy to apply, easy to maintain, economical, and should not stain paved or painted surfaces.
- Some soil binders are not compatible with existing vegetation. Check the supplier's guidelines for applications.
- Avoid overspray onto the traveled way, sidewalks, lined drainage channels, and existing vegetation.

Soil Binders Applications

After selecting an appropriate soil binder, the untreated soil surface must be prepared before applying the soil binder. The untreated soil surface must contain sufficient moisture to assist the agent in achieving uniform distribution. In general, the following steps should be followed:

- Follow the manufacturer's recommendations for the application rates, pre-wetting of the application area, and cleaning of equipment after use.
- Prior to application, roughen embankment and fill areas by rolling with a crimping or punching-type roller or by track walking. Track walking should only be used where rolling is impractical.
- Consider the drying time for the selected soil binder and apply with sufficient time before anticipated rainfall. Soil binders should not be applied during or immediately before rainfall.
- More than one treatment is often necessary, although the second treatment may be diluted or have a lower application rate.
- Generally, soil binders require a minimum curing time of 24 hours before they are fully effective. Refer to the manufacturer's instructions for specific cure times.

For Liquid Agents

- Crown or slope ground to avoid ponding.
- Uniformly pre-wet ground at 0.03 gallons per square yard of area, or according to the manufacturer's recommendations.
- Apply the solution under pressure. Overlap the solution 6 in. to 12 in.
- Allow the treated area to cure for the time recommended by the manufacturer, typically at least 24 hours.
- In low humidity, reactivate chemicals by re-wetting with water at 0.1 gallon per square yard area to 0.2 gallon per square yard.

Selecting a Soil Binder

The properties of common soil binders used for erosion control are provided in Table 7-5. Factors to consider when selecting a soil binder include the following:

- Suitability to situation: Consider where the soil binder will be applied; determine if it needs a high resistance to leaching or abrasion, and whether it needs to be compatible with any existing vegetation. Determine the length of time soil stabilization will be needed and if the soil binder will be placed in an area where it will degrade rapidly. In general, slope steepness is not a discriminating factor for the listed soil binders.
- Soil types and surface materials: Fines and moisture content are key properties of surface materials. Consider a soil binder's ability to penetrate, its likelihood of leaching, and its ability to form a surface crust on the surface materials.
- Frequency of application: The frequency of application can be affected by subgrade conditions, surface type, climate, and maintenance schedule. Frequent applications could lead to high costs. Application frequency may be minimized if the soil binder has good penetration, low evaporation, and good longevity. Also consider that frequent application will require frequent equipment cleanup.

After considering the above factors, the soil binders in Table 7-5 will be generally appropriate, as follows:

Plant Material Based (Short-Lived)

- **Guar:** Guar is a nontoxic, biodegradable, natural galactomannan-based hydrocolloid treated with dispersant agents for easy field mixing. It should be diluted at the rate of 1 pound to 5 pounds per 100 gallons of water, depending on the capacity of the application machine. The recommended minimum application rates are as follows:

Slope (V:H)	Flat	1:4	1:3	1:2	1:1
Lb/Acres	40	45	50	60	70

Table 7-3: Application Rates for Guar Stabilizer

- **Psyllium:** Psyllium is composed of the finely-ground mucilloid coating of plantago seeds that is applied as a dry powder or in a wet slurry to the surface of the soil. It dries to form a firm but re-wettable membrane that binds soil particles together but permits germination and seed growth. Psyllium requires 2 hours to 8 hours of drying time. Psyllium should be applied at a rate of 80 pounds per acre to 200 pounds per acre, with enough water in the solution to allow for a uniform slurry flow.

- **Starch:** Starch is non-ionic, cold-water soluble (pre-gelatinized), granular cornstarch. The material is mixed with water and applied at the rate of 150 pounds per acre. The approximate drying time is 9 hours to 12 hours.

Plant Material Based (Long-Lived)

- **Pitch and Rosin Emulsion:** Generally, a non-ionic pitch and rosin emulsion has a minimum solids content of 48 percent. The rosin should be a minimum of 26 percent of the total solids content. The soil stabilizer should be non-corrosive, water-dilutable, emulsion that upon application, cures to a water-insoluble binding and cementing agent. For soil erosion control applications, the emulsion is diluted and should be applied as follows:
  - For clayey soil: Five parts water to 1 part emulsion
  - For sandy soil: Zero parts water to 1 part emulsion
- The application can be by water truck or hydraulic seeder, with the emulsion/product mixture applied at the rate specified by the manufacturer. The approximate drying time is 19 hours to 24 hours.

Polymeric Emulsion Blends

- ***Acrylic Copolymers and Polymers:*** Polymeric soil stabilizers should consist of a liquid or solid polymer or copolymer with an acrylic base that contains a minimum of 55 percent solids. The polymeric compound should be handled and mixed in a manner that will not cause foaming, or it should contain an anti-foaming agent. The polymeric emulsion should not exceed its shelf life or expiration date; manufacturers should provide the expiration date. Polymeric soil stabilizer should be readily miscible in water, non-injurious to seed or animal life, and non-flammable; provide surface soil stabilization for various soil types without totally inhibiting water infiltration; and not re-emulsify when cured. The applied compound should air cure within a maximum of 36 hours to 48 hours. Liquid copolymer should be diluted at a rate of 10 parts water to 1 part polymer, and applied to soil at a rate of 11,000 liters per hectare (1,175 gallons per acre).
- ***Liquid Polymers of Methacrylates and Acrylates:*** This material consists of a tackifier/sealer that is a liquid polymer of methacrylates and acrylates. It is an aqueous 100 percent acrylic emulsion blend of 40 percent solids by volume that is free from styrene, acetate, vinyl, ethoxylated surfactants, or silicates. For soil stabilization applications, it is diluted with water in accordance with the manufacturer's recommendations and applied with a hydraulic seeder at the rate

of 190 liters per hectare (20 gallons per acre). The drying time is 12 hours to 18 hours after application.

- ***Copolymers of Sodium Acrylates and Acrylamides***: These materials are nontoxic, dry powders that are copolymers of sodium acrylate and acrylamide. They are mixed with water and applied to the soil surface for erosion control at rates that are determined by slope gradient:

Slope Gradient (V:H)	Lbs/Acres
Flat to 1:5	3-5
1:5 to 1:3	5-10
1:2 to 1:1	10-20

Table 7-4: Application Rates for Copolymers

- **Polyacrylamide and Copolymer of Acrylamide:** Linear copolymer polyacrylamide is packaged as a dry-flowable solid. When used as a stand-alone stabilizer, it is diluted at a rate of 1 pound per 100 gallons of water and applied at the rate of 15 pounds per acre.
- **Hydrocolloid Polymers:** Hydrocolloid polymers are various combinations of dry-flowable polyacrylamides, copolymers, and hydrocolloid polymers that are mixed with water and applied to the soil surface at rates of 60 kilograms per hectare to 70 kilograms per hectare (53 pounds per acre to 62 pounds per acre). Drying times are 0 hours to 4 hours.

Cementitious-Based Binders

- **Gypsum:** This is a formulated gypsum-based product that readily mixes with water and mulch to form a thin protective crust on the soil surface. It is composed of high-purity gypsum that is ground, calcined, and processed into calcium sulfate hemihydrate with a minimum purity of 86 percent. It is mixed in a hydraulic seeder and applied at rates of 4,000 pounds per acre to 12,000 pounds per acre. The drying time is 4 hours to 8 hours.

Maintenance and Inspection

- Reapplying the selected soil binder may be needed for proper maintenance. High-traffic areas should be inspected daily, and lower traffic areas should be inspected weekly.
- After any rainfall event, the contractor is responsible for maintaining all slopes to prevent erosion.

- Maintain an unbroken, temporary stabilized area while disturbed soil areas are non-active.
- Repair any damaged, stabilized area and reapply soil binder to exposed areas.

Properties of Soil Binders for Erosion Control				
Chemicals	**Plant-Material Based (Short-Lived)**	**Plant-Material Based (Long-Lived)**	**Polymeric Emulsion Blends**	**Cementitious-Based Binders**
Relative Cost	Low	Low	Low	Low
Resistance to Leaching	High	High	Low to Moderate	Moderate
Resistance to Abrasion	Moderate	Low	Moderate to High	Moderate to High
Longevity	Short to Medium	Medium	Medium to Long	Medium
Minimum Curing Time Before Rain	9 to 18 hours	19 to 24 hours	0 to 24 hours	4 to 8 hours
Compatibility with Existing Vegetation	Good	Poor	Poor	Poor
Mode of Degradation	Biodegradable	Biodegradable	Photodegradable/ Chemically Degradable	Photodegradable/ Chemically Degradable
Labor Intensive	No	No	No	No
Specialized Application Equipment	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher
Liquid/Powder	Powder	Liquid	Liquid/Powder	Powder
Surface Crusting	Yes, but dissolves on re-wetting	Yes	Yes, but dissolves on rewetting	Yes
Cleanup	Water	Water	Water	Water
Erosion Control Application Rate	Varies (1)	Varies (1)	Varies (1)	4,500 to 13,500 kg/ha

(1) See application rate Tables 7-3 and 7-4.

Table 7-5: Properties of Soil Binders for Erosion Control

7.1.6 FIBER MULCH

Definition and Purpose

Using fiber mulch involves placing a uniform layer of wood, vegetable, or pulp fibers, and incorporating it into the soil with a studded roller or anchoring it with a stabilizing emulsion. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

- Fiber mulch is typically used for soil stabilization as a temporary surface cover on disturbed areas until soils can be prepared for re-vegetation and permanent vegetation is established.

- Also, fiber mulch is typically used in combination with temporary and/or permanent seeding strategies to enhance plant establishment.

Limitations

- The availability of erosion control contractors and fiber may be limited prior to the rainy season due to high demand.
- There is a potential for the introduction of weed-seed and unwanted plant material in vegetable fiber such as grass or straw mulch.
- When blowers are used to apply fiber mulch, the treatment areas must be within 150 ft. of a road or surface capable of supporting trucks.
- Fiber mulch applied by hand is more time intensive and potentially costly.
- Fiber mulch may have to be removed prior to permanent seeding or soil stabilization.
- The “punching” of fiber mulch does not work in sandy soils.

Standards and Specifications

- All materials should conform to the Standard Specifications. A tackifier is the preferred method for anchoring fiber mulch to the soil on slopes.
- Crimping, punch roller-type rollers, or track walking may also be used to incorporate fiber mulch into the soil on slopes. Track walking should only be used where other methods are impractical.
- Avoid placing mulch onto the traveled way, sidewalks, lined drainage channels, sound walls, and existing vegetation.
- Fiber mulch with tackifier should not be applied during or immediately before rainfall.

Application Procedures

- Apply loose fiber at a minimum rate of 3,200 pounds per acre or, as indicated in the Standard Specification 625.08.
- If stabilizing emulsion will be used to anchor the fiber mulch, roughen the embankment or fill areas by rolling with a crimping or punching-type roller, or by track walking before placing the mulch. Track walking should only be used where rolling is impractical.
- The fiber mulch must be evenly distributed on the soil surface.
- Anchor the mulch in place by using a tackifier or by punching it into the soil mechanically (incorporating).

- A tackifier acts to glue the mulch fibers together and to the soil surface. The tackifier should be selected based on its longevity and ability to hold the fibers in place.
- A tackifier is typically applied at a rate of 125 pounds per acre. In windy conditions, the rates are typically 178 pounds per acre.
- Methods for holding the fiber mulch in place depend upon the slope steepness, accessibility, soil conditions, and longevity. If the selected method is the incorporation of fiber mulch into the soil, then perform the following:
    - Applying and incorporating fiber should follow the requirements of Standard Specification 625.08.
    - On small areas, a spade or shovel can be used.
    - On slopes with soils that are stable enough and of sufficient gradient to safely support construction equipment without contributing to compaction and instability problems, mulch can be punched into the ground using a knife blade roller or a straight-bladed coulter, known commercially as a crimper.
    - On small areas and/or steep slopes, straw can also be held in place using plastic netting or jute. The netting should be held in place using 11-gauge wire staples, geotextile pins, or wooden stakes.

Maintenance and Inspections

- The key consideration in maintenance and inspection is that the mulch needs to last long enough to achieve erosion control objectives.
- Maintain an unbroken, temporary mulched ground cover while disturbed soil areas are non-active. Repair any damaged ground cover and re-mulch exposed areas.
- The reapplication of fiber mulch and tackifier may be required to maintain effective soil stabilization over disturbed areas and slopes.
- After any rainfall event, the contractor is responsible for maintaining all slopes to prevent erosion

7.1.7 GEOTEXTILES, PLASTIC COVERS, AND EROSION CONTROL BLANKETS/MATS

Definition and Purpose

This BMP involves the placement of geotextiles, mats, plastic covers, or erosion control blankets to stabilize disturbed soil areas and protect soils from erosion by wind or water. This is one of the five temporary soil stabilization alternatives to consider.

Appropriate Applications

These measures are used when disturbed soils may be particularly difficult to stabilize, including the following situations:

- Steep slopes, generally steeper than 1:3 (V:H)
- Slopes where the erosion potential is high
- Slopes and disturbed soils where plants are slow to develop
- Slopes and disturbed soils where mulch must be anchored
- Channels with flows exceeding 3.3 ft. per second
- Channels to be vegetated
- Stockpiles
- Slopes adjacent to environmentally sensitive areas

Limitations

- Blankets and mats are more expensive than other erosion control measures due to labor and material costs. This usually limits their application to areas inaccessible to hydraulic equipment or where other measures are not applicable, such as channels.
- Blankets and mats are generally not suitable for excessively rocky sites or areas where final vegetation will be mowed (because staples and netting can get caught in the mower).
- Blankets and mats must be removed and disposed of prior to the application of permanent soil stabilization measures.
- Plastic sheet is easily vandalized, easily torn, and photodegradable, and must be disposed of at a landfill.
- Plastic results in 100 percent runoff, which may cause serious erosion problems in the areas receiving increased flows.
- The use of plastic should be limited to covering stockpiles, or very small graded areas for short periods of time (such as through one imminent storm event), until alternative measures, such as seeding and mulching, may be installed.
- Geotextile, mats, plastic covers, and erosion control blankets have maximum flow rate limitations; consult the manufacturer for proper selection.

Standards and Specifications

There are many types of erosion control blankets and mats, and selection of the appropriate type should be based on the specific type of application and site conditions.

Selections made by the contractor must be approved with certification compliance made in accordance with the Standard Specifications.

Geotextile

- Materials should be woven polypropylene fabric with a minimum thickness of 0.06 in.; a minimum width of 12 ft.; and a minimum tensile strength of 0.67 kiloNewtons (warp), 0.36 kiloNewtons (fill), in conformance with the requirements in the American Society for Testing and Materials (ASTM) Designation D4491. The fabric should have a UV stability of 70 percent in conformance with the requirements in ASTM Designation D4355. Geotextile blankets should be secured in place with wire staples or sandbags and by keying into the tops of slopes and edges to prevent the infiltration of surface waters under geotextile. Staples should be made of 0.12 in. of steel wire and U-shaped, with 8-in. legs and a 2-in. crown.
- Geotextile materials may be reused if they are suitable for their intended use.

Plastic Covers

- Plastic sheeting should have a minimum thickness of 6 mils and should be keyed in at the top of the slope and firmly placed with sandbags or other weights placed no more than 10 ft. apart. Seams are typically taped or weighted down their entire length, and there should be at least a 12-in. to a 24-in. overlap of all seams. Edges should be embedded a minimum of 6 in. in soil.
- All sheeting should be inspected periodically after installation and after significant rainstorms to check for erosion, undermining, and anchorage failure. Any failure should be repaired immediately. If washout or breakages occur, the material should be re-installed after repairing damage to the slope.

Erosion Control Blankets/Mats

- ***Biodegradable Rolled Erosion Control Products (RECPs)*** are typically comprised of jute fibers, curled wood fibers, straw, coconut fibers, or a combination of these materials. For an RECP to be considered 100 percent biodegradable, the netting, sewing, or adhesive system that holds the biodegradable mulch fibers together must also be biodegradable.
- ***Jute*** is a natural fiber that is made into yarn, which is loosely woven into a biodegradable mesh. It is designed to be used in conjunction with vegetation and has a longevity of approximately one year. The material is supplied in rolled strips, which should be secured to soil with U-shaped staples or stakes in accordance with the manufacturer's recommendations.

- ***Excelsior (curled wood fiber) blanket*** materials should consist of machine-produced mats of curled wood excelsior with 80 percent of the fiber 6 in. or longer. The excelsior blanket should be of consistent thickness. The wood fiber should be evenly distributed over the entire area of the blanket. The top surface of the blanket should be covered with a photodegradable extruded plastic mesh. The blanket should be smolder resistant without the use of chemical additives and nontoxic and non-injurious to plant and animal life. An excelsior blanket should be furnished in rolled strips, a minimum of 48 in. wide, and should have an average weight of 12 pounds per square foot, ± 10 percent, at the time of manufacture. Excelsior blankets should be secured in place with wire staples. Staples should be made of 0.12-in. steel wire U-shaped, with 8-in. legs and a 2-in. crown.
- ***Straw blanket*** should be machine-produced mats of straws with lightweight biodegradable netting top layers. The straw should be attached to the netting with biodegradable threads or glue strips. The straw blanket should be of consistent thickness. The straw should be evenly distributed over the entire area of the blanket. Straw blanket should be furnished in rolled strips a minimum of 6.5 ft. wide, a minimum of 80 ft. long, and a minimum of 6.4 pounds per square foot. Blankets should be secured to the ground using wire staples. Staples should be made of 0.12-in. steel wires and U-shaped, with 8-in. legs and a 2-in. crown.
- ***Wood fiber blanket*** is composed of biodegradable fiber mulch, with extruded plastic netting held together with adhesives. The material is designed to enhance re-vegetation. The material is furnished in rolled strips, which should be secured to the ground with U-shaped staples or stakes in accordance with the manufacturer's recommendations.
- ***Coconut fiber blanket*** should be machine-produced mats of 100 percent coconut fiber with biodegradable netting on the top and bottom. The coconut fiber should be attached to the netting with biodegradable thread or glue strips. The coconut blanket should be of consistent thickness. The coconut fiber should be evenly distributed over the entire area of the blanket. The coconut fiber blanket should be furnished as rolled strips a minimum of 6.5 ft. wide, 80 ft. long, and 6.4 pounds per square foot. Coconut fiber blankets should be secured in place with wire staples. Staples should be made of 0.12-in. steel wire and U-shaped, with 8-in. legs and a 2-in. crown.
- ***Coconut fiber mesh*** is a thin permeable membrane made from coconut or corn fiber that is spun into yarn and woven into a biodegradable mat. It is designed to be used in conjunction with vegetation and typically has a longevity of several years. The material is supplied in rolled strips, which

should be secured to the soil with U-shaped staples or stakes in accordance with the manufacturer's recommendations.

- ***Straw coconut fiber blankets*** should be machine-produced mats of 70 percent straw and 30 percent coconut fiber with a biodegradable netting top layer and a biodegradable bottom net. The straw and coconut fiber should be attached to the netting with biodegradable thread or glue strips. The straw coconut fiber blankets should be of consistent thickness. The straw coconut fiber should be evenly distributed over the entire area of the blanket. Straw coconut fiber blankets should be furnished in rolled strips a minimum of 6.5 ft. wide, 80 ft. long, and 6.4 pounds per square foot. Straw coconut fiber blankets should be secured in place with wire staples. Staples should be made of 0.12-in. steel wires and U-shaped, with 8-in. legs and a 2-in. crown.

- ***Non-biodegradable RECPs*** are typically composed of polypropylene, polyethylene, nylon, or synthetic fibers. In some cases, a combination of biodegradable and synthetic fibers is used to construct the RECP. Netting is used to hold these fibers together and is also typically non-biodegradable.

- ***Plastic netting*** is a lightweight biaxial-oriented netting designed for securing loose mulches like straw to soil surfaces to establish vegetation. The netting is photo-biodegradable. The netting is supplied in rolled strips, which should be secured with U-shaped staples or stakes in accordance with the manufacturer's recommendations.

- ***Plastic mesh*** is an open-weave geotextile that is composed of an extruded synthetic fiber woven into a mesh with an opening size of less than 0.2 in. It is used with re-vegetation or may be used to secure loose fibers to the ground, such as straw. The material is supplied in rolled strips, which should be secured to the soil with U-shaped staples or stakes in accordance with the manufacturer's recommendations.

- ***Synthetic fibers with netting*** form a mat composed of durable synthetic fibers treated to resist chemicals and UV light. The mat is a dense, three-dimensional mesh of synthetic fibers (typically polyolefin) stitched between two polypropylene nets. The mat is designed to be re-vegetated and provide a permanent composite system of soils, roots, and geomatrix. The material is furnished in rolled strips, which should be secured with U-shaped staples or stakes in accordance with the manufacturer's recommendations.

- ***Bonded synthetic fibers*** consist of three-dimensional geomatrix nylon (or other synthetic) matting. Typically, the matting has more than 90 percent open area, which facilitates root growth. It can reinforce roots, anchor vegetation, and protect against hydraulic lift and shear forces created by high-volume discharges. It can be installed over prepared soil, followed by seeding into the mat. Once vegetated, it becomes an invisible composite system of soils, roots, and geomatrix. The material is furnished in rolled strips, which should be secured with U-shaped staples or stakes in accordance with the manufacturer's recommendations.

- ***Combination synthetic and biodegradable RECPs*** consist of biodegradable fibers, such as wood fibers or coconut fiber, with a heavy polypropylene net stitched to the top and a high-strength continuous filament geomatrix or net stitched to the bottom. The material is designed to enhance re-vegetation. The material is furnished in rolled strips, which should be secured with U-shaped staples or stakes in accordance with the manufacturer's recommendations.

Site Preparation

- Proper site preparation is essential to ensure complete contact of the blanket or matting with the soil grade, and shape the area of installation.
- Remove all rocks, clods, vegetation, or other obstructions so that the installed blankets or mats will have complete direct contact with soil.
- Prepare the seed bed by loosening 2 in. to 3 in. of soil.

Seeding

Seed the area before blanket installation for erosion control and re-vegetation. Seeding after mat installation is often specified for turf reinforcement application. When seeding prior to blanket installation, all check slots and other areas disturbed during installation must be re-seeded. Where soil filing is specified, seed the matting and the entire disturbed area after installation and prior to filling the mat with soil.

Anchoring

- U-shaped wire staples, metal geotextile stake pins, or triangular wooden stakes can be used to anchor mats and blankets to the ground.
- Staples should be made of 0.12-in. steel wire and U-shaped, with 8-in. legs and a 2-in. crown.
- Metal stake pins should be 0.188-in. diameter steel with a 1.5-in. steel washer at the head of the pin.
- Wire staples and metal stakes should be driven flush to the soil surface.
- All anchors should be 6 in. to 8 in. long and have sufficient ground penetration to resist pullout. Longer anchors may be required for loose soils.

Installation on Slopes

Installations should be in accordance with the manufacturer's recommendations. In general, these will be as follows:

- Begin at the top of the slope, and anchor the blanket in 6-in. deep by 6-in. wide trench. Backfill the trench and tamp the earth gently.
- Unroll the blanket down-slope in the direction of water flow.
- Overlap the edges of the adjacent, parallel roll 2 in. to 3 in., and staple it every 3 ft.
- When blankets must be spliced, place the blankets end-over-end (shingle style), with a 6-in. overlap. Staple through the overlap area, approximately 12 in. apart.

Temporary Soil Stabilization Removal

When no longer required for work, temporary soil stabilization should become the property of the contractor. Temporary soil stabilization removed from the site of the work should be disposed of outside of highway rights-of-way.

Maintenance and Inspection

- Areas treated with temporary soil stabilization should be inspected weekly and after each heavy rain. Areas treated with temporary soil stabilizations should be maintained to provide adequate erosion control. Temporary soil stabilization should be reapplied or replaced on exposed soils when the area becomes exposed or exhibits visible erosion.
- Installation should be inspected after significant rainstorms to check for erosion and undermining. Any failures should be repaired immediately.
- If washout or breakage occurs, re-install the material after repairing the damage to the slope of the channel.

7.1.8 TEMPORARY CONCETRATED FLOW CONVEYANCE CONTROLS

Temporary concentrated flow conveyance controls consist of a system of measures or BMPs that are used alone or in combination to intercept, divert, convey, and discharge concentrated flows with a minimum of soil erosion, both on-site and downstream (off-site). Temporary concentrated flow conveyance controls may be required to direct run-on around or through the project in a non-erodible fashion. Temporary concentrated flow conveyance controls include the following BMPs:

- Earth dikes, drainage swales, and lined ditches
- Outlet protection/velocity dissipation devices
- Slope drains

7.1.8.1 EARTH DIKES, DRAINAGE SWALES, AND LINED DITCHES

Definition and Purpose

These are structures that intercept, divert, and convey surface run-on, generally sheet flow, to prevent erosion.

Appropriate Applications

- Earth dikes, drainage swales, and lined ditches may be used to:
  - Convey surface runoff down sloping land
  - Intercept and divert runoff to avoid flow over sloped surfaces
  - Divert and direct runoff toward a stabilized watercourse, drainage pipe, or channel
  - Intercept runoff from paved surfaces
- Earth dikes, drainage swales, and lined ditches also may be used:
  - Below steep grades where runoff begins to concentrate
  - Along roadways and facility improvements subject to flood drainage
  - At the top of slopes to divert run-on from adjacent or undisturbed slopes
  - At bottom and mid-slope locations to intercept sheet flow and convey concentrated flows
- This BMP may be implemented on a project-by-project basis with other BMPs, when determined necessary and feasible.

Limitations

- Earth dikes, drainage swales, and lined ditches are not suitable as sediment-trapping devices.
- It may be necessary to use other soil stabilization and sediment controls, such as check dams, plastics, and blankets, to prevent scour and erosion in newly-graded dikes, swales, and ditches.

Standards and Specifications

- Care must be applied to correctly size and locate earth dikes, drainage swales, and lined ditches. Excessively steep, unlined dikes and swales are subject to erosion and gully formation.
- Conveyances should be stabilized.
- Use a lined ditch for high flow velocities.

- Select flow velocity based on careful evaluation of the risks due to erosion of the measure, soil types, overtopping, flow back-ups, washout, and drainage flow patterns for each project site.
- Compact any fills to prevent unequal settlement.
- Do not divert runoff from the highway right-of-way onto other property.
- When possible, install and utilize permanent dikes, swales, and ditches early in the construction process.
- Provide stabilized outlets.

Maintenance and Inspections

- Inspect temporary measures prior to the rainy season, after significant rainfall events, and regularly (approximately once per week) during the rainy season.
- Inspect ditches and berms for washouts. Replace lost riprap, damaged linings, or soil stabilizers as needed.
- Inspect channel linings, embankments, and beds of ditches and berms for erosion and the accumulation of debris and sediment. Remove debris and sediment, and repair linings and embankments as needed.
- Temporary conveyances should be completely removed as soon as the surrounding drainage area has been stabilized, or at the completion of construction.

7.1.8.2 OUTLET PROTECTION/VELOCITY DISSIPATION DEVICES

Definition and Purpose

These devices are placed at pipe outlets to prevent scour and reduce the velocity and/or energy of stormwater flows.

Appropriate Applications

- Outlets of pipes, drains, culverts, slope drains, diversion ditches, swales, conduits, or channels
- Outlets located at the bottom of mild to steep slopes
- Discharge outlets that carry continuous flows of water
- Outlets subject to short, intense flows of water, such as flash floods
- Points where lined conveyances discharge to unlined conveyances
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible.

Limitations

- Loose rock may have stones washed away during high flows.
- If there is not adequate under-drainage and water builds up behind grouted riprap, it may cause the grouted riprap to break up due to the resulting hydrostatic pressure.

Standards and Specifications

- There are many types of energy dissipaters. See FHWA publication HEC-14 for details on types, applications, and design guidelines.
- Install riprap, grouted riprap, or concrete apron at the selected outlet. Riprap aprons are best suited for temporary use during construction.
- Carefully place riprap to avoid damaging the filter fabric.
- For proper operation of apron:
    - Align apron with receiving stream and keep straight throughout its length. If a curve is needed to fit site conditions, place it in the upper section of apron.
    - If the size of the apron riprap is large, protect underlying filter fabric with a gravel blanket.
- Outlets on slopes steeper than 10 percent should have additional protection.

Maintenance and Inspection

- Inspect temporary measures prior to the rainy season, after rainfall events, and regularly (approximately once per week) during the rainy season.
- Inspect the apron for displacement of the riprap and/or damage to the underlying fabric. Repair fabric and replace riprap that has washed away.
- Inspect for scour beneath the riprap and around the outlet. Repair damage to slopes or underlying filter fabric immediately.
- Temporary devices should be completely removed as soon as the surrounding drainage area has been stabilized, or at the completion of construction.

7.1.8.3 SLOPE DRAINS

Definition and Purpose

A slope drain is a pipe used to intercept and direct surface runoff or groundwater into a stabilized watercourse, trapping device, or stabilized area. Slope drains are used with lined ditches to intercept and direct surface flow away from slope areas to protect cut or fill slopes.

Appropriate Applications

- Slope drains may be used on construction sites where slopes may be eroded by surface runoff.
- This BMP may be implemented on a project-by-project basis with other BMPs, when determined necessary and feasible.

Limitations

Severe erosion may result when slope drains fail by overtopping, piping, or pipe separation.

Standards and Specifications

- When using slope drains, limit the drainage area to 10 acres per pipe. For larger areas, use a rock-lined channel or a series of pipes.
- The maximum slope is generally limited to 1:2 (V:H), as energy dissipation below steeper slopes is difficult.
- Direct surface runoff to slope drains with interceptor dikes.
- Slope drains can be placed on or buried underneath the slope surface.
- Recommended materials are PVC, ABS, or comparable pipe.
- When installing slope drains:
    - Install slope drains perpendicular to slope contours.
    - Compact soil around and under the entrance, outlet, and along the pipe's length.
    - Securely anchor and stabilize pipe and appurtenances into soil.
    - Check to ensure that pipe connections are watertight.
    - Protect the area around the inlet with filter cloth. Protect the outlet with riprap or another energy-dissipation device. For high-energy discharges, reinforce riprap with concrete or use a reinforced-concrete device.
    - Protect the inlet and outlet of slope drains; use standard flared-end sections at the entrance and exit for pipe slope drains 12 in. and larger.

Maintenance and Inspection

- Inspect before and after each rain storm and twice monthly until the tributary drainage area has been stabilized. Follow routine inspection procedures for inlets thereafter.
- Inspect the outlet for erosion and downstream scour. If eroded, repair the damage and install additional energy dissipation measures. If downstream scour

is occurring, it may be necessary to reduce flows being discharged into the channel unless other preventive measures are implemented.

- Inspect slope drainage for accumulations of debris and sediment.
- Remove built-up sediment from entrances, outlets, and within drains as required.
- Make sure water is not ponding onto inappropriate areas (e.g., active traffic lanes, material storage areas, etc.).

7.1.9 STREAMBANK STABILIZATION

Definition and Purpose

Drainage systems, including the stream channel, streambank, and associated riparian areas, are dynamic and sensitive ecosystems that respond to changes in land use activity. Streambank and channel disturbance resulting from construction activities can increase the stream's sediment load, which can cause channel erosion or sedimentation and have adverse affects on the biotic system. BMPs can reduce the discharge of sediment and other pollutants and minimize the impact of construction activities on watercourses.

Appropriate Applications

These procedures typically apply to all construction projects that disturb or occur within stream channels and their associated riparian areas.

Limitations

Specific permit requirements such as a 401 certification or a U.S. Army Corps of Engineers (COE) 404 permit, may be included in the contract documents.

Standards and Specifications

Planning

Proper planning, design, and construction techniques can minimize impacts normally associated with in-stream construction activities. Poor planning can adversely affect soil, fish, and wildlife resources, land uses, or land users. Planning should take the following into account -- scheduling, avoiding in-stream construction, minimizing the disturbance area and construction time period, using pre-disturbed areas, selecting a crossing location, and selecting equipment.

Scheduling

Construction activities should be scheduled according to the relative sensitivity of the environmental concerns and in accordance with scheduling. When working in or near streams, work should be performed during the dry season. However, when closing the site at the end of the project, wash any fines (see washing fines) that accumulated in the channel back into the bed material to decrease pollution from the first rainstorm ("first flush") of the season. When working near streams, erosion and sediment controls (see silt fences, etc.) should be implemented to keep sediment out of the stream channel.

Minimizing Disturbance

Minimize disturbance by selecting the narrowest crossing location, limiting the number of equipment trips across a stream during construction, and minimizing the number and size of work areas (equipment staging areas and spoil storage areas). Place work areas at least 50 ft. from the stream channel. Provide stabilized access to the stream when in-stream work is required. Field reconnaissance should be conducted during the planning stage to identify work areas.

Using Pre-Disturbed Areas

Locate project sites and work areas in pre-disturbed areas when possible.

Selecting a Project Site

- Avoid steep and unstable banks, highly erodible or saturated soils, or highly fractured rock.
- Select a project site that minimizes disturbance to aquatic species or habitat.

Selecting Equipment

Select equipment that reduces the amount of pressure exerted on the ground surface and, therefore, reduces erosion potential, and/or use overhead or aerial access for transporting equipment across drainage channels. Use equipment that exerts ground pressures of less than 5 pounds or 6 pounds per sq. in., where possible. Low ground pressure equipment includes wide or high flotation tires 34 in. to 72 in. wide, dual tires, bogie axle systems, tracked machines, lightweight equipment, and central tire inflation systems.

Preservation of Existing Vegetation

Preserve existing vegetation to the maximum extent possible. The preservation of existing vegetation provides the following benefits:

Water Quality Protection

Vegetated buffers on slopes trap sediment and promote groundwater recharge. The buffer width needed to maintain water quality ranges from 16 ft. to 98 ft. On gradual slopes, most of the filtering occurs within the first 33 ft. Steeper slopes require a greater width of vegetative buffer to provide water quality benefits.

As a general rule, the width of a buffer strip between a road and the stream is recommended to be 48 ft. plus four times the percent slope of the land, measured between the road and the top of streambank.

Streambank Stabilization

The root system of riparian vegetation stabilizes streambanks by increasing tensile strength in the soil. The presence of vegetation modifies the moisture condition of slopes (infiltration, evapotranspiration, interception) and increases bank stability.

Riparian Habitat

Buffers of diverse riparian vegetation provide food and shelter for riparian and aquatic organisms. Minimizing impacts to fisheries habitat is a major concern when working near streams and rivers. Riparian vegetation provides shade, shelter, organic matter (leaf detritus and large woody debris), and other nutrients that are necessary for fish and other aquatic organisms.

When working near watercourses, it is important to understand the work site's placement in the watershed. Riparian vegetation in the headwater streams has a greater impact on overall water quality than vegetation in downstream reaches. Preserving existing vegetation upstream is necessary to maintain water quality, minimize bank failure, and maximize riparian habitat downstream of the work site.

Vegetative Stabilization of Disturbed Soil Areas

Disturbed soil areas above the ordinary high water level should be immediately stabilized by using the seeding, mulching, and/or soil binder BMPs listed above. Do not place mulch, fertilizer, seed, and binders below the ordinary water level, as these materials could wash into the channel and impact water quality.

Geotextiles, Plastic Covers, and Erosion Control Blankets/Mats

Install geotextiles, erosion control blankets, and plastic BMPs as described earlier to stabilize disturbed channels and streambanks. Geotextile fabrics that are not biodegradable are not appropriate for in-stream use. Additionally, geotextile fabric or blankets placed in channels must be adequate to sustain anticipated hydraulic forces.

Earth Dikes/Drainage Swales, and Lined Ditches

Convey, intercept, or divert runoff from disturbed streambanks using earth dikes, drainage swales, and lined ditches, as described above.

Limitations

Do not place earth dikes in watercourses, as these structures are only suited for intercepting sheet flow and should not be used to intercept concentrated flow.

Place appropriately-sized outlet protection and energy dissipation devices at outlets of pipes, drains, culverts, slope drains, diversion ditches, swales, conduits, or channels.

Slope Drains

Use slope drains to intercept and direct surface runoff or groundwater from dikes, swales, and lined ditches that intercept flow away from the streambanks, discharging into the lower stream channel with a stable outlet.

Limitations

Appropriately-sized outlet protection/velocity dissipation devices must be placed at outlets to minimize erosion and scour.

7.2 TEMPORARY SEDIMENT CONTROL PRACTICES

Temporary sediment control practices include those practices that intercept and slow or detain the flow of stormwater to allow sediment to settle and be trapped. These practices can consist of installing temporary linear sediment barriers (such as silt fences and sandbag barriers); providing fiber rolls, gravel bag berms, or check dams to break up slope length or flow; or constructing a temporary sediment/de-silting basin on sediment trap. Linear sediment barriers are typically placed below the toe of exposed and erodible slopes, down slope of exposed soil areas, around temporary stockpiles, and at other appropriate locations along the site perimeter.

Temporary sediment control practices include the BMPs listed in Table 7-6.

Temporary Sediment Control BMPs
Silt Fence
Sediment Basin
Sediment Trap
Check Dam
Fiber Rolls
Gravel Bag Berm
Street Sweeping
Sandbag Barrier
Storm Drain Inlet Protection
Streambank Sediment Control

Table 7-6: Temporary Sediment Control BMPs

7.2.1 SILT FENCE

Definition and Purpose

A silt fence is a temporary linear sediment barrier of permeable fabric designed to intercept and slow the flow of sediment-laden sheet flow runoff. Silt fences allow sediment to settle from runoff before water leaves the construction site.

Appropriate Applications

- Below the toe of exposed and erodible slopes
- Down slope of exposed soil areas
- Around temporary stockpiles
- Along streams and channels
- Along the perimeter of a project

Limitations

- Not intended for use as mid-slope protection on slopes greater than 1:4 (V:H).
- Must be maintained.
- Must be removed and disposed of.
- Not intended for use below slopes subject to creep, slumping, or landslides.
- Not intended for use in streams, channels, drain inlets, or anywhere flow is concentrated.
- Not intended to divert flow.

Standards and Specifications

Design and Layout

- The maximum length of slope draining to any point along the silt fence should be 200 ft. or less.
- Slope of area draining to silt fence should be less than 1:1 (V:H).
- Limit to locations suitable for temporary ponding or deposition of sediment.
- Fabric life span generally limited to between five and eight months. Longer periods may require fabric replacement.
- Silt fences should not be used in concentrated flow areas.
- For slopes steeper than 1:2 (V:H) and that contain a high number of rocks or large dirt clods that tend to dislodge, it may be necessary to install additional protection immediately adjacent to the bottom of the slope prior to installing the silt fence. Additional protection may be a chain link fence or a cable fence.
- For slopes adjacent to water bodies or other environmentally-sensitive areas, additional temporary soil stabilization BMPs should be used.

Materials

- Silt fence fabric should be woven polypropylene with a minimum width of 36 in. and a minimum tensile strength of 0.45-kN. The fabric should conform to the requirements in ASTM Designation D4632 and have an integral reinforcement layer. The reinforcement layer should be a polypropylene, or equivalent, net provided by the manufacturer. The permeability of the fabric should be in conformance with the requirements in ASTM Designation D4491. The contractor must submit a certificate of compliance.
- Wood stakes should be commercial-quality lumber of the size and shape shown on the plans. Each stake should be free from decay, splits, or cracks longer than the thickness of the stake or other defects that would weaken the stakes and cause the stakes to be structurally unsuitable.
- Bar reinforcement may be used, and its size should be equal to a number four or greater. End protection should be provided for any exposed bar reinforcement.
- Staples used to fasten the fence fabric to the stakes should be not less than 1.75 in. long and fabricated from 0.06-in or heavier wire. The wire used to fasten the tops of the stakes together when joining two sections of fence should be 0.12-in. or heavier wire.
- Galvanizing of the fastening wire is not required.

Installation

- Generally, silt fences should be used in conjunction with soil stabilization source controls up-slope to provide effective erosion and sediment control.
- The bottom of the silt fence should be keyed to a minimum of 12 in.
- Trenches should not be excavated wider and deeper than necessary for proper installation of the temporary linear sediment barriers.
- Excavation of the trenches should be performed immediately before installation of the temporary linear sediment barriers.
- Construct silt fences with a setback of at least 3 ft. from the toe of a slope. Where a silt fence is determined not to be practical due to specific site conditions, the silt fence may be constructed at the toe of the slope, but as far from the toe of the slope as practical.
- Construct the length of each reach so that the change in base elevation along the reach does not exceed one-third the height of the barrier; in no case should the reach exceed 490 ft.

- Cross barriers should be a minimum of one-third and a maximum of half the height of the linear barrier.

Maintenance and Inspection

- Repair undercut silt fences.
- Repair or replace split, torn, slumping, or weathered fabric.
- Inspect silt fence weekly and after each significant rainfall. Immediately perform any necessary maintenance and repairs.
- Maintain silt fences to provide an adequate sediment holding capacity. Sediment should be removed when the sediment accumulation reaches one-third of the barrier height. Removed sediment should be incorporated in the project or disposed of outside of the right-of-way in conformance with the project requirements.
- Silt fences that are damaged and become unsuitable for their intended purpose should be removed from the site of work, disposed of outside of the highway right-of-way in conformance with the contract requirements, and replaced with new silt fence barriers.
- Holes, depressions, or other ground disturbance caused by the removal of the temporary silt fences should be backfilled and repaired.
- Remove silt fence when no longer needed. Fill and compact post holes and anchorage trench, remove sediment accumulation, and grade the fence alignment to blend with the adjacent ground.

7.2.2 SEDIMENT BASIN

Definition and Purpose

A sediment basin (pond) is a temporary basin formed by excavating and/or constructing an embankment so that sediment-laden runoff is temporarily detained under quiescent conditions, allowing sediment to settle out before the runoff is discharged.

Appropriate Applications

Prior to leaving a construction site, stormwater runoff must pass through a sediment basin or other appropriate sediment removal BMP.

A sediment basin should be used where the contributing drainage area is 3 acres or more. Ponds must be used in conjunction with erosion control practices to reduce the amount of sediment flowing into the basin.

Limitations

Alternative BMPs must be thoroughly investigated for erosion control before selecting temporary sediment basins.

- Sediment basins require large surface areas to permit the settling of sediment.
- Sediment basins are not appropriate for drainage areas greater than 75 acres.
- Sediment basins should not be located in live streams.
- For safety reasons, basins should have protective fencing.
- The size of sediment basins may be limited by the availability of right-of-way.

Standards and Specifications

- Try to limit the contributing area to the sediment basin to only the runoff from the disturbed soil areas. Use temporary concentrated flow conveyance controls to divert runoff from undisturbed areas. This will help to keep the sediment basin as small as possible.

Sediment Basin

At a minimum, sediment basins should be designed as follows:

- If permanent runoff control facilities are part of the project, they should be used for sediment retention. The surface area requirements of the sediment basin must be met. This may require enlarging the permanent basin to comply with the surface area requirements. If a permanent control structure is used, it must have the outlet controls blocked to accommodate the sedimentation design.
- Outlets for sediment basins should be an overflow structure, weir, berm, or floating intake so that discharge is skimmed off of the upper pond surface.
- The use of infiltration facilities for sedimentation basins during construction tends to clog the soils and reduce their capacity to infiltrate. If infiltration facilities are to be used, the sides and bottom of the facility must only be roughly excavated to a minimum of 2 ft. above the final grade. Final grading of the infiltration facility should occur only when all contributing drainage areas are fully stabilized. The infiltration pre-treatment facility should be fully constructed and used with the sedimentation basin to help prevent clogging.
- Sediment basins should be designed for the three-year frequency storm
- Determining Pond Geometry
    - Obtain the discharge from the hydrologic calculations of the peak flow for the three-year runoff event (Q_2). The 10-year peak flow should be used if the project size, expected timing and duration of construction, or

downstream conditions warrant a higher level of protection. If no hydrologic analysis is required, the Rational Method may be used.

- o Determine the required surface area at the top of the riser pipe with the equation:

  $SA = 2 \times Q_2/0.00096$, or 2,080 sq. ft. per cfs of inflow.

  (This equation, along with the minimum depth of pond, will provide the necessary volume for a time of residence to allow a 0.02 mm (medium silt) particle with an assumed density of 2.65 g/cm^3, which has a settling velocity of 0.00096 ft/sec with a safety factor of two, to settle out).

- The basic geometry of the pond can now be determined using the following design criteria:
  - o Required Surface Area (SA), from Step 2, above, at top of riser
  - o Minimum 3.5-ft. depth from top of riser to bottom of pond
  - o Maximum 3:1 interior side slopes and maximum 2:1 exterior slopes

The interior slopes can be increased to a maximum of 2:1 if fencing is provided at or above the maximum water surface.

- One ft. of freeboard between the top of the overflow device and the top of the pond.
- Flat bottom.
- The overflow device should be capable of handling the 10-year sized storm peak flow without overtopping the top of pond.
- Length-to-width ratio between 3:1 and 6:1.
- Typical overflow outlets can be a rock riprapped weir surface discharging to an erosion protected channel or other conveyance system; a vertical pipe or pre-cast structure riser connected to a discharge pipe also discharging to an erosion-protected outlet or other conveyance system; a pumped discharge where the pump intake is located just under the pond surface using anti-vortex baffles; and a floating overflow weir connected to a flexible pipe that allows water to skim immediately from the surface of the water. A floating overflow weir/pipe is usually associated with either a pumped discharge using automatic floats to control the pond surface levels or another permanent control structure to maintain the maximum design water surface.

Maintenance Standards

- Sediment should be removed from the pond when it reaches 1 ft. in depth.
- Inspect sediment basins before and after rainfall events and weekly during the rest of the rainy season. During extended rainfall events, inspect at least every 24 hours.
- Examine basin banks for seepage and structural soundness.
- Check inlet and outlet structures and spillway for any damage or obstructions.
- Repair damage and remove obstructions as needed.

7.2.3 SEDIMENT TRAP

Definition and Purpose

A sediment trap is a temporary containment area that allows sediment in collected stormwater to settle out during infiltration or before the runoff is discharged through a stabilized spillway. Sediment traps are formed by excavating or constructing an earthen embankment across a waterway or low drainage area.

Appropriate Applications

- Sediment traps may be used on construction projects where the drainage area is less than 3 acres. Traps should be placed prior to where sediment-laden stormwater enters a storm drain or watercourse.
- This BMP may be implemented on a project-by-project basis with other BMPs, when necessary and feasible.
- As a supplemental control, sediment traps provide additional protection for a water body or for reducing sediment before it enters a drainage system.

Limitations

- Sediment traps require large surface areas to permit infiltration and the settling of sediment.
- Sediment traps are not appropriate for drainage areas greater than 3 acres.
- Sediment traps only remove large and medium-sized particles and require upstream erosion control.
- Sediment traps are attractive and dangerous to children, requiring protective fencing.
- Sediment traps should not be located in live streams.
- The size of sediment traps may be limited by the availability of right-of-way.

Standards and Specifications

- Construct sediment traps prior to the rainy season and construction activities.
- Traps should be situated according to the following criteria:
  - By excavating a suitable area or where a low embankment can be constructed across a swale.
  - Should be designed for the three-year storm frequency.
  - Where failure would not cause loss of life or property damage.
  - To provide access for maintenance, including sediment removal and sediment stockpiling, in a protected area.
- To determine the sediment trap geometry, first calculate the design SA of the trap, measured at the invert of the weir. Use the following equation:

  $$SA = 2 \times Q_2/0.00096, \text{ or } 2{,}080 \text{ sq. ft. per cfs of inflow}$$

  Where:

  Q_2 = Design inflow based on the peak discharge from the developed three-year runoff event from the contributing drainage area as computed in the hydrologic analysis.

  - To aid in determining sediment depth, all sediment traps should have a staff gauge with a prominent mark 1 ft. above the bottom of the trap.
  - Sediment traps should have a stabilized outlet by skimming the surface water. This is usually performed with an overflow weir, such as a pipe or structural riser discharging by connecting pipe to another conveyance system or erosion protected outlet to a waterway; by a riprapped overflow weir; by pumped discharge where the intake is located just below the trap surface with an anti-vortex baffle; or using a floating skimmer with a flexible pipe.
- Sediment traps may not be feasible on utility projects due to the limited work space or the short-term nature of the work. Portable tanks may be used in place of sediment traps for utility projects.

Maintenance and Inspection

- Inspect sediment traps before and after rainfall events and weekly during the rest of the rainy season. Remove accumulated sediment when the volume has reached one-third the original trap volume.
- Inspect the outlet structure for any damage or obstructions. Repair damage and remove obstructions as needed or as directed by the Resident Engineer (RE).

7.2.4 CHECK DAMS

Definition and Purpose

Check dams reduce scour and channel erosion by reducing flow velocity and encouraging sediment settlement. A check dam is a small device constructed of rock, gravel bags, sandbags, fiber rolls, or other proprietary product placed across a natural or man-made channel or drainage ditch.

Appropriate Applications

Check dams may be installed:

- In small open channels that drain 10 acres or less.
- In steep channels where stormwater runoff velocities exceed 4.9 ft. per second.
- During the establishment of grass linings in drainage ditches or channels.
- In temporary ditches where the short length of service does not warrant the establishment of erosion-resistant linings.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible.

Limitations

- Check dams should not be used in live streams.
- Check dams are not appropriate in channels that drain areas greater than 10 acres.
- Check dams should not be placed in channels that are already grass-lined, unless erosion is expected, as installation may damage vegetation.
- Check dams require extensive maintenance following high-velocity flows.
- Check dams promote sediment trapping, which can be re-suspended during subsequent storms or removal of the check dam.
- Check dams should not be constructed from straw bales or silt fence.

Standards and Specifications

- Check dams should be placed at a distance and height to allow small pools to form behind them. Install the first check dam approximately 16 ft. from the outfall device and at regular intervals based on slope gradient and soil type.
- For multiple check dam installation, backwater from downstream check dams should reach the toe of the upstream dam.

- High flows (typically, a two-year storm or larger) should safely flow over the check dam without an increase in upstream flooding or damage to the check dam.
- Where grass is used to line ditches, check dams should be removed when grass has matured sufficiently to protect the ditch or swale.
- Rock should be placed individually by hand or by mechanical methods (no dumping of rock) to achieve complete ditch or swale coverage.
- Fiber rolls may be used as check dams.
- Gravel bags may be used as check dams with the following specifications:
  - Bag Material: Bags should be either polypropylene, polyethylene, or polyamide woven fabric (minimum unit weight four ounces per square yard), with a mullen burst strength exceeding 300 pounds per sq. in., in conformance with the requirements in ASTM Designation D3786, and a UV stability exceeding 70 percent, in conformance with the requirements in ASTM Designation D4355.
  - Bag Size: Each gravel-filled bag should have a length of 18 in., a width of 12 in., a thickness of 3 in., and a mass of approximately 33 pounds. Bag dimensions are nominal and may vary based on locally-available materials. Alternative bag sizes should be submitted to the RE for approval prior to deployment.
  - Fill Material: Fill material should be between 0.4 in. and 0.8 in. in diameter, and should be clean and free from clay balls, organic matter, and other deleterious materials. The opening of gravel-filled bags should be secured so that gravel does not escape. Gravel-filled bags should be between 28 pounds and 48 pounds in mass.

Installation

- Install check dams along a level contour.
- Tightly abut bags and/or rock and stack using a pyramid approach. Dams should not exceed about 3.5 ft. in height.
- The upper rows of gravel bags or rock should overlap joints in lower rows.

Maintenance and Inspection

- Inspect check dams after each significant rainfall event. Repair damage as needed.
- Remove sediment when the depth reaches one-third of the check dam height.

- Remove accumulated sediment prior to permanent seeding or soil stabilization.
- Remove check dam and accumulated sediment when check dams are no longer needed.
- Removed sediment should be incorporated into the project or disposed of outside of the highway right-of-way in conformance with the contract requirements.

7.2.5 FIBER ROLLS/WATTLES

Definition and Purpose

A fiber roll consists of wood excelsior, rice or wheat straw, or coconut fibers rolled or bound into a tight tubular roll and placed on the toe and face of slopes to intercept runoff, reduce its flow velocity, release the runoff as sheet flow, and provide removal of sediment from the runoff. Fiber rolls may also be used for inlet protection and as check dams under certain situations.

Appropriate Applications

- Use fiber rolls along the toe, top, face, and at-grade breaks of exposed and erodible slopes to shorten slope length and spread runoff as sheet flow.
- Use fiber rolls below the toe of exposed and erodible slopes.
- Fiber rolls may be used as check dams in unlined ditches if approved by the RE.
- Fiber rolls may be used for drain inlet protection if approved by the RE.
- Fiber rolls may be used down slope of exposed soil areas.
- Fiber rolls may be used around temporary stockpiles.
- Fiber rolls may be used along the perimeter of a project.

Limitations

- Runoff and erosion may occur if a fiber roll is not adequately trenched in.
- Fiber rolls at the toe of slopes steeper than 1V:5H may require the use of 20-in. diameter fiber rolls or installations achieving the same protection (i.e., stacked fiber rolls of a smaller diameter).
- Fiber rolls are difficult to move once saturated.
- Fiber rolls could be transported by high flows if not properly staked and trenched in.
- Fiber rolls have a limited sediment capture zone.
- Do not use fiber rolls on slopes subject to creep, slumping, or landslide.

Standards and Specifications

Assembly of Field-Rolled Fiber Roll

- Roll the length of an erosion control blanket into a tube a minimum of 8 in. in diameter.
- Bind the roll at each end and every 4 ft. along the length of the roll with jute-type twine.

Installation

- Slope inclination of 1:4 or flatter: Fiber rolls should be placed on slopes 20 ft. apart.
- Slope inclination of 1:4 to 1:2: Fiber rolls should be placed on slopes 15 ft. apart.
- Slope inclination 1:2 or greater: Fiber rolls should be placed on slopes 10 ft. apart.
- Stake fiber rolls into a 2-in. to 4-in. deep trench.
- Drive stakes at the end of each fiber roll, and space them 2 ft. to 4 ft. apart.
- Use wood stakes with a nominal classification of 3/4 in. by 3/4 in. and a minimum length of 24 in.
- If more than one fiber roll is placed in a row, the rolls should be overlapped, not abutted.

Removal

- Fiber rolls are typically left in place.
- If fiber rolls are removed, collect and dispose of sediment accumulation, and fill and compact holes, trenches, depressions, or any other ground disturbance to blend with the adjacent ground.

Maintenance and Inspection

- Repair or replace split, torn, unraveling, or slumping fiber rolls.
- Inspect fiber rolls weekly and immediately after a significant rain. Perform maintenance as needed.
- Maintain fiber rolls to provide an adequate sediment-holding capacity. Sediment should be removed when the sediment accumulation reaches three-quarters of the barrier height. Removed sediment should be incorporated into the project or disposed of outside of the project limits in conformance with the contract requirements.

7.2.5.1 GRAVEL BAG BERM

Definition and Purpose

A gravel bag berm consists of a single row of gravel bags that are installed end-to-end to form a barrier across a slope to intercept runoff, reduce its flow velocity, release the runoff as sheet flow, and provide some sediment removal. Gravel bags can be used where flows are moderately concentrated such as ditches, swales, and storm drain inlets, to divert and/or detain flows.

Appropriate Applications

This BMP is used for the same purposes as fiber rolls and wattles.

Limitations

- Degraded gravel bags may rupture when removed, spilling contents.
- Installation can be labor intensive.
- Gravel bags have limited durability for long-term projects.
- When used to detain concentrated flows, maintenance requirements increase.

Standards and Specifications

Materials

See the material specifications of gravel bags used for check dams.

Installation

- When used as a linear control for sediment removal:
  - Install along a level contour.
  - Turn the ends of the gravel bag row upslope to prevent flow around the ends.
  - Generally, gravel bag barriers should be used in conjunction with temporary soil stabilization controls up slope to provide effective erosion and sediment control.
- When used for concentrated flows:
  - Stack gravel bags to their required height using a pyramid approach.
  - The upper rows of gravel bags should overlap joints in lower rows.
- Construct gravel bag barriers with a setback at least 3 ft. from the toe of a slope. Where it is determined to not be practicable due to specific site conditions, the gravel bag barrier may be constructed at the toe of the slope, but as far from the toe of the slope as practicable.

Maintenance and Inspection

- Inspect gravel bag berms weekly throughout the rainy season.
- Reshape or replace gravel bags as needed.
- Repair washouts or other damages as needed.
- Inspect gravel bag berms for sediment accumulations, and remove sediments when accumulation reaches one-third of the berm height. Removed sediment should be incorporated into the project or disposed of outside of the project limits in conformance with the contract requirements.
- Remove gravel bag berms when no longer needed. Remove sediment accumulations and clean, re-grade, and stabilize the area.

7.2.6 STREET SWEEPING AND VACUUMING

Definition and Purpose

Street sweeping and vacuuming are practices to remove tracked sediment to prevent the sediment from entering a storm drain or watercourse.

Appropriate Applications

These practices are implemented anywhere sediment is tracked from the project site onto public or private paved roads, typically at points of ingress or egress.

Limitations

Sweeping and vacuuming may not be effective when soil is wet or muddy.

Standards and Specifications

- Kick brooms or sweeper attachments should not be used.
- Inspect potential sediment tracking locations daily.
- Visible sediment tracking should be swept and/or vacuumed daily.
- If not mixed with debris or trash, consider incorporating the removed sediment back into the project.

Maintenance and Inspection

- Inspect ingress/egress access points daily and sweep tracked sediment as needed.
- Be careful not to sweep up any unknown substance or any object that may be potentially hazardous.
- Adjust brooms frequently; maximize the efficiency of sweeping operations.

- After sweeping is finished, properly dispose of sweeper wastes at an approved disposal site in conformance with the contract requirements.

7.2.6.1 SANDBAG BARRIER

Definition and Purpose

A sandbag barrier is a temporary linear sediment barrier consisting of stacked sandbags designed to intercept and slow the flow of sediment-laden sheet flow runoff. Sandbag barriers allow sediment to settle from runoff before water leaves the construction site.

Appropriate Applications

- This BMP has the same application as the gravel bag berms.

Standards and Specifications

Materials

- **Sandbag Material:** Sandbags should be woven polypropylene, polyethylene, or polyamide fabric (minimum unit weight four ounces per square yard), with a mullen burst strength exceeding 300 pounds per sq. in., in conformance with the requirements in ASTM Designation D3786 and with a UV stability exceeding 70 percent, in conformance with the requirements in ASTM Designation D4355. The use of burlap is not acceptable.
- **Sandbag Size:** Each sand-filled bag should have a length of 18 in., a width of 12 in., a thickness of 3 in., and a mass of approximately 33 pounds. Bag dimensions are nominal and may vary based on locally-available materials.
- **Fill Material:** All sandbag fill material should be non-cohesive, permeable material free from clay and deleterious material, conforming to the provisions in Standard Specification 703, “Permeable Backfill.” The requirements for the durability index and sand equivalent do not apply.

Installation and Maintenance

The same installation and maintenance requirements apply as noted for gravel bag berms.

7.2.7 STORM DRAIN INLET PROTECTION

Definition and Purpose

Storm drain inlet protection is achieved with devices used at storm drain inlets that are subject to runoff from construction activities to detain and/or to filter sediment-laden runoff, to allow sediment to settle and/or to filter sediment prior to discharge into storm drainage systems or watercourses.

Appropriate Applications

- Where ponding will not encroach into highway traffic.
- Where sediment-laden surface runoff may enter an inlet.
- Where disturbed drainage areas have not yet been permanently stabilized.
- Where the drainage area is 1 acre or less.

Limitations

- Storm drain inlet protection requires an adequate area for water to pond without encroaching upon the traveled way and should not present an obstacle to oncoming traffic.
- Storm drain inlet protection may be best if other methods of temporary protection are used in conjunction with it.
- Sediment removal may be difficult in high flow conditions or if runoff is heavily sediment laden. If high flow conditions are expected, use other on-site sediment-trapping techniques, such as check dams, in conjunction with inlet protection.
- Frequent maintenance is required.
- Filter fabric fence inlet protection is appropriate in open areas that are subject to sheet flow and for flows not exceeding 0.5 cu. ft. per second.
- Gravel bag barriers for inlet protection are applicable when sheet flows or concentrated flows exceed 0.5 cu. ft. per second, and it is necessary to allow for overtopping to prevent flooding.
- Fiber rolls and foam barriers are not appropriate for locations where they cannot be properly anchored to the surface.
- Excavated drop inlet sediment traps are appropriate where relatively heavy flows are expected and overflow capability is needed.

Standards and Specifications

Identify existing and/or planned storm drain inlets that have the potential to receive sediment-laden surface runoff. Determine if storm drain inlet protection is needed and which method to use.

Methods and Installation

- ***Drainage Inlet Protection Type 1 – Filter Fabric Fence***. The filter fabric fence protection is similar to constructing a silt fence. Do not place filter fabric underneath the inlet grate because the collected sediment may fall into the drain inlet when the fabric is removed or replaced.

- ***Drainage Inlet Protection Type 2 – Excavated Drop Inlet Sediment Trap***. The excavated drop inlet sediment trap is similar to constructing a temporary silt trap around the inlet structure. Use the inlet grate as the overflow discharge control weir for the silt trap. Size the excavated trap to provide a minimum storage capacity calculated at the rate of 67 cu. yd per acre of drainage area.
- ***Drainage Inlet Protection Type 3 – Gravel Bag***. Flow from a severe storm should not overtop the berm. In areas of high clay and silts, use filter fabric and gravel as additional filter media. Construct gravel bags as level berms upstream of the inlet structure. Gravel or sand bags should be used due to their high permeability.
- ***Drainage Inlet Protection Type 4 – Foam Barriers and Fiber Rolls***. Foam barriers or fiber rolls are placed around the inlet and keyed and anchored to the surface. Foam barriers and fiber rolls are intended for use as inlet protection where the area around the inlet is unpaved and the foam barrier or fiber roll can be secured to the surface.

Maintenance and Inspection

General

- Inspect all inlet protection devices before and after every rainfall event and weekly during the rest of the rainy season. During extended rainfall events, inspect inlet protection devices at least once every 24 hours.
- Inspect the storm drain inlet after severe storms in the rainy season to check for bypassed material.
- Remove all inlet protection devices after the site is stabilized, or when the inlet protection is no longer needed.
    - Bring the disturbed area to final grade and smooth and compact it. Appropriately stabilize all bare areas around the inlet.
    - Clean and re-grade the area around the inlet and clean the inside of the storm drain inlet, as it must be free of sediment and debris at the time of final inspection.

Requirements by Method

Type 1 – Filter Fabric Fence

- This method should be used for drain inlets requiring protection in areas where finished grade is established and erosion control seeding has been applied or is pending.

- Make sure the stakes are securely driven in the ground and are structurally sound (i.e., not bent, cracked, or splintered) and are reasonably perpendicular to the ground. Replace damaged stakes.
- Replace or clean the fabric when the fabric becomes clogged with sediment. Make sure the fabric does not have any holes or tears. Repair or replace fabric as needed or as directed by the RE.
- At a minimum, remove the sediment behind the fabric fence when accumulation reaches one-third the height of the fence or barrier height. Removed sediment should be incorporated into the project at locations designated by the RE or disposed of outside of the highway right-of-way, in conformance with the Standard Specifications.

Type 2 – Excavated Drop Inlet Sediment Trap

- This method may be used for drain inlets requiring protection in areas that have been cleared and grubbed, and where exposed soil areas are subject to grading.
- Remove sediment from the trap when the volume of the basin has been reduced by one-half.

Type 3 – Gravel Bag Barrier

- This method may be used for drain inlets surrounded by asphalt concrete or paved surfaces.
- Inspect bags for holes, gashes, and snags.
- Check gravel bags for proper arrangement and displacement. Remove the sediment behind the barrier when it reaches one-third the height of the barrier.

Type 4 – Foam Barriers and Fiber Rolls

- This method may be used for drain inlets requiring protection in areas that have been cleared and grubbed, and where exposed soil areas are subject to grading.
- Check the foam barrier or fiber roll for proper arrangement and displacement. Remove the sediment behind the barrier when it reaches one-third the height of the barrier. Removed sediment should be incorporated into the project at locations designated by the RE or disposed of outside of the highway right-of-way in conformance with the Standard Specifications.

7.2.8 STREAMBANK SEDIMENT CONTROL

These BMPs are used to isolate work on the streambank from the stream channel.

Silt Fences

- Install silt fences to control sediment movement from the working side of the stream bank and the channel bottom.
- If placed within the water, the silt fence should be protected from high velocity flow. The water surface on each side of the silt fence must be level creating a pond on the working side, thus allowing the sediment to settle out.

Fiber Rolls

- Install fiber rolls along the slope contour above the high-water level to intercept runoff, reduce flow velocity, release the runoff as sheet flow, and provide removal of sediment from the runoff. In a stream environment, fiber rolls should be used in conjunction with other sediment control methods, such as a silt fence or gravel bag berm. Install the silt fence, gravel berm, or other erosion control methods along the toe of the slope above the ordinary water level.

Gravel Bag Berm

A gravel bag berm can be used to intercept and slow the flow of sediment-laden sheet flow runoff. In a stream environment, gravel bag berms can allow sediment to settle from runoff before water leaves the construction site, and can be used to isolate the work area from the stream.

Limitations

Gravel bag barriers are not recommended as a perimeter sediment control practice around streams.

Rock Filters

Description and Purpose

Rock filters are temporary erosion control barriers composed of rock that is anchored in place using woven wire sheathing (gabions). Rock filters detain the sediment-laden runoff, retain the sediment, and release the water as sheet flow at a reduced velocity.

Applications

Apply rock filters near the toe of slopes that may be subject to flow and rill erosion.

Limitations

- Inappropriate for drainage areas greater than 5 acres.
- Requires sufficient space for ponded water.
- Ineffective for diverting runoff because filters allow water to slowly seep through.

- Berms difficult to remove when construction is complete.
- Unsuitable in developed areas or locations where aesthetics is a concern.

Specifications

- Rock: Open-graded rock, 0.75 in to 5 in. for concentrated flow applications.
- Rock contained in gabions consisting of woven wire sheathing: 1 in. in diameter, hexagonal mesh, galvanized 20-gauge.
- In construction traffic areas, maximum rock berm heights should be 12 in. Berms should be constructed every 300 ft. on slopes less than 5:100 (V:H) (5 percent), every 200 ft. on slopes between 5:100 (V:H) (5 percent) and 10:100 (V:H) (10 percent), and every 100 ft. on slopes greater than 10:100 (V:H) (10 percent).

Maintenance and Inspection

- Inspect berms before and after each significant rainfall event and weekly throughout the rainy season.
- Reshape berms as needed and replace lost or dislodged rock and/or filter fabric.
- Inspect for sediment accumulation, remove sediment when depth reaches one-third of the berm height or 12 in., whichever occurs first.

K-Rail

Description and Purpose

- This is temporary sediment control that uses K-rails (pre-cast concrete traffic barriers) to form the sediment deposition area, or to isolate the near-bank construction area. Install K-rails at the toe of the slope (see also the description for the BMP "Clear Water Diversion.")
- Barriers are placed end-to-end in a pre-designed configuration, and gravel-filled bags are used at the toe of the barrier and also at their abutting ends to seal and prevent the movement of sediment beneath or through the barrier walls.

Appropriate Applications

This technique is useful at the toe of embankments, and cut or fill slopes.

Limitations

The K-rail method is not watertight, and its proper use should be considered accordingly.

Inspection and Maintenance

- Inspect BMPs daily during construction.
- Maintain and repair BMPs as required.
- Remove accumulated sediment.

7.3 WIND EROSION CONTROL PRACTICES

Wind erosion control consists of applying water and/or other dust palliatives as necessary to prevent or alleviate dust nuisance.

Definition and Purpose

Wind erosion control consists of applying water and/or other dust palliatives as necessary to prevent or alleviate erosion by the forces of wind. Covering small stockpiles or areas is an alternative to applying water or other dust palliatives.

Appropriate Applications

- This practice is implemented on all exposed soils subject to wind erosion.

Limitations

- Its effectiveness depends on soil, temperature, humidity, and wind velocity.

Standards and Specifications

- Water should be applied by means of pressure-type distributors or pipelines equipped with a spray system or hoses and nozzles that will ensure even distribution.
- All distribution equipment should be equipped with a positive means of shutoff.
- Unless water is applied by means of pipelines, at least one mobile unit should be available at all times to apply water or dust palliative to the project.
- Materials applied as temporary soil stabilizers and soil binders will also provide wind erosion control benefits.

Maintenance and Inspection

- Check areas that have been protected to ensure coverage.

7.4 TRACKING CONTROL BMPs

Tracking control consists of preventing or reducing vehicle tracking from entering a storm drain or watercourse. Tracking control BMPs are shown in Table 7-7.

Tracking Control BMPs
Stabilized Construction Entrance/Exit
Stabilized Construction Roadway
Entrance/Outlet Tire Wash

Table 7-7: Tracking Control BMPs

7.4.1 STABILIZED CONSTRUCTION ENTRANCE/EXIT

Definition and Purpose

A stabilized construction access is defined by a point of entrance/exit to a construction site that is stabilized to reduce the tracking of mud and dirt onto public roads by construction vehicles.

Appropriate Applications

- Use tracking control at construction sites:
  - Where dirt or mud can be tracked onto public roads
  - Adjacent to water bodies
  - Where poor soils are encountered
  - Where dust is a problem during dry weather conditions

This BMP may be implemented on a project-by-project basis in addition to other BMPs.

Limitations

Site conditions will dictate the design and need.

Standards and Specifications

- Limit the points of entrance/exit to the construction site.
- Limit the speed of vehicles to control dust.
- Properly grade each construction entrance/exit to prevent runoff from leaving the construction site.
- Route runoff from stabilized entrances/exits through a sediment-trapping device before discharge.
- Design stabilized entrances/exits to support the heaviest vehicles and equipment that will use it.
- Select construction access stabilization (aggregate, asphaltic concrete, concrete) based on longevity, required performance, and site conditions.
- The use of constructed/manufactured steel plates with ribs for entrance/exit access is another alternative.

- If aggregate is selected, place crushed aggregate over geotextile fabric to at least 12 in. deep. Crushed aggregate greater than 3 in. and smaller than 6 in. should be used.
- Designate combination or single-purpose entrances and exits to the construction site.
- Require all employees, subcontractors, and suppliers to use the stabilized construction access.
- All exit locations intended to be used continuously and for a period of time should have stabilized construction entrance/exit BMPs.

Maintenance and Inspection

- Inspect the area routinely for damage and assess the effectiveness of the BMP. Remove aggregate, and separate and dispose of sediment if the construction entrance/exit is clogged with sediment or as directed by the RE.
- Keep all temporary roadway ditches clear.
- Inspect for damage and repair as needed.

7.4.2 STABILIZED CONSTRUCTION ROADWAY

Definition and Purpose

A stabilized construction roadway is a temporary access road. It is designed for the control of dust and erosion created by vehicular tracking.

Appropriate Applications

- Where mud tracking is a problem during wet weather.
- Where dust is a problem during dry weather.
- Adjacent to water bodies.
- Where poor soils are encountered.
- Where there are steep grades and additional traction is needed.

Limitations

- Materials will likely need to be removed prior to final project grading and stabilization.
- Site conditions will dictate design and need.
- A stabilized construction roadway may not be applicable to projects of a very short duration.
- Limit the speed of vehicles to control dust.

Standards and Specifications

- Design stabilized access to support the heaviest vehicles and equipment that will use it.
- Stabilize roadway using aggregate, asphalt concrete, or concrete based on longevity, required performance, and site conditions.
- Coordinate materials with those used for stabilized construction entrance/exit points.
- If aggregate is selected, place crushed aggregate over geotextile fabric to at least 12 in. deep, or place aggregate to a depth suitable for the proposed loadings. Crushed aggregate greater than 75 mm (3 in.) and smaller than 6 in. should be used.

Maintenance and Inspection

- Inspect routinely for damage and repair as needed.
- Keep all temporary roadway ditches clear.

7.4.3 ENTRANCE/OUTLET TIRE WASH

Definition and Purpose

A tire wash is an area located at stabilized construction access points to remove sediment from tires and undercarriages, and to prevent sediment from being transported onto public roadways.

Appropriate Applications

- Tire washes may be used on construction sites where dirt and mud tracking onto public roads by construction vehicles may occur.

Limitations

- Tire washes require a supply of washwater.
- Tire washes require a turnout or double-wide exit to avoid having entering vehicles drive through the wash area.

Standards and Specifications

- Incorporate with a stabilized construction entrance/exit.
- Construct on level ground when possible, on a pad of coarse aggregate greater than 3 in. and smaller than 6 in. A geotextile fabric should be placed below the aggregate.
- Wash rack should be designed and constructed/manufactured for anticipated traffic loads.

- Provide a drainage ditch that will convey the runoff from the wash area to a sediment-trapping device. The drainage ditch should be of sufficient grade, width, and depth to carry the wash runoff.
- Require all employees, subcontractors, and others who leave the site with mud-caked tires and/or undercarriages to use the wash facility.

Maintenance and Inspection

- Remove accumulated sediment in the wash rack and/or sediment trap to maintain system performance.
- Inspect routinely for damage and repair as needed.

7.5 NON-STORMWATER MANAGEMENT PRACTICES

Non-stormwater management BMPs are source control BMPs that prevent pollution by limiting or reducing potential pollutants at their source before they come into contact with stormwater. These practices involve day-to-day operations of the construction site and are usually under the contractor's control. These BMPs are also referred to as good housekeeping practices, which involve keeping a clean, orderly construction site. Table 7-8 lists the non-stormwater management BMPs.

Non-Stormwater BMPs
Water Conservation Practices
De-watering Operations
Temporary Stream Crossing
Clean Water Diversion
Potable Water/Irrigation
Vehicle and Equipment Cleaning
Vehicle and Equipment Fueling
Vehicle and Equipment Maintenance
Pile-Driving Operations
Concrete Curing
Material and Equipment Use Over Water
Concrete Finishing
Structure Demolition Over or Adjacent to Water

Table 7-8: Non-Stormwater BMPs

7.5.1 WATER CONSERVATION PRACTICES

Definition and Purpose

Water conservation practices are activities that use water during the construction of a project in a manner that avoids causing erosion and/or the transport of pollutants off-site.

Appropriate Applications

- Water conservation practices are implemented on all construction sites and wherever water is used.
- Water conservation practices apply to all construction projects.

Limitations

- None identified.

Standards and Specifications

- Keep water equipment in good working condition.
- Stabilize the water truck filling area.
- Repair water leaks promptly.
- The washing of vehicles and equipment on the construction site is discouraged.
- Avoid using water to clean construction areas. Do not use water to clean pavement. Paved areas should be swept and vacuumed.
- Direct construction water runoff to areas where it can infiltrate into the ground.
- Apply water for dust control in accordance with the contract requirements.
- Report discharges immediately.

Maintenance and Inspection

- Inspect water equipment at least weekly.
- Repair water equipment as needed.

7.5.2 DE-WATERING OPERATIONS

Definition and Purpose

De-watering operations are practices that manage the discharge of pollutants when non-stormwater and accumulated precipitation (stormwater) must be removed from a work location so that construction work can be accomplished.

Appropriate Applications

These practices are implemented for discharges of non-stormwater and stormwater (accumulated rain water) from construction sites. Non-stormwater includes, but is not limited to, groundwater, the de-watering of piles, water from cofferdams, water diversions, and water used during construction activities that must be removed from a work area.

Practices identified in this section are also appropriate for implementation when managing the removal of accumulated precipitation (stormwater) from depressed areas at a construction site. Stormwater mixed with non-stormwater should be managed as non-stormwater.

Limitations

- De-watering operations for non-stormwater will require and must comply with applicable local permits, project-specific permits, and regulations.
- Site conditions will dictate the design and use of de-watering operations.
- A de-watering plan should be submitted as part of the SWPPP, detailing the location of de-watering activities, equipment, and the discharge point.
- The controls discussed in this BMP address sediment only. If the presence of polluted water with hazardous substances is identified in the contract, the contractor should implement de-watering pollution controls as required by the contract documents. If the quality of water to be removed by de-watering is not identified as polluted in the contract documents but is later determined by observation or testing to be polluted, the contractor should comply with the contract requirements.
- Where possible, avoid de-watering discharges by using the water for dust control, by infiltration, etc.

Standards and Specifications

- De-watering for accumulated precipitation (stormwater) should follow this BMP and use the treatment measures specified herein.
- A project may require a separate National Pollutant Discharge Elimination System (NPDES) permit prior to the de-watering discharge of non-stormwater. These permits will have specific testing, monitoring, and discharge requirements and can take a significant amount of time to obtain.
- Monitoring for permit compliance will be required.
- Discharges must comply with regional and watershed-specific discharge requirements.
- Additional permits or permissions from other agencies may be required for de-watering cofferdams or diversions.
- De-watering discharges must not cause erosion at the discharge point.

- De-watering records should be maintained for a period of three years.

Maintenance and Inspection

- Inspect all BMPs implemented frequently to ensure they comply with permit requirements, and repair or replace BMPs as necessary to ensure they function as designed.
- Accumulated sediment removed during the maintenance of a de-watering device may be incorporated into the project or disposed of outside of the project limits in conformance with the contract requirements.
- Accumulated sediment that is commingled with other pollutants must be disposed of in accordance with all applicable laws and regulations.

Sediment Treatment

A variety of methods can be used to treat water during de-watering operations from the construction site. Several devices are presented in this section that provide options to achieve sediment removal. The sizes of particles present in the sediment and permit or receiving water limitations on sediment are key considerations for selecting sediment treatment options; in some cases, the use of multiple devices may be appropriate.

***Category 1: Constructed* Sediment Trap**

Description

A sediment trap is a temporary basin with a controlled release structure that is formed by excavation and/or construction of an embankment to detain sediment-laden runoff and allow sediment to settle out before discharging.

Appropriate Applications

- A sediment trap is effective for the removal of trash, gravel, sand, and silt and some metals that settle out with the sediment.

Implementation

- The excavation and construction of related facilities is required.
- Temporary sediment traps should be fenced if safety is a concern.
- Outlet protection is required to prevent erosion at the outfall location.

Maintenance

- Maintenance is required for safety fencing, vegetation, embankment, inlet and outfall structures, as well as other features.
- The removal of sediment is required when the storage volume is reduced by one-third.

Category 2: Mobile Settling Technologies

The devices discussed in this category are typical of tanks that can be used for the sediment treatment of de-watering operations. A variety of vendors are available who supply these tanks.

Weir Tank

Description

A weir tank separates water and waste by using weirs. The configuration of the weirs (over and under weirs) maximizes the residence time in the tank and determines the waste to be removed from the water, such as oil, grease, and sediments.

Appropriate Applications

- The tank removes trash, some settleable solids (gravel, sand, and silt), some visible oil and grease, and some metals (removed with sediment). To achieve high levels of flow, multiple tanks can be used in parallel. If additional treatment is desired, the tanks can be placed in a series or as pre-treatment for other methods.

Implementation

- Tanks are delivered to the site by the vendor, who can provide assistance with set-up and operation.
- Tank size will depend on flow volume, constituents of concern, and residency period required. Vendors should be consulted to appropriately size tanks.

Maintenance

- Periodic cleaning is required based on visual inspection or reduced flow.
- Oil and grease disposal must be performed by a licensed waste disposal company.

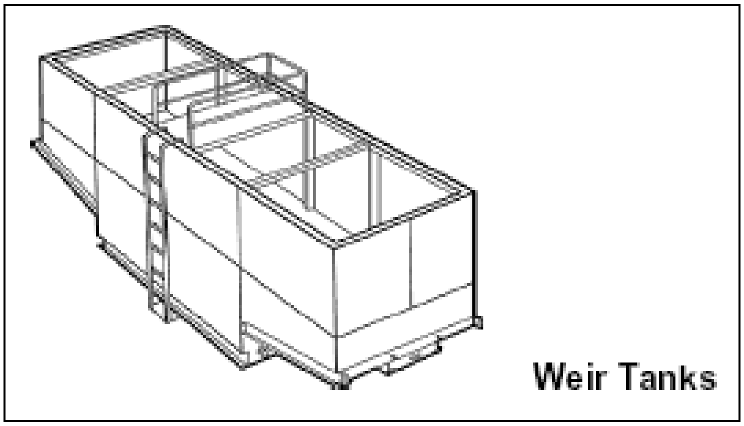


Figure 7-1: Weir Tank

De-Watering Tank

Description

A de-watering tank removes debris and sediment. Flow enters the tank through the top, passes through a fabric filter, and is discharged through the bottom of the tank. The filter separates the solids from the liquids.

Appropriate Applications

- The tank removes trash, gravel, sand, and silt, some visible oil and grease, and some metals (removed with sediment). To achieve high levels of flow, multiple tanks can be used in parallel. If additional treatment is desired, the tanks can be placed in a series or as pre-treatment for other methods.

Implementation

- Tanks are delivered to the site by the vendor, who can provide assistance with set-up and operation.
- Tank size will depend on flow volume, constituents of concern, and residency period required. Vendors should be consulted to appropriately size the tank.

Maintenance

- Periodic cleaning is required based on visual inspection or reduced flow.
- Oil and grease disposal must be performed by a licensed waste disposal company.

Figure 7-2: De-Watering Tanks

Category 3: Basic Filtration Technologies

Gravity Bag Filter

Description

A gravity bag filter, also referred to as a de-watering bag, is a square or rectangular bag made of non-woven geotextile fabric that collects sand, silt, and fines.

Appropriate Applications

- Gravity bag filters are effective for the removal of sediments (gravel, sand, and silt). Some metals are removed with the sediment.

Implementation

- Water is pumped into one side of the bag and seeps through the bottom and sides of the bag.
- A secondary barrier, such as a rock filter bed or gravel bag barrier, is placed beneath and beyond the edges of the bag to capture sediments that escape the bag.

Maintenance

- An inspection of the flow conditions, bag condition, bag capacity, and the secondary barrier is required.
- Replace the bag when it no longer filters sediment or passes water at a reasonable rate.
- The bag is disposed of off- or on-site.

Category 4: Advanced Filtration Technologies

Sand Media Particulate Filter

Description

Water is treated by passing it through canisters filled with sand media. Generally, sand filters provide a final level of treatment. They are often used as a secondary or higher level of treatment after a significant amount of sediment and other pollutants have been removed.

Appropriate Applications

- Sand filters are effective for the removal of trash, gravel, sand, silt, and some metals, as well as the reduction of Biochemical Oxygen Demand (BOD) and turbidity.
- Sand filters can be used for stand-alone treatment or in conjunction with bag and cartridge filtration if further treatment is required.
- Sand filters can also be used to provide additional treatment to water treated through settling or basic filtration.

Implementation

The filters require delivery to the site and initial set-up. The vendor can provide assistance with installation and operation.

Maintenance

The filters require constant service to monitor and maintain the sand media.

Pressurized Bag Filter

Description

A pressurized bag filter is a unit composed of single filter bags made from polyester felt material. The water filters through the unit and is discharged through a header, allowing for the flow to discharge in a series to an additional treatment unit. Vendors provide pressurized bag filters in a variety of configurations. Some units include a combination of bag filters and cartridge filters for enhanced contaminant removal.

Appropriate Applications

- A pressurized bag filter is effective for the removal of sediment (sand and silt) and some metals, as well as the reduction of BOD, turbidity, and hydrocarbons. Oil-absorbent bags are available for hydrocarbon removal.

- Filters can be used to provide secondary treatment to water treated through settling or basic filtration.

Implementation

- The filters require delivery to the site and initial set-up. The vendor can provide assistance with installation and operation.

Maintenance

- The filter bags require replacement when the pressure differential exceeds the manufacturer's recommendation.

Cartridge Filter

Description

Cartridge filters provide a high degree of pollutant removal by using a number of individual cartridges as part of a larger filtering unit. They are often used as a secondary or higher (polishing) level of treatment after a significant amount of sediment and other pollutants are removed. Units come with various cartridge configurations (for use in a series with pressurized bag filters) or with a larger single cartridge filtration unit (with multiple filters within).

Appropriate Applications

- Cartridge filters are effective for the removal of sediment (sand, silt, and some clays) and metals, as well as the reduction of BOD, turbidity, and hydrocarbons. Hydrocarbons can effectively be removed with special resin cartridges.
- Filters can be used to provide secondary treatment to water treated through settling or basic filtration.

Implementation

- The filters require delivery to the site and initial set-up. The vendor can provide assistance.

Maintenance

- The cartridges require replacement when the pressure differential exceeds the manufacturer's recommendation.

7.5.3 TEMPORARY STREAM CROSSING

Definition and Purpose

A temporary stream crossing is a structure placed across a waterway that allows vehicles to cross the waterway during construction, minimizing, reducing, or managing the erosion and downstream sedimentation caused by the vehicles.

Appropriate Applications

Temporary stream crossings are installed at sites:

- Where appropriate permits have been secured (404 permits and 401 certification).
- Where construction equipment or vehicles need to frequently cross a waterway.
- When alternate access routes impose significant constraints.
- When crossing perennial streams or waterways causes significant erosion.
- Where construction activities will not last longer than one year.

Limitations

- Temporary stream crossings will usually disturb the waterway during installation and removal.
- Temporary stream crossings will usually require 401 certification and a COE 404 permit.
- Installation may require de-watering or a temporary diversion of the stream.
- The crossings may become a constriction in the waterway, which can obstruct flood flow and cause flow back-ups or washouts. If improperly designed, flow back-ups can increase the pollutant load through washouts and scouring.
- The use of natural or other gravel in the stream for the construction of a ford crossing will be contingent upon approval by the appropriate agencies.
- Ford crossings may degrade water quality due to contact with vehicles and equipment.
- Ford crossings should not be used in excessively high or fast flows.
- Upon completion of construction activities, the crossing materials must be removed from the stream.

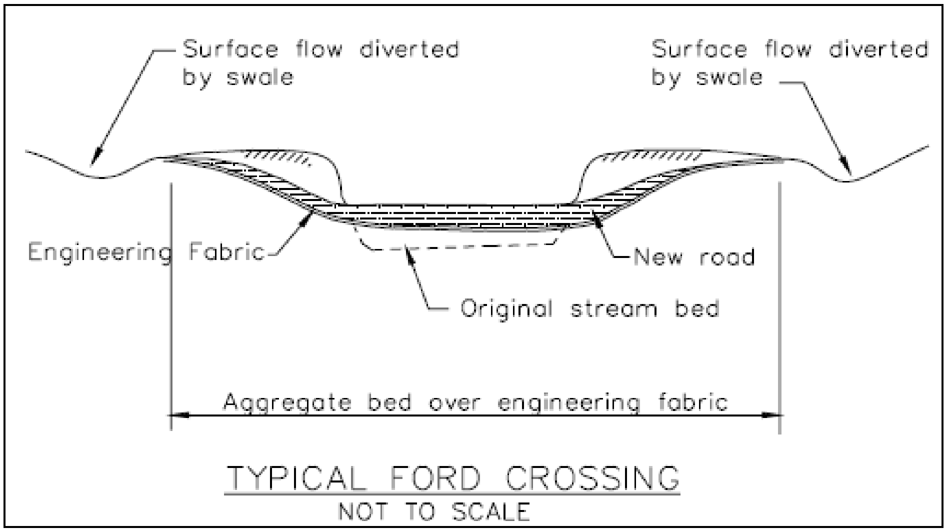


Figure 7-3: Typical Ford Crossing

Standards and Specifications

General Considerations

The location of the temporary stream crossing should address:

- Site selection where erosion potential is low.
- Areas where the side slopes from highway runoff will not spill into the side slopes of the crossing.

The following types of temporary stream crossings should be considered:

- Culverts: Used on perennial and intermittent streams.
- Fords: Appropriate during the dry season in arid areas. Used on dry washes and seasonal streams and low-flow perennial streams. Cellular Confinement System (CCS), a type of ford crossing using manufactured blocks, is also appropriate for use in streams.
- Bridges: Appropriate for streams with high flow velocities, steep gradients, and/or where temporary restrictions in the channel are not allowed.

The design and installation of a temporary stream crossing requires a knowledge of stream flows and soil strength. Designs should be prepared under the direction of, and approved by, a Registered Civil and/or Structural Engineer. Both hydraulic and construction loading requirements should be considered:

- The temporary stream crossing should comply with the requirements for culvert and bridge crossings, particularly if it will remain through the rainy season.

- The temporary stream crossing should provide stability in the crossing and adjacent areas to withstand the design flow. The design flow and safety factor should be selected based on careful evaluation of the risks due to overtopping, flow back-ups, or washout.
- The temporary stream crossing should avoid oil or other potentially hazardous waste materials for surface treatment.

Construction Considerations

- Stabilize construction roadways, adjacent work areas, and the stream bottom against erosion.
- Construct crossings during dry periods to minimize stream disturbance and reduce costs.
- Construct crossings at or near the natural elevation of the stream bed to prevent potential flooding upstream of the crossing.
- Install temporary sediment control BMPs in accordance with sediment control BMPs to minimize the erosion of embankment into flow lines.
- Vehicles and equipment should not be driven, operated, fueled, cleaned, maintained, or stored in the wet or dry portions of a water body where wetland vegetation, riparian vegetation, or aquatic organisms may be destroyed, except as authorized by the RE, as necessary to complete the work.
- Temporary water body crossings and encroachments should be constructed to minimize scour. Cobbles used for temporary water body crossings or encroachments should be clean, rounded river cobble.
- The exterior of vehicles and equipment that will encroach on the water body within the project should be maintained free of grease, oil, fuel, and residues.
- The disturbance or removal of vegetation should not exceed the minimum necessary to complete operations. Precautions should be taken to avoid damage to vegetation by people or equipment. Disturbed vegetation should be replaced with the appropriate soil stabilization measures.
- Riparian vegetation, when removed pursuant to the provisions of the work, should be cut off no lower than ground level to promote rapid re-growth. Access roads and work areas built over riparian vegetation should be covered by a sufficient layer of clean river run cobble to prevent damage to the underlying soil and root structure. The cobble should be removed upon completion of project activities.

- Any temporary artificial obstruction placed within flowing water should only be built from material such as clean gravel that will cause little or no siltation.
- Drip pans should be placed under all vehicles, and equipment should be placed on docks, barges, or other structures over water bodies when the vehicle or equipment will be idle for more than one hour.

Specific Considerations

- Culverts are relatively easy to construct and able to support heavy equipment loads.
- Fords are the least expensive of the crossings, with maximum load limits.
- Temporary fords are not appropriate if construction will continue through the rainy season, if thunderstorms are likely, or if the stream is perennial.
- CCS crossing structures consist of clean, washed gravel and CCS blocks. CCSs are appropriate for streams that would benefit from an influx of gravel such as fish streams; streams or rivers below reservoirs; and urban, channelized streams. Many urban stream systems are gravel-deprived due to human influences such as dams, gravel mines, and concrete channels.
- CCSs allow designers to use either angular or naturally-occurring, rounded gravel, because the cells provide the necessary structure and stability. In fact, natural gravel is optimal for this technique because of the habitat improvement it will provide after removal of the CCS.
- A gravel depth of 6 in. to 12 in. for a CCS structure is sufficient to support most construction equipment.
- An advantage of a CCS crossing structure is that relatively little rock or gravel is needed because the CCS provides the stability.
- Bridges are generally more expensive to design and construct but provide the least disturbance of the stream bed and constriction of the waterway flows.

Maintenance and Inspection

Maintenance provisions should include:

- The periodic removal of debris behind fords, in culverts, and under bridges.
- The replacement of lost protective aggregate from inlets and outlets of culverts.
- The removal of temporary crossing promptly once it is no longer needed.

Inspection should, at a minimum, occur weekly and after each significant rainfall and include:

- Checking for blockage in the channel, debris build-up in culverts, or behind fords and under bridges.
- Checking for erosion of abutments, channel scour, riprap displacement, or piping in the soil.
- Checking for structural weakening of the temporary crossing, such as cracks, and undermining of foundations and abutments.

7.5.4 CLEAR WATER DIVERSION

Definition and Purpose

Clear water diversion consists of a system of structures and measures that intercept clear surface water runoff upstream of a project site, transport it around the work area, and discharge it downstream, with minimal water quality degradation for either the project construction operations or construction of the diversion. Clear water diversions are used in a waterway to enclose a construction area and reduce sediment pollution from construction work occurring in or adjacent to water. Isolation techniques are methods that isolate near shore work from a water body. Structures commonly used as part of this system include diversion ditches, berms, dikes, slope drains, rock, gravel bags, wood, sheet piles, aqua barriers, cofferdams, filter fabric or turbidity curtains, drainage and interceptor swales, pipes, or flumes.

Appropriate Applications

- A clear water diversion is typically implemented where appropriate permits (404 permits and 401 water quality certifications) have been secured and work must be performed in a live stream or water body.
- Clear water diversions are appropriate for isolating construction activities occurring within or near a water body such as streambank stabilization or culvert, bridge, pier, or abutment installation. They may also be used in combination with other methods, such as clear water bypasses and/or pumps.
- Pumped diversions are suitable for intermittent and low-flow streams.
- Excavation of a temporary bypass channel or passing the flow through a pipe called a flume is appropriate for the diversion of streams less than 20 ft. wide, with flow rates less than 99 cu. ft. per second.

Limitations

- Diversion/encroachment activities will usually disturb the waterway during the installation and removal of diversion structures.
- Specific permit requirements or mitigation measures, such as the USACE, Federal Emergency Management Agency (FEMA), etc., may be included in contract documents because of clear water diversion/encroachment activities.

- Diversion/encroachment activities may constrict the waterway, which can obstruct flood flows and cause flooding or washouts. Diversion structures should not be installed without identifying potential impacts to the stream channel.
- Diversion or isolation activities should not completely dam stream flow.
- De-watering and removal may require additional sediment control or water treatment.

Standards and Specifications

General

- Implement the guidelines presented for the streambank protection BMP.
- Where working areas encroach on live streams, barriers adequate to prevent the flow of muddy water into streams should be constructed and maintained between working areas and streams. During construction of the barriers, the muddying of streams should be held to a minimum.
- Diversion structures must be adequately designed to accommodate fluctuations in water depth or flow volume due to tides, storms, flash floods, etc.
- Heavy equipment driven in wet portions of a water body to accomplish work should be completely clean of petroleum residue and water levels should be below the gearboxes of the equipment in use, or lubricants and fuels should be sealed so that an inundation of water does not result in leaks.
- Mechanical equipment operated in the water should not be submerged to a point above any axle of the mechanical equipment.
- The excavation equipment buckets may reach out into the water for the purpose of removing or placing fill materials. Only the bucket of the crane/excavator/backhoe may operate in a water body. The main body of the crane/excavator/backhoe should not enter the water body, except as necessary to cross the stream to access the work site.
- Stationary equipment such as motors and pumps, located within or adjacent to a water body, should be positioned over drip pans.
- When any artificial obstruction is being constructed, maintained, or placed in operation, sufficient water should, at all times, be allowed to pass downstream to maintain aquatic life downstream.
- The exterior of vehicles and equipment that will encroach on a water body within the project should be maintained free of grease, oil, fuel, and residues.

- Equipment should not be parked below the high-water mark, unless allowed by a permit.
- The disturbance or removal of vegetation should not exceed the minimum necessary to complete operations. Precautions should be taken to avoid damage to vegetation by people or equipment. Disturbed vegetation should be replaced with the appropriate soil stabilization measures.
- Riparian vegetation, when removed pursuant to the provisions of the work, should be cut off no lower than ground level to promote rapid re-growth.
- Access roads and work areas built over riparian vegetation should be covered by a sufficient layer of clean river-run rock to prevent damage to the underlying soil and root structure. The rock should be removed upon completion of project activities.
- Drip pans should be placed under all vehicles, and equipment should be placed on docks, barges, or other structures over water bodies when the vehicle or equipment is planned to be idle for more than one hour.
- Where possible, avoid or minimize diversion/encroachment impacts by scheduling construction during periods of low flow or when the stream is dry. Also, see the project permits and contract requirements for scheduling. Scheduling should also consider seasonal flows, fish spawning seasons, and water demands due to irrigation.
- Construct diversion structures with materials free of potential pollutants, such as soil, silt, sand, clay, grease, or oil.

Temporary Diversions/Encroachments

- Construct diversion channels in accordance with the guidelines for the earth dikes, drainage swales, and ditches BMPs.
- In high-flow velocity areas, stabilize the slopes of embankments and diversion ditches using an appropriate liner, in accordance with the geotextiles, plastic covers and erosion control blankets/mats BMPs, or use rock slope protection, as described in the Standard Specifications.
- Where appropriate, use natural stream bed materials such as large cobbles and boulders for temporary embankment/slope protection or other temporary soil stabilization methods.
- Provide for velocity dissipation at transitions in the diversion, such as the point where the stream is diverted to the channel and the point where the diverted stream is returned to its natural channel, in accordance with the guidelines noted under the outlet protection/velocity dissipation devices. BMPs.

Temporary Dry Construction Areas

- When de-watering behind temporary structures to create a temporary dry construction area such as cofferdams, pass pumped water through a sediment settling device, such as a portable tank or settling basin, before returning the water to the water body.
- If the presence of polluted water or sediment is identified in the contract, the contractor should implement de-watering pollution controls as required by the contract documents. If the quality of water or sediment to be removed while de-watering is not identified as polluted in the contract documents, but is later determined by observation or testing to be polluted, the contractor should comply with the contract requirements.
- Any substance used to assemble or maintain diversion structures, such as form oil, should be non-toxic and non-hazardous.
- Any material used to minimize seepage underneath diversion structures, such as grout, should be non-toxic, non-hazardous, and as close to a neutral pH as possible.

Isolation Techniques

Isolation techniques are methods that isolate near-shore work from a water body. Techniques include sheet pile enclosures, water-filled geotextile (aqua dam), gravel berm with impermeable membrane, gravel bags, cofferdams, and K-rail.

Filter Fabric Isolation Technique

Definition and Purpose

A filter fabric isolation structure is a temporary structure built into a waterway to enclose a construction area and reduce sediment pollution from construction work in or adjacent to water. This structure is composed of filter fabric, gravel bags, and steel T-posts.

Appropriate Applications

- Geotextile filter fabric may be used for construction activities such as streambank stabilization or culvert, bridge, pier, or abutment installation. It may also be used in combination with other methods, such as clean water bypasses and/or pumps.
- This method involves the placement of gravel bags or continuous berms to key in the fabric, subsequently staking the fabric in place.
- If stream bed fish spawning gravel (gravel between 1 in. and 4 in.) is used, all other components of the isolation can be removed from the stream, and the gravel can be spread out and left as for the stream bed

habitat. Whether spawning gravel or other types of gravel are used, only clean, washed gravel should be used as infill for the gravel bags or continuous berm.

- This is a method that should be used in relatively calm water in smaller streams.

Limitations

- Do not use if the installation, maintenance, and removal of the structures will disturb sensitive aquatic species of concern.
- Filter fabric is not appropriate for projects where de-watering is necessary.
- Filter fabric is not appropriate to completely dam stream flow.

Standards and Specifications

- For the filter fabric isolation method, a non-woven or heavy-duty fabric is recommended over standard silt fence. Using rolled geotextile allows non-standard widths to be used.
- Anchor filter fabric with gravel bags filled with clean, washed gravel. Do not use sand. If a bag should split open, the gravel can be left in the stream, where it can provide aquatic habitat benefits.
- Another anchor alternative is a continuous berm, made with the continuous berm machine. This is a gravel-filled bag that can be made in very long segments. The length of the berms is usually limited to 20 ft. for ease of handling.

Installation

- Place the fabric on the bottom of the stream, and place either a bag of clean, washed gravel or a continuous berm over the bottom of the fabric, so that a bag-width of fabric lies on the stream bottom. The bag should be placed on what will be the outside of the isolation area.
- Pull the fabric up and place a metal T-post immediately behind the fabric, on the inside of the isolation area; and attach the fabric to the post with three diagonal nylon ties.
- Continue placing fabric as described above until the entire work area has been isolated, staking the fabric at least every 6 ft.

Maintenance and Inspection

- During construction, inspect daily during the work week.

- Schedule additional inspections during storm events.
- Immediately repair any gaps, holes, or scour.
- Remove sediment build-up.
- Remove BMPs upon completion of all construction activity. Recycle or reuse if applicable.
- Re-vegetate areas disturbed by BMP removal if needed.

Turbidity Curtain Isolation Technique

Definition and Purpose

A turbidity curtain is a fabric barrier used to isolate the near-shore work area. The barriers are intended to confine the suspended sediment. The curtain is a floating barrier, and thus does not prevent water from entering the isolated area; rather, it prevents suspended sediment from getting out.

Appropriate Applications

Turbidity curtains should be used where sediment discharge to a stream is unavoidable. They are used when construction activities adjoin quiescent waters such as lakes, ponds, lagoons, bays, and slow-flowing rivers. The curtains are designed to deflect and contain sediment within a limited area and provide sufficient retention time so that the soil particles will fall out of suspension.

Limitations

- Turbidity curtains should not be used in flowing water; they are best suited for use in ponds, lakes, lagoons, bays, and very slow-moving rivers.
- Turbidity curtains should not be placed across the width of a channel.
- Removing sediment that has been deflected and settled out by the curtain may create a discharge problem through the re-suspension of particles and by accidental dumping by the removal equipment.

Standards and Specifications

- Turbidity curtains should be oriented parallel to the direction of flow.
- The curtain should extend the entire depth of the watercourse in calm-water situations.
- In wave conditions, the curtain should extend to within 1 ft. of the bottom of the watercourse, so that the curtain does not stir up sediment by hitting the bottom repeatedly. If it is desirable for the curtain to reach the bottom

in an active-water situation, a pervious filter fabric may be used for the bottom 1 ft.

- The top of the curtain should consist of flexible flotation buoys, and the bottom should be held down by a load line incorporated into the curtain fabric. The fabric should be a brightly-colored impervious mesh.
- The curtain should be held in place by anchors placed at least every 100 ft.
- First, place the anchors. Then tow the fabric out in a furled condition and connect to the anchors. The anchors should be connected to the flotation devices and not to the bottom of the curtain. Once in place, cut the furling lines and allow the bottom of the curtain to sink.
- Sediment that has been deflected and settled out by the curtain may be removed. Consideration must be given to the probable outcome of the removal procedure. Consider whether more of a sediment problem will be created through re-suspension of the particles or by accidental dumping of material during removal. It is recommended that the soil particles trapped by the turbidity curtain only be removed if there has been a significant change in the original contours of the affected area in the watercourse.
- Particles should always be allowed to settle for a minimum of 6 hours to 12 hours prior to their removal or prior to removal of the turbidity curtain.

Maintenance and Inspection

- The curtain should be inspected daily for holes or other problems, and any repairs needed should be made promptly.
- Allow sediment to settle for 6 hours to 12 hours prior to the removal of sediment or curtain. This means that after removing sediment, wait an additional 6 hours to 12 hours before removing the curtain.
- To remove, install furling lines along the curtain, detach from anchors, and tow out of the water.

K-Rail (Pre-cast, Concrete Traffic Barriers) River Isolation

Definition and Purpose

This is a temporary sediment control, or stream isolation method, that uses K-rails to form the sediment deposition area, or to isolate the in-stream or near-bank construction area. Barriers are placed end-to-end in a pre-designed configuration, and gravel-filled bags are used at the toe of the barrier and also at their abutting ends to seal and prevent the movement of sediment beneath or through the barrier walls.

Appropriate Applications

- K-rail isolation can be used in streams with higher water velocities than many other isolation techniques.

Limitations

- The K-rail method does not allow for full de-watering.

Standards and Specifications

- To create a floor for the K-rail, move large rocks and obstructions. Place washed gravel and gravel-filled bags to create a level surface for K-rail to sit.
- Place the bottom two K-rails adjacent to each other and parallel to the direction of flow; fill the center portion with gravel bags. Then place the third K-rail on top of the bottom two; there should be sufficient gravel bags between the bottom K-rails, so that the top one is supported by the gravel. Place plastic sheeting around the K-rails and secure at the bottom with gravel bags.
- Further support can be added by pinning and cabling the K-rails together. Also, large riprap and boulders can be used to support either side of the K-rail, especially where there is a strong current.

Maintenance and Inspection

- The barrier should be inspected at least once daily, and any damage, movement, or other problems should be addressed immediately.
- Sediment should be allowed to settle for at least 6 hours to 12 hours prior to removal of sediment and for 6 hours to 12 hours prior to removal of the barrier.

Stream Diversions

Definition and Purpose

Stream diversions consist of a system of structures and measures that intercept an existing stream upstream of the project, transports it around the work area, and discharges it downstream. The selection of which stream diversion technique to use depends upon the type of work involved, the physical characteristics of the site, and the volume of water flowing through the project.

Appropriate Applications

- Pumped diversions are appropriate in areas where de-watering is necessary.
- Dam-type diversions may serve as temporary access to the site.
- Diversions are appropriate in work areas that require isolation from flows.

Limitations

- Pumped diversions have a limited flow capacity.
- Pumped diversions require the frequent monitoring of pumps.
- Large flows during storm events can overtop dams.
- Flow diversion and re-direction with small dams involves in-stream disturbance and the mobilization of sediment.

Standards and Specifications

- Diversions should be sized to convey design flood flows.
- Pump capacity must be sufficient for design flow; the upper limit is approximately 10 cu. ft. per second (the capacity of two 8-in. pumps).
- Adequate energy dissipation must be provided at the outlet to minimize erosion.
- Dam materials used to create dams upstream and downstream of the diversion should be erosion-resistant; materials such as steel plate, sheet pile, sandbags, continuous berms, inflatable water bladders, etc., would be acceptable.
- When constructing a diversion channel, begin excavation of the channel at the proposed downstream end, and work upstream. Once the watercourse to be diverted is reached and the excavated channel is stable, breach the upstream end and allow water to flow down the new channel. Once flow has been established in the diversion channel, install the diversion weir in the main channel; this will force all water to be diverted from the main channel.

Maintenance and Inspection

- Inspect diversion/encroachment structures before and after significant storms and at least once per week while in service. Inspect daily during construction.
- Pumped diversions require the frequent monitoring of pumps.

- Inspect embankments and diversion channels before and after significant storms and at least once per week while in service for damage to the linings, accumulating debris, sediment build-up, and the adequacy of slope protection. Remove debris and repair linings and slope protection as required. Repair holes, gaps, or scour.

In-Stream Construction Sediment Control

There are three different options currently available for reducing turbidity while working in a stream or river. The stream can be isolated from the area in which work is occurring with a water barrier; the stream can be diverted around the work site through a pipe or temporary channel; or construction practices that minimize sediment suspension can be used.

Whichever technique is implemented, an important thing to remember is that the worst time to release high Total Suspended Solids (TSS) into a stream system might be when the stream is very low. During these times, the flow may be low while the biological activity in the stream is very high. Conversely, the addition of high TSS or sediment during a big storm discharge might have a relatively low impact because the stream is already turbid and the stream energy is capable of transporting both suspended solids and large quantities of bedload through the system. The optimum time to remove in-stream structures may be during the rising limb of a storm hydrograph.

Techniques to Minimize Total Suspended Solids (TSS)

- ***Padding*****:** Padding laid in the stream below the work site may trap some solids that are deposited in the stream during construction. After work is done, the padding is removed from the stream and placed on the bank to assist in re-vegetation.
- ***Clean, washed gravel*****:** Using clean, washed gravel decreases solid suspension, as there are fewer small particles deposited in the stream.
- ***Excavation using a large bucket*****:** Each time a bucket of soil is placed in the stream, a portion is suspended. Approximately the same amount is suspended whether there is a small or large amount of soil placed in the stream. Therefore, using a large excavator bucket will reduce the total amount of soil that washes downstream.
- ***Use of a dozer for backfilling*****:** Using a dozer for backfilling instead of a backhoe follows the same principles -- the fewer times soil is deposited in the stream, the less soil will be suspended.

- ***Partial de-watering with a pump*:** Partially de-watering a stream with a pump reduces the amount of water, and thus the amount of water that can suspend sediment.

Washing Fines

Definition and Purpose

Washing fines is an in-channel sediment control method that uses water, either from a water truck or hydrant, to wash any stream fines that were brought to the surface of the channel bed during restoration back into the interstitial spaces of the gravel and cobbles.

The purpose of this technique is to reduce or eliminate the discharge of sediment from the channel bottom during the first seasonal flows, or first flush. Sediment should not be allowed into stream channels; however, occasionally, in-channel restoration work will involve moving or otherwise disturbing fines (sand and silt-sized particles) that are already in the stream, usually below bank-full discharge elevation. Subsequent re-watering of the channel can result in a plume of turbidity and sedimentation.

This technique washes the fines back into the channel bed. Bedload materials, including gravel cobbles, boulders, and those fines, are naturally mobilized during higher storm flows. This technique is intended to delay the discharge until the fines would naturally be mobilized.

Appropriate Applications

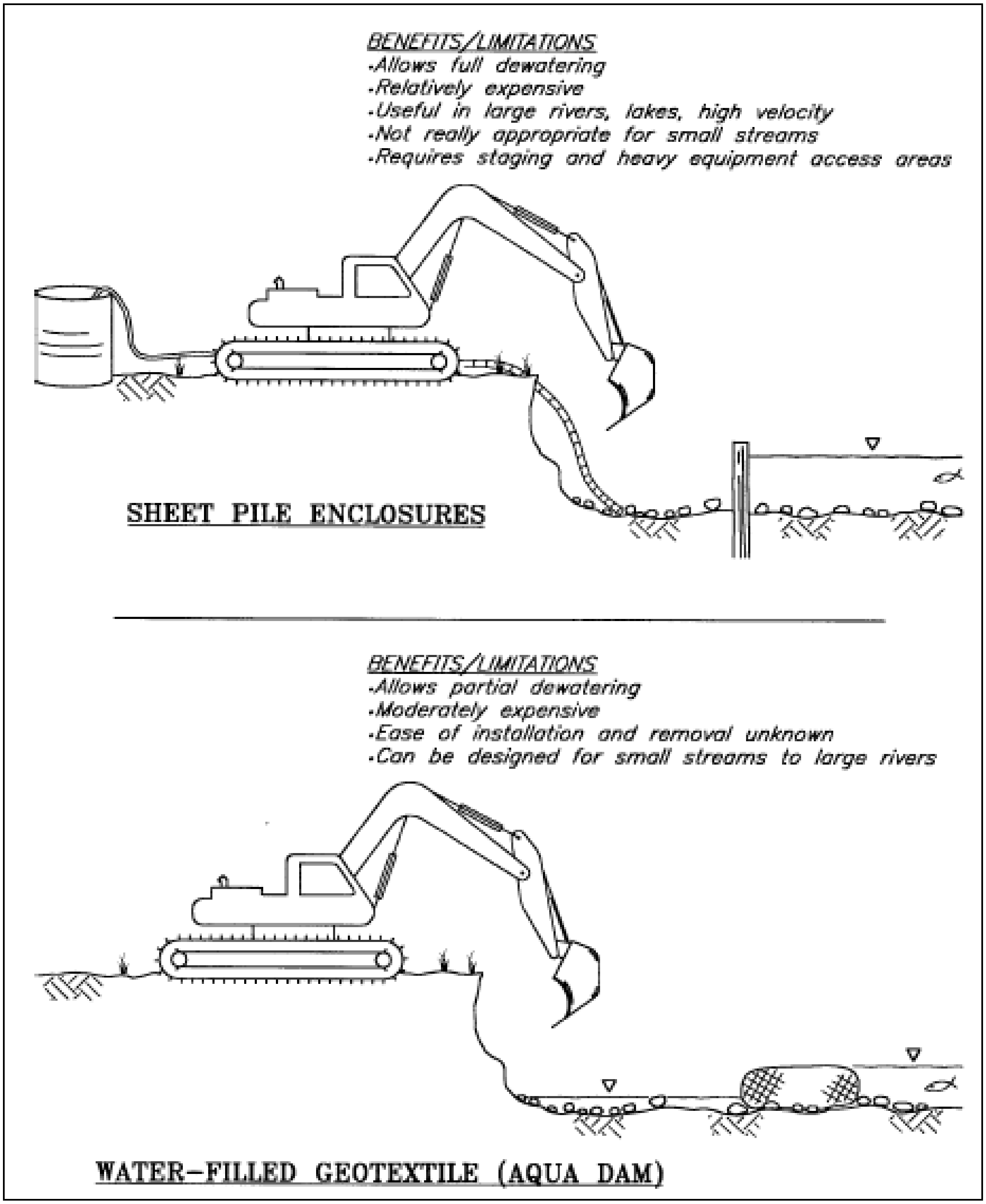
- This technique should be used when construction work is required in channels. It is especially useful in intermittent or ephemeral streams in which work is performed "in the dry" and is subsequently re-watered.

Limitations

- The stream must have sufficient gravel and cobble substrate composition.
- The use of this technique requires consideration of the time of year and timing of expected stream flows.
- The optimum time for the use of this technique is in the dry season.

Standards and Specifications

- Apply water slowly and evenly to prevent runoff and erosion.
- Consult with the Guam Environmental Protection Agency (GEPA) for specific water quality requirements of applied water.



1
2 **Figure 7-4: In-Stream Erosion and Sediment Control Isolation Techniques**

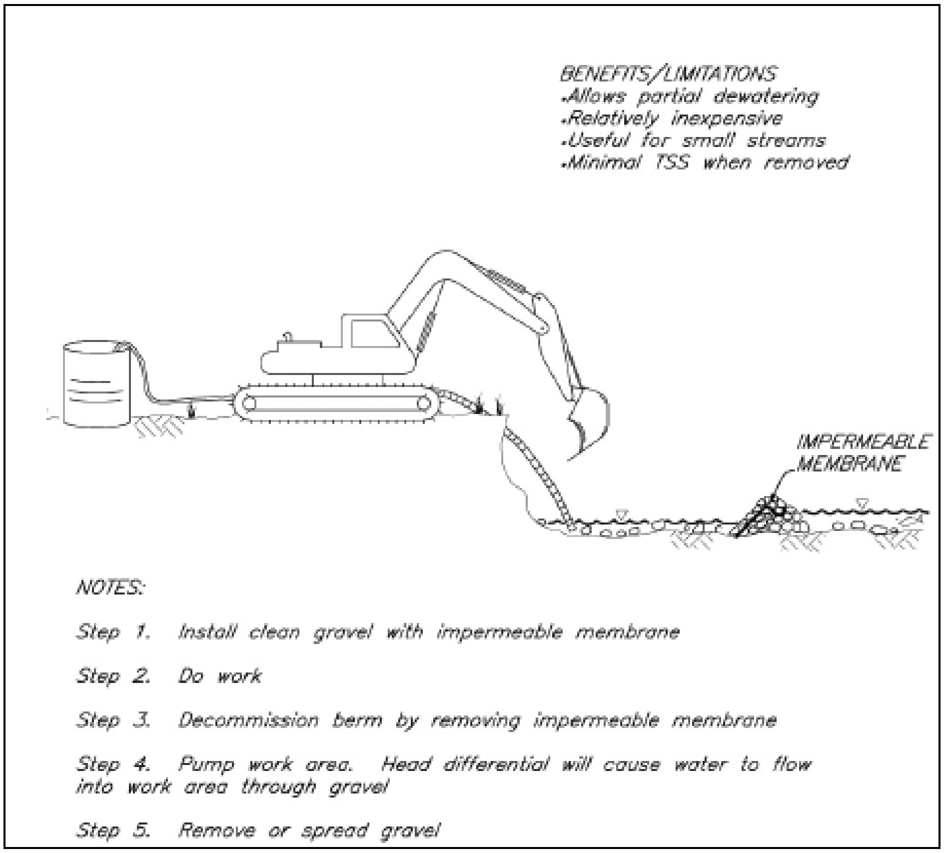


Figure 7-5: Gravel Berm with Impermeable Membrane

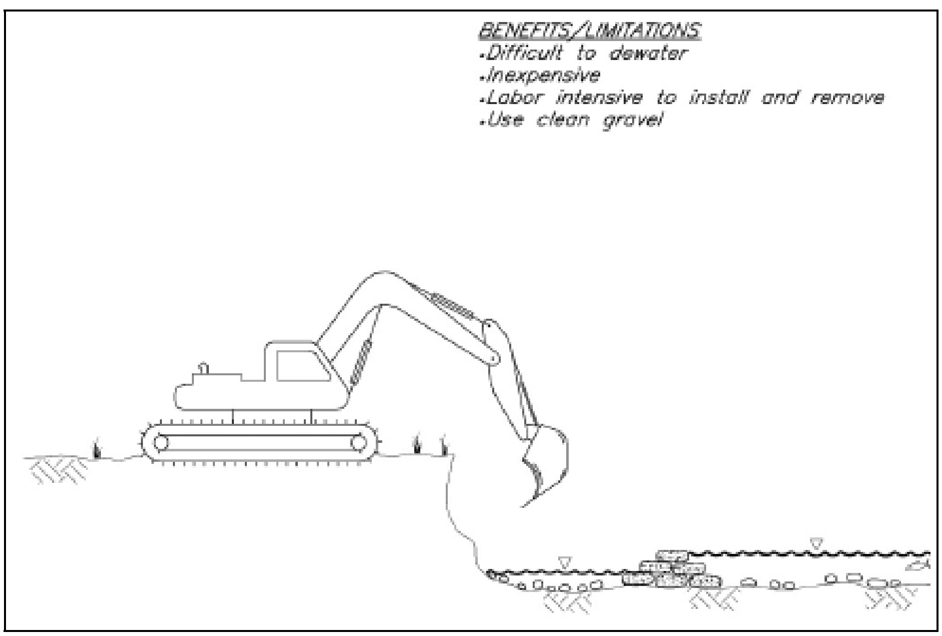
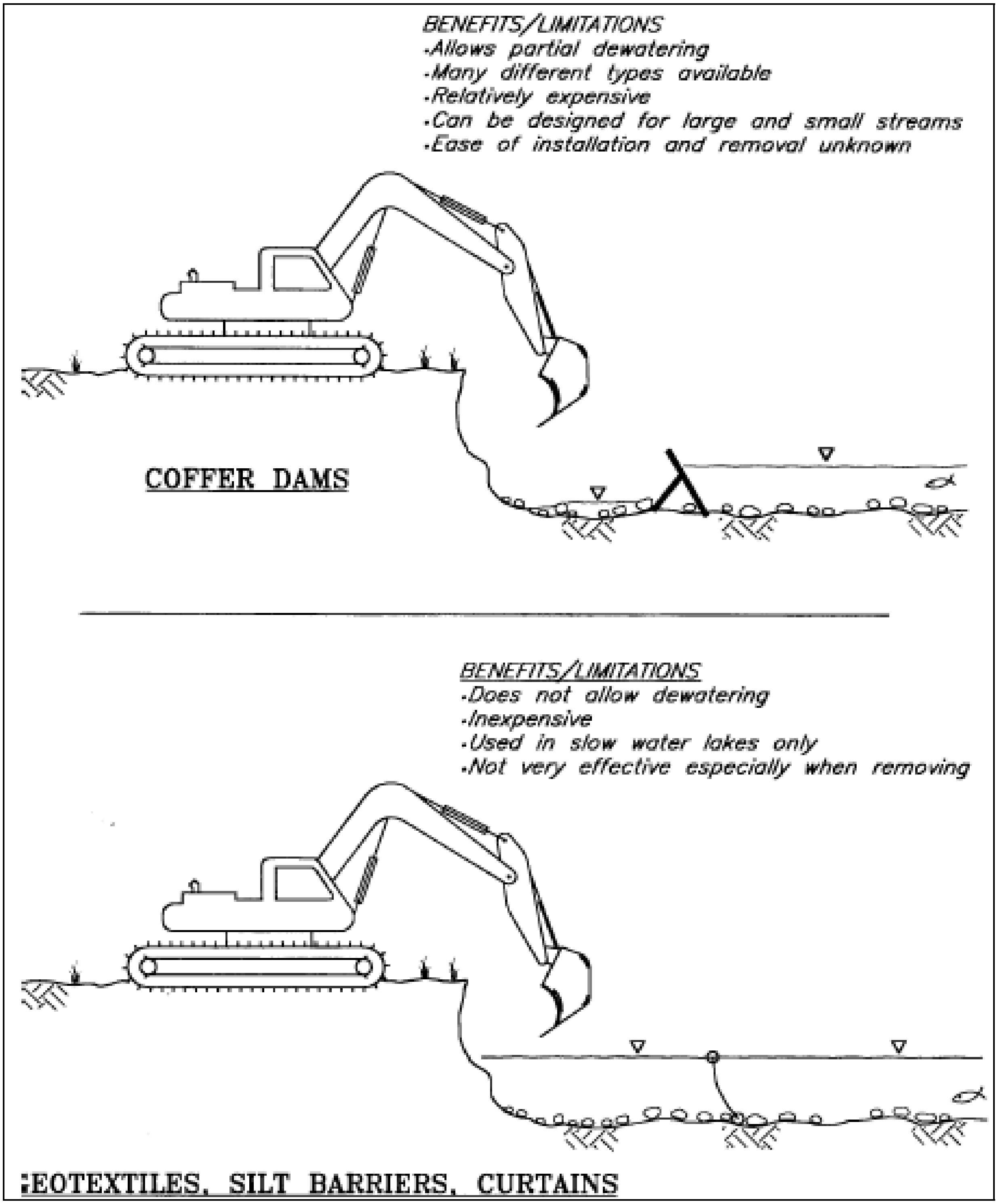


Figure 7-6: Gravel Bag Technique

1 

2 **Figure 7-7: In-Stream Erosion and Sediment Control Isolation**

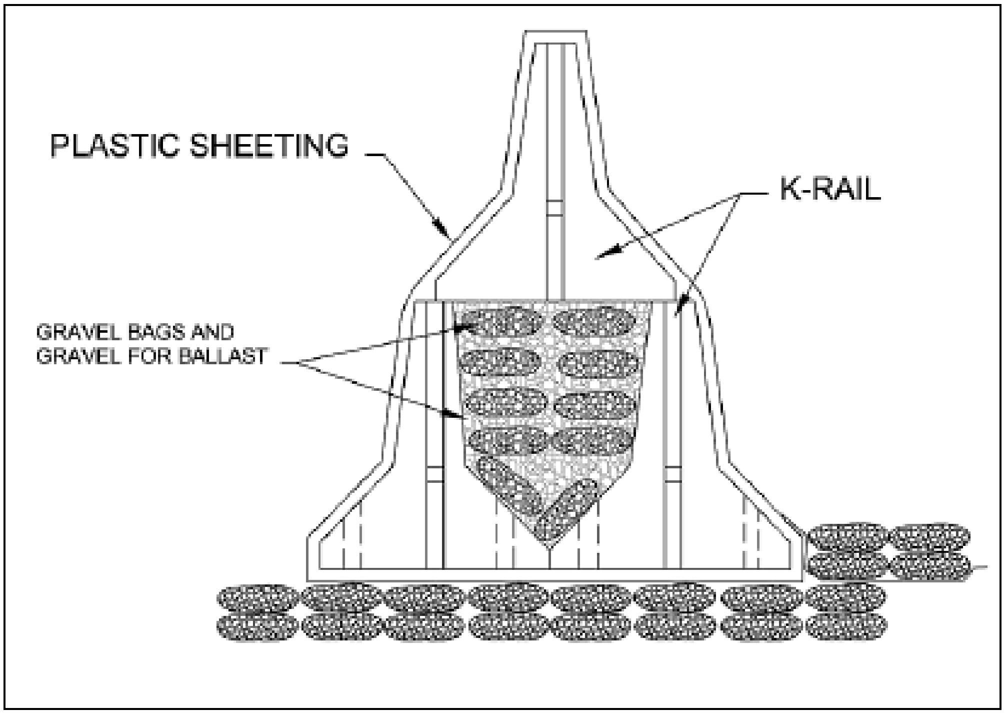


Figure 7-8: K-Rail

7.5.5 POTABLE WATER/IRRIGATION

Definition and Purpose

Potable water/irrigation management consists of practices and procedures to manage the discharge of potential pollutants generated during discharges from irrigation water lines, landscape irrigation, lawn or garden watering, planned and unplanned discharges from potable water sources, water line flushing, and hydrant flushing.

Appropriate Applications

Implement this BMP whenever the above activities or discharges occur at or enter a construction site.

Limitations

- None identified.

Standards and Specifications

- Inspect irrigated areas within the construction limits for excess watering. Adjust watering times and schedules to ensure that the appropriate amount of water is being used and to minimize runoff. Consider factors such as soil structure, grade, time of year, and type of plant material in determining the proper amounts of water for a specific area.

- Equipment or other project washing activities runoff should be quality treated prior to discharge to the storm drain or receiving water body.
- Where possible, direct water from off-site sources around or through a construction site in a way that minimizes contact with the construction site.
- When possible, discharges from water line flushing should be reused for landscaping purposes.
- Shut off the water source to broken lines, sprinklers, or valves as soon as possible to prevent excess water flow.
- Protect downstream stormwater drainage systems and watercourses from water pumped or bailed from trenches excavated to repair water lines.

Maintenance and Inspection

- Repair broken water lines as soon as possible or as directed by the RE.
- Inspect irrigated areas regularly for signs of erosion and/or discharge.

7.5.6 VEHICLE AND EQUIPMENT CLEANING

Definition and Purpose

Vehicle and equipment cleaning procedures and practices are used to minimize or eliminate the discharge of pollutants from vehicle and equipment cleaning operations to a storm drain system or to watercourses.

Appropriate Applications

These procedures are applied on all construction sites where vehicle and equipment cleaning is performed.

Limitations

- None.

Standards and Specifications

- On-site vehicle and equipment washing is discouraged.
- Cleaning vehicles and equipment with soap, solvents, or steam should not occur on the project site unless the resulting wastes are fully-contained and disposed of outside of the project limits in conformance with the contract requirements. Resulting wastes and byproducts should not be discharged or buried within the project limits and must be captured and recycled or disposed of.
- Minimize the use of solvents. The use of diesel for vehicle and equipment cleaning is prohibited.

- Vehicle and equipment washwater should be contained for percolation or evaporative drying away from storm drain inlets or watercourses, and should not be discharged within the project limits. Apply sediment control BMPs if applicable.
- All vehicles/equipment that regularly enter and leave the construction site must be cleaned off-site.
- When vehicle/equipment washing/cleaning must occur on-site, and the operation cannot be located within a structure or building equipped with appropriate disposal facilities, the outside cleaning area should have the following characteristics:
    - Located away from storm drain inlets, drainage facilities, or watercourses
    - Paved with concrete or asphalt and bermed to contain washwaters and to prevent run-on and run-off
    - Configured with a sump to allow for the collection and disposal of washwater
    - Washwaters should not be discharged to storm drains or watercourses
    - Used only when necessary
- When cleaning vehicles/equipment with water:
    - Use as little water as possible. High pressure sprayers may use less water than a hose and should be considered.
    - Use a positive shutoff valve to minimize water usage
    - Facility wash racks should discharge to a sanitary sewer, recycle system, or other approved discharge system and should not discharge to the storm drainage system or watercourses

Maintenance and Inspection

- The control measure should be inspected at a minimum of once a week
- Monitor employees and subcontractors throughout the duration of the construction project to ensure appropriate practices are being implemented
- Inspect sump regularly and remove liquids and sediment as needed

7.5.7 VEHICLE AND EQUIPMENT FUELING

Definition and Purpose

Vehicle and equipment fueling procedures and practices are designed to minimize or eliminate the discharge of fuel spills and leaks into storm drain systems or to watercourses.

Appropriate Applications

These procedures are applied on all construction sites where vehicle and equipment fueling occurs.

Limitations

- On-site vehicle and equipment fueling should only be used where it is impractical to send vehicles and equipment off-site for fueling.

Standards and Specifications

- When fueling must occur on-site, the contractor should select and designate an area to be used.
- Absorbent spill cleanup materials and spill kits should be available in fueling areas and on fueling trucks and disposed of properly after use.
- Drip pans or absorbent pads should be used during vehicle and equipment fueling, unless the fueling is performed over an impermeable surface in a dedicated fueling area.
- Dedicated fueling areas should be protected from stormwater run-on and run-off, and located at least 50 ft. from downstream drainage facilities and watercourses. Fueling must be performed on level grade areas.
- Nozzles used in vehicle and equipment fueling should be equipped with an automatic shutoff to control drips. Fueling operations should not be left unattended.
- Protect fueling areas with berms and/or dikes to prevent run-on, run-off, and to contain spills.
- Use vapor recovery nozzles to help control drips as well as air pollution where required. Ensure the nozzle is secured upright when not in use.
- Fuel tanks should not be "topped-off."
- Vehicles and equipment should be inspected on each day of use for leaks. Leaks should be repaired immediately, or problem vehicles or equipment should be removed from the project site.
- Absorbent spill cleanup materials should be available in fueling and maintenance areas and used on small spills instead of hosing the area down or using burying techniques. The spent absorbent material should be removed promptly and disposed of properly.
- Federal, state, and local requirements should be observed for any stationary above-ground storage tanks.

- Mobile fueling of construction equipment throughout the site should be minimized. Whenever practical, equipment should be transported to the designated fueling area.

Maintenance and Inspection

- Fueling areas and storage tanks should be inspected regularly.
- Keep an ample supply of spill cleanup material on the site.
- Immediately clean up spills and properly dispose of contaminated soil and cleanup materials.

7.5.8 VEHICLE AND EQUIPMENT MAINTENANCE

Definition and Purpose

Vehicle and equipment maintenance involves procedures and practices to minimize or eliminate the discharge of pollutants to the storm drain systems or to watercourses from vehicle and equipment maintenance procedures.

Appropriate Applications

These procedures are applied on all construction projects where an on-site yard area is necessary for the storage and maintenance of heavy equipment and vehicles.

Limitations

- None identified.

Standards and Specifications

- Drip pans or absorbent pads should be used during vehicle and equipment maintenance work that involves fluids, unless the maintenance work is performed over an impermeable surface in a dedicated maintenance area.
- All maintenance areas are required to have spill kits and/or use other spill protection devices.
- Dedicated maintenance areas should be protected from stormwater run-on and run-off and located at least 50 ft. from downstream drainage facilities and watercourses.
- Drip pans or plastic sheeting should be placed under all vehicles and equipment placed on docks, barges, or other structures over water bodies when the vehicle or equipment is planned to be idle for more than one hour.
- Absorbent spill cleanup materials should be available in maintenance areas and disposed of properly after use. Substances used to coat asphalt transport trucks and asphalt-spreading equipment should be non-toxic.

- Use off-site maintenance facilities whenever practical. For long-term projects, consider constructing roofs or using portable tents over maintenance areas.
- Properly dispose of used oils, fluids, lubricants, and spill cleanup materials.
- Do not dump fuels and lubricants onto the ground.
- Do not place used oil in a dumpster or pour into a storm drain or watercourse.
- Properly dispose or recycle used batteries.
- Do not bury used tires.
- Repair fluid and oil leaks immediately.
- Provide spill containment dikes or secondary containment around stored oil and chemical drums.

Maintenance and Inspection

- Maintain waste fluid containers in leak-proof condition.
- Vehicle and equipment maintenance areas should be inspected regularly.
- Vehicles and equipment should be inspected on each day of use. Leaks should be repaired immediately, or the problem vehicles or equipment should be removed from the project site.
- Inspect equipment for damaged hoses and leaky gaskets routinely. Repair or replace as needed.

7.5.9 PILE-DRIVING OPERATIONS

Definition and Purpose

The construction and retrofit of bridges and retaining walls often includes driving piles for foundation support and shoring operations. Driven piles are typically constructed of concrete, steel, or timber. Driven sheet piles are used for shoring and cofferdam construction. The proper control and use of equipment, materials, and waste products from pile-driving operations will reduce the discharge of potential pollutants to the storm drain system or watercourses.

Appropriate Applications

These procedures apply to construction sites near or adjacent to a watercourse or groundwater where permanent and temporary pile-driving operations (impact and vibratory) take place.

Standards and Specifications

- Use drip pans or absorbent pads during vehicle and equipment maintenance, cleaning, fueling, and storage. Refer to the BMPs "Vehicle and Equipment Fueling" and "Vehicle and Equipment Maintenance."
- Have spill kits and cleanup materials available at all pile-driving locations.
- Keep equipment that is in use in streambeds or on docks, barges, or other structures over water bodies, leak free.
- Where possible, park equipment over plastic sheeting or equivalent. Plastic sheeting is not a substitute for drip pans or absorbent pads. The storage or use of equipment in streambeds or other bodies of water should comply with all applicable permits.
- Implement other BMPs as applicable.
- When not in use, store pile-driving equipment away from concentrated flows of stormwater, drainage courses, and inlets. Protect hammers and other hydraulic attachments from run-on by placing them on plywood and covering them with plastic or a comparable material prior to the onset of rain.
- Use less hazardous products, such as vegetable oil, instead of hydraulic fluid, when practicable.

Maintenance and Inspection

- Inspect pile-driving areas and equipment for leaks and spills on a daily basis.
- Inspect equipment routinely and repair equipment as needed (e.g., worn or damaged hoses, fittings, gaskets, etc.).

7.5.10 CONCRETE CURING

Definition and Purpose

Concrete curing is used in the construction of structures such as bridges, retaining walls, and pump houses. Concrete curing includes the use of both chemical and water methods. Proper procedures minimize runoff pollution during concrete curing.

Appropriate Applications

All concrete elements of a structure (e.g., footings, columns, abutments, stems, soffit, decks, etc.) are subject to curing requirements.

Standards and Specifications

Chemical Curing

- Avoid the overspray of curing compounds.

- Minimize the drift of chemical cure as much as possible by applying the curing compound close to the concrete surface. Apply an amount of compound that covers the surface but does not allow any runoff of the compound.
- Use proper storage and handling techniques for concrete curing compounds.
- Protect drain inlets prior to the application of curing compounds.

Water Curing for Bridge Decks, Retaining Walls, and Other Structures

- Direct curing water away from inlets and watercourses to collection areas for removal in accordance with all applicable permits.
- Collect cured water and transport or dispose of water in a non-erodible manner.
- Use wet blankets or a similar method that maintains moisture while minimizing the use and possible discharge of water.

Maintenance and Inspection

- Ensure that employees and subcontractors implement appropriate measures for storage, handling, and the use of curing compounds.
- Inspect any temporary diversion devices, lined channels, or swales for washouts, erosion, or debris. Replace lining and remove debris as necessary.
- Inspect cure containers and spraying equipment for leaks.

7.5.11 MATERIAL AND EQUIPMENT USE OVER WATER

Definition and Purpose

The following outlines procedures for the proper use, storage, and disposal of materials and equipment on barges, boats, temporary construction pads, or similar locations that minimize or eliminate the discharge of potential pollutants to a watercourse.

Appropriate Applications

These procedures should be implemented for construction materials and wastes (solid and liquid) and any other materials that may be detrimental if released. These procedures should be applied where materials and equipment are used on barges, boats, docks, and other platforms over or adjacent to a watercourse.

Standards and Specifications

- Use drip pans and absorbent materials for equipment and vehicles, and ensure that an adequate supply of spill cleanup materials is available. Drip pans should be placed under all vehicles and equipment placed on docks, barges, or other structures over water bodies when the vehicle or equipment is expected to be idle for more than one hour.

- Maintain equipment in accordance with the BMP, "Vehicle and Equipment Maintenance."
- Provide watertight curbs or toe boards to contain spills and prevent materials, tools, and debris from leaving the barge, platform, dock, etc.
- Secure all materials to prevent discharges to receiving waters through wind.
- Identify the types of spill control measures to be employed. Ensure that the staff is trained to handle spills.
- Ensure the timely and proper removal of accumulated wastes.
- Comply with all necessary permits required for construction within or near the watercourse.
- Discharges to waterways should be reported immediately upon discovery. A written discharge notification must follow within seven days.

Maintenance and Inspection

- Inspect equipment for leaks and spills on a daily basis, and make necessary repairs.
- Ensure that employees and subcontractors implement appropriate measures for the storage and use of materials and equipment.

7.5.12 CONCRETE FINISHING

Definition and Purpose

Concrete finishing methods are used for bridge deck rehabilitation, paint removal, curing compound removal, and final surface finish appearances. Methods include sand blasting, shot blasting, grinding, or high-pressure water blasting. Proper procedures minimize the impact that concrete finishing methods may have on runoff.

Appropriate Applications

These procedures apply to all construction locations where concrete finishing operations are performed.

Limitations

- Specific permit requirements may be included in the contract documents for certain concrete finishing operations.

Standards and Specifications

- Follow the containment requirements stated in the contract documents, if any.

- Collect and properly dispose of water and solid waste from high-pressure water-blasting operations.
- Collect water from blasting operations, and transport or dispose of water in a non-erodible manner.
- Direct water from blasting operations away from inlets and watercourses to collection areas for removal (e.g., de-watering), as approved in advance by the RE and in accordance with applicable permits.
- Protect inlets during sandblasting operations.
- Minimize the drift of dust and blast material as much as possible by keeping the blasting nozzle close to the surface.

Maintenance and Inspection

- Follow the inspection procedures as required in the project's contractual specifications.
- At a minimum, inspect containment structures, if any, for damage or voids prior to their use each day and prior to the onset of rain.
- At the end of each work shift, remove and contain the liquid and solid wastes from containment structures, if any, and from the general work area.

7.5.13 STRUCTURE DEMOLITION/REMOVAL OVER OR ADJACENT TO WATER

Definition and Purpose

This section outlines the procedures that should be followed to protect water bodies from debris and wastes associated with structure demolition or removal over or adjacent to watercourses.

Appropriate Applications

Structure demolition/removal over or adjacent to water should be applied in the cases of full bridge demolition and removal, partial bridge removal (e.g., barrier rail, edge of deck) associated with bridge-widening projects, concrete channel removal, or any other structure removal that could potentially affect water quality.

Limitations

- Specific permit requirements may be included in the contract documents.

Standards and Specifications

- Do not allow demolished material to enter the waterway.
- Refer to the BMP, "Clear Water Diversion", to direct water away from work areas.

- Use attachments on construction equipment such as backhoes to catch debris from small demolition operations.
- Use covers or platforms to collect debris.
- Platforms and covers should be approved by the RE.
- Stockpile accumulated debris and waste generated during demolition away from watercourses.
- Ensure the safe passage of wildlife, as necessary.
- Discharges to waterways should be reported to the RE immediately upon discovery. A written discharge notification must follow within seven days.

Maintenance and Inspection

- The contractor must inspect demolition areas over or near adjacent watercourses on a daily basis.
- Any debris-catching devices should be regularly emptied. Collected debris should be removed and stored away from the watercourse and protected from run-on and run-off.

7.6 POST-CONSTRUCTION STORMWATER MANAGEMENT BMPS

Maintenance BMPs are pollution prevention BMPs designed to reduce the discharge of pollutants associated with maintenance activities. Maintenance BMPs apply to ongoing maintenance of existing roadways, newly constructed BMPs and facilities, and other facilities owned or operated by DPW. A list of BMPs is provided in Table 7-9.

Post-Construction Stormwater Management BMPs
Scheduling and Planning
Sediment Control
Silt Fence
Sandbag or Gravel Bag Barrier
Straw Bale Barrier
Fiber Rolls
Check Dam
Concentrated Flow Conveyance Controls
Over Side/Slope Drains
Ditches, Berms, Dikes, and Swales

Post-Construction Stormwater Management BMPs
Temporary Diversion Ditches
Soil Stabilization
Compaction
Wood Mulch
Hydraulic Mulch
Hydroseeding/Handseeding
Straw Mulch
Clear-water Diversion
Work in a Water Body
Sediment Tracking Control
Tire Inspection and Sediment Removal
Waste Management
Spill Prevention and Control
Solid Waste Management
Hazardous Waste Management
Contaminated Soil Management
Sanitary/Septic Waste Management
Liquid Waste Management
Concrete Waste Management
Materials Handling
Material Delivery and Storage
Material Use
Vehicle and Equipment Operations
Vehicle and Equipment Fueling
Vehicle and Equipment Maintenance
Paving Operations Procedures
Water Conservation Practices
Potable Water/Irrigation
Safer Alternative Products

Post-Construction Stormwater Management BMPs
Drainage Facilities
Baseline Stormwater Drainage Facilities Inspection and Cleaning
Enhanced Storm Drain Inlet Inspection and Cleaning Program
Illicit Connection Detection, Reporting, and Removal
Litter and Debris
Litter and Debris
Anti-Litter Signs
Chemical Vegetation Control
Vegetated Slope Inspection
Snow Removal and De-icing Agents
Dewatering Operations (Temporary Pumping Operations)
Sweeping and Vacuuming
Maintenance Facility Housekeeping Practices

Table 7-9: Maintenance BMPs

Potential pollutants of concern for DPW's maintenance activities include petroleum products, sediments, trash and debris, metals, acidic/basic materials, nutrients, solvents, waste paint, herbicides, pesticides, and others. Many of these potential pollutants can be prevented from being discharged through stormwater drainage systems by selecting and implementing BMPs appropriate for the activity and subtask being conducted.

The majority of maintenance activities are performed in dry weather to minimize impacts to water quality; however, conditions may exist which require some activities to be conducted during wet weather.

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APPENDICES

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APPENDIX I

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APPENDIX I

Temporary Erosion and Sediment Control Plans

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TEMPORARY EROSION AND SEDIMENT CONTROL PLAN

The Temporary Erosion and Sediment Control (TESC) plan describes the temporary Best Management Practices (BMPs) selected for stormwater detention and water quality treatment during construction of the project. A BMP is a physical, structural, and/or managerial practice that prevents or reduces the pollution of water. The goal of the TESC plan is to prevent turbid discharges and sediments from leaving the site and to meet Guam's Water Quality Standards. The TESC plan clearly establishes when and where specific BMPs will be implemented to prevent erosion and the transport of sediment from a site during construction. A TESC plan must address the 12 TESC elements, which are described later in this Appendix.

A TESC plan consists of a narrative section and plan sheets. The narrative section includes an analysis of pollution risk for each TESC element, as well as documentation to explain and justify the pollution prevention decisions made for the project. The TESC plan sheets show the BMP locations and other features, such as topography and sensitive area locations, for multiple project stages. It is recommended that large projects that will be under construction for multiple seasons create phased TESC plans, with one year of construction focusing on the wet seasons.

The following information must be included in the narrative:

- Existing site conditions such as topography, drainage, soils, and vegetation
- Potential erosion problem areas
- BMPs chosen to address risks, as well as a list of applicable *Federal Highway Administration (FHWA) Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (FP-03)* (Standard Specifications), the General Special Provisions (GSPs), and the Special Contract Requirements (SCRs).
- Construction phasing/sequence and a general BMP implementation schedule (to be confirmed at a pre-construction meeting with the contractor)
- The actions to be taken if BMP performance goals are not achieved

The contract plan sheets must include the following:

- A north arrow
- Right-of-way, project limits, and property boundaries
- Existing topography including drainage, vegetation, structures, and roads
- Top and bottom of slope catch lines for cut and fill slopes
- Approximate slopes, contours, and the direction of stormwater flow before and after major grading activities

- Areas of soil disturbance and areas that will not be disturbed
- Locations of structural and nonstructural pollution controls (temporary construction BMPs)
- Locations of contractor staging including off-site material storage, stockpiles, waste storage, borrow areas, and vehicle/equipment storage/maintenance areas
- Locations of all surface water bodies including wetlands, streams, and lakes, with the limits of their ordinary high water and buffer zones
- Locations where stormwater or non-stormwater discharges off-site or to a surface water body
- Locations of water quality sampling stations
- Areas where final stabilization has been accomplished and no further construction-phase permit requirements apply

It is required that a TESC plan is prepared and signed by a Certified Erosion and Sediment Control Lead, and the Site Manager is trained and certified.

TESC REPORT OUTLINE

Title Page: The following items should be included on the title page: the project number and name, associated route number and mileposts, name of report, date report was completed, designers' names, and the project engineer's professional civil engineers stamp and signature.

Table of Contents: Both the report and appendix contents should be listed in the Table of Contents.

CHAPTER 1. PROJECT OVERVIEW

The TESC plan describes the measures to be used during construction to protect the waters of Guam from degradation due to sediment transport or water pollution. These measures will require the use of temporary BMPs.

Field conditions during construction may require additional temporary BMPs or a change in placement of the temporary BMPs. The Contractor's Erosion and Sediment Control Lead and the Department of Public Works' (DPW's) representatives should modify this plan if necessary to meet field conditions.

1-1. SITE DESCRIPTION

Besides the narrative, include a vicinity map that shows the project's location on the island, as well as the right-of-way limits, project limits, existing roadways, proposed roadways, drainage basins, flow direction, location of nearby or adjacent construction activities, and sensitive areas (wetlands, streams, receiving water bodies, etc.).

1-1.1. SCOPE OF WORK

Describe the overall project activities and where they will occur (e.g., clearing and grubbing, grading, roadway excavation and embankment, constructing storm sewers, paving with asphalt concrete, constructing temporary BMPs, constructing permanent stormwater detention and infiltration ponds, bridge widening, adding turn lanes, constructing curb and gutter, landscape planters, sidewalks, construction of a bus pullout, fencing, pavement markings, illumination, signalization, traffic control, etc. Call out the construction plan sheets and details.

1-1.2. AREAS IMPACTED

Total area of new impervious surface added _____ sq. ft. or acres

Total area of disturbed soil _____ sq. ft. or acres

1-1.3. EXISTING CONDITIONS

This section presents the existing conditions on and surrounding the project site. Included are descriptions of soils, drainage, off-site water, outfalls, sensitive areas, existing water quality, Water Resource Inventory Areas (WRIAs), adjacent construction, and affected utilities.

1-1.4. SOILS OR SURFACE CONDITIONS

Identify the major soil type identified along the project. Identify other soil types along the project and rank by relative predominance.

1-1.5. DRAINAGE

Provide a list of stream names, locations, drainage pathways, and receiving water bodies.

1-1.6. OFF-SITE WATER

List the potential for off-site water to enter the project limits. State whether there is or is not the potential for off-site water. If applicable, include a discussion about the sources and waterways of off-site water that may enter the project site, and describe the measures to be taken, if any, to keep off-site water from mixing with on-site runoff. The site should be visited on a rainy day to verify conditions. State whether there is or is not an illicit connection that discharges within the project limits.

1-1.7. OUTFALLS

Include a table listing the milepost (and project stationing and control line offset as appropriate), condition, and location of each outfall within the project area.

1-1.8. SENSITIVE AREAS

Summarize the wetland report, areas of critical habitat, sensitive areas specified in basin plans, etc. If applicable, provide reference figures.

1-1.9. EXISTING WATER QUALITY

This section should include the Surface Water Classification for all nearby water bodies and information on impaired water bodies from the Guam Environmental Protection Agency (GEPA) assessment listing. Include the appropriate water quality standards.

1-1.10. AFFECTED UTILITIES

This section should include any utilities within the right-of-way of the proposed construction activities, which may be impacted by this construction project.

1-1.11. PERMITS AND ASSOCIATED REPORTS

Insert below the actual permits required for this project. If necessary, text describing why some permits may or may not be required should be added.

1-1.12. ASSOCIATED REPORTS

Provide a list of reports. Revise to match actual reports and studies related to this project.

1-2. TESC PLAN

1-2.1. CONSTRUCTION STAGING

The narrative should include the description of construction staging and how the TESC will be provided for each stage. During the design phase, if it is impossible to know the timing and duration of a project, the TESC plans should be prepared assuming worst-case conditions for timing and duration.

1-2.2. ELEMENTS OF TESC

The 12 TESC elements are described below. All elements must be considered and included in the TESC plan, unless site conditions render an element unnecessary and the exemption is clearly justified in the narrative of the TESC plan. Common design and procedural BMPs are described for each element, followed by a list of physical BMPs, if applicable. Each element should be described using the following format:

- Risk analysis
- BMPs identified
- GSPs
- SCR

1-2.2.1. TESC Element 1: Mark Clearing Limits

Prior to land-clearing activities, mark all clearing limits on the plan and in the field with high-visibility fences to protect sensitive areas and their buffers (including vegetation to preserve), as well as adjacent properties. Retain duff layer, native topsoil, and existing vegetation in an undisturbed state to the maximum extent practicable.

Physical BMPs:

- Preserving natural vegetation
- Buffer zones
- High-visibility fence

1-2.2.2. TESC Element 2: Establish Construction Access

Access points should be stabilized with a pad of quarry spalls, crushed rock, or equivalent BMP, in accordance with the Standard Specifications. Install stabilized construction access points prior to major grading operations. Limit access points to the fewest number possible, and only one, whenever feasible. Whenever practicable, slope entrances downward into the site to reduce track-out of sediments onto the roadway. If sediment is tracked off-site, roads should be cleaned thoroughly at the end of each day or more frequently, if necessary. Sediment should be removed from roads by shoveling or sweeping, and removed sediment should be transported to a controlled disposal area. If the stabilized construction entrance is not effective in preventing sediment from being tracked onto roads, a tire wash must be used and the wash water must be discharged to a separate on-site treatment system, such as closed-loop recirculation or land application, or discharged to a sanitary sewer (if allowed by individual permit).

Street sweeping is only allowed after sediment is removed from the street. If streets are washed with water, wash water must be treated prior to discharge.

Physical BMPs:

- Stabilized construction entrance
- Street sweeping
- Construction road stabilization
- Tire wash

1-2.2.3. TESC Element 3: Control Flow Rates

Protect downstream properties and waterways from erosion by preventing increases in the volume, velocity, and peak flow rate of stormwater runoff from the site during construction. Install the permanent sediment control facilities to provide flow control as early in the construction process as feasible. Protect infiltration facilities from siltation during the construction phase.

Install retention/detention facilities as one of the first steps in grading for use as infiltration or sedimentation facilities prior to mass grading and the construction of site improvements. Design drainages to account for both on- and off-site water sources. Use vegetated areas that are not identified as wetlands or other sensitive features to infiltrate and dispose of water whenever possible, and mark those areas on the TESC plan sheets.

Non-stormwater (de-watering, line flushing) discharges must also be controlled to protect downstream properties. When non-stormwater discharges are routed through separate storm sewer systems, the flow rate must be controlled to minimize scouring and the flushing of sediment trapped in the system.

Physical BMPs:

- Temporary sediment pond

- Sediment trap
- Stormwater infiltration

1-2.2.4. TESC Element 4: Install Sediment Controls

Install sediment control BMPs prior to soil-disturbing activities. Prior to leaving a construction site or discharging to an infiltration facility, concentrated stormwater runoff from disturbed areas must pass through sediment ponds or traps. Sheet flow runoff must pass through sediment control BMPs specifically designed to remove sediment from sheet flows, such as filter berms, vegetated filter strips, or silt fencing. Because maintaining sheet flows greatly reduces the potential for erosion, runoff should be maintained and treated as sheet flow whenever possible.

Physical BMPs:

- Silt fence
- Fiber Roll
- Check dam
- Temporary sediment pond or trap
- Street sweeping
- Surface roughening
- Level spreader
- Storm drain inlet protection
- Outlet protection
- Preserving natural vegetation
- Portable storage water tanks
- Vegetated filter strip
- Stormwater chemical treatment
- Filter berm (gravel, wood chip, or compost)
- Construction stormwater filtration

1-2.2.5. TESC Element 5: Stabilize Soils

Stabilize all exposed and unworked soils by applying effective BMPs that protect the soil from wind, raindrops, and flowing water. Selected soil stabilization measures must be appropriate for the time of year, site conditions, estimated duration of use, and the water quality impacts that stabilization agents may have on downstream waters or groundwater.

Construction activity, including equipment staging areas, material storage areas, and borrow areas must be stabilized and addressed in the TESC plan as well.

Soil stockpiles are especially vulnerable to slumping when saturated and must be stabilized and protected with sediment-trapping measures. Plastic may be necessary on silty stockpiles, as it is the only BMP that can prevent soil saturation. Stockpiles should be located away from storm drain inlets, waterways, and drainage channels, where possible.

In Guam, cover exposed soil that is not being worked, whether at final grade or not, within the following time limits, using approved soil cover practices:

- July 1st through November 30th – 2 days maximum
- December 1st through June 30th – 7 days maximum
- Immediately, in accordance with the rain forecast

Physical BMPs:

- Preserving vegetation
- Sodding
- Temporary mulching
- Check dam**
- Soil binding using polyacrylamide*
- Fiber Roll**
- Placing erosion control blanket
- Surface roughening***
- Placing compost blanket
- Stabilized construction entrance
- Placing plastic covering
- Construction road stabilization
- Seeding and planting
- Dust control BMPs
- Gravel base
- Bonded fiber matrix

- Mechanically-bonded fiber matrix

*While polyacrylamide alone does help stabilize soils, using it in conjunction with mulch provides more protection for disturbed soil.

**Check dams and fiber rolls alone do not stabilize soils. These BMPs should be used in conjunction with other soil stabilization BMPs.

***Surface roughening alone does not provide soil stabilization. Another BMP should be used in conjunction with surface roughening to protect the soil from raindrop impacts. It must be performed prior to seeding, in accordance with the Standard Specifications.

1-2.2.6. TESC Element 6: Protect Slopes

Design and construct cut-and-fill slopes in a manner that will minimize erosion by reducing the continuous length and steepness of slopes with terracing and diversions; reducing slope steepness; and roughening slope surfaces, considering soil type and its potential for erosion (such as track walking). In addition, all soil must be protected from concentrated flows through temporary conveyances such as diversions and pipe slope drains.

If flow is from seeps or groundwater, use best professional judgment when sizing slope drains. Conveyances exceeding a 10 percent slope should have a solid lining.

To capture sediment and runoff when cutting trenches, place excavated soil on the uphill side of the trench, when consistent with safety and space considerations.

Check dams should be placed at regular intervals within constructed channels that are cut down a slope.

Physical BMPs:

- Channel lining (riprap, grass)
- Subsurface drains
- Temporary pipe slope drain
- Level spreader
- Temporary curb
- Interceptor dike and swale
- Gradient terraces
- Physical BMPs listed under TESC Element 5, with the exception of stabilized entrance and road stabilization

1-2.2.7. TESC Element 7: Protect Drain Inlets

Protect all operable storm drain inlets from sediment with approved inlet BMPs.

Physical BMPs:

- Storm drain inlet protection (above/below grate and grate covers)
- Check dam

1-2.2.8. TESC Element 8: Stabilize Channels and Outlets

All temporary conveyance channels should be designed, constructed, and stabilized to prevent erosion.

Stabilization, including armoring material, adequate to prevent erosion of outlets, adjacent stream banks, slopes, and downstream reaches should be provided at the outlets of all conveyance systems.

Physical BMPs:

- Channel lining (riprap, grass)
- Erosion control blanket
- Level spreader
- Sodding
- Check dam
- Outlet protection
- Temporary seeding and planting

1-2.2.9. TESC Element 9: Control Pollutants

All pollutants, including construction materials, waste materials, and demolition debris, must be handled and disposed of in a manner that does not cause contamination of stormwater. Methods for controlling non-hazardous pollutants must be described in the TESC plan. Wood debris may be chopped and spread on-site. The application of fertilizers and other chemicals should be conducted in a manner and at application rates that will not result in loss of chemicals to stormwater runoff. Manufacturers' label requirements for application rates and procedures must be followed.

Methods for controlling pollutants that can be considered hazardous materials, such as hydrocarbons and pH-modifying substances, must be described in the contractor's Spill Prevention Control and Countermeasures (SPCC) plan.

Stormwater or groundwater that has come into contact with curing concrete must be sampled to ensure Water Quality Standards are not violated. Process water (e.g., concrete washout, slurry water, and hydrodemolition) must be contained and cannot be discharged to the waters of Guam.

1-2.2.10. TESC Element 10: Control Dewatering

When groundwater is encountered in an excavation or other area, control, treat, and discharge it as described in the Standard Specifications.

1-2.2.11. TESC Element 11: Maintain BMPs

A Certified Erosion and Sediment Control Lead should inspect BMPs to ensure they perform their intended function properly until the Project Engineer determines that final stabilization is achieved. Final stabilization means the completion of all soil-disturbing activities and establishment of a permanent vegetative cover or permanent stabilization measures (such as riprap) to prevent erosion. Temporary BMPs should be removed within 30 days after final stabilization is achieved.

Maintain BMPs in accordance with the Standard Specifications. When the depth of accumulated sediment and debris reaches approximately one-third the height of the device, the contractor must remove the deposits. BMP implementation and maintenance should be documented in the Site Log Book. Clean sediments may be stabilized on-site.

1-2.2.12. TESC Element 12: Manage the Project

Apply the following actions on all projects:

1. Preserve vegetation and minimize disturbance and compaction of native soil, except as needed for building purposes.
2. Phase development projects to minimize the amount of soil exposed at any one time and prevent the transport of sediment from the site during construction.
3. Time sediment control BMP installation in accordance with TESC Element 4.
4. To minimize erosion, follow soil cover timing requirements and exposure limits in TESC Element 5 and the Standard Specifications. Projects that infiltrate all runoff are exempt from the above restrictions. Individual contract SCR and DPW directives may be more stringent based on specific location characteristics or changing site and weather conditions.
5. The work of utility contractors and subcontractors is coordinated to meet the requirements of both the TESC and SPCC plans.

1-3. Schedule

A construction schedule must be provided by the contractor. The schedule should specify TESC plan implementation to effectively reduce erosion risks. Include the following in the schedule:

- Installation of perimeter control and detention BMPs prior to soil-disturbing activities.
- Phasing and timing of clearing, grubbing, and grading. Where feasible, work must be phased and timed to minimize the amount of exposed soil at any one time and prevent transport of sediment from the site during construction.
- Application of interim BMP strategies when construction activities interfere with the placement of final-grade BMPs.
- Discussion of how temporary BMPs are to be transitioned into permanent BMPs.
- Implementation of an erosion control inspection and maintenance schedule.

APPENDIX IA

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APPENDIX IA

Correspondence with

Guam Environmental Protection Agency (GEPA)

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Bhatnagar, Rakesh

From: Ivan Quinata [ivan.quinata@epa.guam.gov]
Sent: Wednesday, July 28, 2010 8:13 AM
To: Lahndt, Leslie
Cc: Bradley Dunagan
Subject: Re: FW: GEPA review on Transportation Stormwater Design Manual (TSDM)

Hafa Adai Leslie,

Apologies for the oversight on my part.

Guam EPA has no further comments on the Transportation Stormwater Design Manual (TSDM). However, Guam EPA reserves the right to enforce regulatory compliance as provided for in Guam statutes and regulations.

Ivan

On Thu, Jul 22, 2010 at 6:17 AM, Lahndt, Leslie <Leslie.Lahndt@parsons.com> wrote:

Hello again Ivan....I'm following up on open issues. Can you let me know when I could expect a response from you on this? Thanks.

Leslie Lahndt
PARSONS
TRANSPORTATION GROUP INC

From: Lahndt, Leslie
Sent: Tuesday, July 13, 2010 8:58 AM
To: Ivan Quinata; Margaret Aguilar
Cc: Hixson, Keith; Bhatnagar, Rakesh; Vincent, Carla
Subject: GEPA review on Transportation Stormwater Design Manual (TSDM)

Hello Ivan et al;

See attached e-mail where the TSDM was sent to GEPA for review and comment. We were scheduled to finalize this document last month. Could you please provide me an e-mail or other written communication indication whether you have comments, no further comments, concur with the document, etc?

Once I have this written communication from you I will request DPW/FHWA approve as Final and I will send out copies.

Please let me know, I look forward to hearing from you. If you need to speak to me please call 206 550 6918. Thank you.

Leslie Lahndt
PARSONS
PARSONS TRANSPORTATION GROUP INC
Planning & Design Manager
Guam office
office 671 648 1061 / mobile 671 482 8973 / fax 671 646 0678

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APPENDIX II

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Appendix II

Hydraulic Report

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TABLE OF CONTENTS

HYDRAULIC REPORT

PROCEDURE

Hydraulic reports should be submitted to the Department of Public Works (DPW) or their designated representative, as follows.

REVIEW COPIES

Designers should submit a complete hard copy of the Hydraulic Report to DPW or its designated representative for review.

FINAL COPIES

Upon approval, two paper copies of the Hydraulic Report, one electronic copy (CD) of the report, and the original approval letter should be sent to the following offices:

1. The Construction Office for reference during construction.
2. DPW's Chief Engineer, who will keep it in a secure location as the record of the project stormwater management facilities.

HYDRAULIC REPORT REVISIONS AND SUPPLEMENTS

At times, a hydraulic report may need to be revised due to various elements within a proposed project. There are two ways to submit a change:

1. Revision: A revision is a correction of the existing report either due to an error or omitted design documentation. The designer should submit the revision along with a new title page, stamped and signed by the Project Engineer, showing both the original approval date and the revision date. The revised document should contain a statement immediately behind the cover page that provides a summary of the revisions.
2. Supplement: A supplement is a change that was not part of the original scope of work. The same approval process is required as with the original report; however, the supplement should be a stand-alone document that references the original report.

Either type of change should be prepared documenting the revisions made, with back-up documentation. Include revised plans, calculations, and other updates as warranted in a submittal package to DPW. An approval/concurrence letter will be issued for the supplement.

WRITING A HYDRAULIC REPORT

A Hydraulic Report Outline has been provided below as a starting point for designers. Organizing reports in the outline format will help to expedite the review process. It is recommended that designers read through the outline and determine which sections are applicable to their project. Any sections that are not applicable will include the heading, with the tern "N.A." under the heading in the report. DPW or its designated representatives can be contacted for assistance in preparing a Hydraulic Report.

The Hydraulic Report should contain the elements listed in the outline that apply to the project. Designers should provide a well-organized report so that an engineer with no prior knowledge of the project could read and fully understand the hydraulic/hydrologic design of the project. The report should contain enough information to allow someone else to reproduce the design in its entirety, but at the same time, designers should be brief and concise, careful not to provide duplicate information that could create confusion.

Following and completing the outline does not mean that all of the minimum requirements in the *Highway Runoff Manual* have been addressed. The outline is only a tool to aid the designer in developing a Hydraulics Report. To determine the applicability of the minimum requirements and Best Management Practices (BMPs) for a project, designers should consult the other sections of this Guam Transportation Stormwater Drainage Manual (TSDM).

HYDRAULIC REPORT OUTLINE

Title Page: The following items should be included on the title page: the project number and name, associated route number and mileposts, name of report, date report was completed, designers' names, and both the project engineer's professional civil engineers stamp and signature.

Table of Contents: Both the Hydraulic Report and appendix contents should be listed in the Table of Contents. Number all pages, including maps, figures, and tables both in the report and in the appendices.

CHAPTER 1. PROJECT OVERVIEW

1-1. SITE LOCATION

Note the following: milepost limits, section, township, and range and reference location from nearest village.

1-2. VICINITY MAP

Include a vicinity map with the project location on the island, clearly shown. Whenever possible, highlight major landmarks, delineate water bodies, and label cross streets. A vicinity map may require using two maps with different scales, one for the location on the island, and a second showing the main features of the project including the project limits, mileposts, and other main topographic features.

1-3. SCOPE OF WORK

Introduce the hydraulic features of the project and note why they are being installed. Describe project improvements and where they will occur, and reference attached plan sheets where applicable. It is not necessary to discuss the overall purpose of the project unless it is pertinent to some of the decisions made during the design of hydraulics features.

1-4. AREAS IMPACTED

List the following total areas (in acres): New impervious surfaces, replaced impervious surfaces, total existing impervious surfaces, and total areas being converted from native vegetation to lawn or landscaped (if applicable). Exhibits will need to be included in the report appendix to support the impervious/pervious area calculations.

CHAPTER 2. EXISTING CONDITIONS

2-1. EXISTING CONDITIONS

Include a discussion on the project site conditions and layout as observed during inspection of the site by the designer. The discussion should serve to confirm what is shown on the maps and site plans, as well as note any features that will influence the drainage design.

2-2. EXISTING HYDRAULIC FEATURES

Note any existing drainage features and describe how they operate prior to construction. Also note how project improvements could impact their operation and how they will function during post-construction activities. If needed, use photographs to describe the site. Identify any bridges within the project limits.

2-3. EXISTING DRAINAGE AREAS (DA)

For each DA within the project, provide a description of the general drainage systems and flow patterns. (See Chapter 4 for a detailed description of DAs). Unusual or unique drainage patterns should be discussed. These areas should also be part of the description. The designer should also list any off-site flows. Each DA description should list the eventual downstream water body. Drainage maps delineating entire DAs (i.e., beyond DPW's right-of-way) should be included in the report appendices, as should individual basin area calculations. This section should refer to where the basin information is located in the appendices.

2-4. SOILS

Discuss the soil testing that has been performed at the site. This includes soil pH and resistivity to determine acceptable pipe alternatives, soil borings, soil type from National Resources Conservation Service maps, soil infiltration, groundwater level, etc., for stormwater BMP design.

2-5. OUTFALLS

An outfall can be any structure (man-made or natural) where stormwater from DPW highways is conveyed off the right-of-way. (If no stormwater outfalls leave the DPW right-of-way, the designer should note that instead).

2-6. EXISTING UTILITIES

Note utility conflicts that have been investigated and either are or are not an issue. If there is a conflict, please note the resolution. Utilities should be shown on the drainage plan and profile sheets.

CHAPTER 3. DEVELOPED CONDITIONS

3-1. PROPOSED DRAINAGE BASINS

This section should discuss and tabulate the proposed basins, including what has changed regarding pervious and impervious areas to the existing basins. Maps showing all DAs and drainage basin areas significant to the project (including portions that are off the DPW right-of-way) should be included in the report appendices along with all basin calculations. This section should serve to confirm what is shown on the final drainage plans, profiles, and details. Note that final level plans may not yet be completed but will be checked against the Hydraulic Report during review.

Drainage maps should show basin and sub-basin boundaries, areas, and flow direction arrows. Each drainage basin should be clearly labeled, with the same label referenced in the hydrologic and hydraulic calculations. When the change between existing and post-construction conditions is important to the calculations, the maps should show both conditions, on separate maps, if necessary, for clarity. Maps should always be of an adequate scale to allow reviewers to verify all basin calculations.

3-2. DESIGN STANDARDS

3-2.1. DESIGN FREQUENCY

Note the appropriate design frequencies used to size hydraulic features on the project, and where applicable, show calculations. Include a discussion of the climate and chosen precipitation values for the project.

3-2.2. STORMWATER MANAGEMENT GUIDELINES

State the stormwater management criteria and guidelines used for flow control, basic runoff treatment, and enhanced runoff treatment (if applicable). Include a summary table noting the BMP and the project location (including structure notes for each drainage feature) organized by alignment, drainage basin, station, and offset and/or milepost. The table should include DA-specific pre-project and post-project pervious and impervious surface areas. Also note what percentage of the new (and replaced, if applicable) impervious surface areas are addressed for flow control and runoff treatment according to the stormwater management criteria used for this report. Wherever possible, use the same structure note from the plans in the hydrologic and hydraulic calculations.

3-2.3. OTHER REQUIREMENTS

Note any additional requirements used in the hydraulic calculations that differ or are in addition to those found in the TSDM. Provide a list of references for the guidelines, manuals, basin plans, local agency codes, or technical documents used to develop the hydraulics report, and where possible, include a Web link to the reference.

3-3. PIPE ALTERNATIVES

Note all acceptable pipe alternatives for the project, and provide an engineering justification for any alternatives that are excluded. This should reference the pipe design life in relation to the various site conditions (soil type, pH, soil resisitivity, other corrosion potential and load requirements).

3-4. DOWNSTREAM ANALYSIS

This section focuses on what impact a project will have on the hydraulic conveyance systems downstream and how the impact is mitigated. The analysis should be divided into three sections:

1. A review of the existing conditions
2. An analysis of the project impacts
3. Mitigation alternatives with detail on the selected alternative

3-5. HYDROLOGIC AND HYDRAULIC DESIGN

Hydrologic and hydraulic design calculations for all hydraulic features should be discussed and the results summarized in this section (e.g., culverts, storm drains, stormwater BMPs, inlets, gutters, ditches, stream bank stabilization). Where applicable, it is recommended that the design be divided into the sections described below. The locations of the items on the next page should also be noted, and where there are multiple locations, designers should consider using a table for clarity.

Calculations should include the following:

- Drainage area quantities and assumptions with equivalent area trading
- The equations used for the actual numerical calculations
- A discussion of what assumptions were made to perform the calculations
- How the input parameters were determined

The calculations should always include enough supporting information to allow reviewers to completely duplicate the process used throughout the original design; however, excessive data that duplicates information already provided can often make the calculation process less understandable. Whenever possible, the calculation methodologies described in the TSDM should be followed, including the following:

- Figures from the TSDM
- Standard design forms
- Suggested software

If a different method or software is selected, the reason for not using the standard DPW method should be explained and approved prior to submitting the report. Actual calculations, design forms, exhibits, and output from software used in the project design should be included as part of the report appendices.

All calculations included in the report should be checked by an individual other than the person who prepared the report. The checker should be a person of equal or higher technical level as the designer. The checker should sign and date each sheet of the calculations. The calculation summaries should be included under the following outline sections:

3.5.1 Flow Control BMPs

3.5.2 Runoff Treatment BMPs

3.5.3 Gutter Design

3.5.4 Sag Design

3.5.5 Enclosed Drainage Design

3.5.6 Culvert Design

3.5.7 Ditch Design

3.5.8 Special Stream Design

3.5.9 FloodPlain Mitigation

3.5.10 Bridge Scour Evaluation

3.5.11 Channel Changes

3.5.12 Downstream Analysis

CHAPTER 4. PERMITS AND ASSOCIATED REPORTS

4-1. ENVIRONMENTAL ISSUES, FISH, AND OTHER ENDANGERED HABITAT

Describe any water quality receiving bodies, floodplains, stream crossings, wetlands, steep slopes, or other sensitive areas within the project limits, noting project impacts. Describe any fish passage design issues with culverts within the project limits. Note if fish surveys were conducted and what was determined. Also note if there are any threatened or endangered species within the project limits. This information is usually detailed in the project's Environmental Assessment (EA) reports. Include only an overview summary of the various aspects in this section, and reference the EAs for the details.

4-2. PERMITS/APPROVALS

List all permits, variances, or approvals required by local jurisdictions and resource agencies that are necessary to complete the project. Categorize the permits that are obtained by DPW and those that must be obtained by the contractor for construction. Include a list of environmental commitments as they pertain to stormwater issues that are stated in the EAs, the project's environmental impact statement, permits, and local regulations.

4-3. RIGHT-OF-WAY AND EASEMENTS

Note any additional easements that may be required for completion of the stormwater facilities on the project, noting whether the easement is for permanent facilities, installation and maintenance, or a temporary easement for contractor access or construction. Highlighting and referencing the areas on the attached plan sheets is helpful.

4-4. ADDITIONAL REPORTS OR STUDIES

Where applicable, note other reports and studies conducted and prepared for this project. Examples are the Geotechnical Report (used to note drainage-related special studies needed for the project, including, but not limited to, soil tests, infiltration rates, and well monitoring) and the environmental reports.

CHAPTER 5. INSPECTION AND MAINTENANCE SUMMARY

Maintenance should be consulted prior to starting a project concerning any existing drainage problems or requirements, including maintenance access.

CHAPTER 6. APPENDIX

6-1. ENVIRONMENTAL DOCUMENTATION

The purpose of this section is to document environmental decisions made during the design, including reasons why decisions were made, who made the decisions, and notes on any references used. If pollution-loading calculations are required by the regulatory agencies, these should be included here.

6-1.1. TESC NARRATIVE AND PLAN SHEETS

6-2. BASIN CALCULATIONS AND EXHIBITS

The drainage maps and any exhibits that show how the basins, sub-basins, and flows were calculated should be included along with the hydrology calculations, hydrographs, or other basin hydraulic modeling.

6-3. CALCULATIONS AND PROGRAM OUTPUT

Include all calculations used to create the hydraulics report, including software outputs, inlet calculation spreadsheets, sag analyses, etc. All calculations should be clearly labeled with a file name and initialed (and checked) by an individual other than the one who prepared the report.

6-4. DRAINAGE PLAN SHEETS, DETAILS, AND STRUCTURE NOTES

For culverts and bridge projects, include the Water Surface Elevation and design flow rates for the design frequency storms (usually ordinary high water, 25-year and/or 50-year, 100-year, 500-year and if tidal, mean low, mean high, and mean higher high-water elevations).

6-5. DRAINAGE PROFILE PLAN SHEETS

For culverts and bridge projects, include the Water Surface Elevation and design flow rates for the design frequency storms (usually ordinary high water, 25-year and/or 50-

year, 100-year, 500-year, and if tidal, mean low, mean high, and mean higher high-water elevations). Plans and profiles should be prepared to 1 inch equals a 40-ft. horizontal scale, and 1 inch equals a 4-ft. vertical scale, unless specified otherwise.

6-6. ROADWAY TYPICAL CROSS SECTIONS AND PROFILES

The cross sections should be prepared to a scale of 1 inch equals a 10-ft. horizontal scale and 1 ft. equals a 5-ft. vertical scale, unless specified otherwise. Plans and profiles should be prepared to 1 inch equals a 40-ft. horizontal scale and 1 inch equals a 4-ft. vertical scale, unless specified otherwise.

6-7. MISCELLANEOUS CONTRACT PLAN SHEETS

Include any plan sheets that will aid the reviewer in completely understanding the project. This may include utility plan sheets.

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APPENDIX III

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Appendix III

Establishment of Intensity Duration Relationships for Precipitation in Guam for Design of Transportation-Related Facilities

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INTRODUCTION

The objective of this report is to develop the rainfall Intensity Duration Frequency (IDF) relationship and design storm duration for design of roadway-related drainage facilities for the Island of Guam. The rainfall IDF relationship is one of the most commonly used tools in hydraulic engineering for planning, designing, and operations of various engineering projects. Engineers use precipitation-frequency information in making decisions concerning the size of stormwater management facilities, as stormwater management facilities must be sized to create a logical balance between the safety of the project and the economics of installation, maintenance, and replacement. Accordingly, different aspects of stormwater conveyance, quality treatment, and flow control are designed to different levels or frequencies of storm events. These design storm events are selected based on an updated statistical analysis of the Guam precipitation records.

A one-hour duration storm is recommended for the design of transportation stormwater facilities for Guam. The one-hour storm duration is selected from statistical analysis, which showed that most precipitation on Guam occurs during intense, short duration storms. The probability of getting storms longer than a one-hour duration, as well as having more than one one-hour storm in a day is statistically remote.

The one-hour storm distribution is a hybrid curve based on an analysis of the 15-minute rainfall from the partial duration statistical series, and the lesser 30- and 60-minute precipitation amounts from the one-hour storm series. The subsequent intensities for durations shorter than 15 minutes are somewhat conservative, while the longer duration intensities closely match the statistically-predicted rainfall depths. This report discusses in detail, the statistical analysis comparison of these statistical results to other statistical studies, and includes a discussion of the selection of design storms.

BACKGROUND

Despite its small size, Guam is characterized by one of the highest levels of rainfall variability in the world, with the highest annual rainfall nearly three times the amount of the lowest rainfall. There is a dry season from January to April and a rainy season from July to mid-November. The other months are transitional periods that may be either rainy or dry depending on the nature of the particular year. Exceptionally dry years recur about once every 4 years in correlation with episodes of El Nino Southern Oscillation (ENSO) in the Pacific. Mean annual rainfall ranges from 85 inches in western Guam to 115 inches on the upper slopes of the southern mountains. On average, approximately 55 percent of the rainfall occurs in the rainy season and 15 percent during the dry season, with the remainder falling during transitional months. The prevailing winds blow from the northeast or east for much of the year. The island is regularly affected by typhoons, which bring heavy winds and rains. Lander (2004) suggested that rainfall in Guam is not elevation dependent. Extreme rainfall events in Guam are almost always associated with typhoons, which may cross the island almost anywhere.

The U.S. Army Corps of Engineers (Honolulu) developed the isohyets for the island of Guam (1980). These isohyets represent the local variation in total annual rainfall on Guam with rainfall data before the 1980s. Lately, Guam's need for an accurate and representative rainfall database, rainfall climatology, and a representative set of rainfall distribution maps, both for monthly and seasonal (rainy season, dry season) periods were addressed by report 2001GU1342B, developed by the U.S. Geological Survey (USGS) and the Water and Environmental Research Institute of the Western Pacific, University of Guam (WERI) in 2001. More recently the USDA National Resources Conservation Service (NRCS, 2008) published the frequency analysis for Guam as Technical Note 3.

METHODOLOGY

There are two predominant ways of gathering data for performing precipitation frequency analysis; namely, annual maximum series and partial duration series. Annual maximum series is performed using highest annual maximum rainfall in a year. Only the greatest rainfall in each year is used. The most common objection to using this series is that it uses only one rainfall event per year. Infrequently, there may be other rainfall events in a year that may out-rank many annual rainfalls. Alternately, the partial duration series selects all rainfall above a certain threshold, without regard to number within any given period. The threshold is a matter of debate with various researchers providing various threshold numbers. Irrespective of the threshold, the most important criteria that needs to be accounted is for is independence of the data. Langbein (1949) suggested that the threshold selected be equal to the lowest annual flood, so that at least one flood in each year is included. If long records are available, he suggested using a threshold so that at least three or four storms a year are included. Wan (2009) suggested that threshold values should be large enough (99^{th} percentile) to support data independence without loss of important information.

Frequency analyses of hydrologic data use probability distributions to relate the magnitude of extreme events to their frequency of occurrence. It is in no way a real representation of actual observed rainfall, but as suggested, is the modeling of extreme events. Historically, lack of short term rainfall data has resulted in researchers using transformation techniques to determine short term rainfall estimates. Empirical relationships have been derived to transform one kind of data into another. Often, annual series are transformed into partial duration series for use in design. Therefore, both annual maximum series and partial duration series are generated for analysis. Langbein (1949) demonstrated that the difference between annual maximum series and partial duration series becomes inconsequential for floods greater than about a 5-year recurrence interval.

This report develops frequency intensity curves for the short duration storms on Guam by the following analyses:

- Annual Maximum Series is developed by the traditional way of selecting the largest storm every year. The results are compared with the series developed by the NRCS.
- Partial duration series is developed using the three largest storms in a year. Results are compared to partial duration series developed by NRCS. Whereas NRCS used generalized transformation techniques to develop partial duration series for Guam, this study utilizes the three largest storms selected from each year of record of a rain gauge on Guam.
- An Actual Data Series based on selection of the actual storms is developed. This series selects storms that are at least an hour in duration. One such storm, a one-hour duration storm, is selected from each year of record to develop the series. This series will be compared with the partial duration series developed in this report and primarily used to develop a one-hour design storm distribution for use in roadway drainage design.

DATA SELECTION

Though a significant amount of data is available, short-term (such as 15 minute and hourly) rainfall data is available only for limited stations. There are also limitations in the data such as number of days missing; gauge malfunctions, and others. Hydrosphere made an attempt to identify the data with inferior quality with identifiers. Any data with identifiers associated with bad quality were not included in the study, even though they might have been the significant storm events. Short-term rainfall distribution and selection of design storms is the focus of this study. Rainfall gauges have existed on Guam since the 1940s, but useful and long-duration rainfall data is available only for limited stations (NRCS 2008). Therefore, two major assumptions adopted for analyzing rainfall data were:

1. At least 20 years of rainfall data should be available from stations.
2. Since the objective of the study is to determine IDF for roadway-related facility design purposes, only stations that experience maximum rainfall and have 15-minute data available, should be investigated.

A detailed investigation into the rainfall data obtained from Hydrosphere (2009) suggested that 15-minute rainfall data is available only at three precipitation gauging stations -- Fena Lake, Piti, and Inaranjan. The study of the newly-developed annual rainfall distribution map for Guam (USGS, 2001) also suggests that south-central Guam experiences higher total annual rainfall than northern Guam. See Figure 1 for the location of the Fena Lake rainfall gauge on the annual rainfall distribution map developed by USGS. Therefore, the study stations were further limited to the Fena Lake station (See Table 1), which is centrally located in the south half of the island and has a long record consistent with the other two gauges (Piti and Inaranjan).

Station Name	Station Number	Observation Interval	Years of Record	Latitude Degrees Minutes	Longitude Degrees Minutes	Elevation Feet
Fena Lake	914200	15,60	28	13°22'N	144°42'E	60

Table 1: Fena Lake Station

FREQUENCY ANALYSIS

Frequency analysis is performed using HYFRAN software developed by INRS-Eau in collaboration with Hydro-Quebec Hydraulic Services, Canada. HYFRAN fits statistical distributions to random sample data sets. As shown in Table 2, there are 17 distributions available in the software. The Fena Lake data was analyzed for each series and the distribution was selected on the basis of goodness of fit. The software provides goodness of fit measure using Chi-Square, Empirical moment, and Shapiro-Wilk test.

Distribution	Estimation Methods*
Exponential	MV
Fuites Law	MV, MM, Mn0/n, MMI
Gamma	MV, MM
Generalized Gamma	MV, MM
Inverse Gamma	MV, MM
GEV	MV, MM, MMP
Gumbel	MV, MM, MMP
Halphen A, B, et B -1	MV
Log-Normal	MV
Log-Normal 3 param.	MV, MM
Log-Pearson III	SAM, MM (i.e. BOB), WRC
Law mixed Log-Normal	MV
Law mixed Weibull	MV
Normal	MV
Generalized Pareto	MM, MMP
Pearson	MV, MM
Weibull	MV, MM

Table 2: Statistical Distribution in HYFRAN

Where * MV: maximum likelihood method
* MM: moment method
* MMP: pondered moment method
* Mn0/n : method using n0/n
* MMI : mixed method (Mn0/n and MM)
* SAM: Sundry Averages Method
* WRC: applied moment method on the log of observations.

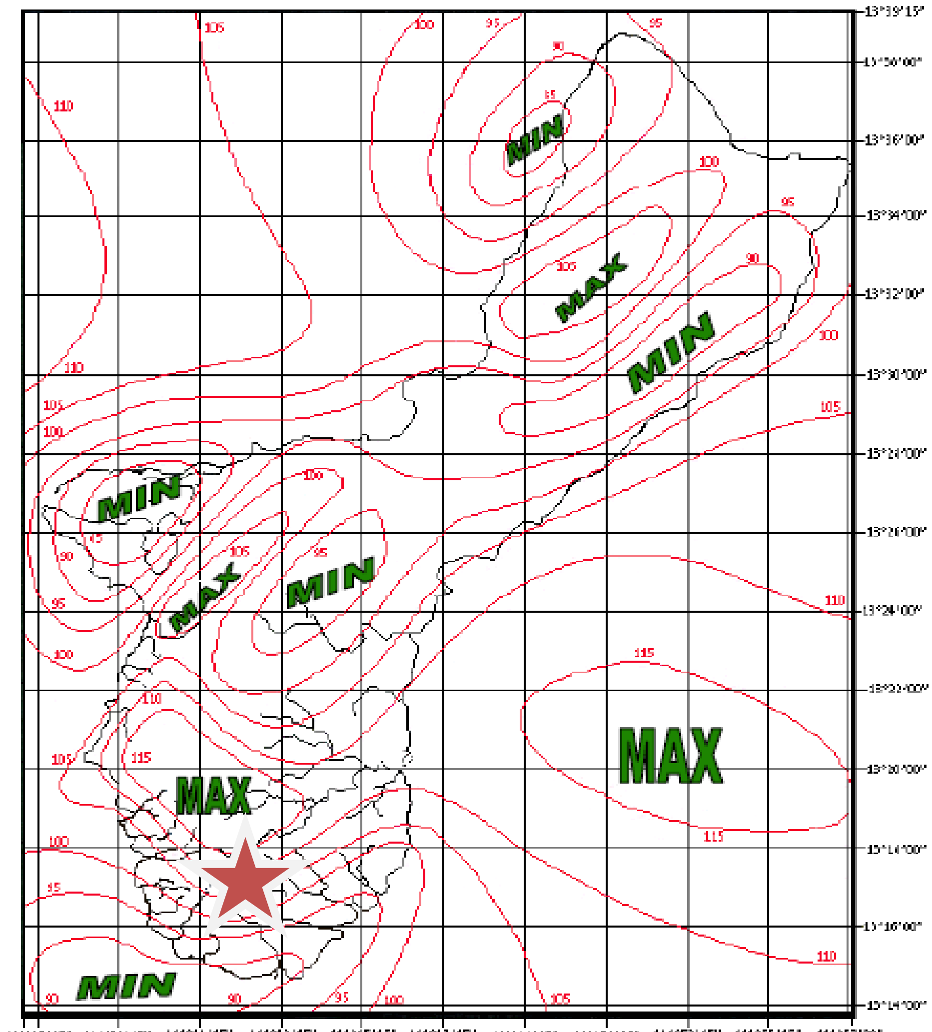

Figure 1: Annual Rainfall Distribution Map for Guam Showing Location of Fena Lake Rain Gauge Station (Adopted from Report 2001GU1342B)

DEVELOPMENT OF SHORT-TERM RAINFALL INTENSITIES

Once a distribution is fitted statistically to the data, the standard software output is generated. The output provides rainfall depths for various return periods. This rainfall depth (inches) is converted into rainfall intensity (inches per hour) for the corresponding period by multiplying the corresponding time fraction. For instance, 15 minutes of rainfall depth is multiplied by four to obtain the intensity per hour.

The intensity duration curve is plotted for each return period and a trend line (statistical curve fitting) is performed to develop the intensity duration equation. The equation is then used to extract short-term rainfall intensities.

Annual Maximum Series

A study of annual maximum precipitation frequency for Fena Lake station was conducted to characterize frequency of precipitation. This report presents the frequency of annual maximum precipitation totals for durations of 15 and 30 minutes and 1 hour; and for recurrence intervals of 2, 5, 10, 25, 50 and 100 years. Data collected from Fena station from 1980 through 2008 was used to compile annual maximum precipitation totals for the calendar year, the same period used in NRCS precipitation-frequency studies, except with the additional years since 2005. See Attachment 1 for the data set.

Results

The Lognormal distribution was found to statistically fit the rainfall data for all durations, and the results shown in Table 3 were obtained. See Attachment 1 for the output from HYFRAN software.

Return Period Years	15 Min.	30 Min.	60 Min.
100	1.57	2.3	3.4
50	1.47	2.16	3.13
25	1.37	2.01	2.86
10	1.22	1.80	2.48
5	1.10	1.63	2.17
2	0.9	1.34	1.68

Table 3: Depth (inches) - Duration Summary - Annual Maximum Series

Rainfall depths were converted to rainfall intensity in inches per hour by multiplying by the time fraction (see Table 4).

Return Period Years	15 Min.	30 Min.	60 Min.
100	6.28	4.60	3.40
50	5.88	4.32	3.13
25	5.48	4.02	2.86
10	4.88	3.60	2.48
5	4.40	3.26	2.17
2	3.59	2.68	1.68

Table 4: Intensity (inches/hour) - Duration Summary - Annual Maximum Series

The intensities obtained were plotted using Microsoft Excel. Curves were developed using the trend line function (curve fitting) to obtain the best fit equation for the curve. Table 5 shows the IDF relationships along with the root mean square (R^2) value of each equation. R^2 value is indicative of the best statistical fit, with values closer to one signifying best fit.

Return Period Years	IDF Equation	R^2 Value
100	$y = 20.79x^{-0.443}$	$R^2 = 0.9999$
50	$y = 20.198x^{-0.455}$	$R^2 = 0.9998$
25	$y = 19.619x^{-0.469}$	$R^2 = 0.9993$
10	$y = 18.519x^{-0.488}$	$R^2 = 0.9966$
5	$y = 17.82x^{-0.51}$	$R^2 = 0.9924$
2	$y = 16.317x^{-0.548}$	$R^2 = 0.9828$

Table 5: IDF Equations for Intensities - Annual Maximum Series

These equations were used to extrapolate the curve to obtain short-term rainfall intensities. See Table 6.

Time (Min.)	2-Year	5-Year	10-Year	25-Year	50-Year
5	6.75	8.44	9.22	9.71	10.19
10	4.62	6.02	6.66	7.08	7.50
15	3.70	4.94	5.51	5.89	6.26
20	3.16	4.29	4.81	5.17	5.51
25	2.80	3.85	4.34	4.67	5.00
30	2.53	3.52	3.98	4.30	4.61
35	2.33	3.27	3.70	4.01	4.30
40	2.16	3.06	3.48	3.77	4.06
45	2.03	2.89	3.29	3.57	3.85
50	1.91	2.74	3.13	3.41	3.67
55	1.82	2.62	3.00	3.26	3.52
60	1.73	2.51	2.88	3.14	3.39

Table 6: Rainfall Intensity (inches/hour) – Annual Maximum Series

The resulting short-term IDF curves, as derived from the Annual Maximum Series, are shown in Figure 2.

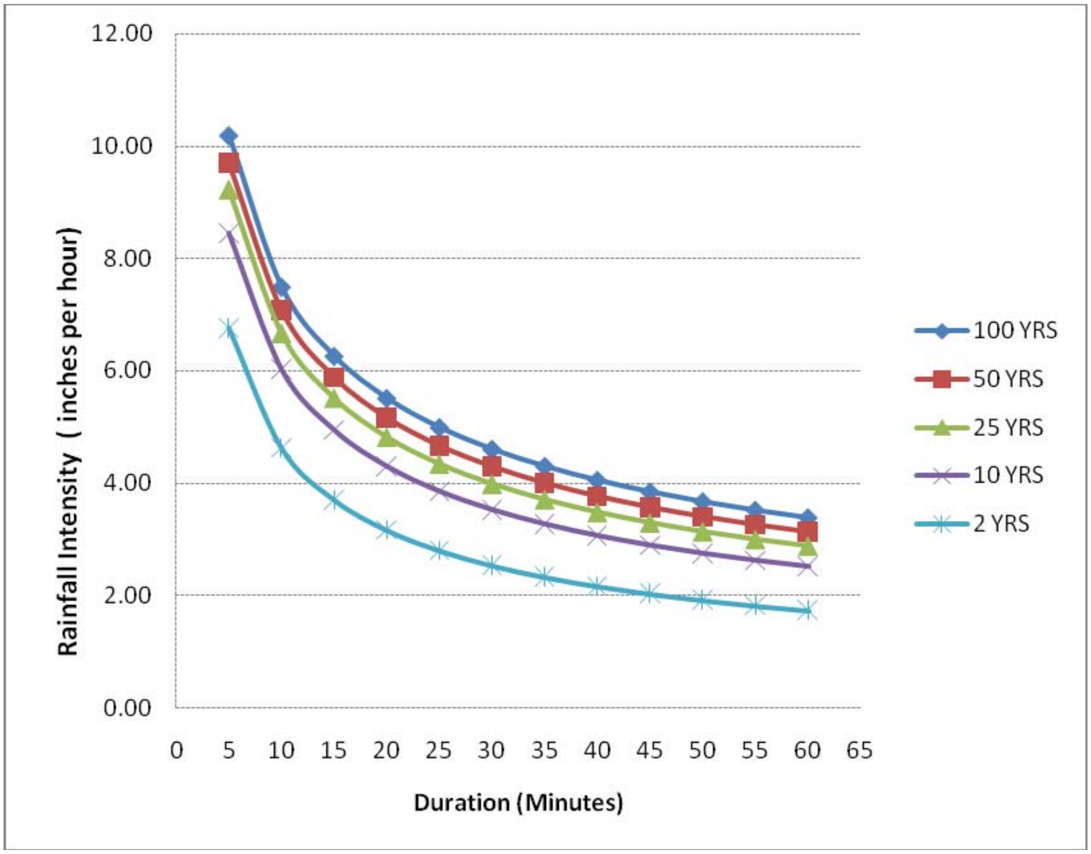

Figure 2: Rainfall Intensity Curves – Annual Maximum Series

Partial Duration Series

As discussed above, it is important for stormwater management to consider design using multiple storms rather than the highest storm in any given year. As suggested by Langbein (1949), three of the largest storms each year were considered for the development of the partial duration series. This report presents the frequency of partial duration precipitation totals for durations of 15 minutes, 30 minutes, and 1 hour; and for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. Data collected from Fena Lake station from 1980 through 2008 was used to compile annual maximum precipitation totals for the calendar year, the period used in previous precipitation-frequency studies. See Attachment 2 for the sample data set.

Results

The Log Pearson Type 3 curve was found to statistically fit the rainfall data for 15 minutes, whereas Lognormal and Gamma distributions were found statically appropriate for 30 minutes and 60 minutes, respectively. The results are shown in Table 7, which shows the rainfall depth for corresponding return periods, as obtained from analysis (see Attachment 2 for output from HYFRAN software).

Return Period Years	15 Min.	30 Min.	60 Min.
100	1.45	2.09	3.01
50	1.34	1.96	2.79
25	1.23	1.83	2.55
10	1.08	1.64	2.2
5	0.96	1.48	1.91
2	0.77	1.21	1.42

Table 7: Rainfall Depth (inches) - Duration Summary - Partial Duration Series

Rainfall depths were converted to rainfall intensities by multiplying by the time fraction (see Table 8).

Return Period Years	15 Min.	30 Min.	60 Min.
100	5.8	4.18	3.01
50	5.36	3.92	2.79
25	4.92	3.66	2.55
10	4.32	3.28	2.2
5	3.83	2.96	1.91
2	3.08	2.42	1.42

Table 8: Intensity (inches/hour) - Duration Summary - Partial Duration Series

The intensities obtained were plotted using Microsoft Excel. The data points were trend-lined (curve-fitted) to obtain the best fit equation for the curve. Table 9 shows the Intensity duration relationships, along with the root mean square value of each equation.

Return Period Years	IDF Equation	R^2 Value
100	$y = 20.891x^{-0.473}$	$R^2 = 1$
50	$y = 19.278x^{-0.471}$	$R^2 = 0.9994$
25	$y = 17.958x^{-0.474}$	$R^2 = 0.9967$
10	$y = 16.479x^{-0.487}$	$R^2 = 0.9889$
2	$y = 14.674x^{-0.559}$	$R^2 = 0.9548$

Table 9: IDF Equations for Intensities- Partial Duration Series

These equations were used to extrapolate the curve to obtain short-term rainfall intensities (see Table 10).

Time (Min.)	2-Year	10-Year	25-Year	50-Year
5	6.0	7.5	9.0	9.8
10	4.1	5.4	6.5	7.0
15	3.2	4.4	5.4	5.8
20	2.7	3.8	4.7	5.1
25	2.4	3.4	4.2	4.6
30	2.2	3.1	3.9	4.2
35	2.0	2.9	3.6	3.9
40	1.9	2.7	3.4	3.6
45	1.7	2.6	3.2	3.5
50	1.6	2.45	3.1	3.3
55	1.6	2.34	2.9	3.1
60	1.73	2.88	3.14	3.39

Table 10: Rainfall Intensities (in/hr) – Partial Duration Series

The resulting short-term IDF curve, as derived from the Partial Duration Series, is shown in Figure 3.

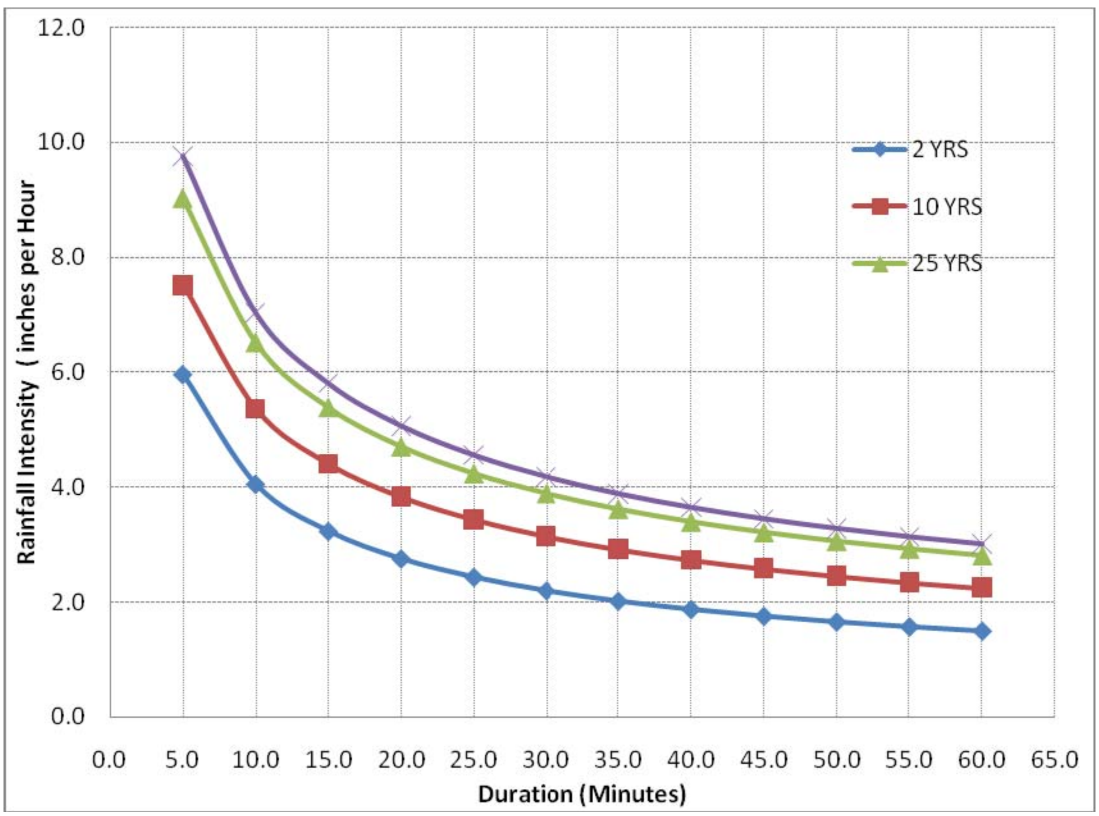

Figure 3: Rainfall Intensity Curves – Partial Duration Series

One – Hour Storm-Based Analysis Series (One-Hour Duration Series)

The above two analyses were performed in accordance with the standard practices followed by the researchers and hydrologists. It is important to note that the procedures described above were developed for performing flood frequency analysis and adopted for precipitation analysis. It is also noteworthy that in the procedure described above, selection of events was carefully performed to ensure that the flood events were independent. For precipitation analysis, this assumption should not be a limiting factor, because the occurrence of short-duration rainfall events is to a large extent independent; that is, any storm in a given day should not affect the next storm either in the same day or any other day. Based on this assumption, a daily peak series was developed for a one-hour storm.

The series included daily peak storm values to mimic the real rainfall scenario. The series of storms selected had a duration of at least one hour or more. One hour or more storms are defined as storms for which the actual duration was at least one hour from the 15-minute rainfall data; that is, 15-minute rainfall data showed at least four consecutive positive values in a day. Also, the most intense 15-minute storms were selected. These were storms demonstrating maximum rainfall depth for the first 15 minutes, even though these storms may not produce the maximum rainfall total in one hour. The reason for this type of selection is to analyze the rainfall distribution of storms that start as intense storms and last at least an hour. This report presents the frequency of actual precipitation totals for durations of 15 minutes, 30 minutes, and 1 hour; and for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. Data collected from the Fena Lake station from 1980 through 2008 was used to compile the annual maximum one-hour storm precipitation totals for the calendar year, the period used in previous precipitation-frequency studies. See Attachment 3 for the data sample.

Results

The Lognormal curve was found to statistically fit all rainfall data for all durations. The following results were obtained. See Attachment 3 for output from HYFRAN software. Table 11 shows the rainfall depth for corresponding return periods, as obtained from analysis.

Return Period Years	15 Min.	30 Min.	60 Min.
100	1.14	2.07	3.00
50	1.00	1.83	2.71
25	0.87	1.60	2.42
10	0.69	1.30	2.03
5	0.56	1.07	1.72
2	0.38	0.74	1.25

Table 11: Depth (in) - Duration Summary – 1 Hour Storm Based Series

Rainfall depths were converted to rainfall intensities by multiplying by the time fraction (see Table 12).

Return Period Years	15 Min.	30 Min.	60 Min.
100	4.56	4.14	3.00
50	3.99	3.66	2.71
25	3.46	3.20	2.42
10	2.78	2.60	2.03
5	2.26	2.14	1.72
2	1.52	1.48	1.25

Table 12: Intensity (in/hr) - Duration Summary – 1-Hour Duration Series

The intensities obtained were plotted using Microsoft Excel. The plotted points were trend-lined (curve-fitted) to obtain the best fit equation for the curve. Table 13 shows the intensity duration relationships as developed, along with the root mean square value of each equation.

Return Period Years	IDF Equation	R^2 Value
100	$y = 5.3568e^{-0.01x}$	$R^2 = 0.987$
50	$y = 4.6392e^{-0.009x}$	$R^2 = 0.986$
25	$y = 3.9787e^{-0.008x}$	$R^2 =0.985$
10	$y = 2.5164e^{-0.006x}$	$R^2 = 0.978$
2	$y = 1.6496e^{-0.004x}$	$R^2 = 0.953$

Table 13: IDF Equations for Intensities- 1-Hour Storm Series

These equations were used to extrapolate the curve to obtain one-hour rainfall intensities. See table 14 for results of rainfall intensities.

Time (Min.)	2-Year	10-Year	25-Year	50-Year	100-Year
5	1.62	2.44	3.82	4.44	5.10
10	1.58	2.37	3.67	4.24	4.85
15	1.55	2.30	3.53	4.05	4.61
20	1.52	2.23	3.39	3.87	4.39
25	1.49	2.17	3.26	3.70	4.17
30	1.46	2.10	3.13	3.54	3.97
35	1.43	2.04	3.01	3.39	3.77
40	1.41	1.98	2.89	3.24	3.59
45	1.38	1.92	2.78	3.09	3.42
50	1.35	1.86	2.67	2.96	3.25

Time (Min.)	2-Year	10-Year	25-Year	50-Year	100-Year
55	1.32	1.81	2.56	2.83	3.09
60	1.30	1.76	2.46	2.70	2.94

Table 14: Rainfall Intensities (in/hr) - 1-Hour Storm Series

Resulting short-term IDF curve as derived from the One-Hour Storm Series is shown in Figure 4.

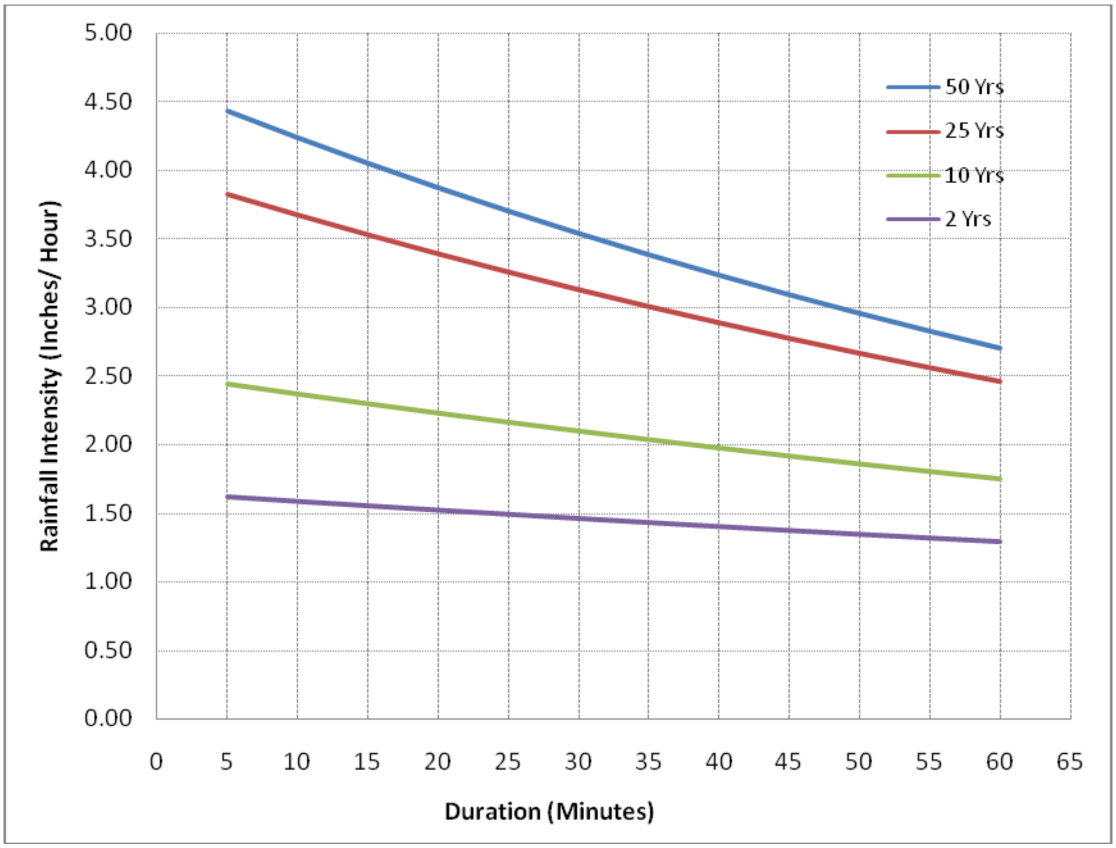

Figure 4: Rainfall Intensity Curves – 1-Hour Storm Series

Analysis for Selection of Storm for Design of Stormwater Management Facilities

Typically, a 24-hour storm is used as a basis for the design of stormwater facilities. However, many transportation departments use other storms to better fit local conditions. This section describes the analysis of recurrence intervals for various storms as they occur on Guam. An analysis was performed on the actual short-term rainfall (storm) events to ascertain the duration of storms on a daily basis. It was found that between a period of 1980 and 2008, 3,405 storm events were at least 15 minutes long, 1,027 events were at least 30 minutes long, 359 storms lasted 45 minutes or less, and only 185 storms lasted an hour. There was no evidence of a 24-hour duration rainfall event over a period of 28 years. This does not suggest that 24-hour storms do not happen, but that the probability is remote. This concurs with the general observation that Guam is frequented by intense short duration storms on an almost daily basis, with a storm rarely lasting more than an hour. A statistical curve fitting was performed on the observations and it was determined that the probability of getting two one-hour storms in a day is less than 2 percent, and the probability of getting three one-hour storms in a day is less than 0.1 percent (see Figure 5). Similarly, the probability of getting two 15-minute storms in a day is 98 percent (see Figure 6).

It is therefore reasonable to design stormwater management facilities in Guam for a one-hour storm as the probability of two one-hour storms happening in a day is less than 2 percent; or in other words, there is a 98 percent chance that two one-hour storms will not occur in one day. Based on this probability, it is safe to infer that probability of back-to-back, one-hour storms is further remote. Considering the probability and economics, it is suggested that stormwater facilities be designed for a one-hour duration storm. For flow control designs, it will be very realistic to detain the one-hour storm and release that runoff volume within a six-hour period to better mimic existing hydrology.

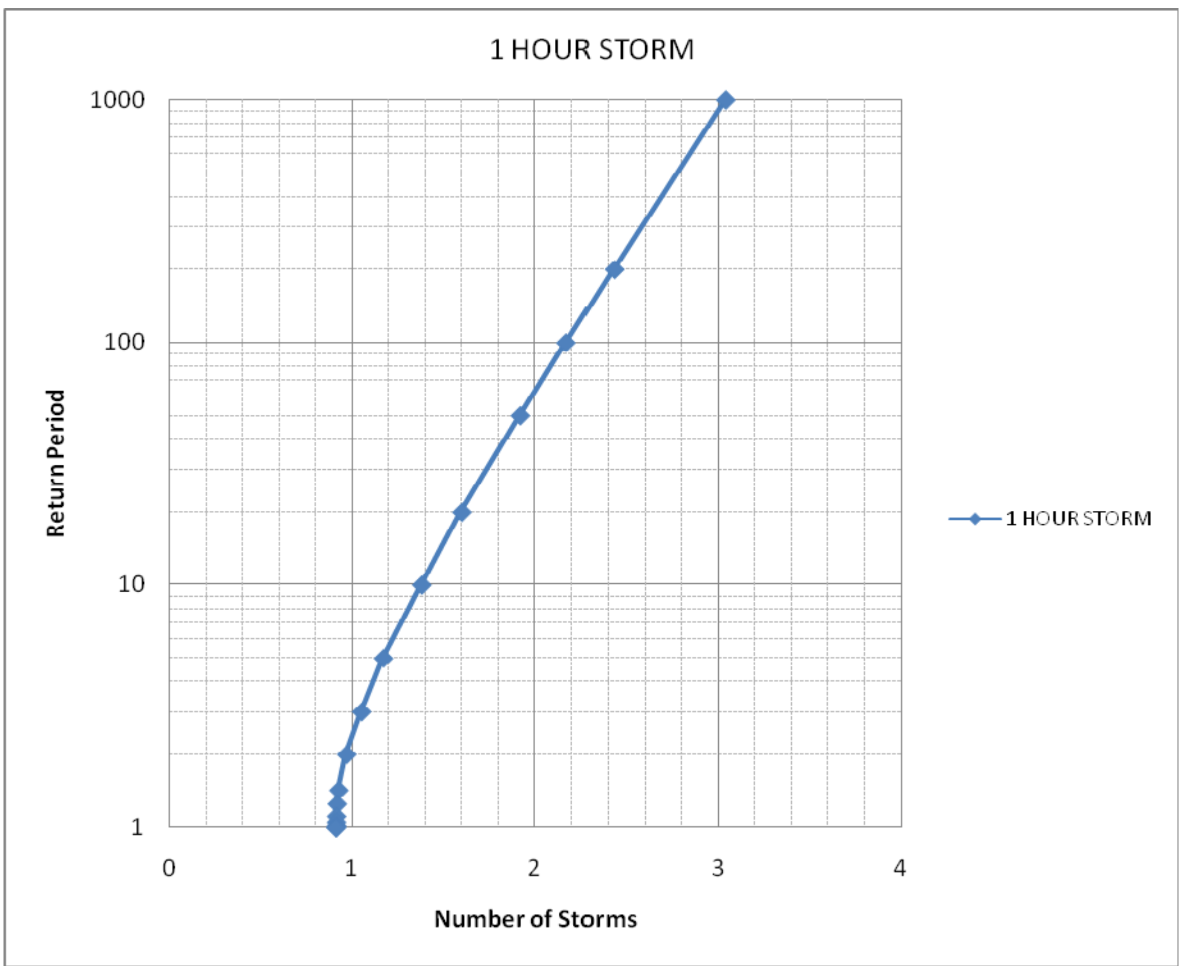

Figure 5: Probability of Recurrence of 1-Hour Storm in a Day

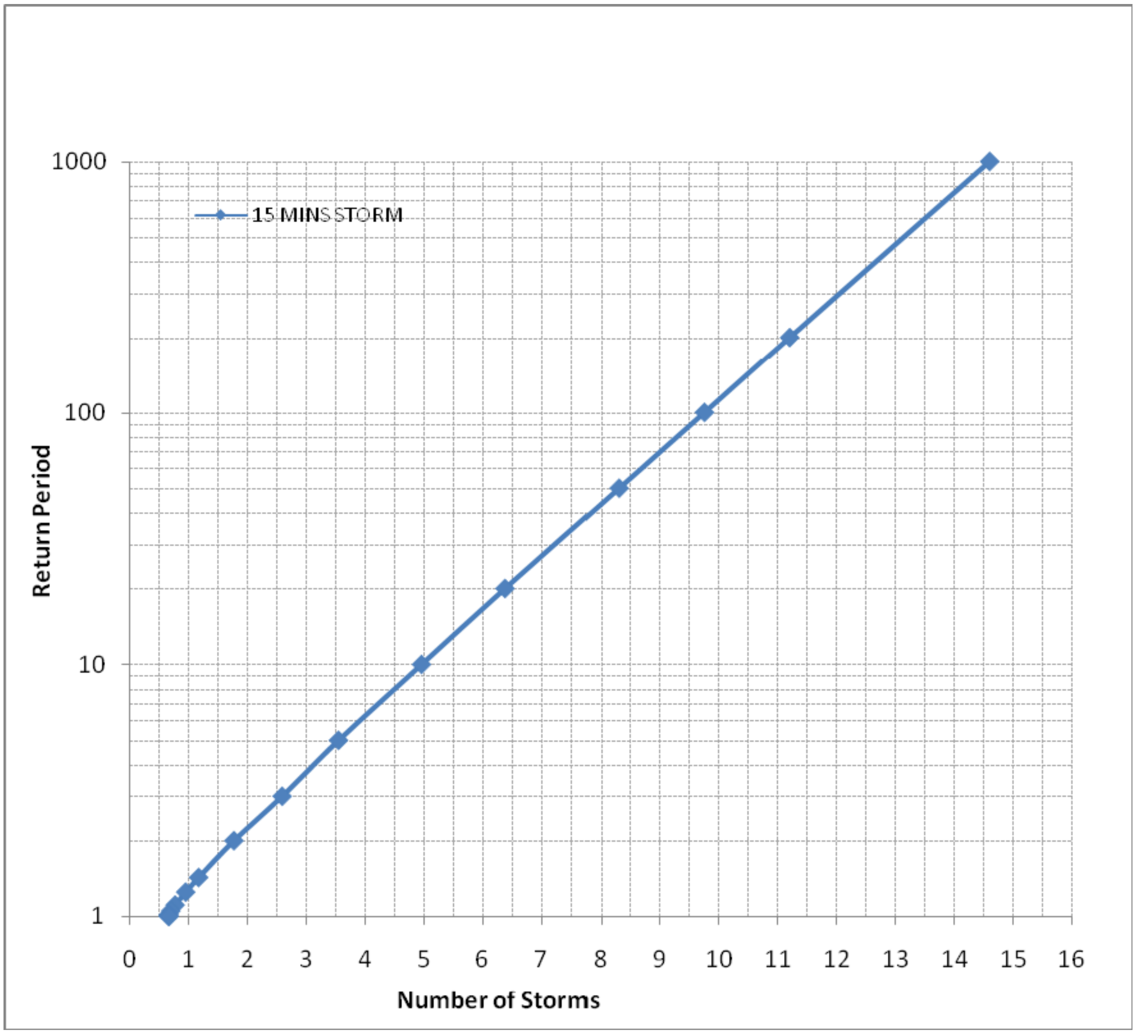

Figure 6: Probability of Recurrence of 15-Minute Storms in a Day

Comparison of Results and Discussion

The results were compared with results obtained from a recent study by NRCS (2008) (see Table 15 for the annual maximum series and Table 16 for the partial duration series).

Annual Maximum Series

	15 Min.		30 Min.		60 Min.	
Return Period	NRCS	Report	NRCS	Report	NRCS	Report
2	0.86	0.90	1.33	1.34	1.88	1.68
5	1.04	1.10	1.66	1.63	2.39	2.17
10	1.16	1.22	1.88	1.80	2.72	2.48
25	1.31	1.37	2.16	2.01	3.15	2.86

	15 Min.		30 Min.		60 Min.	
Return Period	NRCS	Report	NRCS	Report	NRCS	Report
50	1.42	1.47	2.36	2.16	3.46	3.13
100	1.53	1.57	2.56	2.30	3.77	3.40

Table 15: Comparison with NRCS - Annual Maximum Series

Partial Duration Series

	15 Min.		30 Min.		60 Min.	
Return Period	NRCS	Report	NRCS	Report	NRCS	Report
2	0.91	0.77	1.43	1.21	2.03	1.42
5	1.06	0.96	1.69	1.48	2.44	1.91
10	1.17	1.08	1.89	1.64	2.75	2.20
25	1.31	1.23	2.16	1.83	3.16	2.55
50	1.42	1.34	2.36	1.96	3.47	2.79
100	1.53	1.45	2.56	2.09	3.78	3.01

Table 16: Comparison with NRCS-Partial Duration Series

1-Hour Storm Series vs Partial Duration Series (PDS)

	15 Min.		30 Min.		60 Min.	
Return Period	PDS	1-Hour	PDS	1-Hour	PDS	1-Hour
2	0.77	0.38	1.21	0.74	1.42	1.25
5	0.96	0.56	1.48	1.07	1.91	1.72
10	1.08	0.69	1.64	1.30	2.20	2.03
25	1.23	0.87	1.83	1.60	2.55	2.42
50	1.34	1.00	1.96	1.83	2.79	2.71
100	1.45	1.14	2.09	2.07	3.01	3.00

Table 17: Comparison of Actual Duration Series and partial Duration Series

Review of the annual maximum series and partial duration series for Fena Lake station suggests that values obtained by this report are within close proximity with the NRCS values for the extreme event modeling. It is important to note that the partial duration series in NRCS was created using transformation techniques, whereas the partial duration series created in this report was developed from taking into account the three largest storms in a year. In both cases extreme events were modeled.

Whereas, the comparison of the One-Hour Storm Series with the partial duration series suggests there is a significant difference (see Table 17). One of the reasons for the significant difference is that the partial duration series includes short-duration, more intense, thundershowers that occur over small areas in less than one hour in duration. These extreme events were not selected in development of the one-hour duration series, as it has been generally observed that the extreme events are shorter than a one-hour duration on Guam. Therefore, the one-hour storm series does not represent extreme storm events, but does represent the duration and distribution of actual storms that occur on Guam, which are generally an hour or less in duration.

To analyze the rainfall distribution of the partial duration series and the One-Hour series, the ratios of 15-minute to 60-minute and 30-minute to 60-minute rainfalls were calculated based on the assumption that the rainfall is from a one-hour duration storm. Results are displayed in Table 18. The intent is to determine the approximate location of the storm peak.

	15 Min./60 Min.		30 Min./60 Min.	
Return Period	PDS	1-Hour Series	PDS	1-Hour Series
2	0.54	0.30	0.85	0.59
5	0.50	0.33	0.77	0.62
10	0.49	0.34	0.75	0.64
25	0.48	0.36	0.72	0.66
50	0.48	0.37	0.70	0.68
100	0.48	0.38	0.69	0.69

Table 18: Rainfall Depth Ratios

Rainfall depths for the One-Hour storm modeling are approximately 35 percent lower than the partial duration events. The difference is largest for the 15-minute duration with the difference diminishing to less than 10 percent for the 30-minute to 60-minute ratio for all recurrence intervals. Also, if the ratio of 15-minute to 60-minute and 30-minute to 60-minute is evaluated for both the One-Hour storm and the partial duration series, it suggests that for both scenarios, 70 percent of the one-hour rainfall is captured within the first 30 minutes. But for the 15-minute to 60-minute ratio, it suggests that for the PDS, the range of capture is between 48 to 54 percent, whereas it is 30 to 40 percent for the actual series for all recurrence intervals. This shows that extreme events dump about 20 percent more rainfall within the first 15 minutes. Since the data studied is based on 15 minute records, it can be inferred that most one-hour storms peak within 15 minutes. Since no rainfall data is available for a shorter duration, the exact storm peak time cannot be determined. Even so, this confirms the general observation of the very intense short duration storms on Guam, with longer duration storms being sparse and less intense.

Since the main objective of this report is to determine the intensity, duration, and distribution of short-term rainfall to be used for the design of transportation facilities, it is suggested that a synthetic one-hour rainfall be created with 15-minute rainfall depths adopted from partial duration series and adopting one-hour storm rainfall depths for longer durations. This is a more balanced approach as it captures the actual rainfall distribution for the one hour duration storm, while allowing for a more conservative design using the higher intensities of the shorter durations. See Table 19 for recommended synthetic rainfall depths by duration and storm frequencies.

Return Period	15 Min.	30 Min.	60 Min.
2	0.77	0.74	1.25
5	0.96	1.07	1.72
10	1.08	1.3	2.03
25	1.23	1.6	2.42
50	1.34	1.83	2.71
100	1.45	2.07	3.0

Table19: Synthetic Rainfall Depth (in)-Duration for the 1-Hour Storm

CONCLUSION

Extreme events modeling revealed similarities between results obtained in this report with other researchers; whereas actual rainfall events were shown to be significantly shorter in duration than the 6-hour to 24-hr events typically used for design of stormwater management facilities.

The recommended storm distribution is a hybrid curve based on 15-minute rainfall from the partial duration series and the milder 30- and 60-minute rainfalls from the One Hour storm series. The subsequent rainfall is conservative for durations shorter than 15 minutes and mimics actual rainfall for longer durations. In support of the synthetic rainfall intensities, Chip Guard (NRCS, 2008) suggests using five-minute rainfall intensities in range of 5.4 to 11.4 inches per hour for a return period of 2 years to 100 years. These results are comparable and within that range.

In order to balance the economics and safety, it is recommended that a one-hour synthetic design rainfall be used for the design of highway stormwater facilities for Guam. Stormwater management systems that will be developed using the selected design storm events and intensity curves will size the drainage facilities to better match actual rainfall conditions. This will help the designer to prepare an efficient design that provides for the public safety, while minimizing project costs.

The following tables and graphs present the recommended rainfall depth duration curves, intensity duration curves, and cumulative rainfall distribution for the one-hour storm.

Return Period Years	15 Min.	30 Min.	60 Min.
2	3.08	1.48	1.25
5	3.84	2.14	1.72
10	4.32	2.60	2.03
25	4.92	3.20	2.42
50	5.36	3.66	2.71
100	5.80	4.14	3.00

Table 20: Rainfall Intensity (in/hr) - Synthetic 1-Hour Rainfall

Return Period Years	IDF Equation	R^2 Value
100	$y = 20.971x^{-0.476}$	$R^2 = 0.999$
50	$y = 20.04x^{-0.492}$	$R^2 = 0.995$
25	$y = 19.187x^{-0.512}$	$R^2 = 0.985$
10	$y = 18.086x^{-0.545}$	$R^2 = 0.962$
2	$y = 16.322x^{-0.651}$	$R^2 = 0.885$

Table 21: Rainfall Intensity Equations-Synthetic 1-Hour Rainfall

Time (Min.)	2-Year	10-Year	25-Year	50-Year	100-Year
5	5.72	7.52	8.43	9.08	9.75
10	3.65	5.16	5.91	6.46	7.01
15	2.80	4.13	4.81	5.29	5.78
20	2.32	3.53	4.15	4.59	5.04
25	2.01	3.13	3.70	4.11	4.53
30	1.78	2.83	3.37	3.76	4.15
35	1.61	2.61	3.12	3.49	3.86
40	1.48	2.42	2.91	3.26	3.62
45	1.37	2.27	2.74	3.08	3.43
50	1.28	2.14	2.60	2.92	3.26
55	1.20	2.04	2.47	2.79	3.11
60	1.14	1.94	2.37	2.67	2.99

Table 22: Rainfall Intensities - Synthetic 1-Hour Rainfall

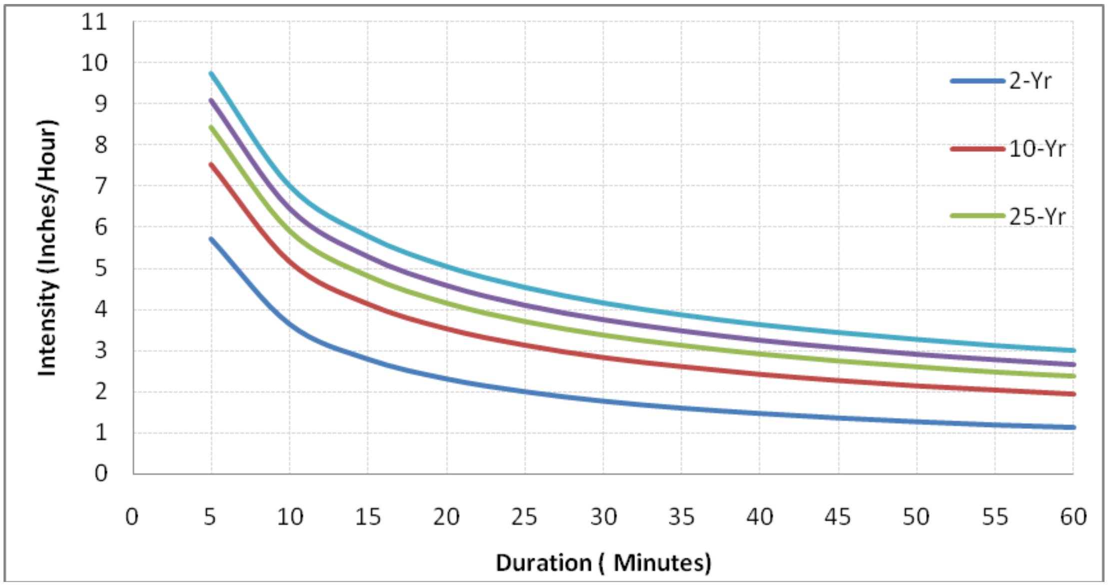

Figure 7: Intensity Duration Curve - Synthetic 1-Hour Rainfall

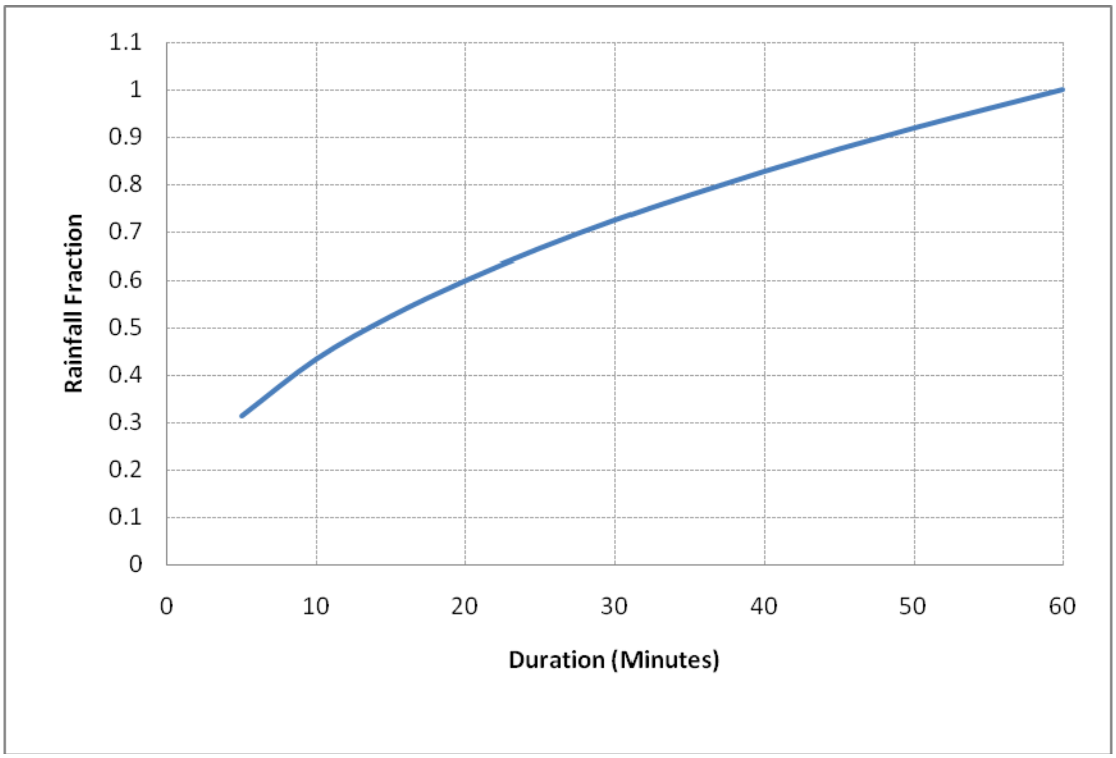

Figure 8: Design Rainfall Distribution for 1-Hour Storm

Time (Min.)	Rainfall Fraction
5	0.315
10	0.435
15	0.525
20	0.600
25	0.666
30	0.725
35	0.778
40	0.828
45	0.875
50	0.919
55	0.960
60	1.000

Table 23: One Hour Synthetic Rainfall Fractions

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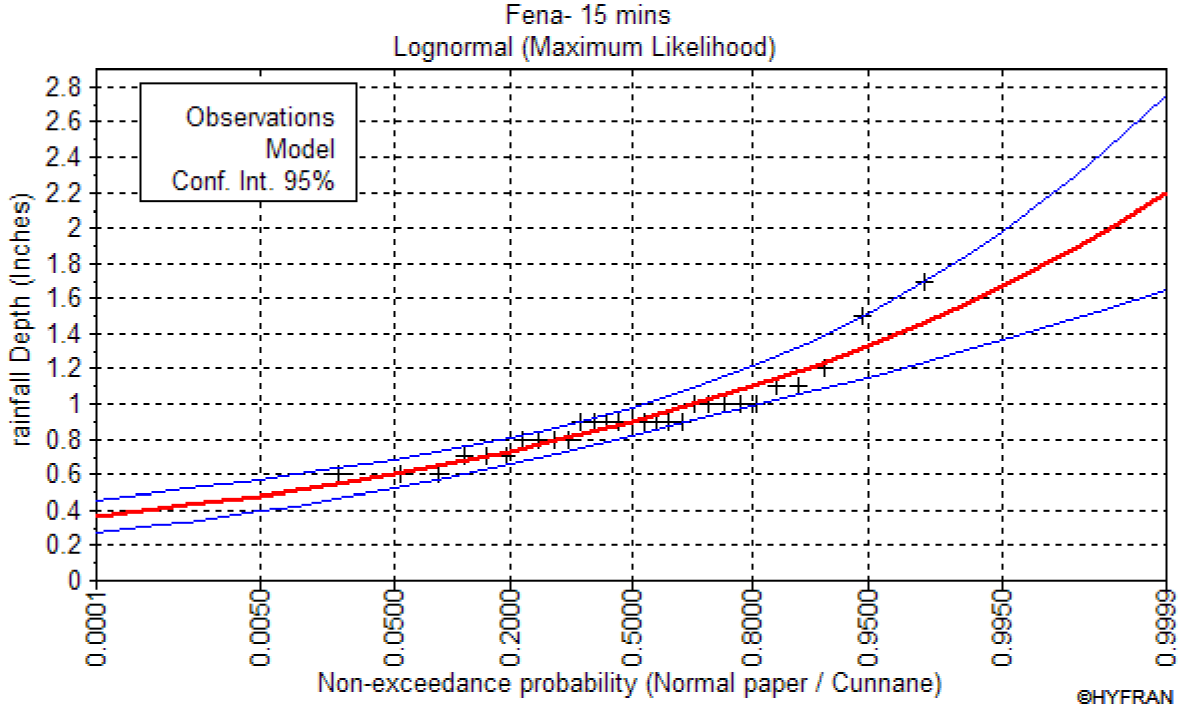
ATTACHMENT 1

ANNUAL MAXIMUM SERIES

SAMPLE DATA SET

	15 MIN	30 MIN	1 HR
1980	1	1.7	2.6
1981	1	1.5	1.9
1982	1	1	1.2
1983	0.8	1	1.4
1984	1	1.5	2.4
1985	0.9	1.3	1.8
1986	0.9	1.5	1.8
1987	0.6	1.1	1.2
1988	1.7	1.7	1.8
1989	0.8	1.1	1.7
1990	0.6	1	1.2
1991	0.9	1.5	1.7
1992	1.1	1.9	2.1
1993	0.9	1.3	2
1994	1	1.4	1.8
1995	0.9	1.7	2.4
1996	0.9	1.7	2.4
1997	1.1	2	3.5
1998	0.9	1.2	1.3
1999	0.8	1.4	1.5
2000	0.7	1	1.3
2001	0.9	1.4	2.3
2002	0.8	1.5	1.3
2003	0.7	1	1.4
2004	1.2	1.3	1.7
2005	1.5	2	1.9
2006	0.7	1.2	1.3
2007	0.9	0.9	0.9
2008	0.6	1	1.1

Hyfran Results



Fena- 15 mins

Results of the fitting

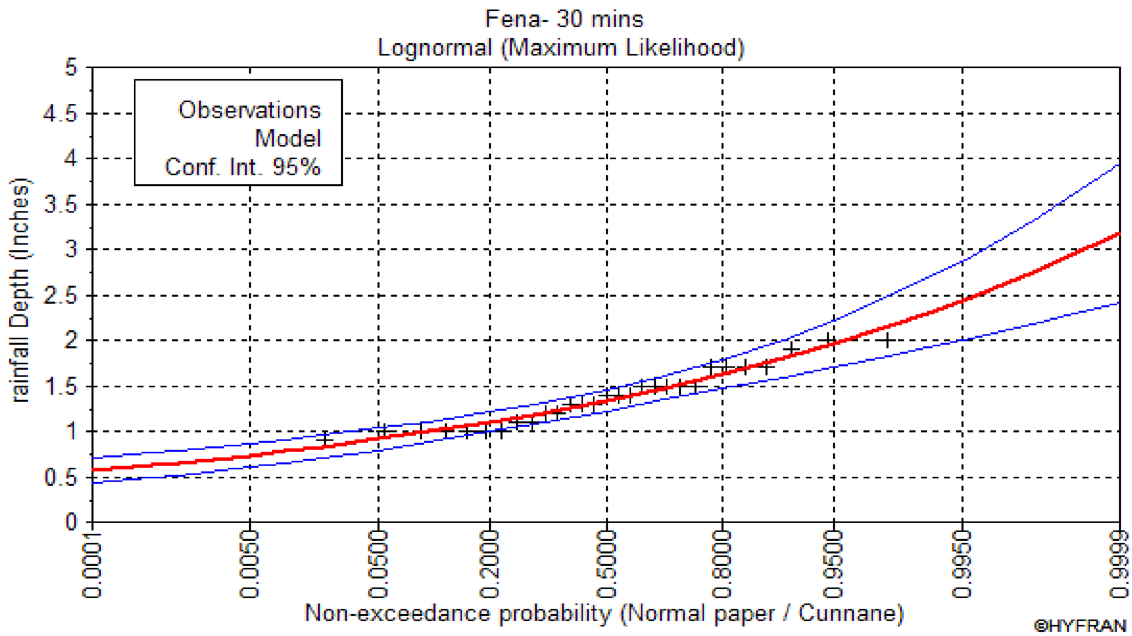
Lognormal (Maximum Likelihood)

Number of observations 29

Parameters
mu -0.10808
sigma 0.240697

Quantiles
q = F(X) : non-exceedance probability
T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	0.9999	2.2	0.281	1.65	2.75
2000	0.9995	1.98	0.228	1.54	2.43
1000	0.999	1.89	0.206	1.49	2.29
200	0.995	1.67	0.157	1.36	1.98
100	0.99	1.57	0.137	1.3	1.84
50	0.98	1.47	0.117	1.24	1.7
25	0.96	1.37	0.0984	1.18	1.56
20	0.95	1.33	0.0924	1.15	1.51
10	0.9	1.22	0.0743	1.08	1.37
5	0.8	1.1	0.0574	0.986	1.21
3	0.6667	0.996	0.0466	0.904	1.09
2	0.5	0.898	0.0401	0.819	0.976
1.4286	0.3	0.791	0.0378	0.717	0.865
1.25	0.2	0.733	0.0383	0.658	0.808
1.1111	0.1	0.659	0.0401	0.581	0.738
1.0526	0.05	0.604	0.0418	0.522	0.686
1.0204	0.02	0.547	0.0437	0.462	0.633
1.0101	0.01	0.513	0.0447	0.425	0.6
1.005	0.005	0.483	0.0455	0.394	0.572
1.001	0.001	0.427	0.0465	0.335	0.518
1.0005	0.0005	0.407	0.0467	0.315	0.498
1.0001	0.0001	0.367	0.0468	0.275	0.458



Fena- 30 mins
Lognormal (Maximum Likelihood)
Observations
Model
Conf. Int. 95%
rainfall Depth (Inches)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.0001
0.0050
0.0500
0.2000
0.5000
0.8000
0.9500
0.9950
0.9999
Non-exceedance probability (Normal paper / Cunnane)
©HYFRAN

Fena- 30 mins

Results of the fitting

Lognormal (Maximum Likelihood)

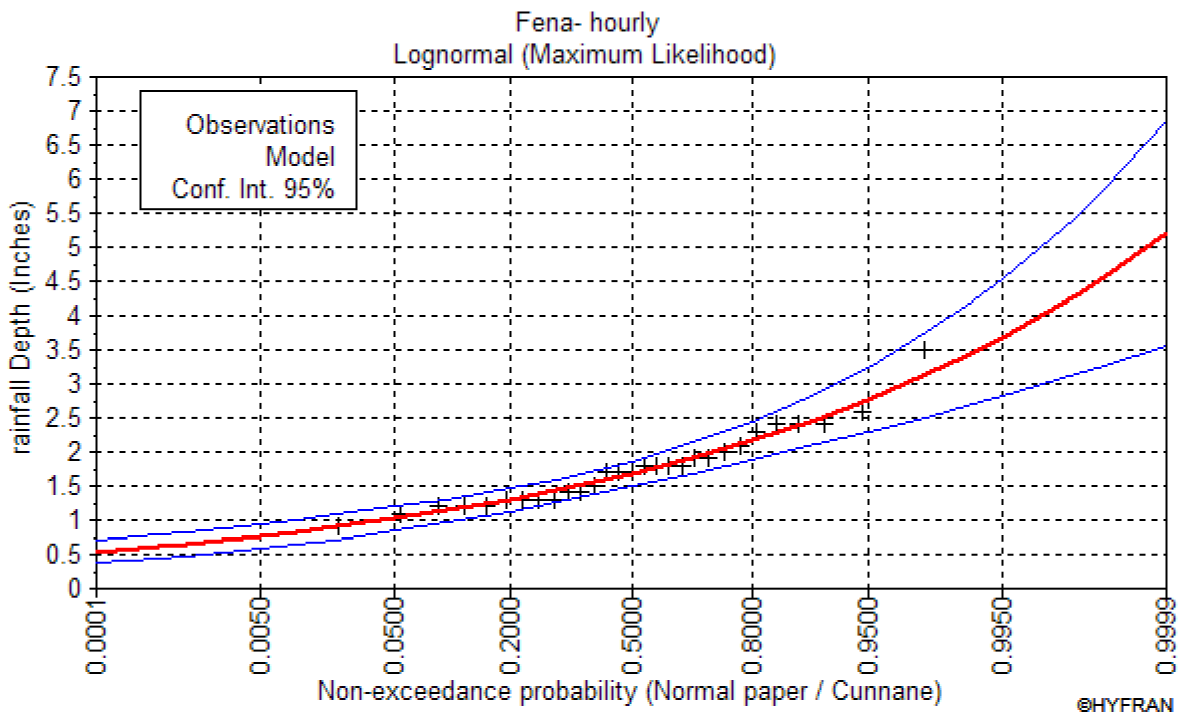
Number of observations 29

Parameters

mu	0.290497
sigma	0.232671

Quantiles
q = F(X) : non-exceedance probability
T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	0.9999	3.18	0.392	2.41	3.95
2000	0.9995	2.88	0.319	2.25	3.5
1000	0.999	2.74	0.289	2.18	3.31
200	0.995	2.43	0.222	2	2.87
100	0.99	2.3	0.194	1.92	2.68
50	0.98	2.16	0.166	1.83	2.48
25	0.96	2.01	0.14	1.74	2.28
20	0.95	1.96	0.131	1.7	2.22
10	0.9	1.8	0.106	1.59	2.01
5	0.8	1.63	0.0821	1.47	1.79
3	0.6667	1.48	0.0668	1.35	1.61
2	0.5	1.34	0.0578	1.22	1.45
1.4286	0.3	1.18	0.0547	1.08	1.29
1.25	0.2	1.1	0.0555	0.99	1.21
1.1111	0.1	0.992	0.0583	0.878	1.11
1.0526	0.05	0.912	0.0611	0.792	1.03
1.0204	0.02	0.829	0.0639	0.704	0.954
1.0101	0.01	0.778	0.0656	0.65	0.907
1.005	0.005	0.734	0.0668	0.603	0.865
1.001	0.001	0.651	0.0686	0.517	0.786
1.0005	0.0005	0.622	0.0691	0.486	0.757
1.0001	0.0001	0.563	0.0695	0.427	0.699


Fena- hourly
Lognormal (Maximum Likelihood)
Observations
Model
Conf. Int. 95%
rainfall Depth (Inches)
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.0001
0.0050
0.0500
0.2000
0.5000
0.8000
0.9500
0.9950
0.9999
Non-exceedance probability (Normal paper / Cunnane)
©HYFRAN

Fena- hourly

Results of the fitting

Lognormal (Maximum Likelihood)

Number of observations 29

Parameters

mu	0.517041
sigma	0.304168

Quantiles

q = F(X) : non-exceedance probability
T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	0.9999	5.2	0.839	3.55	6.84
2000	0.9995	4.56	0.663	3.26	5.86
1000	0.999	4.29	0.591	3.13	5.45
200	0.995	3.67	0.437	2.82	4.53
100	0.99	3.4	0.375	2.67	4.14
50	0.98	3.13	0.316	2.51	3.75
25	0.96	2.86	0.26	2.35	3.37
20	0.95	2.77	0.242	2.29	3.24
10	0.9	2.48	0.19	2.1	2.85
5	0.8	2.17	0.143	1.89	2.45
3	0.6667	1.91	0.113	1.69	2.13
2	0.5	1.68	0.0947	1.49	1.86
1.4286	0.3	1.43	0.0863	1.26	1.6
1.25	0.2	1.3	0.0857	1.13	1.47
1.1111	0.1	1.14	0.0873	0.965	1.31
1.0526	0.05	1.02	0.089	0.842	1.19
1.0204	0.02	0.898	0.0905	0.72	1.08

T	q	XT	Standard deviation	Confidence interval (95%)	
1.0101	0.01	0.826	0.091	0.648	1
1.005	0.005	0.766	0.0911	0.587	0.945
1.001	0.001	0.655	0.0902	0.478	0.832
1.0005	0.0005	0.616	0.0895	0.441	0.792
1.0001	0.0001	0.541	0.0873	0.37	0.712

ATTACHMENT 2

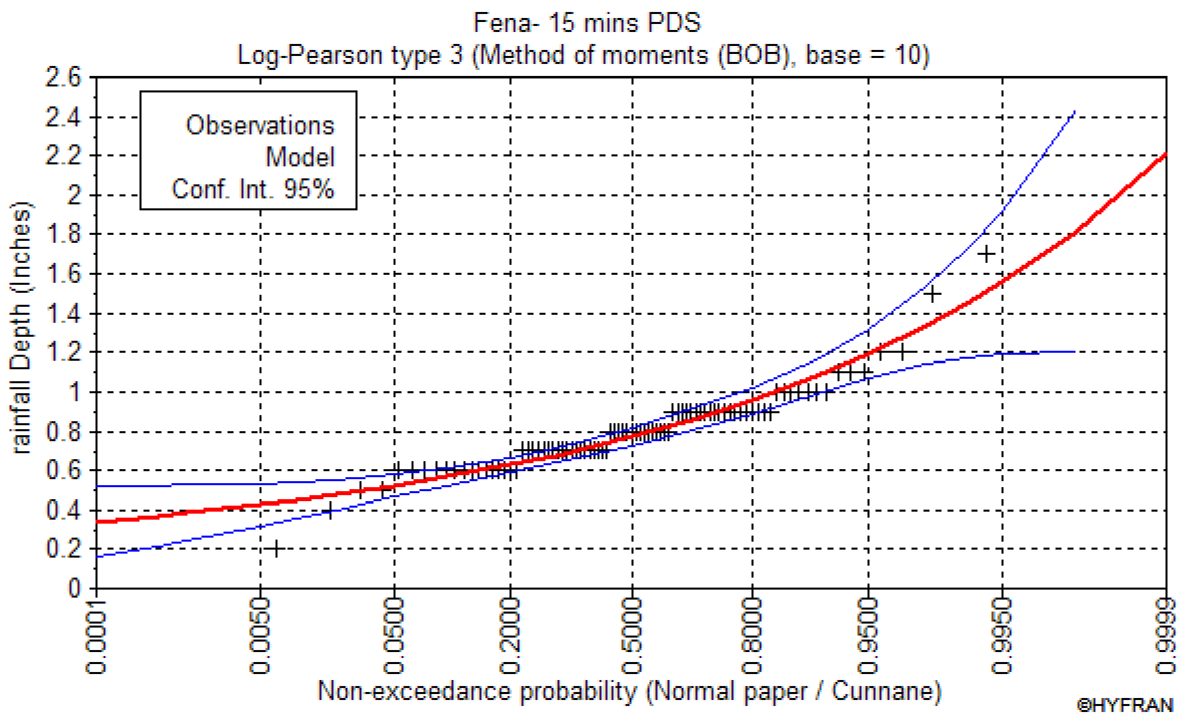
PARTIAL DURATION SERIES

SAMPLE DATA SET

15 min	high		2nd high		3rd high	
	1	1980-01-01	0.9	1980-01-01	0.8	1980-01-01
	1	1981-01-01	0.9	1981-01-01	0.7	1981-01-01
	1	1982-01-01	0.9	1982-01-01	0.7	1982-01-01
	0.8	1983-01-01	0.7	1983-01-01	0.7	1983-01-01
	1	1984-01-01	0.9	1984-01-01	0.9	1984-01-01
	0.9	1985-01-01	0.7	1985-01-01	0.7	1985-01-01
	0.9	1986-01-01	0.9	1986-01-01	0.8	1986-01-01
	0.6	1987-01-01	0.6	1987-01-01	0.5	1987-01-01
	1.7	1988-01-01	0.9	1988-01-01	0.7	1988-01-01
	0.8	1989-01-01	0.6	1989-01-01	0.6	1989-01-01
	0.6	1990-01-01	0.6	1990-01-01	0.5	1990-01-01
	0.9	1991-01-01	0.9	1991-01-01	0.8	1991-01-01
	1.1	1992-01-01	0.8	1992-01-01	0.7	1992-01-01
	0.9	1993-01-01	0.7	1993-01-01	0.6	1993-01-01
	1.00	1994-01-01	1.00	1994-01-01	1	1994-01-01
	0.9	1995-01-01	0.8	1995-01-01	0.8	1995-01-01
	0.9	1996-01-01	0.8	1996-01-01	0.8	1996-01-01
	1.1	1997-01-01	0.9	1997-01-01	0.9	1997-01-01
	0.9	1998-01-01	0.8	1998-01-01	0.7	1998-01-01
	0.8	1999-01-01	0.8	1999-01-01	0.7	1999-01-01
	0.7	2000-01-01	0.6	2000-01-01	0.6	2000-01-01
	0.9	2001-01-01	0.8	2001-01-01	0.7	2001-01-01
	0.8	2002-01-01	0.7	2002-01-01	0.7	2002-01-01
	0.7	2003-01-01	0.6	2003-01-01	0.6	2003-01-01
	1.2	2004-01-01	0.9	2004-01-01	0.7	2004-01-01
	1.5	2005-01-01	1.2	2005-01-01	1.1	2005-01-01
	0.7	2006-01-01	0.7	2006-01-01	0.6	2006-01-01
	0.9	2007-01-01	0.6	2007-01-01	0.2	2007-01-01
	0.6	2008-01-01	0.6	2008-01-01	0.4	2008-01-01

30 min	high		2nd high		3rd high
	1.7	1980-01-01	1.3	1980-01-01	1.3
	1.5	1981-01-01	1.2	1981-01-01	1.1
	1	1982-01-01	1	1982-01-01	0.9
	1	1983-01-01	1	1983-01-01	1
	1.5	1984-01-01	1.4	1984-01-01	1.2
	1.3	1985-01-01	1.2	1985-01-01	1.2
	1.5	1986-01-01	1.4	1986-01-01	1.3
	1.1	1987-01-01	1.1	1987-01-01	1
	1.7	1988-01-01	1.7	1988-01-01	1.1
	1.1	1989-01-01	1	1989-01-01	0.9
	1	1990-01-01	0.9	1990-01-01	0.9
	1.5	1991-01-01	1.3	1991-01-01	1.3
	1.9	1992-01-01	1.3	1992-01-01	1.2
	1.3	1993-01-01	1.1	1993-01-01	1.1
	1.4	1994-01-01	1.4	1994-01-01	1.4
	1.7	1995-01-01	1.6	1995-01-01	1.6
	1.7	1996-01-01	1.4	1996-01-01	1.3
	2	1997-01-01	1.8	1997-01-01	1.7
	1.2	1998-01-01	1.1	1998-01-01	1
	1.4	1999-01-01	1.2	1999-01-01	1
	1	2000-01-01	0.9	2000-01-01	0.8
	1.4	2001-01-01	1.4	2001-01-01	1.3
	1.5	2002-01-01	1.3	2002-01-01	1
	1	2003-01-01	1	2003-01-01	0.9
	1.3	2004-01-01	1.2	2004-01-01	1.2
	2	2005-01-01	1.8	2005-01-01	1.4
	1.2	2006-01-01	1.2	2006-01-01	1.1
	0.9	2007-01-01	0.9	2007-01-01	0.7
	1	2008-01-01	0.9	2008-01-01	0.6

hourly	high		2nd high		3rd high	
	2.6	1980-01-01	2.5	1980-01-01	2.4	1980-01-01
	1.9	1981-01-01	1.6	1981-01-01	1.3	1981-01-01
	1.2	1982-01-01	1.1	1982-01-01	1	1982-01-01
	1.4	1983-01-01	1.1	1983-01-01	1	1983-01-01
	2.4	1984-01-01	2.1	1984-01-01	1.6	1984-01-01
	1.8	1985-01-01	1.5	1985-01-01	1.1	1985-01-01
	1.8	1986-01-01	1.8	1986-01-01	1.6	1986-01-01
	1.2	1987-01-01	1.1	1987-01-01	1	1987-01-01
	1.8	1988-01-01	1.7	1988-01-01	1.4	1988-01-01
	1.7	1989-01-01	0.9	1989-01-01	0.8	1989-01-01
	1.2	1990-01-01	1.1	1990-01-01	1.1	1990-01-01
	1.7	1991-01-01	1.5	1991-01-01	1.5	1991-01-01
	2.1	1992-01-01	2.1	1992-01-01	1.6	1992-01-01
	2	1993-01-01	1.1	1993-01-01	1	1993-01-01
	1.8	1994-01-01	1.5	1994-01-01	1.2	1994-01-01
	2.4	1995-01-01	2.2	1995-01-01	2	1995-01-01
	2.4	1996-01-01	1.7	1996-01-01	1.2	1996-01-01
	3.5	1997-01-01	3	1997-01-01	2.1	1997-01-01
	1.3	1998-01-01	1.1	1998-01-01	0.9	1998-01-01
	1.5	1999-01-01	1.3	1999-01-01	1.1	1999-01-01
	1.3	2000-01-01	1.2	2000-01-01	1.2	2000-01-01
	2.3	2001-01-01	1.2	2001-01-01	1.2	2001-01-01
	1.3	2002-01-01	1.1	2002-01-01	1.1	2002-01-01
	1.4	2003-01-01	0.9	2003-01-01	0.9	2003-01-01
	1.7	2004-01-01	1.7	2004-01-01	1.5	2004-01-01
	1.9	2005-01-01	1.3	2005-01-01	1.1	2005-01-01
	1.3	2006-01-01	1.3	2006-01-01	1.3	2006-01-01
	0.9	2007-01-01	0.6	2007-01-01	0.3	2007-01-01
	1.1	2008-01-01	0.7	2008-01-01	0.7	2008-01-01


Fena- 15 mins PDS
Log-Pearson type 3 (Method of moments (BOB), base = 10)
Observations
Model
Conf. Int. 95%
rainfall Depth (Inches)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.0001
0.0050
0.0500
0.2000
0.5000
0.8000
0.9500
0.9950
0.9999
Non-exceedance probability (Normal paper / Cunnane)
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Fena- 15 mins PDS

Results of the fitting

Log-Pearson type 3 (Method of moments (BOB), base = 10)

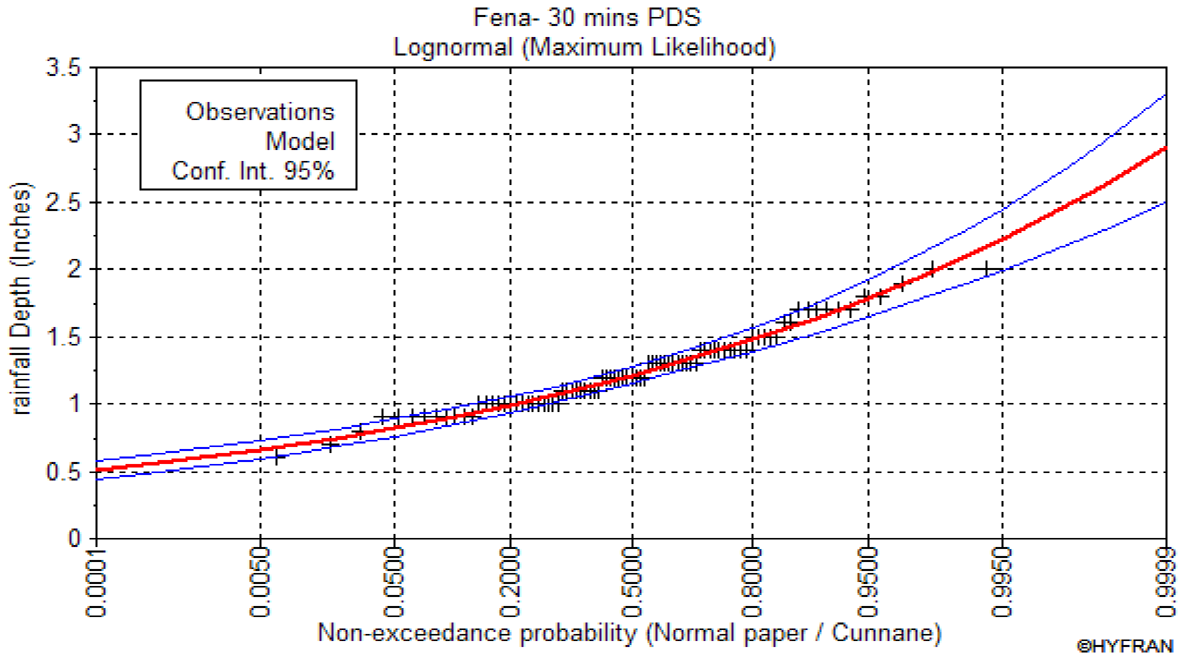
Number of observations 87

Parameters

alpha	3/29/1900
lambda	4/3/1900
m	###########

Quantiles
q = F(X) : non-exceedance probability
T = 1/(1-
q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	1/0/1900	2.21	0.57	N/D	N/D
2000	1/0/1900	1.94	0.38	1.47	2.73
1000	1/0/1900	1.82	0.31	1.40	2.37
200	1/0/1900	1.56	0.18	1.36	2.21
100	1/0/1900	1.45	0.14	1.26	1.85
50	1/0/1900	1.34	0.10	1.21	1.69
25	1/0/1900	1.23	0.07	1.16	1.54
20	1/0/1900	1.19	0.06	1.08	1.33
10	1/0/1900	1.08	0.04	1.00	1.18
5	1/0/1900	0.96	0.03	0.89	1.03
3	1/0/1900	0.86	0.03	0.80	0.919
2	1/0/1900	0.77	0.02	0.71	0.818
1.4286	1/0/1900	0.68	0.02	0.63	0.713
1.25	1/0/1900	0.63	0.02	0.59	0.658
1.1111	1/0/1900	0.57	0.02	0.53	0.607
1.0526	1/0/1900	0.52	0.03	0.47	0.589
1.0204	1/0/1900	0.48	0.04	0.41	0.585
1.0101	1/0/1900	0.45	0.05	N/D	N/D
1.005	1/0/1900	0.43	0.06	N/D	N/D
1.001	1/0/1900	0.38	0.07	N/D	N/D
1.0005	1/0/1900	0.37	0.08	N/D	N/D
1.0001	1/0/1900	0.34	0.09	N/D	N/D


Fena- 30 mins PDS
Lognormal (Maximum Likelihood)
Observations
Model
Conf. Int. 95%
rainfall Depth (Inches)
3.5
3
2.5
2
1.5
1
0.5
0
0.0001
0.0050
0.0500
0.2000
0.5000
0.8000
0.9500
0.9950
0.9999
Non-exceedance probability (Normal paper / Cunnane)
©HYFRAN

Fena- 30 mins PDS

Results of the fitting

Lognormal (Maximum Likelihood)

Number of observations 87

Parameters

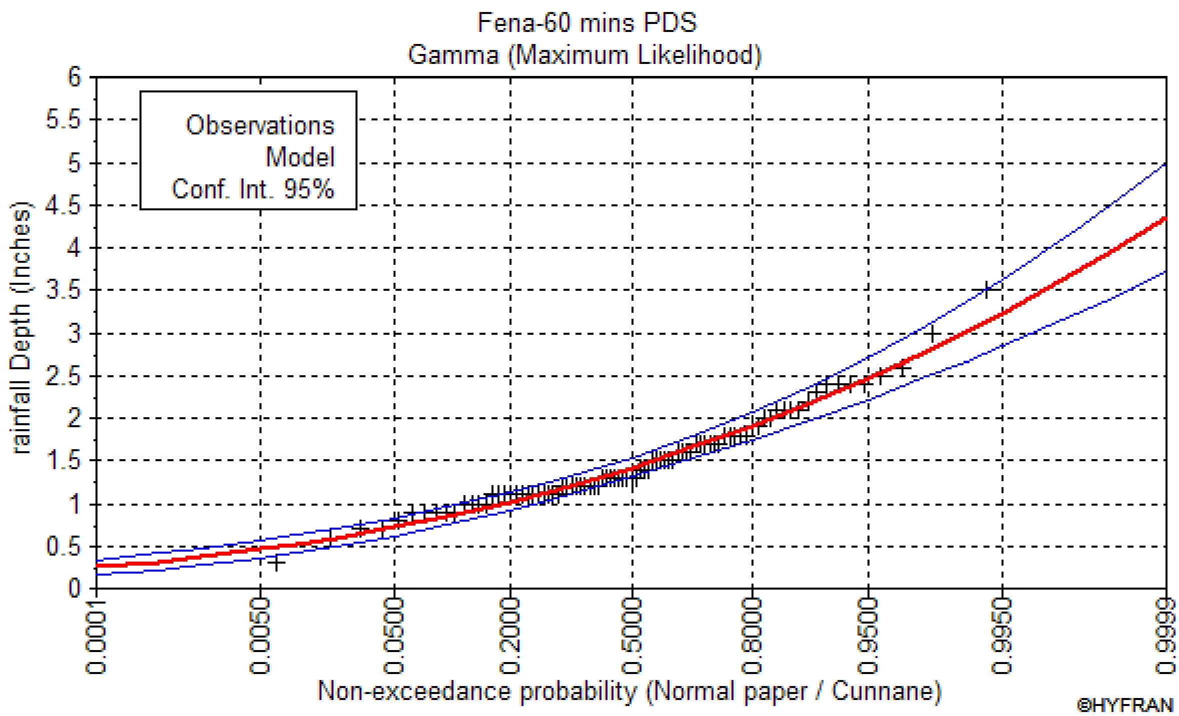
mu	0.19187
sigma	0.23521

Quantiles

q = F(X) : non-exceedance probability

T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	0.9999	2.91	0.207	2.5	3.31
2000	0.9995	2.63	0.169	2.3	2.96
1000	0.999	2.51	0.153	2.21	2.81
200	0.995	2.22	0.117	1.99	2.45
100	0.99	2.09	0.102	1.89	2.29
50	0.98	1.96	0.0877	1.79	2.14
25	0.96	1.83	0.0737	1.68	1.97
20	0.95	1.78	0.0692	1.65	1.92
10	0.9	1.64	0.0559	1.53	1.75
5	0.8	1.48	0.0434	1.39	1.56
3	0.6667	1.34	0.0354	1.27	1.41
2	0.5	1.21	0.0306	1.15	1.27
1.4286	0.3	1.07	0.0288	1.01	1.13
1.25	0.2	0.994	0.0292	0.937	1.05
1.1111	0.1	0.896	0.0306	0.836	0.956
1.0526	0.05	0.823	0.0319	0.76	0.885
1.0204	0.02	0.747	0.0334	0.682	0.813
1.0101	0.01	0.701	0.0342	0.634	0.768
1.005	0.005	0.661	0.0348	0.593	0.729
1.001	0.001	0.586	0.0357	0.516	0.656
1.0005	0.0005	0.559	0.0359	0.488	0.629
1.0001	0.0001	0.505	0.036	0.435	0.576


Fena-60 mins PDS
Gamma (Maximum Likelihood)
Observations
Model
Conf. Int. 95%
rainfall Depth (Inches)
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.0001
0.0050
0.0500
0.2000
0.5000
0.8000
0.9500
0.9950
0.9999
Non-exceedance probability (Normal paper / Cunnane)
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Fena-60 mins PDS

Results of the fitting

Gamma (Maximum Likelihood)

Number of observations 87

Parameters

alpha 5.125316

lambda 7.605498

Quantiles

q = F(X) : non-exceedance probability

T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	0.9999	4.35	0.326	N/D	N/D
2000	0.9995	3.91	0.275	N/D	N/D
1000	0.999	3.71	0.252	N/D	N/D
200	0.995	3.23	0.2	N/D	N/D
100	0.99	3.01	0.177	N/D	N/D
50	0.98	2.79	0.154	2.14	3.57
25	0.96	2.55	0.131	2.13	3.24
20	0.95	2.47	0.124	2.06	2.78
10	0.9	2.2	0.101	1.96	2.43
5	0.8	1.91	0.0795	1.77	2.07
3	0.6667	1.66	0.0653	1.55	1.8
2	0.5	1.42	0.056	1.31	1.56
1.4286	0.3	1.16	0.0523	1.05	1.29
1.25	0.2	1.02	0.0523	0.908	1.14
1.1111	0.1	0.849	0.0533	0.73	0.95
1.0526	0.05	0.722	0.0541	0.598	0.814
1.0204	0.02	0.597	0.0542	0.464	0.682

1.0101	0.01	0.523	0.0538	0.383	0.606
1.005	0.005	0.462	0.0531	0.317	0.544
1.001	0.001	0.354	0.0507	0.202	0.434
1.0005	0.0005	0.317	0.0494	0.165	0.397
1.0001	0.0001	0.249	0.0463	0.1	0.326

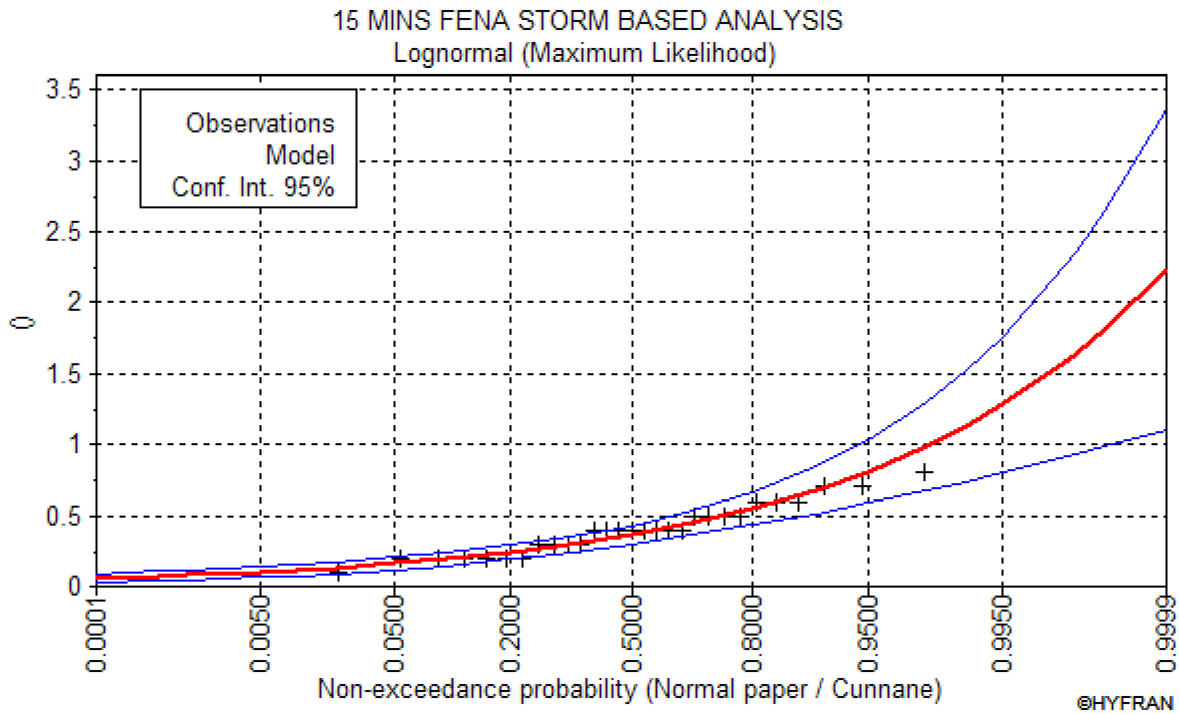
ATTACHMENT 3

ACTUAL 1-HOUR STORM SERIES

SAMPLE DATA SET

15 MINS		30 MINS		45 MINS		60 MINS	
0.4	1980-06-01	1.3	1980-06-01	2.1	1980-06-01	2.2	1980-06-01
0.4	1981-07-20	0.9	1981-07-20	1.3	1981-07-20	1.4	1981-07-20
0.2	1982-05-23	0.8	1982-05-23	0.9	1982-05-23	1.1	1982-05-23
0.2	1983-09-08	0.6	1983-09-08	0.7	1983-09-08	0.8	1983-09-08
0.4	1984-12-04	0.5	1984-12-04	0.6	1984-12-04	1.2	1984-12-04
0.4	1985-07-31	0.6	1985-07-31	0.7	1985-07-31	0.8	1985-07-31
0.6	1986-02-27	0.7	1986-02-27	0.8	1986-02-27	1.2	1986-02-27
0.4	1987-11-22	0.8	1987-11-22	1	1987-11-22	1.1	1987-11-22
0.5	1988-06-03	1	1988-06-03	1.6	1988-06-03	1.8	1988-06-03
0.2	1989-04-20	0.5	1989-04-20	0.6	1989-04-20	0.8	1989-04-20
0.4	1990-05-27	1	1990-05-27	1.1	1990-05-27	1.4	1990-05-27
0.4	1991-05-31	1.3	1991-05-31	1.7	1991-05-31	2	1991-05-31
0.3	1992-08-27	0.5	1992-08-27	0.8	1992-08-27	0.9	1992-08-27
0.3	1993-09-25	0.4	1993-09-25	0.9	1993-09-25	1.1	1993-09-25
0.3	1994-09-08	0.5	1994-09-08	0.8	1994-09-08	1.5	1994-09-08
0.5	1995-08-20	1.2	1995-08-20	1.9	1995-08-20	2	1995-08-20
0.8	1996-04-04	1.7	1996-04-04	2.2	1996-04-04	2.4	1996-04-04
0.6	1997-08-01	1	1997-08-01	1.4	1997-08-01	1.9	1997-08-01
0.2	1998-09-22	0.5	1998-09-22	0.7	1998-09-22	1	1998-09-22
0.5	1999-02-15	0.8	1999-02-15	1	1999-02-15	1.1	1999-02-15
0.5	2000-09-07	0.8	2000-09-07	1.1	2000-09-07	1.2	2000-09-07
0.6	2001-07-13	1.2	2001-07-13	1.9	2001-07-13	2	2001-07-13
0.7	2002-09-26	1.3	2002-09-26	1.7	2002-09-26	1.8	2002-09-26
0.3	2003-07-16	0.6	2003-07-16	0.9	2003-07-16	1	2003-07-16
0.4	2004-10-13	0.5	2004-10-13	0.8	2004-10-13	1.1	2004-10-13
0.2	2005-08-26	0.6	2005-08-26	1	2005-08-26	1.1	2005-08-26
0.7	2006-10-08	1.1	2006-10-08	1.3	2006-10-08	1.4	2006-10-08
0.1	2007-05-09	0.3	2007-05-09	0.4	2007-05-09	0.5	2007-05-09
0.2	2008-01-10	0.6	2008-01-10	1.2	2008-01-10	1.5	2008-01-10

Hyfran Results



15 MINS FENA STORM BASED ANALYSIS

Results of the fitting

Lognormal (Maximum Likelihood)

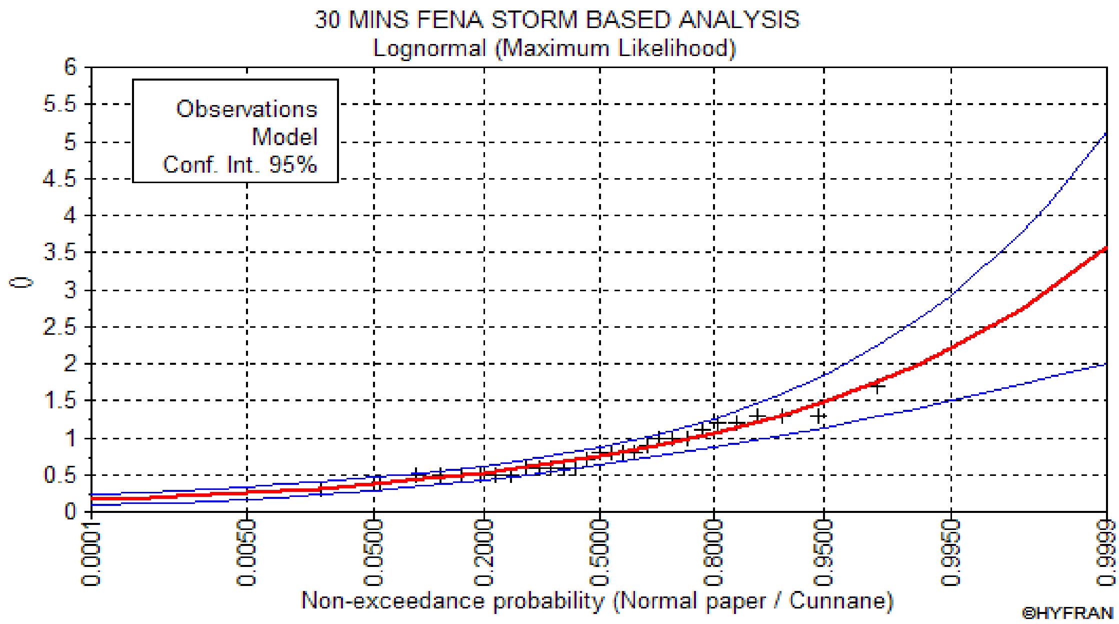
Number of observations 29

Parameters

mu	-1.01197
sigma	0.488046

Quantiles
q = F(X) : non-exceedance probability
T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	0.9999	2.23	0.578	1.1	3.37
2000	0.9995	1.81	0.422	0.984	2.64
1000	0.999	1.64	0.363	0.931	2.35
200	0.995	1.28	0.244	0.8	1.76
100	0.99	1.13	0.2	0.739	1.52
50	0.98	0.991	0.16	0.677	1.3
25	0.96	0.854	0.125	0.61	1.1
20	0.95	0.811	0.114	0.588	1.03
10	0.9	0.679	0.0838	0.515	0.844
5	0.8	0.548	0.0581	0.434	0.662
3	0.6667	0.448	0.0425	0.365	0.532
2	0.5	0.364	0.0329	0.299	0.428
1.4286	0.3	0.281	0.0273	0.228	0.335
1.25	0.2	0.241	0.0255	0.191	0.291
1.1111	0.1	0.194	0.024	0.147	0.241
1.0526	0.05	0.163	0.0229	0.118	0.208
1.0204	0.02	0.133	0.0216	0.0911	0.176
1.0101	0.01	0.117	0.0206	0.0763	0.157
1.005	0.005	0.103	0.0197	0.0647	0.142
1.001	0.001	0.0804	0.0178	0.0456	0.115
1.0005	0.0005	0.0729	0.017	0.0396	0.106
1.0001	0.0001	0.0592	0.0153	0.0291	0.0892


30 MINS FENA STORM BASED ANALYSIS
Lognormal (Maximum Likelihood)
Observations
Model
Conf. Int. 95%
Q
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
0.0001
0.0050
0.0500
0.2000
0.5000
0.8000
0.9500
0.9950
0.9999
Non-exceedance probability (Normal paper / Cunnane)
©HYFRAN

30 MINS FENA STORM BASED ANALYSIS

Results of the fitting

Lognormal (Maximum Likelihood)

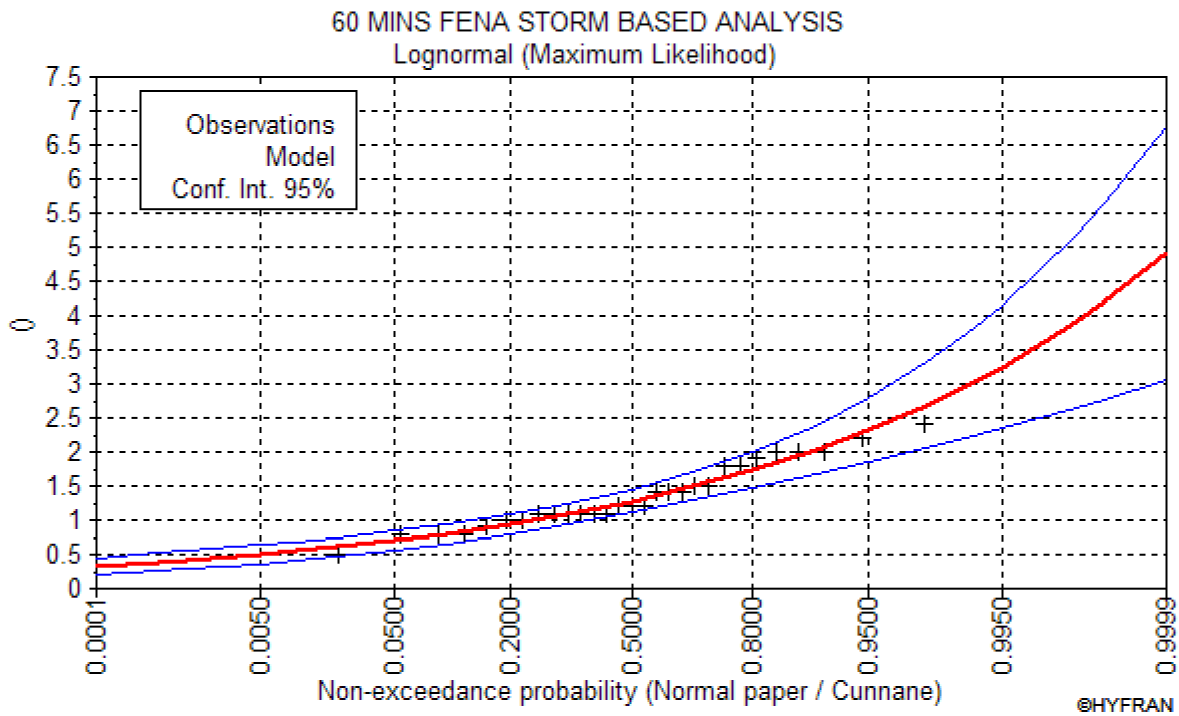
Number of observations 29

Parameters

mu	-0.290007
sigma	0.419978

Quantiles
q = F(X) : non-exceedance probability
T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	0.9999	3.57	0.795	2.01	5.13
2000	0.9995	2.98	0.597	1.81	4.15
1000	0.999	2.74	0.521	1.72	3.76
200	0.995	2.21	0.363	1.5	2.92
100	0.99	1.99	0.302	1.4	2.58
50	0.98	1.77	0.247	1.29	2.26
25	0.96	1.56	0.196	1.18	1.95
20	0.95	1.49	0.18	1.14	1.85
10	0.9	1.28	0.136	1.02	1.55
5	0.8	1.07	0.0971	0.875	1.26
3	0.6667	0.896	0.0732	0.753	1.04
2	0.5	0.748	0.0584	0.634	0.863
1.4286	0.3	0.6	0.05	0.502	0.699
1.25	0.2	0.526	0.0479	0.432	0.619
1.1111	0.1	0.437	0.0463	0.346	0.528
1.0526	0.05	0.375	0.0453	0.286	0.464
1.0204	0.02	0.316	0.044	0.23	0.402
1.0101	0.01	0.282	0.0428	0.198	0.366
1.005	0.005	0.254	0.0417	0.172	0.335
1.001	0.001	0.204	0.0389	0.128	0.281
1.0005	0.0005	0.188	0.0377	0.114	0.262
1.0001	0.0001	0.157	0.035	0.0884	0.225


60 MINS FENA STORM BASED ANALYSIS
Lognormal (Maximum Likelihood)
Observations
Model
Conf. Int. 95%
Q
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.0001
0.0050
0.0500
0.2000
0.5000
0.8000
0.9500
0.9950
0.9999
Non-exceedance probability (Normal paper / Cunnane)
©HYFRAN

60 MINS FENA STORM BASED ANALYSIS

Results of the fitting

Lognormal (Maximum Likelihood)

Number of observations 29

Parameters

mu	0.257495
sigma	0.365753

Quantiles
q = F(X) : non-exceedance probability
T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	0.9999	5.04	0.978	3.12	6.96
2000	0.9995	4.31	0.753	2.84	5.79
1000	0.999	4.01	0.664	2.71	5.31
200	0.995	3.32	0.475	2.39	4.25
100	0.99	3.03	0.401	2.24	3.82
50	0.98	2.74	0.332	2.09	3.39
25	0.96	2.45	0.268	1.93	2.98
20	0.95	2.36	0.249	1.87	2.85
10	0.9	2.07	0.191	1.69	2.44
5	0.8	1.76	0.14	1.49	2.03
3	0.6667	1.51	0.108	1.3	1.73
2	0.5	1.29	0.0879	1.12	1.47
1.4286	0.3	1.07	0.0775	0.916	1.22
1.25	0.2	0.951	0.0755	0.803	1.1
1.1111	0.1	0.81	0.0748	0.663	0.956
1.0526	0.05	0.709	0.0746	0.563	0.855
1.0204	0.02	0.61	0.074	0.465	0.755
1.0101	0.01	0.552	0.0732	0.409	0.696
1.005	0.005	0.504	0.0721	0.363	0.646
1.001	0.001	0.418	0.0692	0.282	0.553
1.0005	0.0005	0.388	0.0678	0.255	0.521
1.0001	0.0001	0.332	0.0644	0.206	0.458