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STORMWATER MANAGEMENT & WATER QUALITY MANUAL

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STATE OF MISSOURI
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CITY OF COLUMBIA, MISSOURI

STORMWATER MANAGEMENT
&
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CHAPTER 1 DESIGN MANUAL OVERVIEW

1.1 INTRODUCTION

This manual sets forth stormwater management criteria and design methodology to be used by developers and their engineers and planners to control the peaks, volumes and quality of stormwater discharges from their developments. The manual provides developers, engineers and planners flexible tools to control the peaks, volumes and quality of stormwater discharges, all-important for maintaining stream stability and water quality. Use of this manual can lead developers to a unified up-to-date strategy for managing stormwater quantity and quality. This stormwater management can protect life, property, and the environment, and subsequently improve quality of life for the citizens of Columbia.

This manual is Columbia's initial attempt to prescribe state-of-the-art water quality and quantity protection practices for the Columbia area, based on current knowledge. The manual is intended to be a "living document" to be updated periodically as advances in water quality and quantity protection practices evolve. Future versions hopefully will reflect lessons learned from implementing the methods and practices currently recommended in this manual, particularly those involving water quality monitoring data, performance assessments and stream stability analysis.

1.2 MISSION STATEMENT

The mission of the City of Columbia Stormwater Management Ordinance and the Stormwater Management and Water Quality Manual is to protect the quality of life by limiting the amount of stormwater runoff as much as possible and by protecting those natural resources necessary for watershed health and integrity. This is primarily accomplished by mimicking natural hydraulics, hydrology and rainwater treatment. This mission statement is best accomplished by considering the following:

- Natural Streams are an asset to the community and should be regarded as such.
- The presence and protection of natural resources is fundamental to the quality of life of the citizens of Columbia and every facet of the stormwater system must recognize this.
- The best method of management is to preserve, restore and mimic natural processes.
- One of the best ways to manage stormwater runoff is to generate as little as possible and treat stormwater as near the source as possible.

1.3 BACKGROUND

Columbia has developed this manual based on the Mid-America Regional Council and the Kansas City Chapter of the American Public Works Association's 5600 Manual and Best Management Practices for Water Quality Manual as a proactive, integrated, watershed-based approach to stormwater management to (1) balance future development with environmental health and quality of life, and (2) comply with new water quality regulations such as the National Pollution Discharge Elimination System (NPDES) Phase II requirements. By implementing new policies and practices, Columbia seeks to reduce flooding, conserve water, improve water quality, protect wildlife habitat, and create community amenities. To that end, Columbia provides this document to assist developers, engineers and planners to create more environmentally sensitive site designs. Use of stormwater BMPs and practices outlined in this manual is one way Columbia hopes to achieve the goals of environmentally sound development and resource conservation.

The term "BMP" originated in the agriculture industry as a reference to practices, which reduce farmland erosion and improve crop yield. In the broadest sense, a stormwater BMP is any action or practice aimed at reducing flow rates and pollution concentrations in urban runoff; examples include site planning practices, public education efforts, open space preservation, pollution prevention practices, and engineered natural treatment systems. This manual describes two classes of BMPs: non-structural and structural. Non-structural controls minimize contact of pollutants with rainfall and runoff. Structural controls are facilities constructed for treating and controlling stormwater runoff.

This manual furnishes clear, understandable guidance for planning, designing and implementing the stormwater management facilities and best management practices. The manual provides design guidance with respect to controlling stormwater peaks, volumes and water quality, and provides effective methods by which these parameters can be addressed with a unified approach. Much of the foundation of the manual is based on established criteria such as Natural Conservation Service (NRCS) soil curve numbers and their hydrologic models. As previously mentioned, it is anticipated this manual will be a living document with beneficial amendments made as more information is available as to efficiency ratings of certain best management practices and other information becomes part of the mainstream stormwater management database of knowledge.

1.4 APPLICABILITY

For applicability requirements for use of this manual refer to Chapter 12A-87 of the City Code of Ordinances.

1.5 VARIANCES

The variance procedure is set out in the stormwater management ordinance in Chapter 12A-110 of the City Code of Ordinances.

1.6 DEFINITIONS

Best Management Practices (BMP): Activities, practices and procedures which control soil loss and reduce or prevent water quality degradation caused by nutrients, animal wastes, toxins, organics and sediment in the runoff. BMPs may either be structural (grass swales, terraces, retention and detention ponds, and others); or non-structural (disconnection of impervious surfaces, directing downspouts onto grass surfaces and educational activities).

Bioengineered Channel: A channel, which embodies biological, ecological, and engineering concepts to convey stormwater runoff, prevent soil erosion, control sedimentation, and provide wildlife habitat. The channel may be stabilized entirely with native materials or may selectively incorporate man-made structural materials.

Bioretention: Soil and plant-based stormwater management practices designed to filter runoff from developed communities by mimicking vegetated systems that naturally control hydrology through detention, filtration, infiltration, and evapotranspiration.

Bottomlands: Low-lying lands along a watercourse subject to frequent flooding.

Channel Lining: Includes any type of material used to stabilize the banks or bed of an engineered channel including, but not limited to, vegetation.

Channel Protection Detention: Detention designed to detain runoff in a way to prevent erosion of downstream channels.

City: City of Columbia

Contractor: The individual, firm, partnership, joint venture, or corporation contracting with the Owner for performance of the work described in these specifications and plans.

Controlled Area: That part of the surface area where peak discharges are controlled by a detention facility.

Curve Number (CN): A runoff coefficient developed in the U.S. Natural Resource Conservation Service (NRCS) family of hydrologic models by combining land use and one of four hydrologic soil types on a parcel of land.

Design Storm: The combination of rainfall depth, duration, and distribution of a hypothetical rainfall event with a given likelihood of occurring in any year.

Detention Facility: A storm water management facility controlling storm water runoff from a site or watershed. The allowable runoff specified for detention facilities in Chapter 6 is intended to manage maximum storm water release rates to minimize flooding and does not address impacts on downstream erosion, water quality or the environment.

Detention Storage: The volume occupied by water above the level of the principal spillway crest during operation of a stormwater detention facility.

Developer: Any person, partnership, association, corporation, public agency, or governmental unit proposing to or engaged in "development".

Development: 1) The improvement of property for any purpose involving building or construction; 2) Subdivision, or the division of a tract or parcel of land into two (2) or more parcels; 3) the combination of any two (2) or more lots, tracts, or parcels of property for any purpose; 4) the preparation of land for any of the above purposes; or, 5) land disturbance that requires the issuance of a *Land Disturbance Permit* in accordance with the provisions of Chapter 12A.

Director: The Director of Public Works

Dry Detention Facility: Any detention facility designed to permit no permanent impoundment of water.

Dry Swale: An open, vegetated, drainage channel or depression with an engineered soil matrix and underdrains designed to filter stormwater runoff.

Easement: Authorization by a property owner for the use by another for a specified purpose, of any designated part of the property.

Emergency Spillway: A device or devices used to discharge water under conditions of inflow that exceed the design outflow from the primary spillway detention facility. The emergency spillway functions primarily to prevent damage to the detention facility that would permit the sudden release of impounded water.

Engineer: See 'Registered Professional Engineer.'

Engineered Channel: An open drainage channel, which has been explicitly designed to convey stormwater runoff in accordance with this manual and as approved by the Director.

Engineered Swale: An open drainage channel designed to convey and infiltrate the entire runoff volume from a Water Quality Storm.

Extended Detention Wetland: A land area that is permanently wet or periodically flooded by surface or groundwater, and has developed hydric soil properties that support vegetation growth under saturated soil conditions. It may have been engineered with adequate capacity to detain large storm flows.

FHWA: Federal Highway Administration.

Floodplain: A relatively level surface of stratified alluvial soils on either side of a watercourse, which is inundated during flood events.

Filter Strip: A grassed area that accepts sheet flow runoff from adjacent surfaces. It slows runoff velocities and filters out sediment and other pollutants. Filter strips may be used to treat shallow, concentrated, and evenly distributed storm flows.

First Flush: The quantity of initial runoff from a storm or snowmelt event that commonly contains elevated pollutant concentrations. Often the first flush contains most of the pollutants in drainage waters produced by the event.

Freeboard: The difference in elevation between the top of a structure such as a dam or open channel and the maximum design water surface elevation or high water mark. It is an allowance against overtopping by waves or other transient disturbances.

Grassed Channel: A broad, mildly sloped, open channel designed to convey stormwater runoff to a downstream point and to filter pollutants while doing so.

Hydrologic Soil Group (HSG): NRCS soil grouping according to runoff producing characteristics. The chief criterion is capacity of soil (absent vegetation) to permit infiltration. Soils are grouped from HSG A (greatest infiltration and least runoff) to D (least infiltration and greatest runoff).

Impact Stilling Basin: A pool placed below an outlet spillway and designed for reducing discharge energies in order to minimize downstream erosive effects.

Impervious Surface: A surface that prevents the infiltration of stormwater.

Improved Channel: Any channel changed by grading or the construction of lining materials as approved by the Director.

Incision: Adjustment of the channel bed elevation downwards, typically in response to some type of disturbance.

Increased Runoff: Increase in volume or peak flow of stormwater runoff.

Indigenous Plant: A plant native to this area prior to European settlement.

Infiltration: Percolation of water into the ground.

Infiltration System: A system allowing percolation of water into the subsurface of the soil. This may recharge shallow or deep groundwater.

Level of Service (LS): The level of water quality protection recommended for a development or provided by a postdevelopment stormwater management system. The LS requirement for the development is determined by the change in runoff from the predevelopment condition. The LS provided by the stormwater management system is determined by a combination of detention and water quality treatment.

Low-drop Structures: A step pool energy dissipation structure typically constructed out of rock or concrete with a design vertical drop of 2 feet or less per step.

Meander Amplitude: The linear distance between the apex of one meander and the apex of the next meander in a naturally curving stream.

Meander Length: The length measured along the thalweg of one complete waveform.

Meander Wavelength: The length of one complete waveform, measured as the straight-line linear distance along the valley between two analogous points on a waveform.

National Pollutant Discharge Elimination System (NPDES): Defined in Section 402 of the Clean Water Act, this provides for the permit system that is key for enforcing the effluent limitations and water quality standards of the Act. The Phase II Final Rule—published in the Federal Register on December 8, 1999—requires NPDES permit coverage for stormwater discharges from certain regulated, small, municipal, separate storm sewer systems (MS4s) and from land areas between 1 and 5 acres disturbed by construction.

Native Species: Plant and animal species that exist in the region where they have evolved.

Natural Stream: Any river, creek, channel, or drainageway that has an alignment, bed and bank materials, profile, bed configuration, and channel shape predominately formed by the action of moving water, sediment migration, and biological activity. The natural channel's form results from regional geology, geography, ecology, and climate.

Open Channel: A maintained earthen or lined waterway with an open water surface as approved by the Director.

Ordinary High Water Mark: A line on the bank established by the fluctuations of water and indicated by physical characteristics such as clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas.

Owner: The owner of record of real property.

Pervious Pavement: A special type of pavement that allows water to infiltrate the surface layer and enter into a high-void, aggregate, sub-base layer. The captured water is stored in the reservoir layer until it either infiltrates the underlying soil strata or is routed through an underdrain system to a conventional stormwater conveyance system.

Plans: The approved plan drawings, profiles, typical cross-sections, working drawings, etc., and exact reproductions thereof, which show the location, character, dimensions, and details of the work to be done.

Point bars: Depositional features generally occurring on the inside of stream bends and opposite cut banks.

Pollutant: Anything, which causes or contributes to pollution. Pollutants may include, but are not limited to: paints, varnishes, and solvents; oil and other automotive fluids; non-hazardous liquid and solid wastes, yard wastes; refuse, rubbish, garbage, litter, or other discarded or abandoned objects, articles, and accumulations, which may cause or contribute to pollution; floatables; pesticides, herbicides, and fertilizers; hazardous substances and wastes; sewage, fecal coliform and pathogens; dissolved and particulate metals; animal wastes; wastes and residues that result from constructing a building or structure; including but not limited to sediments, slurries and concrete rinsate and noxious or offensive matter of any kind.

Pools: A deep reach of a stream. Often the reach of a stream between two riffles; a small and relatively deep body of quiet water in a stream or river.

Predevelopment: The time period prior to a proposed or actual development activity at a site. Predevelopment may refer an undeveloped site or a developed site that will be redeveloped or expanded.

Primary Outlet Works: A device such as an inlet, pipe, weir, etc., used to discharge water during operation of a storage facility under the conditions of the 1% storm or more frequent event.

Principal Spillway: A device such as an inlet, pipe, or weir used to discharge water during operation of the facility under conditions of the design storm.

Principal Stream: Stream Segments included in FEMA Flood Insurance Studies where the limits of the 1% floodplain and 1% base flood elevations have been determined.

Rain Garden: A small depression planted with native wetland and prairie vegetation, rather than a turfgrass lawn, where runoff collects and infiltrates. Rain gardens are most often used in residential areas.

Registered Professional Engineer: A licensed engineer who is registered with and authorized to practice engineering within Missouri.

Riffles: Shallow rapids in an open stream, where the water surface is broken into waves by obstructions such as natural channel armoring or bedrock outcrop wholly or partly submerged beneath the water surface.

Riparian Buffers: Bands of native herbaceous and woody vegetation along ephemeral, perennial and intermittent streams and open bodies of water. Buffers have three primary benefits. Riparian Buffers improve stream stability through mechanical and hydrological (via evapotranspiration) reinforcement of the streambanks. In addition to providing physical stability, the soils, plants and microorganisms capture and treat sediment and other pollutants in surface runoff water before these enter the adjoining surface waterbody. Buffers improve water quality and habitat by shading the stream and providing the leaf detritus necessary for beneficial aquatic life.

Riparian Zone: The vegetated band along the fringe of a stream or other water body.

Sand Filter: A self-contained bed of sand used to treat wastewater or diverted stormwater runoff; the water subsequently is collected in underground pipes for additional treatment or discharge.

Sediment Storage: The volume allocated to contain accumulated sediments within a detention facility.

Site: A tract or contiguous tracts of land owned and/or controlled by a developer or owner. Platted subdivisions, industrial and/or office commercial parks, and other planned unit developments shall be considered a single site. This shall include phased development where construction at a tract or contiguous tracts of land may occur in increments.

Storm: A rainfall event used for design, which is defined by the probability such an event, will be equaled or exceeded in any one year. When designing in accordance with these criteria, the storm event probabilities used are: 1%, 2%, 4%, 10%, 50% and 100%.

Storm Drainage System: All of the natural and man-made facilities and appurtenances such as ditches, natural channels, pipes, culverts, bridges, open improved channels, swales, street gutters, inlets, and detention facilities, which serve to convey surface drainage.

Stormwater Detention Facility: Any structure, device, or combination thereof with a controlled discharge rate less than its inflow rate.

Stormwater Management Facilities: May also be referred to as Structural Treatment Practices (STPs) and includes measures, primarily structural, which are determined to be the most effective, practical means of preventing or reducing point source or non-point source pollution inputs to stormwater runoff and subsequently into water bodies. These facilities are also used to control volume and peak rates of runoff from developing and redeveloping sites.

Streams: See "Natural Streams"

Swale: an engineered channel conveying stormwater from more than two lots; often the property owner maintains the swale but an easement is required when requested by the City.

Thalweg: The deepest part of a channel cross-section. The dominant thread of stream flow creates the thalweg.

Topsoil: Fertile, friable soil of uniform quality and consisting of the soil series A horizon, without a mixture of subsoil materials or soil series B horizon, and shall be reasonably free from materials such as hard clods, stiff clay, hardpan, partially disintegrated stone, large stone or any other impurities. Topsoil shall be reasonably free from grass, roots, or debris, which are considered to be harmful to plant establishment and growth.

Total Suspended Solids (TSS): Matter suspended in stormwater excluding litter, debris, and other gross solids exceeding 1 millimeter in diameter.

Tributary Area: All land draining to the point of consideration, regardless of ownership.

Treatment Rating (TR): A relative ranking of a BMP's stormwater treatment based on actual or assumed water quality benefits.

Treatment Train: The series of BMPs (or other treatments) used to achieve biological and physical treatment efficiencies necessary for removing pollutants from stormwater (or other wastewater flows).

Tree Preservation: Maintenance of existing trees and shrubs in a healthy and undamaged condition.

Uplands: Lands elevated above the floodplain that are seldom or never inundated.

Value Rating (VR): The assumed water quality improvement value of a cover type or BMP, based on its water quality treatment efficiency and ability to retain stormwater.

Water Quality: The chemical, physical, and biological characteristics of water. This term also can refer to regulatory concerns about water's suitability for swimming, fishing, drinking, agriculture, industrial activity, and healthy aquatic ecosystems.

Water Quality Storm: The storm event that produces less than or equal to 90 percent stormwater runoff volume of all 24-hour storms on an annual basis.

Water Quality Volume (WQv): The storage needed to capture and treat 90 percent of the average annual stormwater runoff volume. It is calculated by multiplying the Water Quality Storm times the volumetric runoff coefficient and site area.

Watershed: All the land area that drains to a given body of water (also described as a basin, catchment, and drainage area).

Waveform: A complete cycle of two channel bends in opposite directions.

Wet Detention Facility: A detention facility that is designed to include permanent storage of water in addition to the temporary storage used to control discharge rates from the facility.

Wet Pond: A constructed system with sufficient capacity to detain flood volumes and to store the WQv in a permanent pool.

Wetland Treatment System: A stormwater or wastewater treatment system consisting of shallow ponds and channels vegetated with aquatic or emergent plants. This system relies on natural microbial, biological, physical, and chemical processes to treat stormwater or wastewater.

Work: Work shall mean the furnishing of all labor, materials, equipment, and other incidentals necessary or convenient to the successful completion of the project.

1.7 GOALS AND OBJECTIVES

The overall goal of this manual and the Stormwater Management Ordinance is to mitigate and reduce the environmental impact of increased stormwater runoff due to development, to control large water quantities produced by developing watersheds and to minimize quality impairment of runoff from impacted areas. This goal is accomplished through this manual by combining water quantity and water quality management using much of the existing natural system to maintain current conditions and prevent further deterioration of streams in the watershed.

Peak flows and overall quantity of stormwater runoff can be maintained after development, possibly reduced where conditions allow. Stormwater management facilities can regulate peak flows and assist the BMPs in improving stormwater quality by mitigating extreme Ph values and assisting removal of sediment, petroleum-based materials, biochemical oxygen demand, metals, bacteria, nutrients, toxic organic compounds and other substances which may be present in harmful concentrations.

This manual sets out the basic goals for all developments to maintain pre-development peak flows, runoff volumes and water quality. In other words, developments should not increase the velocity or quantity of water or the amount of pollutants leaving the site, essentially mimicking pre-existing hydrology. In order to accomplish this, the four basic water resource protection goals need to be addressed on each development site. These four water resource protection goals are: flood control, channel protection (stability), groundwater recharge, and finally, pollutant removal.

1.8 PRINCIPALS OF STORMWATER QUANTITY

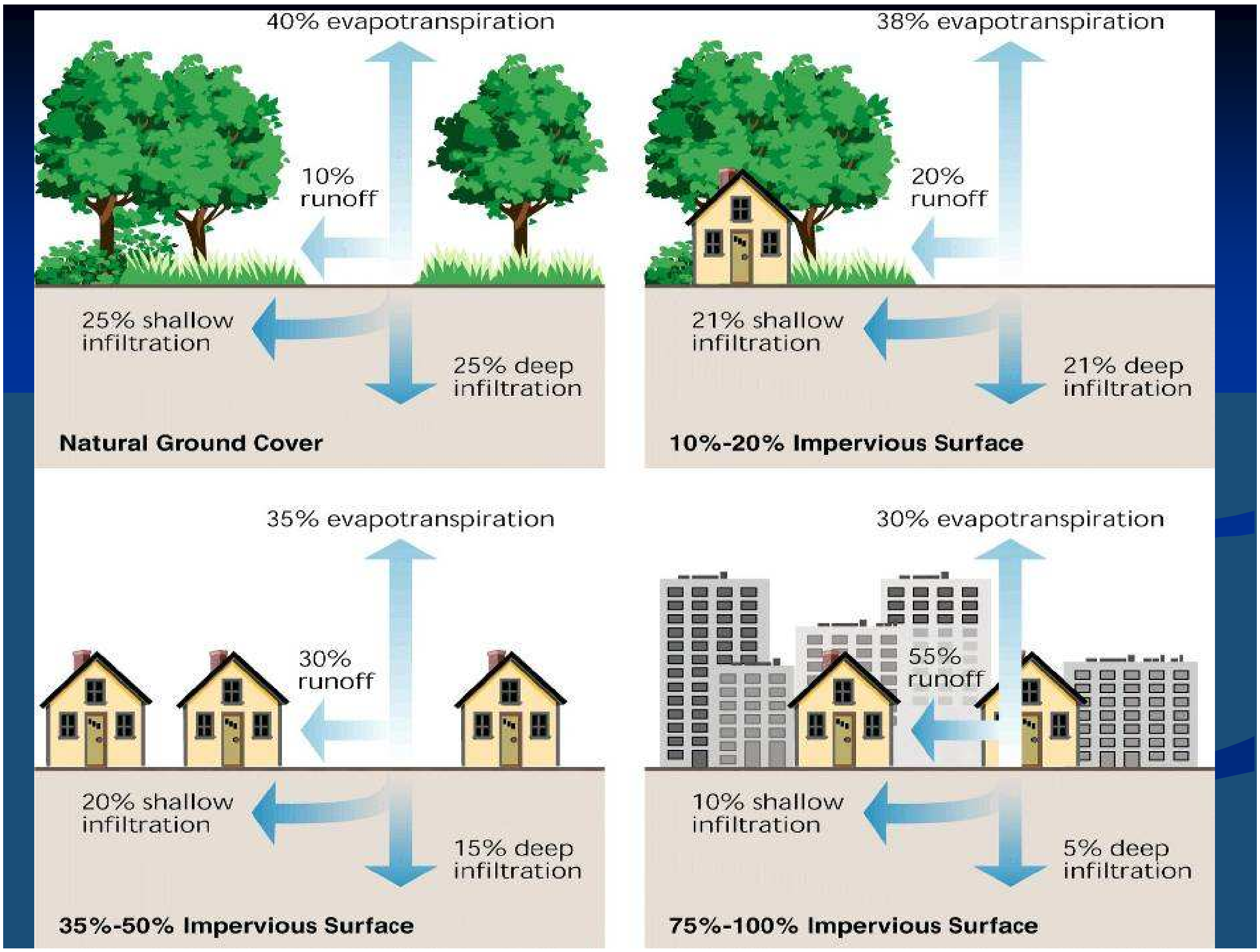
The hydrological effects of urbanization include a disruption of the natural water balance with increased flood peaks, increased stormwater runoff (volume), more frequent flooding, increased bankfull flows, and lower dry weather flows. This flow regime, often referred to as urban hydrology, is detrimental to the receiving streams in a developing watershed and commonly results in highly degraded channels with heavy sediment loads and reduced water quality. This manual provides guidance and direction through the use of stormwater management practices to control and minimize the impact of urbanization on the receiving streams.

Channels respond to increases in flow volumes and more frequent recurrence by altering width, depth, velocity, suspended load, meander radius, wavelengths and pool and riffle. Historically, detention and retention structures have been constructed to address these impacts (degradation) to streams. However, previous efforts have addressed larger storm events while allowing smaller events (less than the 50% storm event) to be handled on a pass-through basis. Experience has shown that even limiting the 50% storm event post-construction runoff to the 50% storm predevelopment runoff peak does not provide stream protection. Numerous studies have concluded the increased frequency and duration of these post-construction 50% storm events do significant damage to the receiving streams.

This manual addresses this issue by requiring the capture of the water quality volume storm for treatment, as well as requiring the 100% storm event pre- and post-development peak flows to be matched. Additionally, water quality BMPs such as bio-retention areas and dry cells serve to increase times of concentration for the post-development settings and provide some water quantity benefits in the post-development runoff hydrograph for calculation for overall detention requirements and watershed timing.

Stormwater volume control is more difficult to accomplish but practices such as infiltration (undisturbed areas with natural vegetation), evapotranspiration, short-term detention or retention, and establishment of artificial or induced baseflows are strategies which can be used successfully to reduce the impact of increased volume on the receiving streams. See Figure 1.8 below:

Figure 1.8



Source: EPA Fact Sheet. EPA 841-F-03-003

1.9 PRINCIPALS OF STORMWATER QUALITY

This manual requires certain water quality goals and provides tools for meeting these goals. The water quality goals and tools are based on several basic water quality concepts. Stormwater management proceeds from thorough site analysis to planning and to site design, and is unique for each site and development project. Proposed design in a stormwater management system is sensitive to site characteristics including slopes, soils and cover types, infiltration capacity, and detention. These characteristics can be preserved, restored and imitated through stormwater management techniques aimed at providing optimum site runoff water quality. Additional water quality BMPs may be applied for further reduction of pollutants in runoff where water quality goals cannot be achieved through site design alone.

Section 1.7 recommends stormwater management goals for Columbia. These goals are the basis for Columbia's stormwater management program. The goals cover both stormwater quantity and quality management, and provide options for various watershed conditions and levels of stringency. Section 1.10 discusses water quality concepts used to develop this manual and how they apply to water quality BMPs that are applied to meet water quality goals. This section is not comprehensive – more detailed water quality information may be obtained from the following resources:

- Chapter 1 of the *2000 Maryland Stormwater Design Manual, Volume I* from the Maryland Department of Environment includes a good discussion of basic stormwater management concepts.

- *The Stormwater Manager's Resource Center* (www.stormwatercenter.net) is directed to practitioners, local government officials, and others who need technical assistance on stormwater management issues.

Section 1.12 provides references and a brief description for several other BMP manuals.

1.10 WATER QUALITY CONCEPTS

Studies have shown that atmospheric deposition distributes most stormwater pollutants. A full range of pollutants is present in virtually all runoff—whether from yards, roads, or rooftops—because of this atmospheric redistribution. The pollutants are mobilized and impact surface water quality when rainfall produces runoff that carries the contaminants into surface waters. For this reason, impervious surfaces are the major source of stormwater pollutants in urban areas (Claytor and Schueler 1996). Runoff volumes and peak velocities are determined primarily by the site's cover type and soils, and other factors such as slope, distance, and existing drainage features (USDA 1986). Runoff quantity and water quality are linked, and this linkage forms the basis for this manual.

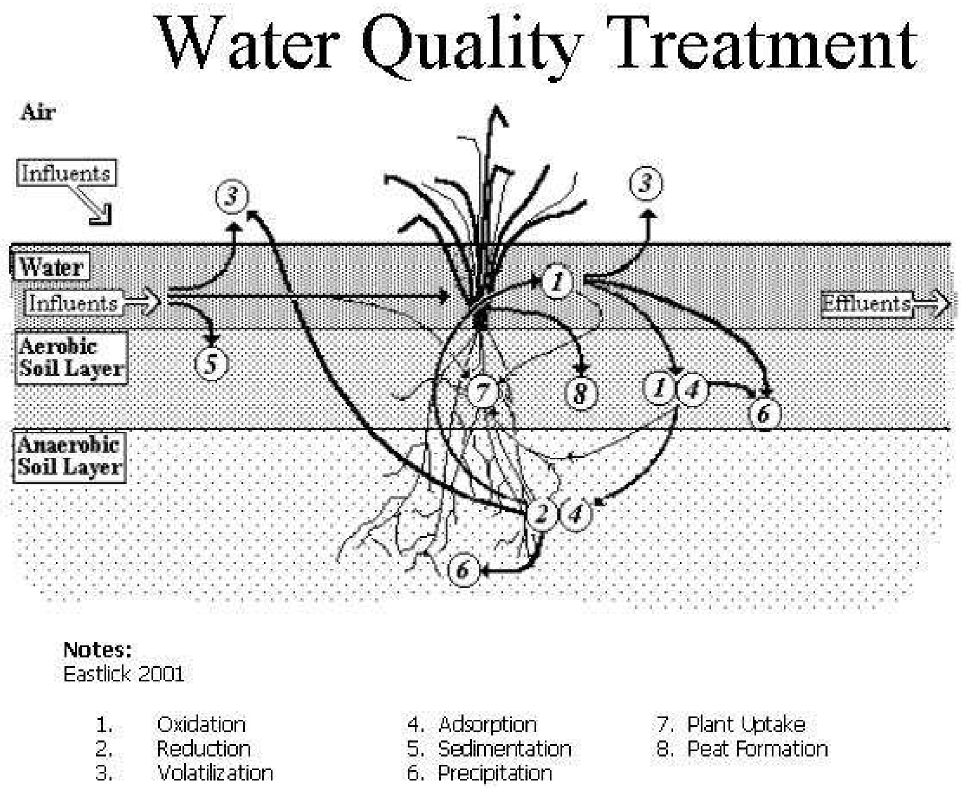
The first step in water quality management is to maintain or reduce the amount of runoff generated within a watershed. Treatment is then applied to the remaining runoff to remove some of the pollutant load. BMPs are the key to both approaches, described below.

Preserving a site's infiltration capacity is a relatively inexpensive non-structural measure to reduce runoff rates, volumes, and pollutant loads. Stormwater runoff rates and volumes and water quality are influenced heavily by infiltration capacity (USDA 1986; Claytor and Schueler 1996). Urbanization shortens a watershed's response to precipitation mainly by reducing infiltration and decreasing travel time. An impervious surface decreases travel time by preventing infiltration and speeding runoff. Furthermore, faster runoff velocities reduce the opportunity for pollutants to settle out or be removed by natural processes.

Most urban areas are only partially covered by impervious surfaces, however, and natural infiltration rates to underlying soils are influenced primarily by soil type and by plant cover. Any disturbance of a soil profile and cover type can change infiltration characteristics significantly (USDA 1986). Site designs can preserve existing pervious surfaces (open space and vegetation, especially native species), incorporate pervious landscaping and vegetated cover, and reduce and disconnect impervious cover. Pervious cover, and especially vegetation, allows water infiltration that minimizes runoff, erosion, and potential for downstream pollution. Vegetation helps reduce erosion and filters sediment and other pollutants from stormwater runoff by creating a natural buffer to reduce the velocity of surface water. Native vegetation and open space provide aesthetic and habitat benefits. Site development practices also can protect soils from compaction and restore high-quality native soil characteristics. Appendix A discusses non-structural BMPs in considerable detail.

Stormwater quality can be improved significantly by treating the remaining runoff volumes with structural BMPs. Structural BMPs are designed to provide two factors: 1) infiltrate and reduce the amount of runoff, and/or 2) to filter and detain runoff to reduce discharge velocities and remove pollutants. Infiltration systems represent an example of the former, while bioretention areas (vegetated depressions designed to collect and treat runoff through an engineered matrix of soils and plant roots) represent an example of a filtration practice. As shown in Figure 1.10 below, filtration and detention BMPs remove pollutants by several processes, including physical settling and filtering by plants and soil media, aeration, adsorption onto soils, and biological processes in the root zone.

Figure 1.10
Natural Treatment Processes



Some practices can also be designed to serve both functions, such as by locating the underdrain 6" or so above the bottom of the bioretention cell. Appendix B includes descriptions and design criteria for several structural BMPs.

Not all runoff contains high concentrations of pollutants, however. The initial rainfall mobilizes pollutants that have built up on pervious and impervious surfaces. The pollutants are more concentrated in this "first flush," and concentrations gradually diminish as rainfall continues. To be efficient and cost-effective, water quality BMPs must be sized and designed to treat this more concentrated runoff rather than the extreme flood events that are managed by conventional stormwater systems. The design storm for water quality BMPs is the water quality volume (WQv). The WQv is defined as the storage needed to capture and treat 90 percent of the average annual stormwater runoff volume. WQv is a function of the Water Quality Storm, which is the storm event that produces less than or equal to 90 percent volume of all 24-hour storms on an annual basis.

The following section discusses application of non-structural and structural BMPs.

1.11 TREATMENT TRAIN APPROACH

A single BMP may not suffice to meet the stormwater management and design objectives for a development. The preferred approach for water quality improvement is a combination or series of stormwater BMPs called a "treatment train." This set of biological and physical treatments successively removes pollutants from stormwater flows. A treatment train also can reduce the physical volume of runoff, thus reducing stormwater management costs while improving water quality (Texas APWA 1998).

While many practitioners focus on engineered structural BMPs, a treatment train combines site development strategies, management and housekeeping practices, and engineered solutions. What is not imposed on a site or development can be more important than the applied engineered BMPs. This vital first step is called Site Fingerprinting. By this we mean that the designer accommodates the natural features and landforms. Site fingerprinting avoids disturbance of riparian areas, steep slopes or highly erodible soils. Site fingerprinting also minimizes grading and incorporates the land contours into the design. Avoidance is the best strategy to deal with most problems – the most cost-effective practice is to limit the generation of runoff by preserving or creating natural areas and vegetation that soak up precipitation, slow runoff, and filter sediment. Engineered solutions then deal with the remaining runoff volume most effectively at the source. Infiltration and filtration BMPs placed at the source also reduce runoff volumes and peak flows from smaller, more frequent storms (see Chapter 2 for a discussion of water quality and hydrology). Finally, what cannot be absorbed or treated at the source must be routed through larger BMPs for detention and treatment prior to discharge from the site. Pollution prevention is also applied so that contaminants are not released from a site where they can be picked up by runoff and carried into surface water bodies. Selection of treatment train components is based on a combination of local and state stormwater requirements, site characteristics, development needs, runoff sources, financial resources, and BMP characteristics (such as space requirements, design capacities, and construction and maintenance costs).

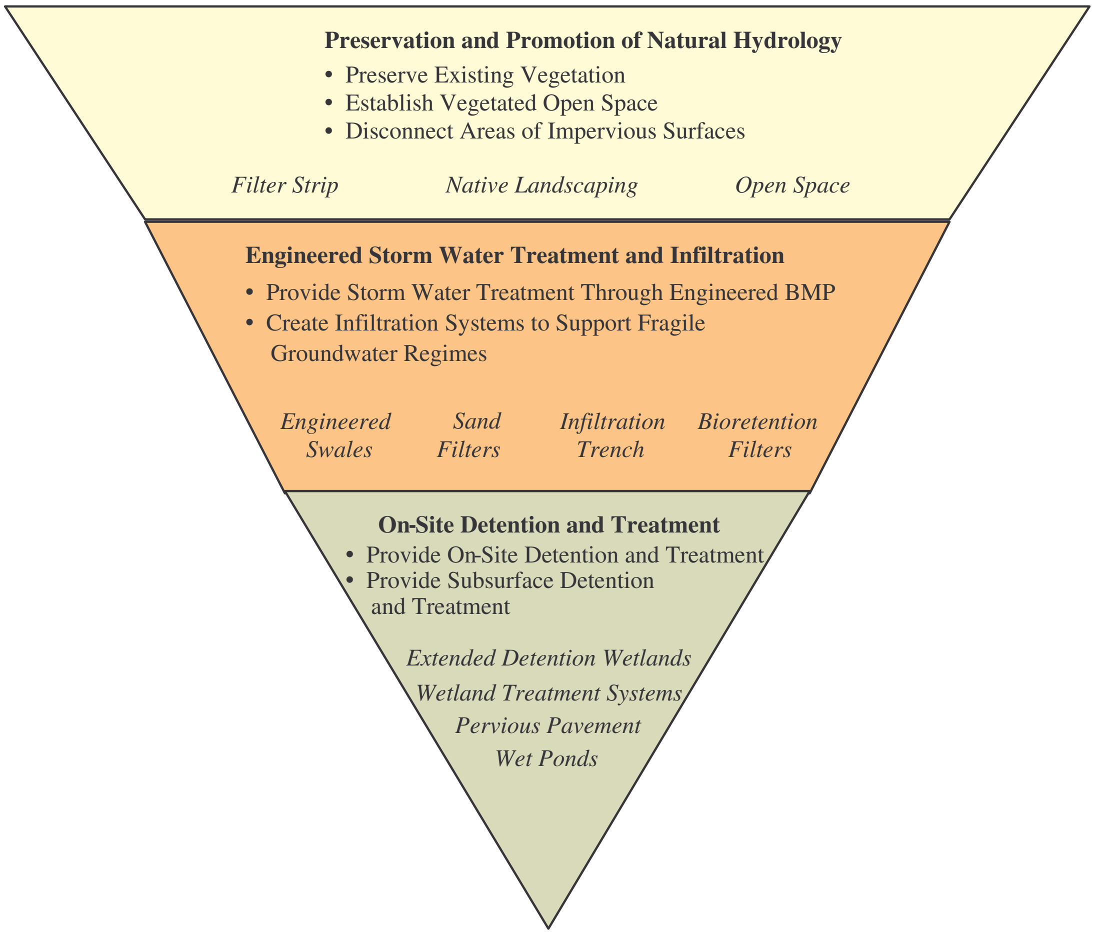
Before choosing a sequence of treatment practices, a planner must understand the site conditions and hydrological characteristics of the site's drainage area, and the requirements for water quality treatment. Developments are required to manage stormwater flow rate from the site in accordance with this manual. This manual includes guidelines for determining a development's approximate water quality impact and selecting an appropriate BMP package for the site and development. At a minimum, the predevelopment quality of the site must be maintained if possible. The procedure for ranking the predevelopment condition of the site and for selecting a BMP package, which will maintain that condition, is in Chapter 6. This procedure includes a method for determining how much treatment a development should include. Methods for determining site hydrology and for calculating the WQv are also described in Chapter 2.

Selecting a combination of practices, which meet basic requirements, is up to the developer and the site design team. The “right” treatment train best satisfies stormwater management requirements and the project goals, and it offers the most overall value for the development. Treatment train practices which generally follow the Hierarchy of Stormwater Best Management Practices (see Figure 1.11) usually provide the most benefit at the least cost and the greatest flexibility in addressing needs of the site design. The treatment train may include the following components, in order of preference:

- Site fingerprinting starting with preserved open space and natural vegetation, specifically avoidance of disturbance near water bodies
- Minimize disturbance during construction and impervious surfaces after construction
- Created open space with native vegetation
- Infiltration practices at the source of runoff—including rain gardens, infiltration trenches or similar BMP’s
- Filtration systems at the source of runoff—such as vegetated filter strips, sand filters, or bioretention basins
- Engineered swales for capture at the source or conveyance between BMPs
- Detention structures such as channel protection detention basins, wetlands, extended detention wetlands, and wet ponds.

FIGURE 1.11.1

HIERARCHY OF STORM WATER BEST MANAGEMENT PRACTICES



The following examples illustrate hypothetical treatment trains for three types of sites:

Residential subdivision: (1) preserve native prairie remnant as common open space; (2) landscape with native vegetation; and (3) use dry swales to convey and treat runoff from landscaped streets and yards.

Commercial development: (1) establish native landscaping in and around buildings and parking areas to break up impervious areas; incorporate shade trees to cool parking lot runoff (2) use bioretention cells in parking lots.

Office park: (1) place filter strips around building downspouts and parking lots, leading to (2) infiltration basins; (3) use dry swales to treat runoff from streets and convey it to (4) a wet pond.

Three useful references for conservation development strategies are:

- Growing Greener Booklet from the National Lands Trust (http://www.natlands.org/planning/growgreen.html)
- Better Site Design: A Handbook for Changing Development Rules in Your Community (http://www.cwp.org/)
- Low-Impact Development Design Strategies – An Integrated Approach (http://lowimpactdesign.org/)

The following paragraphs discuss each stage of the treatment train in more detail. Appendices A and B discuss how to select and design BMPs.

Preserving and incorporating native areas into the design of the site or establishing open space with native vegetation is commonly the first stage of a treatment train. The more land left in an undisturbed state or returned to a natural state through native landscaping, the greater the water infiltration that minimizes runoff, erosion, and potential for downstream pollution. It is important to note that preservation is far more effective than recreation because many Central Missouri soils have dramatically reduced infiltration capacity once compacted. It takes many years or extensive soil reconditioning to reestablish the pre-disturbance soil performance.

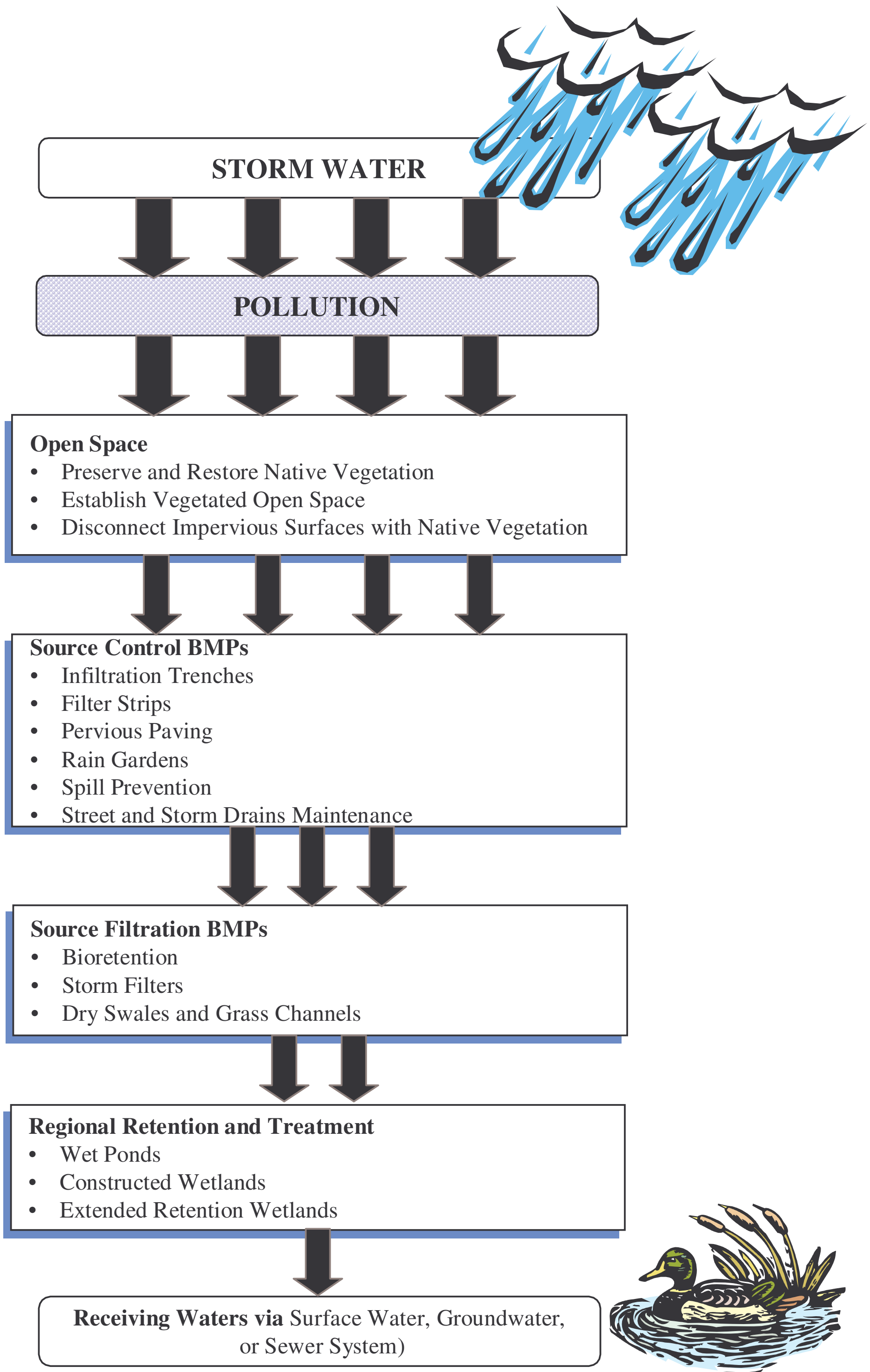
The proposed land use or site design may not allow for sufficient open space to manage all runoff from precipitation which falls on or runs onto a site. Runoff, which contacts pollutants (from rooftops, sidewalks, driveways, parking lots, roadways and so on), is most efficiently managed close to its origin. Often, the second stage of the treatment train controls runoff at its sources. Examples include pervious vegetated areas (such as lawns or specially designed filter strips around parking lots and buildings), infiltration trenches and basins, pervious pavement parking lots, and residential rain gardens (Texas APWA 1998). When considering lawns for treatment, it is important to note that conventional lawns are themselves sources of pollution because the intensive application of fertilizers, herbicides and pesticides can overwhelm any benefit provided by the filtration. Alternatives such as native Buffalo grass or No-Mow fescue mixes require little or no chemical input and provide the aesthetic benefits of a lawn with much better water quality performance. Source controls can maximally infiltrate and substantially reduce runoff, which contains pollutants (for example, runoff from the smaller storms such as the Water Quality Storm). In addition, reducing peak runoff rate—even from smaller rain events—decreases stress on downstream control facilities that consequently can be smaller. Peak reduction from reducing impervious surfaces or detaining these smaller events is a function of site and BMP design; it should be calculated and applied by the site engineer or stormwater planner as part of the design process.

Open space and infiltration practices alone may not suffice to manage all runoff from a site because of inadequate space, soils and geology, slopes, or other factors. Engineering filtration systems at or near the source of runoff is the next stage of the treatment train. Filtration systems route the most contaminated "first flush" of rainfall (the WQv) through an engineered natural filter. Examples of filtration systems include sand filters, bioretention, dry swales, and grassed channels (Center for Watershed Protection 2000b, Claytor and Schueler 1996). Note that by omitting underdrains, planners may use bioretention and sand filters for infiltration (see Appendix B). These practices also detain smaller rain events, as they are designed to treat the Water Quality Storm. The stormwater engineer or planner should estimate the maximum volume of detention available and required.

Devising stormwater detention practices is the last stage of the treatment train. Detention generally applies to large developments; it provides solutions for sites where space inadequacy precludes stormwater treatment closer to the source. Detention may be the preferred option where predevelopment site conditions are of low quality. "Wet" detention detains and manages releases from larger rainfall events—usually up to and including the 100-year return interval event — and includes a treatment component sized for the WQv. Many examples and designs are discussed in Appendices B and C.

Finally, proper maintenance and pollution prevention practices can limit stormwater runoff pollution further. Routinely cleaning and periodically refurbishing BMPs helps them function as designed. Maintenance practices (such as sweeping streets and parking lots) remove pollutants before rainfall can mobilize them. Surely many pollutants result from airborne emissions and deposits, but some chemicals enter surface water from spills and leakage from equipment (Claytor and Schueler 1996). Pollution prevention strategies can contain common sense practices not included in most treatment trains— containment barriers around chemical storage areas to confine potential spills, berms around fueling stations to prevent stormwater run-on, or vehicle and equipment maintenance to prevent leakage (Texas APWA 1998). Chapter 6 includes information on such practices. Figure 1.11.2 illustrates an elementary treatment train concept.

FIGURE 1.11.2
STAGES OF A TREATMENT TRAIN



1.12 SUMMARY OF BMP SELECTION METHODS

Chapter 6 presents the "Level of Service Method," a BMP selection method designed for Columbia based on nationally recognized research and practices. This is not the only BMP application procedure, however. A number of jurisdictions throughout the U.S. have adopted their own methods for implementing water quality principles into workable development ordinances and design criteria.

Water quality planners, engineers, and developers may want to consult other manuals and guidance on a case-by-case basis. A number of the better-known methods are described below:

- *2000 Maryland Stormwater Design Manual, Volumes I & II*. Maryland Department of Environment, Water Management Administration. October 2000.

  This State of Maryland publication specifies 14 mandatory performance standards that apply to any construction activity disturbing 5,000 or more square feet of earth. The manual provides selection guidance for pretreatment, non-structural BMPs, and structural BMPs designed to remove 80 percent of the average annual post-development total suspended solids load and 40 percent of the average annual post-development total phosphorous load. The redevelopment policy specifies a 20 percent reduction in impervious surface area below existing conditions. Where impractical due to site constraints, this manual requires the use of BMPs to meet the equivalent in water quality control of a 20% decrease in impervious surface area. Additional BMPs are provided for stormwater "hot spots" or highly polluting land uses. This text also includes a good discussion of basic stormwater management concepts.

- Minnesota Urban Small Sites BMP Manual. Metropolitan Council. July 2001.

  This manual provides voluntary BMP application and design guidance for small sites (less than 5 acres). The manual furnishes general siting and selection criteria, design guidance, and operation and maintenance recommendations for 40 BMPs—along with relative rankings of each based on treatment suitability, physical feasibility, and community acceptance.

- *Stormwater Management Manual, Revision #2*. The City of Portland, Oregon, Environmental Services Department. September 2002.

  The City of Portland requires that all development projects with over 500 square feet of impervious development footprint area, and all redevelopment projects redeveloping over 500 square feet of impervious surface, treat runoff from the additional impervious areas. Portland requires treatment and removal of 70 percent of total suspended solids (TSS) from runoff generated by a design storm up to and including 0.83 inches of rainfall over a 24-hour period. The manual provides a list of acceptable BMPs and simplified sizing and design guidance for each based on the impervious area treated. It also includes a performance-based BMP selection method for designing and customizing BMPs.

- *Urban Best Management Practices for Nonpoint Source Pollution*. Wyoming Department of Environmental Quality, Water Quality Division. February 1999.

  This text is a general reference for water quality principles, and for selecting and applying BMPs geared toward semi-arid climates.

- *Urban Storm Drainage Criteria Manual Vol. 3 – Best Management Practices*. Urban Drainage and Flood Control District, Denver, Colorado. September 1999.

  Denver's Urban Storm Drainage Criteria Manual provides water quality management guidance for local jurisdictions, developers, contractors, and commercial and industrial operations. This manual includes discussions of water quality principles and hydrology; in-depth selection and design criteria for a number of BMPs; standard engineering details; operations and maintenance guidelines; and BMP design worksheets. The manual is geared toward semi-arid climates

- ASCE Database www.bmpdatabase.org

1.13 INITIAL MEASURES AND MINIMUM PRACTICES

The Level of Service Method described in Chapter 6 of this manual is detailed and flexible enough for a wide variety of sites and development types. Additionally the following BMPs are important in a comprehensive stormwater management program and should be considered and utilized whenever possible in conjunction with the level of service method:

- Preserve natural systems

- Introducing community-wide stream buffer systems through enactment of stream setback ordinances

- Applying soil protection and reconstruction to residential developments

- Capturing runoff from all impervious surfaces in non-residential developments using bioretention areas

- Discouraging or eliminating direct connections of impervious areas to storm drains.

- Regulating commercial and industrial "hot spots."

Descriptions of these minimum practices follow. (General siting and design guidance are discussed in Appendices A and B and detailed design specifications for each of these measures are included in Appendix E.

1.13.1 Natural Systems Preservation

Natural streams provide numerous water quality, ecological and quality of life benefits. Protection through conservation and preservation of natural streams is a national environmental objective as set forth in the Clean Water Act. Streams and their associated wetlands provide critical habitat for plants and wildlife, water quality treatment and improved infiltration of rainfall, which lessens flood impacts, recharges groundwater and preserves baseflow. Natural Streams provide recreational and open space in communities, improve aesthetics, provide natural landscapes and enhance adjacent property values. Stable steams in nature maintain a shape and plan, profile and section that most efficiently transport the water and sediment supplied to them. The geometry and processes of natural streams involve unique terminology and concepts not common to engineered channels or pipe systems. Common features of stream geometry and characteristics are presented in Figures 5.1.4.1A&B in Appendix F. Certain definitions are contained in the Section 1.6 *Definitions*. More complete information regarding the character and function of natural streams is given in Interagency (2001).

Guidance on stream protection is given in Wegner (1999), National Academy of Sciences (1999), and Heraty (1995). Natural streams should be preserved as systems and not segmented on a project-by-project basis, as the frequent intermixing of natural and man-made systems tends to degrade the function of both.

1.13.2 Hydrology Controls for Channel Protection

Urbanization in the absence of stormwater management causes many stressors to the natural channel system. The channels respond to the stressors (flow volume increases, shortened times of concentration, longer peaks, flashier flows, and lowered baseflow) by altering width, depth, velocity, suspended loads, meander radius, wavelengths and pool and riffle. Avoiding significant changes in flow volume, rate and time of concentration, reduces the likelihood of major changes in stream form.

Flow volume, rate and time of concentration control include practices, which encourage infiltration, evapotranspiration, extended detention or retention and the establishment of an induced or artificial baseflow. A successful strategy would require limitations on flow rate, duration and magnitude of post-development discharges at a number of discharge points, including common storms such as the 100% storm. The tail of hydrographs would probably need to mimic groundwater base flow. The cumulative effect of multiple detention/retention structures on duration of high flows would have to be considered. The impact of large impoundments or retention lakes on trapping sediment and interrupting sediment transport would also have to be considered. Volume control for channel protection would likely require significantly different control requirements than traditional detention practices that focused primarily on flood control from extreme events (1% storm).

This manual sets out practices and guidance to address many of these factors and reduce the impact of development on the receiving streams.

1.13.3 Stream Buffers

The "riparian zone" (the heavily vegetated band along the fringe of a stream) is an integral part of the stream system. For example, preservation of a 100-foot riparian buffer—only about 5 percent of the land in a typical watershed—can yield disproportionate benefits. This buffer limits development in the floodplain and controls streambank erosion; it removes pollutants from adjacent properties; and it can serve as a greenway park (Haag, Mazzeo, and Schulte 2001). Buffers also provide financial returns to communities—research indicates that a comprehensive system of stream buffers that typically takes up about 5 percent of a community's developable land may increase adjacent property values by as much as 33 percent (Chesapeake Bay Foundation 1996).

Columbia's stream buffer ordinance may be found in Chapter 12A of the City Code of Ordinances.

1.13.4 Soil Preservation

An important measure to protect water quality is soil protection and restoration on all residential developments. Both stormwater runoff volumes and water quality are heavily influenced by infiltration capacity (USDA 1986; Claytor and Schueler 1996). Preserving the soil's capacity to infiltrate precipitation is a relatively inexpensive non-structural measure that can be implemented as part of a development's sediment and erosion control program. Credit can be taken in the Level of Service Method for this practice.

Urbanization shortens a watershed's response to precipitation mainly by reducing infiltration and decreasing travel time. An impervious surface decreases travel time by preventing infiltration and speeding runoff, and should be limited as much as is practical. However, most urban areas are only partially covered by impervious surfaces, and the soil remains an important factor in producing runoff. Natural infiltration rates to underlying soils are primarily influenced by soil type and by plant cover. Any disturbance of a soil profile by mixing native soil profiles, introducing off-site fill materials, and increasing soil compaction can significantly change infiltration characteristics (USDA 1986).

Restoring infiltration characteristics of the entire soil profile in residential areas (and other developments) after disturbance will also benefit water quality. These requirements can help residential developments maximally infiltrate stormwater for given vegetation and cover types without structural treatment measures. A detailed soil protection and restoration specification is in Appendix E.

1.13.5 Bioretention

Stormwater runoff from impervious surfaces in non-residential land uses (commercial, office, and manufacturing) should be treated. These land uses generate more impervious surface than residential developments and this significantly impacts a community's water quality. Impervious area for residential land uses typically ranges from 12 to 65 percent, while industrial and commercial areas may include 72 to 85 percent impervious area (USDA 1986). Because most pollutants originate from atmospheric deposition, impervious surfaces are the major source of stormwater pollutants in urban areas (Claytor and Schueler 1996).

Communities can significantly impact their water quality by treating runoff from non-residential impervious surfaces such as rooftops and parking lots. Treatment of runoff from all new impervious surfaces by using bioretention areas (vegetated depressions designed to collect and treat runoff from the Water Quality Storm through an engineered matrix of soils and plant roots) is an effective and efficient practice to remove pollutants from stormwater runoff and to increase the time of concentration. Effective bioretention cells typically require only about 5 percent of the total impervious area. They are easily designed and planned as part of the site's required open space. In practice, these units are maintained in the same manner as decorative landscaped beds—minimizing maintenance costs and increasing value-added benefits. Implementing this one standardized practice in all developments can minimize design, inspection, and maintenance costs.

This practice can be utilized (and is encouraged) in the Level of Service Method prescribed in this manual (Chapter 6).

Detailed construction guidance for bioretention is in Appendix C.

1.13.6 Eliminate Direct Connections

Direct connections include downspouts and sump pumps which flow directly onto pavement or which are piped into stormwater inlets. If this water is allowed to flow over pervious surfaces, some of the water will infiltrate. This measure requires close attention to site drainage patterns to minimize associated problems such as soggy yards.

1.13.7 Regulate "Hot Spots"

Land uses that contribute greater concentrations of hydrocarbons, metals, and other pollutants are called "hot spots" and may require additional measures to manage the quality of their runoff (Claytor and Schueler 1996). Industry-specific BMPs should be employed on these commercial or industrial hotspot activities. Chapter 6 includes management practices for various land uses (adapted from the City of Portland, Oregon [2002]).

1.14 REQUIREMENTS OF OTHER AGENCIES

Rules and regulations of other agencies also pertain to drainage systems, which may or may not compliment these criteria. When conflicts are encountered, the more stringent criteria shall govern.

The following agencies have jurisdiction over streams and/or drainage systems and often require permits. Other regulations, permits and requirements may not be limited to these agencies.

- Federal Emergency Management Agency (FEMA)
- U S. Army Corps of Engineers
- Missouri Department of Natural Resources
- Other Municipal Ordinances (Flood Plain Development Ordinance, Stream Buffer Ordinance, and Erosion Control Ordinance)

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CHAPTER 2 HYDROLOGY

2.1 Scope

This section sets forth the hydrologic parameters to be used in computations to determine volumes and peak rates of storm water runoff.

2.2 Computation Methods for Runoff

Runoff rates to be accommodated by each element of the proposed storm drainage system shall be calculated using the criteria of this section for land use runoff factors, rainfall, and system time.

Any nationally accepted computer modeling program using NRCS methodologies such as WinTR-55, HEC-HMS, Haestad Methods, InteliSOLVE or others as approved by the Director is acceptable.

The following methods of computations are allowed for the following drainage areas:

TABLE 2.2.1

Computational Method	0-20 Acres	20-100 Acres	More than 100 Acres
Rational *	X	X	
NRCS Methodology *	X	X	X

* All Modeling requiring a hydrograph shall be done using NRCS Methodology.

2.2.1 Rational Method

The Rational Method may be used to calculate peak rates of runoff to elements of enclosed and open channel systems, including inlets, when the total upstream area tributary to the point of consideration is less than 100 acres. The Rational Method is defined as follows:

$Q = KCiA$, where

Q = Peak rate of runoff to system in cfs

C = Runoff coefficient as determined in accordance with Table 2.2.1.2

i = Rainfall intensity in inches per hour as determined in accordance with Figure 2.2.1.1 in Appendix F.

K = Dimensionless coefficient to account for antecedent precipitation as follows, except the product of $C \cdot K$ shall not exceed 1.0.

TABLE 2.2.1.1

ANTICEDENT PRECIPITATION COEFFICIENTS

Design Storm	K
10% and more frequent	1.0
4%	1.1
2%	1.2
1%	1.25

TABLE 2.2.1.2

RUNOFF COEFFICIENTS

LAND USE/ZONING	AVERAGE PERCENT IMPERVIOUS	AVERAGE PERCENT PERVIOUS	RATIONAL METHOD "C"
1. Business			
Downtown Area	95	5	0.87
Neighborhood Areas	85	15	0.81
2. Residential			
Single-Family Areas	35	65	0.51
Multifamily Areas	60	40	0.66
Churches & Schools	75	25	0.75
3. Industrial			
Light Areas	60	40	0.66
Heavy Areas	80	20	0.78
Parks, Cemeteries	10	90	0.36
Railroad Yard Areas	25	75	0.45
4. Undeveloped Areas	0	100	0.3

TABLE 2.2.1.2 Continued

LAND USE/ZONING	AVERAGE PERCENT IMPERVIOUS	AVERAGE PERCENT PERVIOUS	RATIONAL METHOD "C"
5. All Surfaces			
Impervious: asphalt			
Concrete, roofs, etc.	100	0	0.9
Turfed Areas	0	100	0.3
Wet detention basins	100	0	0.9

Rational Method "C" for Non-Standard Land Use/Zoning Classifications

The "C" value can be calculated from any type of land use and known percent impervious surface from the following equation:

$C = 0.3 + 0.6 * I$, where:
I = percent impervious divided by 100

Unzoned But Master Planned Areas

Areas whose future land use is defined by an adopted land use plan shall be assigned runoff coefficients for the land use indicated on such plan.

3. Agricultural and Unplanned Areas

Proposed Conditions: Undeveloped areas designated as agricultural or those areas for which no specific land use is indicated shall be assigned a minimum of 35% impervious surface for purposes of the design of storm drainage systems (C=0.51).

4. Time of Concentration

Time of Concentration (T_C) is equal to the overland flow time to the most upstream inlet or other point of entry to the system, Inlet Time (T_I), plus the time for flow in the system to travel to the point under consideration, Travel Time (T_T).

$$T_C = T_I + T_T$$

Inlet Time

T_I shall be calculated by the following formula or determined graphically from Figure 2.2.1.2 in Appendix F, but shall not be less than 5.0 minutes nor greater than 15.0 minutes:

$$T_I = 1.8 \cdot \frac{(1.1 - C)D^{1/2}}{S^{1/3}}$$ where:

T_I = Inlet Time in minutes

C = Rational Method Runoff Coefficient as determined in accordance with this section

D = Overland flow distance parallel to slope in feet
(100 feet shall be the maximum distance used for overland flow)

S = Slope of tributary area surface perpendicular to contour in percent.

Travel Time

T_T shall be calculated as the length of travel in the channelized system divided by the velocity of flow. Velocity shall be calculated by Manning's equation assuming all system elements are flowing full without surcharge. Travel time may be determined graphically from Figure 2.2.1.3 in Appendix F in lieu of calculation.

Modeling Unimproved Areas Upstream
When the upstream area is unimproved, use Ti = 15 minutes for the first 100’ from the most distant ridge line. Then use the following table to calculate Tt to account for future development.

AVERAGE CHANNEL SLOPE PERCENT	**VELOCITY IN FT/SEC**
< 2	7
2 to 5	10
> 5	15

2.2.2 NRCS Unit Hydrograph Method

NRCS methodologies must be used for areas 100 acres or larger and for detention basin routing and may be used for areas less than 100 acres. The NRCS unit hydrograph method includes the use of the NRCS unit hydrograph, the Type II rainfall distribution, 24-hour storm duration and NRCS TR-55 or WinTR55 methodologies for calculating time of concentration and runoff coefficients with the following exception: overland flow length in the time of concentration calculation is limited to 100 feet (as established in the most current version of TR-55).

A. The rainfall depths for Boone County Missouri are:

TABLE 2.2.2.1

24-HOUR RAINFALL DEPTHS FOR BOONE COUNTY, MISSOURI

Recurrance Interval	% chance in given year	Depth (in)
1	100	3
2	50	3.5
5	20	4.5
10	10	5.2
25	4	5.9
50	2	6.6
100	1	7.3

B. Runoff Coefficients:

Standard Land Use/Zoning Classifications. Runoff coefficients for various land use and zoning classifications by soil group may be found in Table 2.2.2.2 in Appendix F. This information is also available in TR-55 and WinTR-55, a free program available on the National Resource Conservations Service's website.

Composite Coefficients. For areas not listed in Table 2.2.2.2 (office parks, shopping centers, trailer parks, etc.), a composite runoff coefficient based on the actual percentages of pervious and impervious surfaces shall be used.

Curve Number Coefficients for disturbed soils. All Curve Numbers for disturbed soils or soils to be disturbed shall be one letter greater than the Curve Number in the undisturbed condition.

Curve Number Coefficients for water quality. Areas with water quality practices shall have runoff curve numbers calculated according to Section 2.3 in this chapter.

Unzoned But Master Planned Areas. Areas whose future land use is defined by an adopted land use plan shall be assigned runoff coefficients for the land use indicated on such plan.

Agricultural and Unplanned Areas.

1. **Existing Conditions**

   For purposes of determination of development impact, undeveloped areas whose current land use is agriculture (crops, pasture, meadow) shall be assigned a maximum of 0% impervious surface or a maximum Curve Number of 78 (equivalent to good condition pasture, grassland or range on D soils).

2. **Proposed Conditions**

   Undeveloped areas designated as agricultural or those areas for which no specific land use is indicated shall be assigned a minimum of 35% impervious surface for purposes of the design of storm drainage systems (CN = 89).

3. **Redevelopment Areas**

   Areas in redevelopment shall be assigned a maximum Curve Number of 78 (equivalent to good condition pasture, grassland or range on D soils) for the pre-redevelopment condition.

C. Rainfall Mass

Two rainfall mass distributions are acceptable for modeling: the NRCS Type 2, twenty-four hour rainfall distribution, and the Huff distribution from Bulletin 71 – Rainfall Frequency Atlas of the Midwest. The distributions are given in Appendix F in Tables 2.2.2.3 and 2.2.2.4 respectively.

***NRCS Type 2**

The NRCS Type 2 distribution is based upon Technical Paper 40, Rainfall Frequency Atlas of the United States published in 1961. The distribution is maximized so that shorter more intense rainfalls are built into the distribution. This allows peak flows for short times of concentration to be calculated using a 24-hour storm, but this distribution is not based upon observed rain events. The Type 2 distribution is built into most hydrology software and does not need to be input.

Huff Distribution

The Huff Distribution comes from Bulletin 71, Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992) published by NOAA and the Illinois State Water Survey. The "Huff Distribution" is actually a family of curves applicable to different sized watersheds and different types of storms. The distribution is expressed as cumulative percentages of total duration and total rainfall accumulation. The table given in Appendix F is for drainage areas less than 10 square miles. For larger areas, refer to Bulletin 71.

Four distributions are given in Table 2.2.2.4. Each distribution represents the quartile of a storm in which the majority of rain falls, and each is associated with a different storm duration. Storms with durations of 6 hours or less, 6 to 12 hours, 12 to 24 hours, and greater than 24 hours tend to be associated with the first, second, third, and fourth quartile respectively. The vast majority of modeling within the City will require use of the first quartile distribution.

D. Unit Hydrographs

The NRCS Dimensionless Unit Hydrograph (either curvilinear or triangular) shall be the basis for computation of runoff hydrographs.

E. Time of Concentration and Lag Time

Time of Concentration for NRCS methods shall be calculated using the method described in TR-55. Except that the maximum overland flow length shall be 100 feet.

Modeling Unimproved Areas Upstream

When the upstream area is unimproved, use Ti = 15 minutes for the first 100’ from the most distant ridge line. Then use the following table to calculate Tt to account for future development.

AVERAGE CHANNEL SLOPE PERCENT	VELOCITY IN FT/SEC
< 2	7
2 to 5	10
> 5	15

Lag Time

Lag Time (T_L) is the calculated time between the maximum rainfall intensity of a storm and the point of maximum discharge on the outlet hydrograph. Lag Time is used instead of time of concentration for unit hydrograph models. It shall be calculated as $3/5^{th}$ the time of concentration (T_c). The NRCS software, TR-55 and WinTR-55 calculate and apply lag time automatically. In other software the lag time may need to be calculated from Tc as indicated above and input into the program.

F. Hydrograph Routing

Routing of hydrographs through storage elements or reservoirs shall be by modified-Puls level pool routing. Routing through channels shall be by the Muskingum-Cunge method.

G. Calibration and Model Verification

All design discharge estimates should be calibrated to the extent possible using reliable gauge data, high water marks, or historical accounts. Model results should be evaluated to verify that they are reasonably conservative as compared to observed data and standard practice. Model calibration shall not be used to justify discharge estimates that are lower than those provided by the baseline unit hydrograph method, unless unusual site specific factors justify, where the hydrologic impact of such factors must be thoroughly examined and documented. Engineers shall recognize the significant uncertainty associated with design discharge estimates and provide estimates that are reasonably conservative and protective of the public interest. To permit model verification, discharge rates (expressed as absolute discharge or discharge per acre of tributary area) shall be plotted relative to tributary area and compared to regression formula results, gauge estimates, and/or known historical extremes.

2.3 WATER QUALITY HYDROLOGY METHODS

Sizing BMPs properly is critical to their success. Design detention and retention BMPs to capture and treat the Water Quality Volume (WQv). Design conveyance BMPs to handle peak discharge of the WQv. WQv is defined as the storage needed to capture and treat 90 percent of the average annual stormwater runoff volume. WQv is based on the Water Quality Storm and volumetric runoff coefficient and site area. The Water Quality Storm is defined as the storm event that produces less than or equal to 90 percent volume of all 24-hour storms on an annual basis. The Water Quality Storm rainfall for Columbia is 1.3 inches.

Two methods can be used to estimate the WQv for a proposed development—the Short-Cut Method and the Small-Storm Hydrology Method. Use the Short-Cut Method (Claytor and Schueler 1996) only for sites with one predominant type of cover and a drainage area less than 10 acres:

WQv = P * Rv

Where:

WQv = Water Quality Volume (in watershed inches)
P = Rainfall event in inches (the Water Quality Storm or other appropriate amount, with the approval of the city engineer)
Rv = Volumetric runoff coefficient
0.05 + 0.009(I)
I = Percent site imperviousness

The Small Storm Hydrology Method (Claytor and Schueler 1996) is based on the volumetric runoff coefficient (Rv), which accounts for specific characteristics of the pervious and impervious surfaces of the drainage catchment. This method may be used for all drainage areas. Rv's used to compute the volume of runoff are identified in Table 2.3.1. The Small Storm Hydrology Method is:

WQv = P * Weighted Rv

Where:

Weighted Rv = $\sum$(Rv1*Ac1)+(Rv2*Ac2)+…(Rv_i*Ac_i)/Total Acreage
Rv_i = Volumetric runoff coefficient for impervious cover type *i*
Ac_i = Acreage of impervious cover type *i*
Total Acreage = Total acreage of the drainage area

A reduction factor may be applied to the Rv values for drainage areas with disconnected impervious surfaces. The pervious surface flow path below an impervious area must be at least twice the length of the impervious flow path and some method must be used to spread the flow to a similar width as the impervious width. The reduction factors are provided in Table 2.3.2.

TABLE 2.3.1

VOLUMETRIC COEFFICIENTS FOR URBAN RUNOFF FOR DIRECTLY CONNECTED IMPERVIOUS AREAS (CLAYTOR AND SCHUELER 1996)

Rainfall (inches)	Flat roofs and large unpaved parking lots	Pitched roofs and large impervious areas (large parking lots)	Small impervious areas and narrow streets	Silty soils HSG-B	Clayey soils HSG-C and D
0.75	0.82	0.97	0.66	0.11	0.20
1.00	0.84	0.97	0.70	0.11	0.21
1.25	0.86	0.98	0.74	0.13	0.22
1.30	0.86	0.98	0.74	0.13	0.22
1.50	0.88	0.99	0.77	0.15	0.24

TABLE 2.3.2

REDUCTION FACTORS TO VOLUMETRIC RUNOFF COEFFICIENTS FOR DISCONNECTED IMPERVIOUS SURFACES (CLAYTOR AND SCHUELER 1996)

Rainfall (inches)	Strip commercial and shopping center	Medium-to-high-density residential with paved alleys	Medium-to-high-density residential without alleys	Low-density residential
0.75	0.99	0.27	0.21	0.20
1.00	0.99	0.38	0.22	0.21
1.25	0.99	0.48	0.22	0.22
1.30	0.99	0.50	0.22	0.22
1.50	0.99	0.59	0.24	0.24

To convert WQv from watershed inches to volume in cubic feet:

WQv (in cubic feet) = [WQv (in watershed inches)/12]*A

where: A = Watershed area (in square feet)

To size a conveyance BMP correctly, calculate the peak discharge for the Water Quality Storm. Use the following procedure for estimating the peak discharge for the Water Quality Storm (Claytor and Schueler 1996):

1. Calculate a Curve Number (CN) based on the previously calculated WQv:

   $$CN = 1000/[10 + 5P + 10Q - 10(Q^2 + 1.25\ QP)^{1/2}]$$

   where

   P = Water Quality Storm rainfall (inches)
   Q = Runoff volume (inches)—equal to WQv (watershed inches)

2. Determine Time of Concentration (Tc):

   $$Tc = (L^{0.8}[(1000/CN)-9]^{0.7})/(1140 * Y^{0.5})$$

   where

   Tc = Time of concentration (hours)
   L = Flow length (feet)
   CN = Runoff Curve Number
   Y = Average watershed slope (percent)

   Use a minimum of 0.1 hours for Tc.

3. Use Table 2.3.3 or TR-55 to determine Initial Abstraction (Ia).

TABLE 2.3.3

Ia VALUES FOR VARIOUS CURVE NUMBERS

Curve Number	Ia (in.)	Curve Number	Ia (in.)
61	1.279	78	0.564
62	1.226	79	0.532
63	1.175	80	0.500
64	1.125	81	0.469
65	1.077	82	0.439
66	1.030	83	0.410
67	0.985	84	0.381
68	0.941	85	0.353
69	0.899	86	0.326
70	0.857	87	0.299
71	0.817	88	0.273
72	0.778	89	0.247
73	0.740	90	0.222
74	0.703	91	0.198
75	0.667	92	0.174
76	0.632	93	0.151
77	0.597	94	0.128

4. Compute Ia/P and use Figure 2.3.1 in Appendix F or Exhibit 4-II in TR-55 to determine the unit peak discharge (qu) for the appropriate Tc**.**

   If Ia/P is outside of the limiting values of Figure 2.3.1, the limiting value should be used.

   Convert this value from cfs/sm/in to cfs/ac/in, multiplying by (1 square mile/640 acre).

5. Calculate the peak discharge:

   Qp = qu * A * WQv

   where

   Qp = Peak discharge (cubic feet per second [cfs])

   qu = Unit peak discharge (cubic feet per second/acre/inch of runoff)

   A = Drainage area (acres)

WQv = Water Quality Volume (watershed inches)

For computing runoff volume and peak rate for storms larger than the Water Quality Storm, use the published CN's from TR-55, and follow the prescribed procedures in TR-55 or other approved methods.

WATER QUALITY HYDROLOGY EXAMPLE CALCULATIONS

Example 1

3-acre office park, 70% Impervious, 30% Lawn and Landscaping

Flow length = 400 feet, average watershed slope = 4%

Calculate WQv in watershed inches:

Because this is a small site with one predominant type of cover, use the Short-Cut Method.

P = 1.3 inches
Rv = 0.056 + 0.009 (70%)
= 0.68
WQv = (1.3)(0.68)
= 0.88 watershed inches

Convert WQv to cubic feet:

$$WQv = \frac{0.88\text{in}}{12\text{in}/\text{ft}} * 3\text{acres} * 43560\frac{\text{ft}^2}{\text{acre}}$$
$$= 9583.2 \text{ ft}^3$$

Calculate peak discharge for the Water Quality Storm:

1. CN= 1000 / [10 + 5 * 1.3 + 10 * 0.88 – 10(0.88^2 + 1.25 * 0.88 * 1.3)$^{1/2}$]
   = 95.7

2. Tc = (400$^{0.8}$ [(1000 / 95.7) - 9]$^{0.7}$) / (1140 * 4$^{0.5}$)
   = 0.07 hours

*Use 0.10 hours (minimum Tc)

3. from Table 4-1 in TR-55

CN = 95 , Ia = 0.105
CN = 96 , Ia = 0.083

Using linear interpolation, CN = 95.7 , Ia = 0.090

4. Ia/P = 0.090 / 1.3 = 0.07

From Figure 2.3.1 in Appendix F, the limiting value for Ia/P = 0.10.
Therefore using Ia/P = 0.10 ,

$$qu = 1000 \text{ cfs / sm / in} * \frac{1\text{sm}}{640\text{acre}}$$

qu = 1.56 cfs / ac / in

5. Qp = (1.56 cfs / ac / in)(3 ac)(0.88 in)
   = 4.12 cfs

Example 2

12 – acre commercial development and park, 2 acres flat rooftops, 2.3 acres impervious parking, 0.7 acres narrow streets, 7 acres green space (hydrologic soils group C).

Flow length = 1000 feet, Average watershed slope = 2%

Calculate WQv in watershed inches:

Use Small Storm Hydrology Method.

P = 1.3 inches

Weighted Rv = [(0.86)(2 ac) + (0.98)(2.3 ac) + (0.75)(0.7 ac) + (0.22)(7 ac)] / 12 ac

= 0.50

WQv = (1.3 in)(0.50)

= 0.65 watershed inches

Convert WQv to cubic feet:

$$WQv = \frac{0.65\text{in}}{12\text{in}/\text{ft}} * 12\text{ac} * 43560\frac{\text{ft}^2}{\text{ac}} +$$

$= 28314\ ft^3$

Calculate peak discharge for the Water Quality Storm:

1. CN = $1000 / [10 + 5 * 1.3 + 10 * 0.65 - 10(0.65^2 + 1.25 * 0.65 * 1.3)^{1/2}]$
   = 92.3

2. Tc = $(1000^{0.8} [(1000 / 92.3) - 9]^{0.7}) / (1140 * 2^{0.5})$
   = 0.24 hours

3. From Table 2.3.3,
   CN = 92 , Ia = 0.174
   CN = 93 , Ia = 0.151

Using linear interpolation, CN = 92.3 , Ia = 0.167

4. Ia/P = 0.13
   From Figure 2.3.1 in Appendix F,

$$qu = 750 \text{ cfs / sm / in} * \frac{1\text{sm}}{640\text{acre}}$$

$$qu = 1.17 \text{ cfs / ac / in}$$

5. Qp = (1.17 cfs / ac / in)(12 ac)(0.65 in)

   = 9.13 cfs

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CHAPTER 3 HYDRAULICS

3.1 Hydraulic Calculations for Pipes, Culverts, and Open Channels

3.1.1 Gravity versus Pressure Flow for Enclosed Systems

Two design philosophies exist for sizing storm drains under the steady uniform flow assumption. The first is referred to as open channel, or gravity flow design, in which the water surface within the conduit remains open to atmospheric pressure. Pressure flow design, on the other hand, requires that the flow in the conduit be at a pressure greater than atmospheric. For a given flow rate, design based on open channel flow requires larger conduit sizes than those sized based on pressure flow. While it may be more expensive to construct storm drainage systems designed based on open channel flow, this design procedure provides a margin of safety by providing additional headroom in the conduit to accommodate an increase in flow above the design discharge. Under most ordinary conditions, it is recommended that storm drains be sized based on a gravity flow criteria at full flow or near full. However, pressure flow design is allowed. As hydraulic calculations are performed, frequent verification of the existence of the desired flow condition should be made. Storm drainage systems can often alternate between pressure and open channel flow conditions from one section to another (U.S. Department of Transportation Federal Highway Administration, 1996).

A. Gravity Flow

For gravity flow conditions, Manning's formula shall be used as described below.

$$Q = \frac{1.486}{n} A \cdot R^{2/3} S^{1/2}$$ where:

Q = Discharge in cubic feet per second

A = Cross sectional area of flow in square feet

n = Roughness Coefficient (see Table 3.1.1.1 in Appendix F)

R = Hydraulic radius $R = \frac{A}{P}$ in feet

S = Slope in feet per foot

P = Wetted perimeter in feet

B. Pressure Flow

In closed conduits flowing under pressure flow, the hydraulic grade line (HGL) will be above the crown of the pipe. In this case, the Bernoulli equation shall be used to calculate pipe capacity: $\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 + h_f + h_m$ where:

$\frac{p_1}{\gamma}$ = upstream system pressure head (ft)

$\frac{v_1^2}{2g}$ = upstream velocity head (ft)

z_1 = elevation of upstream system invert (ft)

$\frac{p_2}{\gamma}$ = downstream pressure head (ft)

$\frac{v_2^2}{2g}$ = downstream velocity head (ft)

z_2 = downstream invert elevation (ft)

h_f = system friction loss (ft)

h_m = system junction (so-called minor) losses (ft)

Pipe friction losses, h_f, may be calculated using the friction slope method. This derivation of Manning's equation is from (FHWA, 1996).

$$h_f = S_f \cdot L = \frac{(Q \cdot n)^2}{(1.486 A \cdot R^{2/3})^2} \cdot L \quad \text{where:}$$

S_f = friction slope, ft/ft

Note: For normal flow, S_f = HGL slope. However, due to numerous inlets, junctions, changes in direction and slope etc., and due to the nature of rainfall, storm drainage systems are often in unsteady, gradually varied or rapidly varied flow regimes in which this is not true.

Junction (so-called minor) losses, h_m, shall be calculated by:

$$h_m = k \cdot \frac{v^2}{2g} \qquad \text{where:}$$

k = Coefficient as shown in Table 3.1.1.2 in Appendix F

$\frac{v_2^2}{2g}$ = downstream velocity head (ft)

A step-by-step procedure for manual calculation of the HGL using the energy loss method is presented in Section 7.5 of FHWA's Urban Drainage Design Manual (FHWA, 1996). For most drainage systems, computer methods such as HYDRA, StormCAD, CulvertMaster, SWMM, or InteliSOLVE are the most efficient means of evaluating the HGL and designing the system elements.

3.1.2 Culverts

Classified as having either entrance or outlet control. Either the inlet opening (entrance control), or friction loss within the culvert and/or backwater from the downstream system (outlet control) will control the discharge capacity. Culverts must be analyzed for both types of flow. Whichever produces the highest headwater depth must be used.

A. Entrance Control

Entrance control occurs when the culvert is hydraulically short (when the culvert is not flowing full) and steep. The flow regime at the entrance is critical as the water falls over the brink (water passes from subcritical to supercritical flow). If the tailwater covers the culvert completely (i.e., a submerged exit), the culvert will be full at that point, even though the inlet control forces the culvert to be only partially full at the inlet. The transition from partially full to full occurs in a hydraulic jump, the location of which depends on the flow resistance and water levels. If the flow resistance is very high, or if the headwater and tailwater levels are high enough, the jump will occur close to or at the entrance. Design variables for culverts operating under entrance control shall be determined from Figures 3.1.2.1 through 3.1.2.7.

B. Outlet Control

If the flow in a culvert is full for its entire length, then the flow is said to be under outlet control. The discharge will be a function of the differences in tailwater and headwater levels, as well as the flow resistance along the barrel length. Design variables for culverts operating under outlet control shall be determined from Figures 3.1.2.8 through 3.1.2.14.

Alternatively, refer to the Federal Highway Administration website for these charts and more (www.fhwa.dot.gov/bridge/hec05.pdf). Download applicable design manuals, reports, and FHWA hydraulics engineering software such as Bridge Waterways Analysis Model (WSPRO), FHWA Culvert Analysis, and HDS 5 Hydraulic Design of Highway Culverts from:www.fhwa.dot.gov/bridge/hydsoft.htm. HEC-RAS may also be used for culvert analysis.

3.1.3 Open Channels/Bridges

Proper evaluation of the velocity, depth, and width of flow requires analyses of the structures and conditions that impact the flow. Boundary flow conditions upstream and downstream from the open channel system must be established. The standard-step backwater method, using the energy equation, can be used to determine the depth, velocity, and width of flow. Major stream obstructions, changes in slope, changes in cross-section, and other flow controls can cause significant energy loss. In these cases, the energy equation does not apply and the momentum equation must be used to determine the depth, velocity, and width of flow.

Hydraulic calculations for open channels may also be made by the U.S. Army Corps of Engineer's 'HEC-RAS River Analysis System' computer programs. The HEC-RAS system is intended for calculating water surface profiles for steady and unsteady, gradually varied flow. The system can handle a full network of channels, a dendritic system, or a single river reach. HEC-RAS is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles. (Available from http://www.hec.usace.army.mil/software/hec-ras/).

3.2 Analysis of Systems by Computer Models

The following list provides commonly used computer programs for analyzing specific hydraulic systems. This is not an exhaustive list and alternates may be used with approval by the Director.

A. Enclosed pipe systems in gravity flow

SWMM Transport (EPA)
HYDRA (FHWA)
StormCad (Haested Methods)
DR3M (USGS)
InteliSOLVE

B. Enclosed pipe systems in pressure flow

SWMM EXTRAN (EPA)
MOUSE (DHI)
HYDRA (FHWA)
StormCad (Haested Methods)
InteliSOLVE

C. Culverts

HY8 (FHWA)
WSPRO (USGS)
CulvertMaster (Haested Methods)
HEC-RAS (USACE)

D. Open Channels and Culverts/Bridges

HEC-RAS (USACE)
WSPRO (USGS)
HYCHL (FHWA)
SWMM Transport and EXTRAN (EPA)
DR3M (USGS)

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CHAPTER 4 ENCLOSED SYSTEMS

Enclosed conveyance systems consisting of inlets, conduits and manholes may be used to convey storm water runoff where site conditions will not permit the stable and non-erosive use of natural or engineered channels. Where used, such systems must be designed in accordance with design criteria and performance standards given below.

4.1 General Guidance

4.1.1 Where storm drainage along the side lot lines of residential property is to be in conduit, the conduit shall extend to a point at least thirty (30) feet to the rear of the front building line or ten (10) feet beyond the rear line of the structure, whichever is greater. At low points in the street (sump condition) a surface swale shall be provided over this area to contain at least a 100-year storm.

4.1.2 Where culverts are placed under roadways, they shall extend to at least the limits of the right-of-way or the toe of the roadway embankment, whichever is greater, except that culverts shall not outlet on hillsides.

4.1.3 Pipe drains or culverts constructed to intercept the flow of ditches or channels, which may be enclosed in a conduit at a future time, shall be installed at adequate depth to permit their extension at the same required depth.

4.1.4 Curb inlets shall be installed at or near intersections where they are deemed necessary for the safety of pedestrian and vehicular traffic. Curb inlets shall be placed to intercept the storm water before it reaches the crosswalks. No curb inlet shall be located within a crosswalk.

4.1.5 In non R-1 and R-2 areas, or planned district equivalents, tributary areas which drain across public sidewalks must not exceed three thousand (3,000) square feet of impervious area, including roofs discharging upon paved areas, or nine thousand (9,000) square feet of sodded areas, or in proportional amounts for a combination of such areas. Paved, roofed, or impervious areas exceeding three thousand (3,000) square feet shall be provided with drains for discharge into storm conduits, channels, or street gutters.

4.1.6 Any concentration of surface flow in excess of 2.0 cfs for 10-year frequency rain shall be intercepted before reaching the street right-of-way and shall be carried by an enclosed storm drain to connect with a drainage structure at the low point in the street right-of-way or to discharge to a watercourse.

4.1.7 The enclosed system shall start where there are 2 acres or 6 platted lots of contributing drainage area, whichever is less overall area.

4.1.8 Inlets in yard areas must be side-open inlets to prevent clogging due to leaves, grass, and other yard debris.

4.2 Existing Drainage Systems

Existing on-site drainage system pipes, structures, and appurtenances within the project limits may be retained as elements of an improved system providing:

- They are in sound structural condition.
- Their hydraulic capacity, including surcharge, is equal to or greater than the capacity required by these criteria.
- Easements exist or are dedicated to allow operation and maintenance.

Discharge from an existing upstream storm drainage system shall be computed assuming its capacity is adequate to meet the performance criteria given below. The computed discharge shall be used to design the new downstream system even if the actual capacity of the existing upstream system is less.

4.3 Inlet Design

4.3.1 Type

Only Type M curb opening inlets shall be used on public streets for design flows. Grated inlets, with pedestrian and bicycle friendly grates where appropriate, may be used to pick up trickle flows. Other inlets or combinations of inlets must be approved by the Director.

4.3.2 Configuration

Opening length, inside	4.0 ft (min)
Width, perpendicular to curb line, inside	3.0 ft (min)
Setback curb line to face	1.5 ft (min)
Opening, clear height	8.0 in.(min)
Gutter depression at inlet	8.0 in.(min)
Throat Section lengths	
(a) Upstream Gutter Transition	10.0 ft (min)
(b) Both sides in sump and upstream side on slopes	10.0 ft (min)
(c) Downstream on slopes	5.0 ft (min)

These minimum dimensions are illustrated by Figure 4.3.2.1 in Appendix F.

4.3.3 Design Method

Inlets shall be designed using Figures 4.3.3.1 and 4.3.3.2 in Appendix F. Note that the Theoretical Captured Discharge (left side of chart) is the design capacity. A 20% reduction for clogging factor shall be used for all inlets. Deflectors must be used when the street grade is greater than or equal to 4%.

4.3.4 Location/Spread of flow in streets

Inlets shall be located to provide clear driving lanes for various street classifications as specified below.

4.3.5 Spread in streets

A. Local residential streets – inlets shall be spaced at such an interval as to provide one clear lane of traffic having a minimum width of 10 feet during the peak flows of a design storm having a 10 year frequency.

B. Collector streets and local non-residential streets – inlets shall be spaced at such an interval as to provide one clear lane of traffic having a minimum width of 12 feet during the peak flows of a design storm having a 25 year frequency. The clear lane shall be centered on the centerline of the roadway.

C. Arterial streets – inlets shall be spaced to provide one clear lane of traffic in each direction during the peak flows of a design storm having a 25 year frequency. Two lanes of traffic being defined as 20 feet in width, being 10 feet on either side of the crown, for undivided roadways, and as one 12 foot wide lane on each side of the median for divided roadways.

D. In addition to the inlet spacing requirements for limiting width of flow, inlets shall be located to limit gutter flow from crossing the street centerline at the time of peak discharge for the design storm to the following limits:

CONDITION CAUSING FLOW TO CROSS STREET CENTERLINE	MAXIMUM DISCHARGE, (CFS)
Transitions to superelevation	1.0
Sump at midblock	Not Allowed
Overflow of non-gutter flow	See 4.5

Note: For new development, any inlets at intersections shall be positioned outside the curb return and sidewalk ramps.

4.3.6 Freeboard Requirements

Any opening through which surface water is intended to enter (or may backflow from) the system shall be 0.5 feet or more above the hydraulic grade line in the inlet during the design storm, specified in Table 4.5.1.1, where such calculation must include junction (so-called “minor”) losses.

4.4 Gutter Flow

4.4.1 Gutter Capacity

Gutter capacity may be determined from Izzard's Formula below (see 4.4.1.1for graphical solution):

$$Q = \frac{0.56z \cdot S_O^{1/2} \cdot D^{8/3}}{n}$$ where:

Q = The gutter capacity in cubic feet per second

z = The reciprocal of the average cross-slope, including gutter section, in feet per foot

S_O= The longitudinal street grade in feet per foot

D = The depth of flow at curb face in feet

n =Manning's "n", see Table 3.1.1.1

A. Street Grade on Vertical Curves, S_O

The following formula shall be used to determine the street grade at any point on a vertical curve using plus for grades ascending forward and minus for grades descending forward, in feet per foot.

$$S_O = S_1 + \frac{x \cdot (S_2 - S_1)}{L}$$ where:

S_O = The street grade on a vertical curve at point x, in feet per foot

S_1 = The street grade at the PC of a vertical curve, in feet per foot

S_2 = The street grade at the PT of a vertical curve, in feet per foot

x = The distance measured from the PC to point x on a vertical curve, in feet

L = The total length of a vertical curve, in feet

4.5 Protection for Streets

4.5.1 Street Crossings

Concentrated flow not conveyed in the gutter system, shall be conveyed under streets to prevent vehicles from being swept from the roadway in infrequent storms. These crossings (bridges, culverts or underground systems) must be designed to completely convey flood flows without street overtopping in accordance with the following table:

TABLE 4.5.1.1
DESIGN STORM CAPACITY FOR STREETS

Street Classification	Min. Design Storm Capacity	Design Storm Return Interval
Arterial	1%	100 year
Collector and Local Non-Residential	4%	25 year
Residential	10%	10 year

4.5.2 Roadway Overtopping

Concentrated flow in excess of the minimum design storm may only overtop the roadway if the following conditions are met:

- The span of the structure opening is less than 20 feet.

- The peak stormwater runoff from the 1% storm is 250 cfs or less unless a guard rail is installed on the downstream side of the roadway.

Such overflow depths at low points in roadways during the 1% storm will be limited to 7 inches measured at the high point in the roadway cross section; except that it also shall not exceed 14 inches at the deepest point in the roadway cross section. Depths may be limited where necessary by reverse grading the downstream right of way area, by lengthening the vertical curve of the roadway, by reducing roadway crown, or by other similar means. Roadway overtopping depths shall be determined by integrating the broad crested wier formula across the roadway profile. Each incremental flow can be determined by using the formula:

$$q = Clh^{3/2}$$

where:

q = the flow for an increment of profile length (width of flow)
l = the incremental width
C = a flow coefficient that shall not exceed 3.0
H= the average depth of flow at each increment

The total flow Q is the sum of the incremental flows. Depth determinations can be made through an iterative process where successive depths are chosen, Q is calculated for each depth and then compared to the known Q at the overtopping point.

Overflow protection criteria provides additional accessibility criteria at major stream crossings for emergency personnel, and provides the public with protection against injury and property damage.

4.6 Enclosed Pipe Systems

4.6.1 General Requirements and Guidance

A. The crown(s) of pipe(s) entering a drainage structure should be at or above the crown of the pipe exiting from the structure and must provide a minimum fall of the invert in the structure of 0.2 feet. Alternatively, the crowns of the pipes may be at or above the HGL of normal flow at design frequency.

B. The maximum spacing between manholes shall be 400 feet for 30 inch diameter or less; 600 feet for pipes more than 30 inch diameter.

C. Prefabricated wye and tee connections may be utilized provided at least one of the pipes is greater than 30 inches in diameter.

D. Short radius bends may be used on 33 inch and larger pipes when flow must undergo a direction change at a junction or bend. A manhole shall always be located at the end of such short radius bend. A headloss coefficient equal to that of a similar deflection at a structure shall be used for the bend/manhole combination for HGL calculations.

E. Select pipe size and slope so that the velocity of flow will increase progressively, or at least will not appreciably decrease, at inlets, bends or other changes in geometry or configuration.

F. Pipes shall be installed in a straight line and grade for all pipes 30 inches in diameter and smaller.

G. Do not discharge the contents of a larger pipe into a smaller one, even though the capacity of the smaller pipe may be greater due to steeper slope.

H. Conduits are to be checked at the time of their design with reference to critical slope. If the slope on the line is greater than critical slope, the unit will likely be operating under entrance control instead of the originally assumed normal flow. Conduit slope should be kept below critical slope if at all possible. This also removes the possibility of a hydraulic jump within the line.

I. Avoid meandering, off-setting, and unnecessary angular changes; angular changes in alignment should be limited to a maximum of 90 degrees.

J. Pipes should be parallel or perpendicular with the centerline of streets unless otherwise unavoidable.

4.6.2 Capacity

Capacity shall be determined in accordance with Chapter 3. Minimum design pipe size shall be 12-inch in diameter; 15-inch in diameter for pipe under street pavement. For partially full pipe flow, Figure 4.6.2.1 can be used to obtain hydraulic parameters of the flow.

4.6.3 Pressure Flow

After considering the discussion presented at the beginning of Chapter 3, an enclosed system may be designed to operate with pressure flow, for the design storms specified in Table 4.5.1.1 if all the following conditions are met:

A. The Hydraulic Grade Line (HGL) must be 0.5 feet below any openings to the ground or street at all locations.

B. Appropriate energy losses for bends, transitions, manholes, inlets, and outlets, are used in computing the HGL. This is addressed in the hydraulics section.

C. Energy methods (Bernoulli's equation) must be used for the computations.

4.6.4 Outfalls and Energy Dissipation

A. The outfall, as defined in Chapter 5 of all enclosed systems shall include energy dissipation sufficient to transition outlet flows to velocities and applied shear stresses consistent with the normal flow conditions in the receiving channel for the range of flows up to and including the 1% storm. Calculations, at a minimum, shall include the 100%, the 10% and the 1% storms.

B. Figure 4.6.4.1 provides guidance for riprap aprons for various size pipes and limitations on the use of aprons.

C. Outfalls shall not be permitted on hillsides. Flow shall be piped or run in an engineered channel to a point as outlined in Section 5.1.5.

D. Energy dissipation for lateral outflows to natural streams and edge of buffer outfalls to riparian buffers shall follow the guidance in Section 5.1.5.

E. Effective energy dissipating structures shall be provided to meet the requirements stated in Tables 5.1.4.1 and 5.2.7.1 when conditions are beyond the limitations of rock aprons. Examples of energy dissipating structures are:

- Hydraulic Jump Basins
- Impact Baffle Basins
- Plunge Pool and Plunge Basin

- Slotted-Grating or Slotted Bucket Dissipaters
- Stilling Basins
- Internal Pipe Rings

1. The suitability of each method is site dependent. The FHWA computer program HY8 Energy (downloadable free from the FHWA hydraulics website) lists methods and applicability. Energy dissipaters shall be designed according to the criteria and procedures defined in professionally acceptable references. Several such references include:

- United States. Department of the Interior. Bureau of Reclamation. Design of Small Dams. 1987 ed. Denver: GPO, 1987.

- United States. Department of the Interior. Bureau of Reclamation. A Water Resource Technical Publication. Engineering Monograph No. 25. Hydraulic Design of Stilling Basins and Energy Dissipaters. 1978 ed. GPO, 1978.

- Federal Highway Administration (FHWA), 1983. Hydraulic Design of Energy Dissipaters for Culverts and Channels, Hydraulic Engineering Circular (HEC) No. 14, along with HY8Energy design software

- US Army Corps of Engineers, 1994. Hydraulic Design of Flood Control Channels, US Army Corps of Engineers Engineer Manual EM 1110-2-1601.

- Bridge Scour and Stream Instability Countermeasures Experience, Selection, and Design Guidance (Latest Edition), National Highway Institute,HEC No. 23.

- River Engineering for Highway Encroachments, Highways in the River Environment, U.S. Department of Transportation, Federal Highway Administration, Publication No. FHWA NHI 01-004, December 2001.

2. Grade control shall be provided downstream of the dissipator or shall be constructed integrally with it. In addition, the developing agencies' recommendations for armoured transition to natural channel shall be included as part of the design.

4.6.5 Minimum Pipe Slope

The minimum allowable pipe slope for any pipe is 0.4 %.

4.6.6 Velocity Within the System

The velocity within the system shall be between 2 and 15 feet per second for the design flow.

4.6.7 Loading Conditions for Structures

Shall be in accordance with City of Columbia Street and Storm Sewer Specifications and Standards.

4.7 Overflow Provisions

Each conveyance element of the stormwater drainage system (whether open, enclosed, or detention) shall include an overflow element if the in-system capacity is less than the 1% storm flows. Overflow systems shall:

4.7.1 Be designed to route downstream any amount of the 1% storm exceeding the in-system design capacity specified in Table 4.5.1.1, in section 4.5, while providing 1 foot of freeboard to low exterior sill or low opening of adjacent structures.

4.7.2 Include streets, engineered channels, redundant piping, spillways, parking lots, drives or combinations thereof.

4.7.3 Limit the maximum water surface elevation generated by the 1% storm as specified in Section 4.5.2.

4.7.4 Conform to local standards regarding dedicated easements and/or restricted uses for overflow systems; consult with the City for requirements.

4.7.5 Be limited to the natural drainage basins. Transfer of overflow out of a natural drainage basin (e.g. a thoroughfare straight-graded through a drainage basin with a sump in another drainage basin) may sometimes be allowed at the discretion of the Director. These overflows must be added to the overflows in the receiving drainage basin and the combined overflow must still meet the criteria within this chapter.

4.8 Easements

Permanent easements shall be dedicated to the City for operation and maintenance of the storm drainage facilities. Easement width shall not be less than 16 feet, or the outside width of the pipe or conveyance structure plus 5 feet or cover the 100yr spread; whichever is greater. Easements shall be centered on the pipe.

4.8.1 Permanent

The Director may require wider easements when other utilities are located within the same easement and/or when the depth of cover is greater than 4 feet.

4.8.2 Temporary

Temporary construction easements of sufficient width to provide access for construction shall be acquired when the proposed work is located in areas developed prior to construction.

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CHAPTER 5 OPEN CHANNELS

5.1 NATURAL STREAMS

5.1.1 Scope

This section sets forth requirements for the protection of natural streams as a conveyance for stormwater. Unless otherwise provided for by City, State, or Federal ordinance, regulation, or standards, existing natural streams shall be preserved and protected in accordance with this section. Where natural streams are not preserved, the drainage will be handled through systems designed in accordance with Chapter 4, Enclosed Systems or Section 5.2, Engineered Channels.

5.1.2 Stream Preservation and Buffers Zones:

Stream buffers shall be per the City of Columbia Stream Buffer Ordinance in Chapter 12A of the City Code of Ordinances.

5.1.3 In Stream Construction - General Requirements:

If construction is proposed within the inner stream buffer as defined in Chapter 12A-233 of the ordinances, a stream assessment is required. The information generated by the stream assessment shall be used in designing the bridges, culverts, utility work, stormwater outfalls (other than edge of buffer outfalls) and any other in-buffer infrastructure. Construction in streams or their buffer zones shall conform to the general requirements of this subsection and to the appropriate specific requirements of the subsections following:

A. Stream Assessment

A stream assessment shall be conducted in accordance with Section 5.1.4 for all construction within the inner stream buffer zone except for discharge outfalls. Along streams for which no official buffer exists, (i.e. streams in land which was platted prior to the passage of the stream buffer ordinance) the language of the buffer ordinance (Article X of Chapter 12A) will be applied to determine how close to a stream work can be done without requiring an assessment.

Purpose: A stream assessment provides basic knowledge about the stream: bed and bank material, vegetation, general erosion trends, debris and sediment, bank full depth, etc. These things have a direct effect on potential designs.

As part of the assessment, a rating will be determined; if the stream rates poor the engineer should consult with someone who specializes in stream work; if fair, the engineer should be sure to address those items that rated poorly when designing grade control; if good, the engineer can generally imitate the existing riffle.

B. Hydraulic and Geomorphic Energy Management

The pre-project and post-project hydraulic and energy grade lines for the 100%, 10%, and 1% storm flows shall be plotted. The region of a stream where in-stream construction causes a change in these grade lines is considered the zone of influence. The engineer shall provide adequate sediment transport and channel protection designs within the zone of influence. The extent of the zone of influence downstream shall be generally limited by energy dissipation and grade control. The upstream limit of the zone may extend a distance beyond the construction as a drawdown or backwater curve. Within the zone of influence, the energy of the flow on the channel will be evaluated for the potential of excessive scour, deposition, initiation of headcuts, or other instability. Use of vegetation to increase bank resistance and minimize increases or abrupt changes in velocities is recommended. Bank or bed stabilization may be required in areas of unavoidable velocity or depth increase.

C. Sediment Transport Continuity

The minimum post-project applied shear to the bed of the channel in the zone of influence at the 100%, 10%, and 4% ultimate-conditions storm flow shall not be less than 90% of the minimum pre-project applied shear in the zone, so as to maintain the ability of the channel to transport sediment. If such shear stresses cannot be maintained, the engineer will evaluate the potential for future sediment removal or maintenance.

D. Transitions

In-stream structures shall be designed to gradually blend into the natural channel and provide a smooth transition of both geometry and roughness.

E. Repair of Disturbed Banks

The side slopes of banks where construction occurs shall be restored with vegetation as quickly as possible.

F. Professional Judgment

Natural streams are complex, variable, and strongly governed by local geology and climate. These standards are based on general guidelines of good practice on typical local streams and may not be optimal or sufficient in all cases. Specific requirements may be increased or waived by the Director if conditions warrant and decisions should be guided by prudent engineering and fluvial geomorphic judgment.

5.1.4 Stream Assessment

The Steam Assessment provides the framework for engineers to gather stream data needed to develop a general indication of the stream condition and to possibly help guide design. A stream assessment, as required above, will extend a minimum of one wavelength up and downstream of the area to be impacted by construction. (or 10 channel widths in streams with ill-defined meander patterns.) It shall include the components listed below, except as modified by the Director to better fit project needs. An example submittal is shown in Figures 5.1.4.1A and B in Appendix F.

A. Plan Form Analyses and Inventory

The plan-view of the natural stream using aerial photographs or planning-level aerial survey shall be plotted to an appropriate scale. Full topographic surveys of the entire reach study area is not required. The following items shall be shown:

1. Ordinary high water mark.

2. Top of bank.

3. Ground contours (if available).

4. "Bank-full" and floodplain for the 1% ultimate-conditions storm (see paragraph B).

5. Thalweg, locations of riffles and pools, and spacing between riffles (see paragraph C).

6. Exposed bedrock, areas of differing bed and bank soil or rock materials, and the D50 and shear stress ratio at each riffle (see paragraph D)

7. Active scour and depositional areas, point bars, and islands.

8. Vegetation within the buffer zone, called out as mowed grass, mowed with trees, unmowed grass and plants, wooded, and bare. Trees greater than 6" diameter within 25 feet of the top of bank shall be located individually or by group. The species of dominant trees should be noted.

9. Meander length, wavelength, meander amplitude, bank-full width, and radius of curvature for each bend.

10. Total meander and valley length and sinuosity for the reach.

11. Photographs of main channel, streamside vegetation, and each riffle, appropriately referenced to plan-view location.

B. Bank-full Width, Depth and Discharge

The geomorphic "bank-full" width, depth, and discharge shall be estimated using field indicators as detailed in Chapter 7 of USDA (1994). If field indicators are inconclusive, "bank-full" flow shall be estimated as the elevation and spread of the of the 1-year storm flow, based on routing the 1-year storm flow through the existing channel using Mannings equation at a representative cross section. This assumption is intended to provide a rough upper estimate of the bank-full flow.

C. Longitudinal Profile and Sections

The elevations of the profile along the thalweg shall be field surveyed to the nearest 0.1 ft. and the following features noted: riffles, pools, exposed bed rock, and advancing headcuts (areas of bed elevation change that appear to be actively migrating upstream). The top of left and right bank and any field indicators of bank-full flow such as limits of woody vegetation or top of point bars shall be plotted at correct elevation along the profile. The bank-full flow and 1% (100-yr) storm flow profiles shall be plotted.

One field cross section shall be surveyed through each pool and riffle, and the depth and width of bank-full flow and floodplain for the 1% storm shall be shown on each section.

Where pools and riffles are not well defined, survey one cross section every 7 channel widths.

D. Bed and Bank Materials Analyses

The type of rock exposed in the bed and banks shall be identified. Bank soils shall be reported by Uniform Soil Classification using the visual-manual procedures (ASTM D 2488-00). Estimate the median partical size (D50) for each reach where the bed material visually changes. A shear stress ratio shall be calculated for each riffle based on the applied shear at bank-full flow divided by the critical shear of the D50 particle in the riffle, using methods and tables described below.

E. Critical Shear Stress Analysis

The Shear stress ratio shall be determined in accordance with the guidelines below:

1. The average applied shear stress (τ_o) may be calculated from the hydraulic data as follows:

   $\tau_o = \gamma$ RS

   where γ is the specific weight of water (62.4 pcf), R is the hydraulic radius at bank-full flow, and S is the water surface slope along the main channel bank-full flow, averaged over several bends in the area of the intervention. Effective flow may be calculated using methods described in detail in USACE 2001 or may be assumed to be equivalent to the 100% storm.

2. The critical shear stress, τ_c, is that at which particles in the bed or bank are entrained and scour ensues.

   Critical shear stresses are listed in Table 5.1.4.1 in Appendix F. This table presents critical shear for sediment-laden water and where noted, clear water. The user must exercise judgment as to future conditions. Clear water values may be used below a heavily piped area, concrete channels designed to contain the future flows or immediately below a managed detention pond.

3. The ratio of average boundary stress to critical stress is the shear stress ratio:

   shear stress ratio = τ_o / τ_c

   If bed and bank materials are distinct, then the shear stress ratio should be calculated for each. If the shear stress ratio of either streambed or bank is greater than one, the channel is prone to near-term adjustment and any interventions should be designed to prevent accelerated erosion. If the bed consists of rock, then the shear stress ratio is not applicable, unless the rock is prone to fracturing, slaking, or break-up, in which case the median size of particle should be used for calculation of the ratio.

F. Plan-Form Ratios

The following ratios shall be calculated, and those that lie outside the typical range shall be noted. Streams are highly variable and ratios outsides these ranges do not necessarily indicate problems:

Ratio	Typical Range
Thalweg length / Valley length (sinuosity)	1.1 to 1.5
Meander length / Bank-full width	10 to 14
Radius of curvature / Bank-full width	2 to 5
Riffle Spacing / Bank-full width	5 to 7

G. Channel Condition Scoring Matrix

Using information summarized above, the channel condition scoring matrix given in Table 5.1.4.2 in Appendix F shall be completed. A rating of 12 indicates a stream of moderate stability that will likely require only standard levels of protection during construction. A rating between 12 and 18 indicates that special measures may be necessary to address those issues rated as poor in the assessment. Streams with a rating greater than 18 may exhibit significant system-wide instability and should be studied in more detail by experts in river engineering and fluvial geomorphology. (This scoring system is newly developed and its results shall be considered provisional.)

H. Using the Stream Assement Data and the Channel Condition Scoring Matrix

For channels with a score of 9.8 to 12, use the data gathered in the Stream Assesment (stream shape, bed and bank material, allowable shear, bank full depth and width, etc.) to guide channel intervention designs. For scores of 12 to 18, use the data not only to guide the design, but to make accommodations for those parameters that were rated fair and poor in the design. For scores of 18 or greater, additional analysis is necessary to identify dominant process driving instability.

5.1.5 Discharge Outfalls

Energy management and sediment continuity checks are not required; however, energy dissipation shall be provided to reduce post-development shear stress to pre-development shear stress at the outfall. Discharge points for outflows from enclosed systems or constructed channels shall be designed as one of the following:

A. Primary Outfall

Primary outfalls are those where the entire upstream channel is replaced by an enclosed system or constructed channel which discharges flow in line with the direction of the downstream segment. Energy dissipation shall be provided at the outlet to reduce velocities per Section 4.6.4. Grade control downstream of the outlet and energy dissipater shall be provided to prevent undermining of the outfall by future headcuts per Section 5.1.8. The alignment and location of the outfall and associated energy dissipater and grade control should make a smooth transition into the downstream channel. Primary outfalls shall be used whenever the contributing drainage area of the outfalls is greater than 80% of the downstream channel.

B. Tributary Outfall

Tributary outfalls are primary outfalls located on a tributary to a larger downstream segment. Energy dissipation and transition to natural stream flow should take place in the tributary at least ten channel widths upstream of the confluence. Grade control in the tributary upstream of the confluence shall be provided. Tributary outfalls may be used in all situations of tributary flow.

C. Lateral Outfall

Lateral outfalls are small outfalls that discharge from the banks of a natural stream. Outfalls shall be located to enter on a riffle or from the outside of a bend, but should generally not enter from the inside of a bend. Outfall pipes shall be oriented perpendicular to the flow of the stream with the invert at or slightly below top of the next downstream riffle. Outfalls shall be flush with or setback from the bank. The bank shall be shaped to provide a smooth transition and protected with reinforced vegetation (preferred) or rip-rap. If the outfall is in a bend, it shall be set back from the existing bank a sufficient distance to account for future meander migration, and the transition shall be graded and reinforced with vegetation. Rip-rap or hard armor protection should not be used in a bend. Perpendicular outfalls may only be used when the contributing drainage area of the outfall is less than 40% of that in the downstream channel.

D. Edge of buffer Outfall

Edge-of-buffer outfalls are discharge points in the outer half of the riparian buffer that return the discharge to diffused overland flow. Outfalls shall be designed to spread flow and allow overland flow and infiltration to occur. Overland flow shall be directed to run in the outer portion of the buffer parallel to the channel direction to increase length of flow and prevent short-circuiting directly into the stream. Low weirs and berms may be graded to direct flow and encourage short-term ponding. The buffer zone utilized for infiltration shall be maintained in dense, erosion-resistant vegetation designed to withstand the shear stresses of a 10% storm. Edge-of-buffer outfalls that are part of a system of upland drainage using multiple small, distributed overland swales and ditches instead of pipes may provide significant infiltration and water quality treatment. Edge-of-buffer outfalls shall only be used if each individual outfall can be designed to operate without scour or the formation of gullies.

At no time shall Edge of buffer outfalls discharge into a buffer area with an average slope greater than 2% from receiving stream flowline elevation to the edge of buffer outfall flowline elevation.

5.1.6 Culverts, Bridges, and Above Grade Crossings

A. Crossings should generally be located on a riffle. If the width of the roadway, pathway or above grade crossing is large relative to the length of the riffle, then grade control structures shall be provided at the riffles upstream and downstream to isolate the impact of the crossings. If a crossing cannot be made at a riffle, avoid armoring a pool and place at-grade grade control structures at the riffle immediately upstream and downstream of the crossing. Maintain sediment transport continuity and avoid altering the channel cross-section.

B. Realignment of channels to accommodate crossings and their approach should be avoided and minimized as much as possible. Any areas relocated shall have the banks stabilized in accordance with Section 5.1.9 and shall be included in the reach isolated by upstream and downstream grade control.

C. For bridges the multi-stage channel shape should be maintained and additional area to convey the design flow shall be above the elevation of the bank-full discharge.

D. For multi-cell pipe and culvert crossings that have a cumulative width larger than the bank-full width, those cells wider than the bank-full width shall have a flowline located at the lowest estimated bank-full depth, or a weir wall or other structure upstream of the culvert opening shall be installed with a height to prevent access to the cell during flows less than bank-full flow. The weir wall shall be designed so that the hydraulic efficiency at the 1% ultimate conditions storm is not reduced. Without these features, the culvert will have a tendency to build up deposits and lose capacity or require frequent maintenance, particularly when crossings are located in sharp bends or streams with high sediment loads.

E. Culverts shall be designed so that there is no backwater effect at all flows up to the 50% storm discharge. Energy management and sediment transport continuity shall be checked.

5.1.7 Below Grade Stream Crossings

A. Below grade stream crossings primarily include utility pipelines. Crossings should generally be at riffles and grade control structures constructed at the riffle, in addition to or constructed integrally with any encasement of the line the utility may require.

B. If riffle crossing is not feasible, the crossing should be in a pool that is protected by a downstream grade control structure. The top of crossing elevation should be at least two feet below the top of grade control. Crossings under pools should not be armored directly, but are protected by downstream grade control.

C. Below grade crossings shall be perpendicular to the stream whenever possible. If a perpendicular crossing is not feasible, the grade control protecting the crossing shall be perpendicular.

D. Constriction or alteration of the pre-existing channel shape shall be avoided. If alteration occurs, sediment transport continuity and energy management shall be verified. Stream banks shall be repaired using vegetative methods whenever possible and the hydraulic roughness of the repaired stream bank should match that of the undisturbed stream banks.

5.1.8 Grade Control

A. Where grade control structures are required, they shall be placed in locations where the stream bed profile will support the creation or continuance of a riffle. The flowline of the grade control shall match the existing riffle.

B. Where stream slope is less than 2%, the Newberry-style grade control structure detailed in Figure 5.1.8.1 is recommended. Structures shall be constructed from durable stone sized using USACE methodology for steep channels (USACE EM 1110-2-1601, page 3-8, Equation 3-5). Rock shall generally comply with USACE gradations as given in (USACE EM 1110-2-1601, Hydraulic Design of Flood Control Channels, Chapter 3). Shotrock with sufficient fines to fill voids may be used. The use of filter fabric and uniform gradations of stone are discouraged in stream beds.

C. Where grades are in excess of 2%, low-drop step structures should be used.

D. Alternate styles of grade control may be approved by the Director. Guidance for grade control design is given in Thomas et.al.

E. Construction of new grade controls structures may be waived by the Director if it is determined that existing riffles are adequate to prevent or retard advancing headcuts, or if it is preferable to The City to accept the risk of future headcut than to further disturb the channel.

5.1.9 Bank Stabilization Projects

A. Bank stabilization projects should generally be limited to cases where existing buildings or infrastructure face significant property damage or safety issues. Projects to stabilize banks to facilitate reductions in buffer widths for new construction shall be avoided.

B. Prior to stabilization, the causes of the instability should be considered, including the stream's current phase of channel evolution (Interagency, 2001, Chapter 7) and direction of meander migration. Stabilization may be unnecessary if a channel has ceased incision and widening and is in the process of deposition and restoration. If stability issues appear widespread or complex, a systematic evaluation of the stream system by professionals with expertise in river engineering and fluvial geomorphology may be justified.

C. Instability caused by geotechnical failure (slumping of banks due to weak soils in the adjacent slopes) shall be distinguished from fluvial failure (erosion of banks caused by stream flows). For geotechnical issues, a geotechnical engineer shall evaluate the slope stability. Geotechnical designs shall provide for a 1.5 factor of safety (ratio of theoretical resisting forces to driving forces) against slope failure where it would endanger buildings, roadways, or other infrastructure, unless a lower factor of safety is approved by the Director.

D. Bank stability projects shall have a design life greater than the useful life of the facility being protected, or a life cycle cost analyses shall be performed that considers replacement and repair over the entire protection period. Responsible parties for future maintenance shall be identified.

E. Stabilization should begin and end at stable locations along the bank. Bank stabilization should be limited to areas of potential erosion and are rarely required on the inside of bends. For long projects, stabilization may alternate from side to side and is rarely necessary across an entire cross section. The existing cross section should be mimicked to the extent practical and need not be planar or uniform over the entire length. Grade control shall be provided at the riffle both upstream and downstream of the stabilization to isolate it from the surrounding stream and protect the foundation from undercutting. Control at intermediate points for longer projects may also be required. Energy management and sediment transport continuity shall be checked, and energy dissipation provided if necessary.

F. "Hard-Armor" projects are those projects that use rip-rap, placed stone, gabions, retaining walls, or other rigid structures to provide geotechnical and fluvial stability. Such projects shall be designed in accordance with EM 1110-2-1205 (USACE, 1989), EM1110-2-1601 (USACE, 1994), or HEC-11 (FHWA 1989). Materials shall be sized to prevent dislodgement in the 1% storm. Gradation should comply with USACE or FHWA recommendations. Stones should be placed to maintain roughness and variations. All material shall be well placed to ensure interlock and stability. Materials shall be keyed into the bed and banks with adequate allowance for scour along the toe and the structure should have adequate foundation. Vertical walls should be avoided when possible as they tend to concentrate scour at their toe and are typically smoother than the natural channel.

G. Soil bioengineering involves the use of living vegetation in combination with soil reinforcing agents such as geogrids to provide bank stabilization by increasing soil shear resistance, dewatering saturated soils, and by reducing local shear stresses through increased hydraulic roughness.

H. Bio-engineering projects shall be designed in accordance with the principals of NRCS (1996) and Gray and Sotir (1996). Designs will be tailored to the urban environment by consideration of the requirement for immediate functionality upon construction, the extreme variability and high shear stress of urban flows and the availability of mechanized equipment and skilled operators.

I. Selection of plants and specifications for planting methods and soil amendments shall be prepared by a professional competent in the biological and stabilization properties of plants.

J. Plants selected shall be appropriate to local conditions and shall be native varieties to the greatest extent practical. Evaluation of local conditions includes assessment of site microclimate, bank slope, soil composition, strength and fertility, type and condition of existing vegetation, proximity to existing infrastructure, soil moisture conditions and likelihood of wildlife predation. Engineering factors influencing plant selection include frequency, height and duration of inundation, near-bank shear stress, size and volume of bed load as well as depth and frequency of scour.

K. Plants may be either locally harvested or purchased from commercial nurseries. When harvesting, no more than 10% of a given stand may be removed and no plant on the state rare or endangered species list may be harvested or damaged in harvesting operations. Plant material grown near the metropolitan area is adapted to local climatic conditions and is preferred over more remote sources. Some species such as red maple are particularly sensitive to locale and may only be used if locally available. Seed, plant plugs, rhizomes, whips, live stakes, bare root and container stock may be used. Turf grasses, noxious or invasive species shall not be used. A variety of plant species shall be used to provide greater reliability to a design. For critical functions such as protection from toe scour a minimum of three species should generally be employed.

L. Soil bioengineering methods are properly applied in the context of a relatively stable stream system, and relevant general requirements for all stream bank stabilization projects given in this section apply to bio-engineered projects. Soil bioengineering alone is not appropriate when the zone of weakness lies below the root zone of the plantings, or when rapid draw down can occur, such as in a spillway or dam embankment.

M. Composite methods are those which employ both hard armor and soil bio-engineering. Typically, armor for toe protection in critical locations is provided, with soil-bioengineering for the remainder. Design principals for both hard armor and soil-bioengineering shall be observed as appropriate.

N. In-stream Stability Structures: In-stream structures are used to focus flow, control grade, dissipate energy and selectively lower near-bank stress. Stream barbs, weirs, guide vanes, vegetative sills, longitudinal peak stone, and grade controls are among the more commonly used in-stream structures. When constructed of natural material such as rock, such structures also create aquatic habitat. They may be used alone or in combination with hard armor, bio-engineering or composite methods. In-stream structure design is a river engineering practice and is beyond the scope of this standard. Preliminary guidance and references for the design of some common structures is given in Castro (1999) and Interagency (2001).

5.1.10 Stream Restoration

Restoration of urban streams is defined as the re-establishment of natural channel geometry, materials and vegetative buffers with the intent of restoring natural geometry and functions to streams that have been disturbed or eliminated. While there are significant potential ecological and quality of life benefits from stream restoration, successful design is data-intensive and requires an interdisciplinary approach. Design of stream restoration projects is beyond the scope of this standard. Interagency (2001) describes the general procedures, benefits, and requirements of stream restoration.

5.2 ENGINEERED CHANNELS

5.2.1 Scope

The criteria in this section apply to created open channels or modified existing open channels where a stream buffer does not exist.

5.2.2 Easements

Permanent easements shall be dedicated to the City for all open channels.

A. Engineered Channels

Easements shall be 16 feet wide or wide enough to contain the water surface from the 1% return frequency storm, whichever is greater. Easements shall be continuous between street rights-of-way. When an improved channel begins or ends at a point other than the right-of-way of a dedicated street, a 16-foot or wider easement graded to provide maintenance equipment access shall be dedicated from the end of the channel to a street right-of-way. These are minimum requirements.

Generally, easements shall be required for swales that collect stormwater runoff from more than two properties or as required by the City.

B. Roadside Channels

Roadside ditches are engineered channels that are located wholly or partly within the street right-of-way. Roadside ditches in the street right-of-way do not require an easement. Otherwise, roadside ditches shall have a dedicated easement from the street right-of-way extending to five feet outside of the top of the outside bank of the channel.

5.2.3 Design Storm

Engineered channels shall be designed to completely contain the 1% return frequency storm and be stable during the 10% return frequency storm.

5.2.4 Velocity

Flow velocity in open channels (with the exception of roadway gutters) shall not exceed the following:

Flow depths greater than 6” - 6 feet per second
Flow depths 6” or less - 15 feet per second (or whatever the lining can withstand, whichever is less)

5.2.5 Freeboard

Freeboard shall not be required above the design headwater pool elevation at the culvert entrance. However, the low floor of adjacent structures shall be 1’ above the 1% return frequency storm water surface elevation.

5.2.6 Channel Linings

A. Minimum lining height shall be the selected design storm water profile plus at least a 0.5-foot freeboard.

B. All channel linings, except turf, shall contain provision for relieving back pressures and water entrapment at regular intervals and shall be provided with a filter underlayment to prevent soil piping.

C. Lining height on the outside bend of curves shall be increased by:

$$y = \frac{D}{4}$$ where:

y = Increased vertical height of lining in feet
D = Depth of design flow in feet

D. Increased lining height shall be transitioned from y to zero feet over a minimum of:

$30 \times y$ feet downstream from the point of tangency (P.T.).

$10 \times y$ feet upstream from the point of curvature (P.C.).

5.2.7 Lining Material

The types of lining material listed in Table 5.2.7.1 in Appendix F shall be used to control damage and erosion. All riprap and gabion linings shall be designed with a filter fabric. The design of the lining material shall protect the channel for conditions up to the 1% storm. This criterion may be reduced to the 10% storm if the Director approves and if responsibility for repair of channel linings in storms greater than 10% is clearly established.

Other types of lining materials not specifically listed in Table 5.2.7.1 in Appendix F may be used when approved by the Director.

Concrete lined open channel bottoms are discouraged.

5.2.8 Side Slopes

Side slopes shall not be steeper than:

- 3 horizontal to 1 vertical for turf lining.
- 2.5 horizontal to 1 vertical for all other lining materials, unless a geotechnical analysis indicates a steeper slope can be used.
- Side slopes may need to be flatter than 3H:1V, if necessary to stabilize slopes.

5.2.9 Alignment Changes

Alignment changes shall be achieved by curves having a minimum radius of:

$$R = \frac{V^2 \cdot W}{8D}$$ where:

R = Minimum radius on centerline in feet
V = Design velocity of flow in feet per second
W = Width of channel at water surface in feet
D = Depth of flow in feet

5.2.10 Vertical Wall Channels

Vertical walls may be used for structural lining of improved channels when site conditions warrant; subject to the following special requirements:

- Walls shall be designed and constructed to act as retaining walls.
- Adequate provisions shall be made for pedestrian entry/exit from the channel.

5.2.11 Energy Management

Use of grade control structures can be used to manage boundary shear.

Energy dissipation structures shall be designed in accordance with Natural Stream Section.

CHAPTER 6 DETENTION/RETENTION AND WATER QUALITY

This chapter sets forth the design criteria and requirements for detention and for water quality treatment.

Detention is required for all new development in order to prevent flooding problems from developing in the future. In some cases where future flooding problems can be shown to be of minimal concern, detention which focuses on protecting downstream channels may be installed instead of flood prevention detention.

Likewise, water quality treatment is required for all new development. The amount and configuration of water quality treatment is determined by applying the Level of Service Method outlined in Section 6.8, Water Quality Goals and BMP Selection.

Detention and water quality requirements for redevelopment projects depend in part on language in the City of Columbia Code of Ordinances 12A-87. For redevelopment projects where detention is required and downstream problems exist, the detention requirements are determined on a case-by-case basis. For redevelopment where detention is required but no known problem exists downstream, the amount of detention required is reduced as presented in Figure .6.8.1 Stormwater Redevelopment

6.1 Detention

The default detention requirement is Flood Prevention Detention.

Channel protection detention (which sometimes uses less space) may be installed if it can be shown that flooding problems will not develop downstream. This can be shown by one of three methods;

1. Performing a flood study downstream of the proposed development to the point of interest; where the development constitutes 10% of the total watershed. The flood study must be performed based on the parameters in Section 6.1.1. If the post development water surface is within two feet or less of the lowest entry to a structure, and/or if a road is overtopped by 6.5 inches or more (at the deepest point of the driving surface) in the 100-year event, then a flooding problem will be assumed to exist. Otherwise, channel protection detention may be used.

2. Demonstrating that the outflow from the channel protection detention basin meets or exceeds requirements for flood protection detention, i.e. the peak flow goals are met for all the required events. If this can be demonstrated, then channel protection detention may be used without performing the flood study.

3. Demonstrating, with proper supporting information, that there are no structures or roads that can flood downstream to the point of interest (as described in number 1 above). This must be demonstrated to the satisfaction of City staff and the supporting information must include, at a minimum, a drawing showing the drainage area with the most up-to-date aerial topo and planimetrics showing structures and roads. Structures and/or roads more recent than the aerials must be drawn on the topo based on field surveys.

6.1.1 Flood Study Parameters

A. Hydrology
   NRCS modeling as given in Chapter 2 using a fully developed condition in all areas contributing to the point of interest.

B. Hydraulics
   Use the Army Corps of Engineers HEC-RAS program with flow analyzed as subcritical. The modeling of the stream may need to be carried downstream beyond the point of interest to account for backwater effects of bridges, culverts or other stream obstructions.

C. The City hydrology model will be made available to the engineer. As part of the study, the engineer will modify and/or add to that model and provide a copy of the approved hydrology and hydraulics model back to the City before a permit will be issued for the development.

6.2 Access and Easements

Permanent access and buffers must be provided for maintenance of a detention and/or water quality facility with the following minimum requirements:

6.2.1 The water surface of the design storage pool shall be a minimum of 20 feet from building structures. A greater distance may be necessary when the detention facility might compromise foundations or if slope stability is a consideration. The vertical seperation between the maximum ponding elevation and the lowest floor of applicable surrounding structures shall be a minimum of 2.0 feet.

6.2.2 A 15 foot wide access strip, with cross slopes less than 5 horizontal to 1 vertical, shall be provided around the perimeter of the facility, unless it can be demonstrated that all points of the facility can be maintained with less access provided.

6.2.3 The property owner shall also maintain a minimum 15 foot wide reinforced turf or gravel surface access route to the 2-year storm elevation in the detention facility from a street or parking lot at slopes no greater than 12%.

6.2.4 Structures, inlet pipes, outlet pipes, spillways, and appurtenances required for the operation of the facility shall also be provided access which is no less than easement widths established in Chapter 4 and 5, Enclosed Systems and Open Channels, respectively.

In developments where a public street is proposed across the top of the dam of a permanent lake, a right-of-use agreement shall be executed between the City of Columbia and the developer/owner. This right-of-use agreement shall specify that the City of Columbia will maintain the street pavement, sidewalks, street curb inlets and accompanying piping. The ownership, mainteneance of the dam, outlet structures and overflow spillway shall be the responsibility of the developer/owner or the homeowners association.

Easements shall be provided per the Stormwater Management Ordinance.

6.3 Maintenance and Continued Performance

Maintenance responsibility (for instance, whether it is the responsibility of the developer or the Homeowner's Association) for all elements of the detention facility shall be designated prior to construction of any stormwater management facility.

6.4 Performance Criteria

6.4.1 General Provisions

A. Detention/retention facilities shall have 1,000 acres or less area tributary to the facility.

B. Dams which are greater than 10 feet in height but do not fall into State or Federal requirement categories shall be designed in accordance with the latest edition of SCS Technical Release No. 60, "Earth Dams and Reservoirs", as highest hazard rated structures.

C. All lake and pond development must conform to local, state, and federal regulations. Legal definitions and regulations for dams and reservoirs can be found in the Missouri Code of State Regulations, Division 22.

D. For redevelopment projects the required detention is some percentage of what would be required if the site were being developed from a greenfield.

The basin shall be sized using CN=78 for the pre- condition and the actual post redevelopment CN for the post- condition. Then calculate an intermediate CN which represents the percentage reduction in detention specified in Figure 6.8.1..

For example, if the flow chart specifies a 75% reduction in detention, and the post-redevelopment CN=90,
then 90-78=12,
12*0.75=9,
and 78 + 9 = 87.

Therefore, use a pre-development CN of 87 and calculate the basin size and outlet(s) as normal.

6.4.2 Computational Methods

A. Time of Concentration and Travel Time

Refer to Chapter 2, Hydrology for acceptable hydrology methods.

B. Temporary Storage Volume

A preliminary value of the storage requirement may be obtained through methods outlined in (SCS, 1986, Chapter 6) or other acceptable methods. The storage shall be checked during routing of design hydrographs through the basin and adjusted appropriately.

C. Hydrograph Routing

The storage indication method (Modified Puls) of routing a hydrograph through a detention basin may be utilized. Reference: Chow, 1964.

D. Release Rate

Channel Protection
Release rate for the channel protection volume shall be such that the time between the centers of mass of the inflow and outflow hydrographs of the 1-year storm shall be at least 24 hours, except that one half inch shall be the smallest control orifice size. (See section 6.4.3.H.)

Flood Protection
The maximum release rate from any development and redevelopment shall be controlled by limiting the post-development storm water release rates to the predevelopment rates for the 1, 2, 10 and 100 year storms (the 100%, 50%, 10% and 1%, respectively) .

Where flood protection detention is installed in redeveloping areas as outlined in Section 6.4.1.D, the predevelopment rate shall be determined per Chapter 2, Sections 2.2.2.B and 2.2.2.E.

6.4.3. Primary Outlet Works

The primary outlet shall be designed to meet the following requirements:

A. The outlet shall be designed to function without requiring attendance or operation of any kind or requiring use of equipment or tools, or any mechanical devices.

B. All discharge from the detention facility when inflow is equal to or less than the 25-year inflow shall be via the Primary outlet.

C. The design discharge rate via the outlet shall continuously increase with increasing head and shall have hydraulic characteristics similar to weirs, orifices or pipes.

D. For dry detention basins, the design shall allow for discharge of at least 80 percent of the detention storage volume within 24 hours after the peak or center of mass of the inflow has entered the detention basin, except that discharges for channel protection basins shall be governed by 6.4.2.D.

E. Retention basins (Ponds) shall be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack. A reverse-slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris.

F. The Director may require openings be protected by trash racks, grates, stone filters, or other approved devices to insure that the outlet works will remain functional.

G. Spillways shall be configured such that the outlet pipe(s) is readily accessible for maintenance when clogged. For instance, this means that maintenance workers will not have to wade through water more than knee deep to access the outlet pipe(s).

H. Control structures that are small require particular attention to prevent clogging. One way of doing so is to make an underdrain system the primary outlet for the very small basins. To do so, the soil above the underdrain should be free draining (a bioretention type mix should work) such that the soil and the inlet perforations of the underdrain provide far in excess of the design discharge. The control for the basin can then be provided by a perforated cap on the underdrain outlet.

6.4.4 Emergency Spillways

The emergency spillway may either be combined with the outlet works or be a separate structure or channel meeting the following criteria:

A. Capacity

In cases where the impoundment/emergency spillway is not regulated by either State or Federal agencies, the emergency spillway shall be designed to pass the 1% storm with 1 foot of freeboard from the design stage to the top of dam, assuming zero available storage in the basin and zero flow through the primary outlet. This design provides an added level of protection in the event of a clogged primary outlet or a subsequent 1% storm event that occurs before the flood pool from the initial storm event recedes to the principal outlet elevation.

6.4.5 Draw Down Provision

Drain works consisting of valves, gates, pipes, and other devices as necessary to completely drain the facility in 72 hours or less when required for maintenance or inspection shall be provided. Pumping will be considered as an alternative if the design engineer can show this is a readily available, viable solution.

6.4.6 Erosion Control

Primary outlet works, emergency spillways, and drain works, as well as conveyance system entrances to detention basins, shall be equipped with energy dissipating devices as necessary to limit shear stresses on receiving channels. See Table 5.1.4.1 in Appendix F for shear stress criteria.

6.5 Detention Methods

In addition to the foregoing criteria, the following shall be applicable, depending on the detention alternative(s) selected:

6.5.1 Wet Bottom Basins/Retention Facility

For basins designed with permanent pools:

A. Sediment Forebay

A sediment forebay shall be provided to trap coarse particles. Refer to Section B.13 in Appendix B for guidance.

B. Minimum Depth

The minimum normal depth of water before the introduction of excess stormwater shall be four feet plus a sedimentation allowance of not less than 5 years accumulation. Sedimentation shall be determined in accordance with the procedures shown in Figure 6.5.1 in Appendix F.

C. Depth for Fish

If the pond is to contain fish, at least one-quarter of the area of the permanent pool must have a minimum depth of 10 feet plus sedimentation allowance.

D. Side Slopes

The side slopes shall conform as closely as possible to regraded or natural land contours, and should not exceed three horizontal to one vertical. Slopes exceeding this limit shall require erosion control, safety measures and a geotechnical analysis.

6.5.2 Dry Bottom Basins/Detention Facility

For basins designed to be normally dry:

A. Sediment Forebay

A sediment forebay shall be provided to trap coarse particles and shall be designed (minimum) to the standard below.

Volume: V = 0.1-0.25 watershed-inches of volume per impervious acre in the are draining to the basin.

Surface Area: As (sf) = 0.066*WQv for I < 75%
As (sf) = 0.008*WQv for I ≥ 75%

Where: WQv = Water Quality Volume
I = Site Imperviousness

Depth: D = 3ft minimum to avoid resuspension of particles

Forebays must have an underdrain

See Design of Stormwater Filtering Systems (Claytor and Schueler, 1996) and Stormwater Management Pond Design Exaple (Claytor, 1995) for more information.

B. Interior Drainage

Provisions must be incorporated to facilitate interior drainage to outlet structures. Grades for drainage facilities shall not be less than ½ percent unless water quality features requiring flat surfaces are incorporated in the bottom.

C. Earth Bottoms

Earth bottoms shall be sodded or vegetated with appropriate native, non-invasive vegetation. A turf-type tall fescue blend is an acceptable alternative.

D. Side Slopes

The side slopes of dry ponds should be relatively flat to reduce safety risks and help to lengthen the effective flow path. Slopes shall not be steeper than three horizontal to one vertical and at least 25% of the perimeter shall have a slope of 5 to 1 or flatter.

E. Multipurpose Feature

These shall be designed to serve secondary purposes for recreation, open space, or other types of use which will not be adversely affected by occasional or intermittent flooding, if possible.

6.5.3 Rooftop Storage

Detention storage may be met in total or in part by detention on roofs. Details of such designs shall include the depth and volume of storage, details of outlet devices and downdrains, elevations and details of overflow scuppers, and emergency overflow provisions. Consideration shall also be given to wave action on structural loading conditions. Connections of roof drains to sanitary sewers are prohibited. Design loadings and special building and structural details shall be subject to approval by the Director.

6.5.4 Parking Lot Storage

Paved parking lots may be designed to provide temporary detention storage of stormwater on a portion of their surfaces. Generally, such detention areas shall be in the more remote portions of such parking lots. Depths of storage shall be limited to a maximum depth of seven inches, and such areas shall be located so that access to and from parking areas is not impaired.

6.5.5 Ponds and Lakes

Detention storage and/or stormwater quality treatment in natural ponds or lakes is not allowed. Detention storage and/or stormwater quality treatment in naturalized ponds and lakes is strongly discouraged. “Naturalized” in this context refers to ponds and lakes which were not created for urban stormwater management which have native vegitation on the banks and/or which have native plants or animals in the permanent pool.

Using such ponds or lakes for stormwater storage and treatment will likely lead to accelerated eutrophication which will ruin the water body or cause greatly increased maintenance.

6.5.6 Other Storage

All or a portion of the detention storage may also be provided in underground or surface detention areas, including, but not limited to, oversized storm sewers, vaults, tanks, swales, etc.

6.6 Required Submittals

6.6.1 The Owner shall submit the following information and data to the Director.

A. Elevation-area-volume curves for the storage facility including notation of the storage volumes allocated to runoff, sediment, and permanent residual water storage for other uses (wet basins only).

B. Inflow hydrographs for all design storms.

C. Stage-discharge rating curves for each emergency spillway, primary outlet works and combined outlets and overflows.

D. Routing curves for all design storms with time plotted as the abscissa and the following plotted as ordinates:

1. Cumulative inflow volume.
2. Cumulative discharge volume.
3. Cumulative storage.
4. Stage elevation

E. Operation and maintenance procedures for the facility including frequency of inspection and cleaning.

6.7 Additional Requirements:

6.7.1 Access

Provisions shall be made to permit access and use of auxiliary equipment to facilitate emptying, cleaning, maintenance, or for emergency purposes.

6.7.2 Underground Storage

Underground detention facilities shall be designed with adequate access for maintenance (cleaning and sediment removal). Such facilities shall be provided with positive gravity outlets. Venting shall be sufficient to prevent accumulation of toxic or explosive gases.

6.8 Water Quality Goals and BMP Selection

Water quality goals and BMP selection shall be met by following the August 2009 edition of the "Manual of Best Management Practices for Stormwater Quality" developed by the Kansas City Mid-America Regional Council (MARC) and the Kansas City Metro Chapter of the American Public Works Association (APWA), hereafer referred to as the KCBMP Manual.

Sections 4 through 8 of the above manual are adopted with exceptions and additions as noted below:

A. Exceptions
   1. Section 4.1 Development Conditions

   2. Figures 4 and 5 in Section 4.2.

   3. The steps for determining a Level of Service for previously developed sites in section 4.2.

   4. Section 5.1 Stream Buffers

B. Additions

   1. Value Ratings. The following practices have been evaluated and assigned a Value Rating based on the method outlined in the KCBMP Manual.

		Value Ratings				
BMP	Median Expected Effluent EMC TSS (mg/L)	Water Quality Value	Volume Reduction	Temperature Reduction	Oils/ Floatables Reduction	Overall Value Rating
Extensive Vegetated Roof [1]		2	1	1	2	6.0
Channel Protection Detention	20-50	2	1	0	1	4.0
Downstream Defender	20-50	2	0	0	1	3.0
Up-Flo Filter	20-50	2	0	0	2	4.0

First Defense	20-50	2	0	0	1	3.0
Aqua-Swirl		1	0	0	2	3.0
Inlet Filter Bag						3.0
ADS Water Quality Unit	20-50	2	0	0	1	3.0

		Value Ratings				
BMP	Median Expected Effluent EMC TSS (mg/L)	Water Quality Value	Volume Reduction	Temperature Reduction	Oils/ Floatables Reduction	Overall Value Rating
Stormtech Isolator Row[2]	20-50	2	0[2]	0[2]	1	3.0[2]
Stormtech Isolator Row (extended detention) [3]	20-50	2	1[3]	1[3]	1	5.0[3]
Contech CDS	~50	1	0	0	2	3.0
ADS Water Quality Unit in Series with Stormtech Isolator Row		4.5	1	1	2	8.5
ADS BayFilter	20-50	2	0	0	1	3.0
Flexstorm PC Inlet Filter[4]		1	0	0	2	3.0
First Defense in Series with Stormtech Isolator Row (extended detention)		4	1	1	2	8.0

1 This value is for a vegetated roof with a minimum growing medium thickness of 3 inches and a water retention/storage layer. The vegetation must be suitable for such locations, for example, sedum varieties. The plan for the roof should be prepared by an experience vegetated roof designer.

2 In order to receive this rating, follow manufacterer's recommendations and the following requirements apply:

1. Proposed uses and designs of the device must be in general conformance with the information and methodologies provided in the University of New Hampshire Stormwater Center *Final Report on Field Verification Testing of the StormTech Isolator Row Treatment Unit (June 2008)* and NJCAT *Technology Verification StormTech Isolator Row (August 2007)*.
2. The StormTech Isolator Row is approved as an off-line treatment process only. Storage should be provided for a minimum of 100% of the Water Quality Volume.

3. Provide two layers of geotextile fabric under the base of the system and one layer of geotextile fabric over the system. The maximum apparent opening size shall be 212 microns.

[3] In order to receive this rating, follow manufacterer's recommendations and the following requirements apply:

1. Proposed uses and designs of the device must be in general conformance with the information and methodologies provided in the University of New Hampshire Stormwater Center *Final Report on Field Verification Testing of the StormTech Isolator Row Treatment Unit (June 2008)* and NJCAT *Technology Verification StormTech Isolator Row (August 2007).*
2. The StormTech Isolator Row is approved as an off-line treatment process only. Storage should be provided for a minimum of 100% of the Water Quality Volume.
3. The water quality volume shall be detained for a minimum of 40 hours.
4. Provide two layers of geotextile fabric under the base of the system and one layer of geotextile fabric over the system. The maximum apparent opening size shall be 212 microns.
5. Provide a minimum of 12" of clean rock below the flow line of the perforated underdrain pipe to the extent of the footprint of the practice.

[4] Due to a smaller storage capacity, some inlet filters may need to be maintained more often than other practices. The maintenance agreement must be configured to reflect a reasonable maintenance schedule based on the capacity of the practice and the type of surface and the amount of area draining to it.

6.8.1 Water Quality for Redevelopment Sites

(Note: For further explanation of the detention requirement given in the chart below, see 6.4.1.D.)

Figure 6.8.1 Stormwater Management in Redevelopment

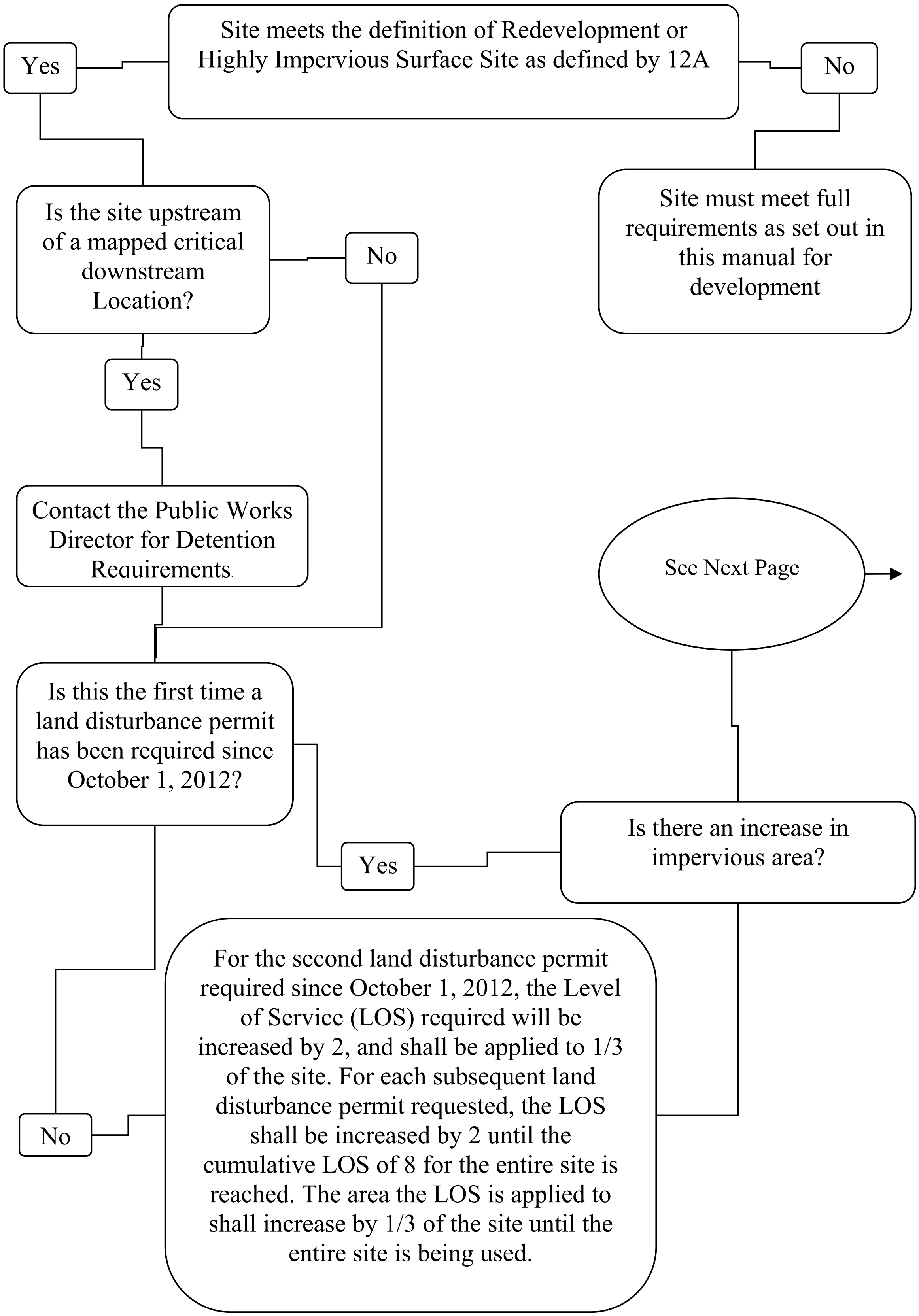
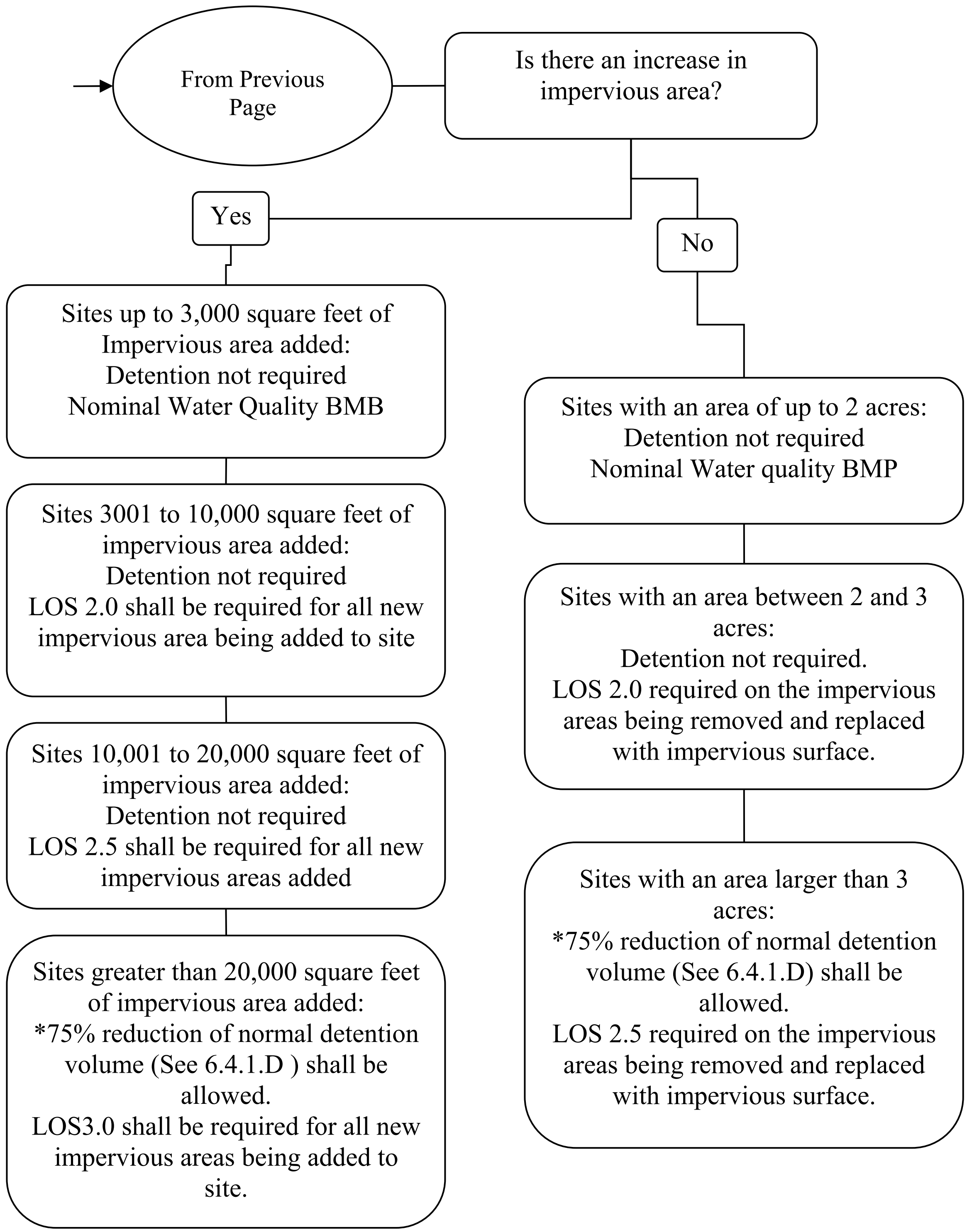


Figure 6.8.1 Stormwater Management in Redevelopment (continued)



*For each subsequent redevelopment the reduction is reduced by 25% until the site has achieved the normal detention required for new development.

6.8.2 Further Guidance/Requirements

A. KCBMP Section 8.5.5 Porous Pavement Design Requirements and Considerations

1. Three (or less)-to-one impervious-to-pervious shall govern the surface area of the pervious pavement.
2. Landscaped area (including turf, but excepting tree islands) must drain away from porous pavemets.
3. If roof drains are routed directly to the rock storage layer beneath the pavement, pretreatment must be provided to remove sediments and debris. The pretreatment must be easily accessible for cleaning and must be sized to allow the design flow into the storage layer in a 50% clogged condition.
4. Signage must be specified as part of the plan and installed with the development to clearly delineate the area of porous pavement and prohibit the uses of sand or cinders in winter conditions and prohibit sealing the area.
5. Stone used under the pavement must be double washed.

B. KCBMP Sections 8.1 Rain Gardens, 8.2 Infiltration Basins, and 8.3 Infiltration Trenches

1. Infiltration practices require a soils report per 12A-88 (f) (3). The design infiltration rate shall be 20% of the rate determined by the soils report.
2. Stormwater infiltration practices shall not be allowed to treat areas that may constitute stormwater hotspots as outlined in Section 4.4 of the KCBMP Manual.
3. Sand and stone in infiltration basins must be double washed.

6.8.3 Small Area BMP

For small impervious areas (less than 3000 square feet) a rain garden equal to 20% of the contributing impervious area may be installed. This area is to catch, filter and infiltrate the water quality storm from the impervious area.

These BMPs should be kept a minimum of 10 feet from building foundations. It is the desing engineer's responsibility to ensure that the BMP does not cause damage to adjacent structures, properties or operations.

Guidance for the small area BMPs may be found in Appendix A.

An extensive vegetated roof, a minimum of 3" thick, may be used for buildings. This option will provide other benefits such as increased roof life and less energy required for cooling than other buildings. It is strongly encouraged to work with a designer who has experience in detailing green roofs if this option is chosen.

6.8.4 Conflicting Language, Definitions or Rules

In any conflict between the KCBMP Manual and City Ordinances or other sections of the City of Columbia Stormwater Management and Water Quality Manual, the City of Columbia ordinances and manual shall take precedence.

CHAPTER 7 PLAN REQUIREMENTS

7.1 Scope

This section governs the preparation of plans for stormwater systems

7.2 General

The plans shall include all information necessary to build and check the design of storm drainage systems and related appurtenances. The plans shall be arranged as required by the Director. Plans shall be prepared and certified by a Registered Professional Engineer, licensed in the State of Missouri, and shall be submitted to the Director for review. The submittal shall consist of the following:

7.2.1 Calculation Summary

7.2.2 Required Plan Sheets

7.3 Calculation Summary

The Engineer shall submit a summary of all calculations and investigation analysis: hydraulic, hydrologic, erosion and sediment control, structural, geotechnical and others as necessary to adequately and fully explain the designs being submitted. The calculation summary shall indicate the methods outlined in Chapters 1 - 6 which were used to perform the calculations and determine the final results. These results shall be submitted on the forms labeled Figures 7.3.1, 7.3.2, 7.3.3, 7.3.4 and 7.3.5 in Appendix F. All the information required on the forms shall be provided. The Director may require additional supporting documentation when the results cannot be verified using the methods indicated in the summary.

7.4 Required Plan Sheets

The plans shall consist of:

7.4.1 Title sheet

7.4.2 General layout sheets

7.4.3 Plan and profile sheets, these may be combined or separate

7.4.4 Cross-section sheets

7.4.5 Drainage area map and table

7.4.6 Standard and special detail sheets, City standard structures are assumed where applicable

7.4.7 Traffic control plans (if required)

7.4.8 Temporary erosion control plans

7.4.9 Grading plans (if required)

7.4.10 Property line and easement sheets (if required)

Each sheet shall contain a sheet number, including the individual sheet number and the total number of sheets, proper project identification and all revision dates. The Engineer's seal shall appear on all sheets.

7.5 Sheet Sizes

Plans shall be submitted on 24 inch by 36 inch sheets.

7.6 Scales

Plans shall be drawn at a scale appropriate to clearly present the design and of not more than one (1) inch equals one hundred (100) feet. Bar Scales shall be shown on each sheet for each scale.

7.7 Required information for Title Sheet

7.7.1 Name of project.

7.7.2 Index to sheets.

7.7.3 A location map adequately showing the project location in relation to major streets, with north arrow and scale. Map shall be oriented with north arrow up.

7.7.4 A signature block for City approval.

7.7.5 Name, address and telephone number of the consulting engineer and owner/developer.

7.7.6 A legend of symbols shall be shown that apply to all sheets.

7.7.7 List containing name and telephone number of each utility company and state One-Call system.

7.7.8 Engineer's seal, signed and dated

7.7.9 Other information as required by the Director.

7.8 Required Information for General Layout Sheet

7.8.1 General Notes: Minor construction notes shall appear on the proper plans and profile sheets.

7.8.2 North arrow and bar scale. North arrow should be oriented up or to the right.

7.8.3 Surveyed or aerial base map detail indicating existing man-made or natural topographical features, such as buildings, fences, trees, channels, ponds, streams, etc. and existing utilities.

7.8.4 Subdivision information including, but not limited to Rights-of-Way, Property and lot lines, existing and proposed easements, subdivision nomenclature, Street names and other pertinent information impacting the project.

7.8.5 Identification and location of all existing and proposed drainage features.

7.8.6 Elevation and location of all applicable benchmarks: All elevations shall be based upon city datum. A minimum of two (2) benchmarks are required for each project.

7.8.7 Survey control line or base line with adequate ties to land lines.

7.8.8 Locations of test borings if taken.

7.8.9 Existing and finish grade contours at intervals of 2.0 feet or less in elevation; or equivalent detail indicating existing and finish grades and slopes.

7.8.10 The lowest elevation for the top of foundation for each lot. This elevation typically respresents the elevation of the top of the foundation however, in cases where a full basement or crawlspace is constructed the elevation will represent the lowest opening through the foundation into the basement or crawlspace. This elevation will need to be high enough to protect the structure from flooding per 4.7.1.

7.8.11 Addresses of homes abutting the projects, and current homeowner names associated with properties impacted by the project.

7.9 Required Information for Plan and Profile Sheets

7.9.1 North arrow and bar scale. North should be oriented up or to the right.

7.9.2 Existing man-made and natural topographic features, such as buildings, fences, trees, channels, ponds, streams, etc., and all existing and proposed utilities.

7.9.3 Identification and location of each storm drainage segment and existing utilities affecting construction.

7.9.4 Length, size and slope of each line or channel segment. The profile shall indicate the hydraulic grade line of the underground as well as the overland design flows.

7.9.5 Right-of-Way, property, easement lines and street names. The 1 percent floodplain and applicable stream buffers.

7.9.6 Location of test borings representing depth of drilled hole and refusal elevation if applicable.

7.9.7 Headwater elevation at the inlet end of each culvert.

7.9.8 Invert elevations in and out and top elevations of each structure shall be shown. At least two elevations shall be shown for inlet tops matching sloped grades.

7.9.9 Each utility line crossing the alignment shall be properly located and identified as to type, size and material. This information shall be to the best information available and provided through records, field prospecting and or excavation.

7.9.10 All station and invert elevations of manholes, junction boxes, inlets and other significant structures.

7.9.11 The profile shall show existing grade above the centerline as a dashed line, proposed finish grades or established street grades by solid lines. Each line shall be properly identified. The proposed sewer shall be shown as solid lines properly showing the inside top and bottom of pipe.

7.9.12 All structures shall be shown and labeled with appropriate drawing references.

7.10 Cross-Section Sheets

Cross-sections shall be drawn for all open channels. Sections shall be drawn at all structures, intersecting drainage systems, grade breaks and change in section. Additional sections may be required by City to adequately convey design. Cross-sections shall also provide for overflow drainage paths that are designated to convey overland flows in excess of underground system capacity. The following shall be indicated on each section.

7.10.1 Existing and proposed grades.

7.10.2 Elevation of proposed flow-lines.

7.10.3 Cut and fill end areas if required for bid quantities.

7.11 Drainage Area Map

The drainage area map shall be supported by a drainage table tabulating the physical properties of the drainage sub-basins, as well as the hydrologic and hydraulic properties of the design. The drainage map shall have the following.

7.11.1 North arrow and bar scale. North should be oriented up or to the right.

7.11.2 Drainage area boundaries for all watersheds including sub-watersheds of analysis including pass through waters, inlet drainage areas, culvert drainage areas and other points of interest.

7.11.3 Drainage system nomenclature matching that on the “designed” systems shown in the plans.

7.12 Standard and Special Detail Sheets

Detail sheets shall be included to show all details of appurtenances, materials and construction. Details shall conform to the requirements of the City and are to be drawn clearly and neatly with proper identifications, dimensions materials and other information necessary guide desired construction. City standard structures are assumed where applicable.

7.13 Traffic Control Plans

Traffic control plans shall conform to design and principals contained the most recent copy of Manual of Uniform Traffic Control Devices (MUTCD) and the City of Columbia Traffic Control Manual for Street Construction and Maintenance Operations.

7.14 Grading and Erosion Control Plan Sheets

Grading and erosion control plan sheets shall be per Chapter 12A of the City Code of Ordinances.

7.15 Property Line and Easement Sheets

Separate property line and easement sheets may be required by the Director. The information on this sheet shall be sufficient to display the existing and proposed property line and easement changes relative to the project.

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APPENDIX A

GENERAL GUIDANCE
FOR SMALL-AREA BMPS

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APPENDIX A
STRUCTURAL GUIDANCE FOR SMALL-AREA BMPS

A.1 Overview

The small-area BMP is meant to provide treatment for small areas with minimal design effort. The intent is to provide treatment of, and to infiltrate, rainfall events up to the water quality storm, 1.3 inches, which constitutes 90% of the average annual rainfall in central Missouri.

A.2 Rain Garden

A.2.1 Design Criteria

1. Excavation Depth = 3 feet minimum, Bottom Sand Layer = 6", Soil Depth = 27 inches, Mulch Depth = 3 inches
2. Ponding Depth depends on infiltration rate at Excavation Depth.

   For infiltration rates of less than 3 inches/day, configure the basin so that runoff from the impervious area soaks into the planting area but does not pool above the mulch.

   For infiltration rates of 3 inches/day or greater, build the basin so that water pools above the mulch to the same depth as the infiltration rate.
3. Bottom Surface Area = 20% of contributing impervious surface, must be flat but not required to be smooth.
4. The contributing area must be stabilized before final excavation and installation of the rain garden. A partial hole, 2 feet, deep may be dug and used as a sediment trap, with the sediment and remainder of soil dug out just before installing planting soil. Do not allow machinery on bottom surface of rain garden. If machinery must enter rain garden area, start digging at one end and work out so that machinery does not track on bottom of finished excavation. Excavation must be flat but not smooth. Do not scrape the bottom smooth since this will harm infiltration. When the bottom of the basin is approved, place 6 inches of sand then place the planting soil mix.
5. Planting Soil Mix: 80% coarse sand (concrete sand will work), 10% compost and 10% sandy loam topsoil.

6. Planting soil may be mixed inside or outside of the basin. To mix inside, place sand, compost and sandy loam in 6-inch, 1-inch and 1-inch lifts respectively. Till the compost and sandy loam into the 6 inches of sand thoroughly before placing and tilling the next lift. Alternatively, the sand, compost and sandy loam may be mixed outside the basin and placed in the basin in lifts of 8”. Lightly tamp or lightly water each lift of either method to encourage settling of the fill. Avoid overtamping or overwatering (and causing ponding) before basin is finished.
7. A 3-inch layer of shredded hardwood mulch or landscaping rock (hardwood mulch is preferred) should be placed on the surface.
8. Place a berm or otherwise construct the rain garden such that a flat, 6” ponding area, the same size as the bottom of the basin (the same as the design square footage), is formed over the mulch layer to catch and temporarily hold water from the impervious area until it can soak through the planting bed into the soil below.
9. See Diagram A.2.1 for further installation guidelines.

A.2.2 Planting

1. Plants are necessary for the proper function of a rain garden. A minimum plant density must be achieved in accordance with the following table. Actual location and spacing of the plants should be determined based on aesthetics and the health of the plants as well as considerations of other infrastructure such as overhead power lines.

Plant Types	**Plant Spacing**	**Coverage Area**
Grasses/Flowers	1.5 feet	7
Small Shrubs (<10 feet tall)	6 feet	75
Large Shrubs / Small Trees (10 to 25 feet tall)	8 feet	135
*Large Trees	16 feet	540

*Large trees must be installed 3-5 feet beyond the edge of the rain garden.

2. Generally, a mix of types is best to help the basin function optimally. Plants in a rain garden must be able to withstand very wet periods as well as hot, dry periods. Native plants that are adapted to wetland or mesic wetland sites will generally perform best. Consult Appendix A in the Kansas City BMP manual for more guidance as well as Appendix D in this manual.

3. Rain gardens which collect water from pavement should have salt tolerant plants.

4. It is strongly recommended that a landscape professional be consulted for help planning, installing and maintaining the plants.

A.2.3 Maintenance

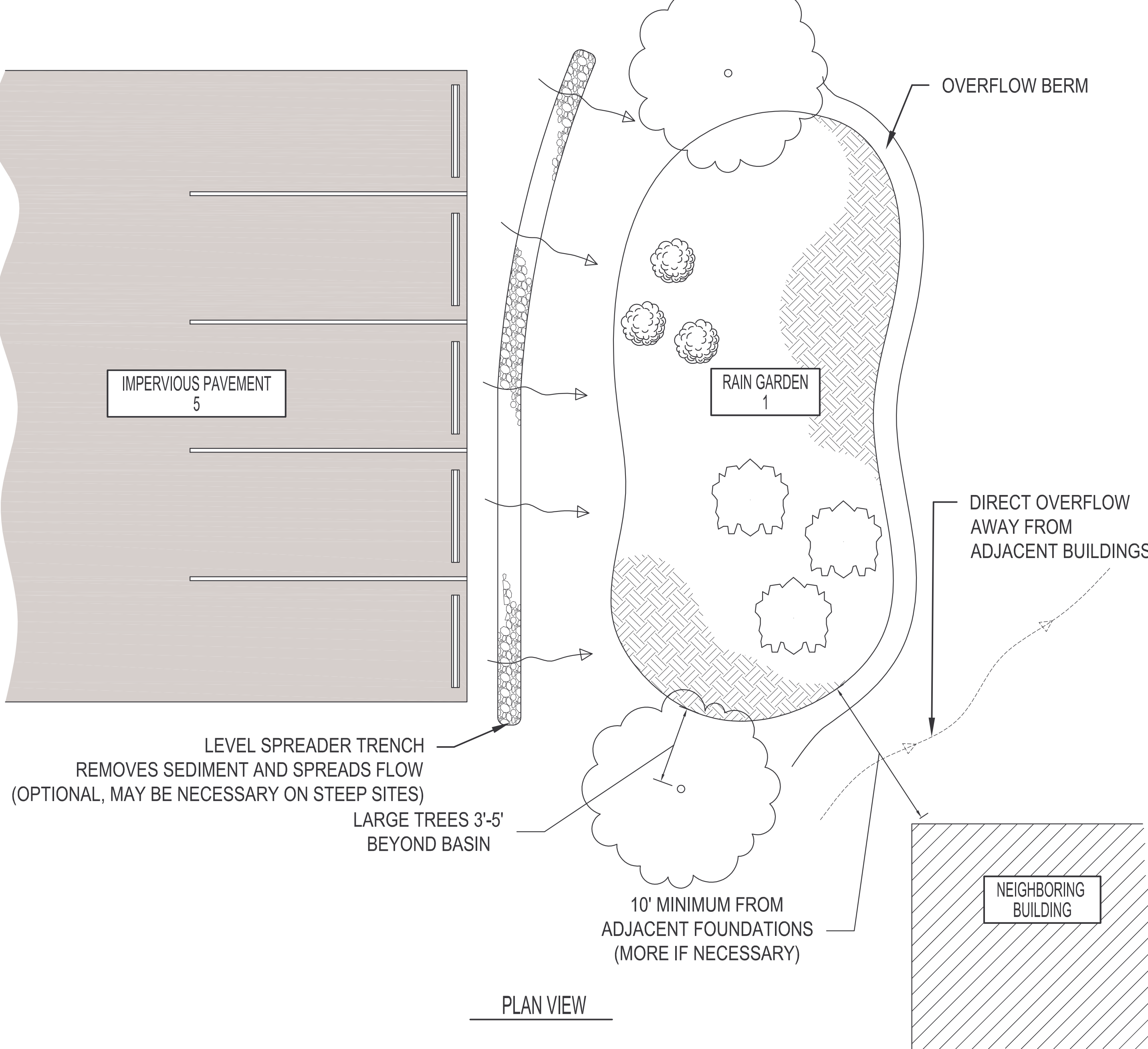
1. Rain gardens should be weeded weekly until native plants are established. And, per City Ordinance they must be kept free of weeds (plants that are in the garden by design will not be considered weeds.)

2. Water plants as needed during the first year of establishment and as needed during dry periods thereafter.

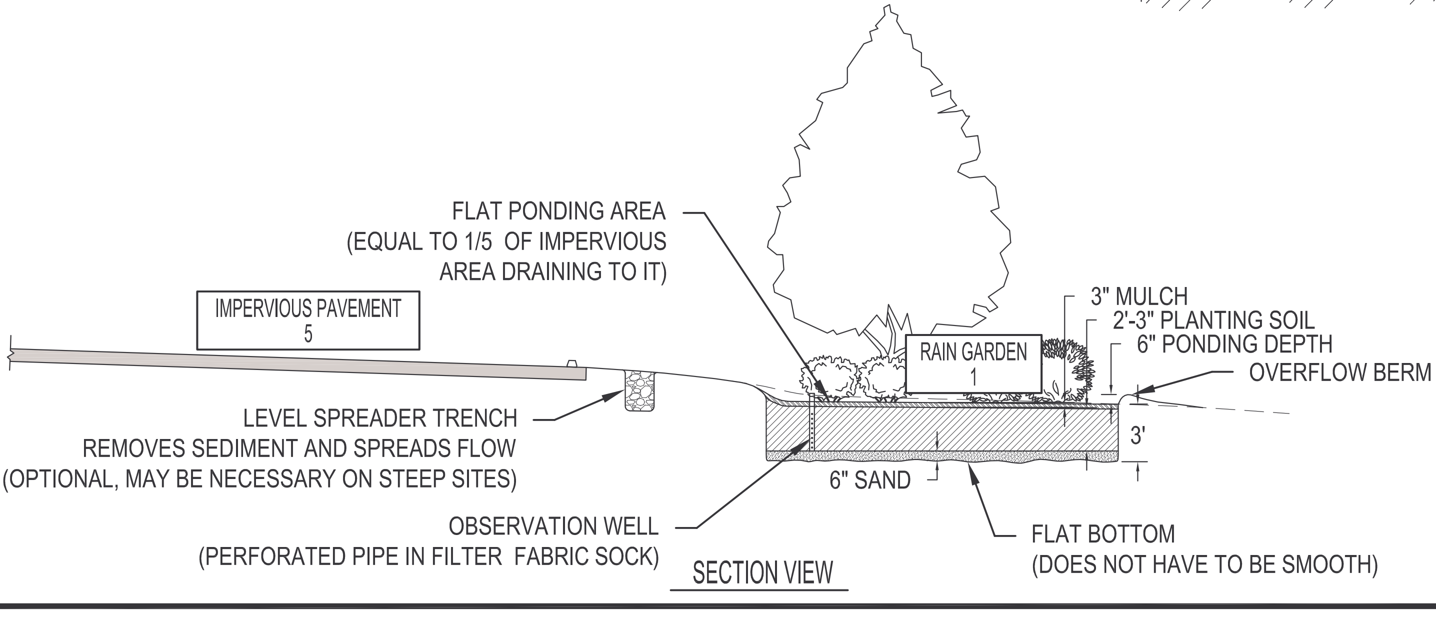
3. Avoid using fertilizer in and around the rain garden.

4. After the garden is established dead grasses and flower stems and leaves should be removed each spring by mowing or burning. (Allowing the stems, leaves and seeds to remain through the winter is not necessary, but it can provide food and cover to birds and other animals.)

Typical Maintenance Activities for Rain Gardens	
Activity	**Frequency**
Water Plants	As needed during first growing season and as needed during dry periods thereafter
Re-mulch bare spots	As needed
Treat diseased trees and shrubs	As needed
Inspect soil and repair eroded areas	Monthly
Remove litter and debris	Weekly
Add additional mulch	Once per year



PLAN VIEW



SECTION VIEW

APPENDIX D

RECOMMENDED PLANT MATERIALS

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APPENDIX D

TABLE D-1 RECOMMENDED PLANT MATERIALS FOR BMPs

Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
GRASSES																	
Prairie Cordgrass (Spartina pectinata)	P	W	T	G/BG	M/S	X		X	X	X	X			X	X	X	
Switchgrass (Panicum virgatum)	P	W	T	G	M/S	X	X	X	X	X	X			X	X	X	X
Western Wheatgrass (Pascopyrum smithii)	P	C	M	G/YG	M/S	X	X		X					X			X
Indian Grass (Sorghatrum nutans)	P	W	T	G	D/M	X	X	X	X	X	X	X		X		X	X
Big Bluestem (Andropogon gerardii)	P	W	T	G	M	X	X	X	X	X	X			X	X	X	X
Little Bluestem (Schizachyrium scoparium)	P	W	M	BG/G	D/M	X	X	X	X	X	X	X		X		X	X
Side Oats Grama (Bouteloua curtipendula)	P	W	M	P/G	D/M	X	X	X	X	X	X	X		X			
Canada Wildrye (Elymus canadensis)	P	C	T	G	D/M	X	X		X	X	X	X					
Virginia Wildrye (Elymus virginicus)	P	C	M	G	M	X	X	X	X	X	X			X	X	X	
Buffalograss (Buchloe dactyloides)	P	W	S	BG/G	D/M/S	X	X		X	X	X	X	X	X			
Redtop (Agrostis gigantea)	P	C	T	R/G	D/M/S	X	X		X	X	X	X					
Bermuda (Cynodon dactylon)	P	W	S	G	D/M/S		X		X	X	X	X	X	X			X
Blue Grama (Bouteloua gracilis)	P	W	S	BG	D	X	X		X	X	X	X	X	X			

APPENDIX D

TABLE D-1 RECOMMENDED PLANT MATERIALS FOR BMPs

Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
Hairy Grama (Bouteloua hirsuta)	P	W	S	BG	D	X	X		X	X	X	X	X	X			
Alta or Kentucky 31 Fescue (Festuca elatior var. arund.)	P	C	M	G	D/M/S	X	X		X	X	X	X		X			X
Kentucky Bluegrass (Poa pratensis)	P	C	S	BG	D/M	X	X		X	X	X	X		X			X
Perennial Ryegrass (Lolium perenne var. derby)	P	C	M	G	D/M	X	X		X	X	X	X		X			X
Red Creeping Fescue (Festuca rubra)	P	C	S	G/R	D/M	X	X		X	X	X	X		X			X
Prairie Dropseed (Sporobolus heterolepsis)	P	W	M	G	D/M	X	X		X	X	X	X		X			
Saltgrass (Distichlis stricta)	P	W	S	G	M/S		X	X	X	X	X	X	X	X		X	
Vine Mesquite (Panicum obtusum)	P	P	S	G	M/S		X	X	X	X	X	X	X	X		X	
Timothy (Phleum pratense)	P	C	M	G	M	X	X		X	X	X						X
Bottlebrush Grass Hystrix patula (Elymus hystrix)	P	C	M	G	M		X		X	X	X			X			
Woodland Brome Bromus pubescens	P	C	M	G	M		X		X	X	X			X			X
Seed Oats (Avena sativa)	A	C	T	G/BG	D/M	X			X								X
Annual Rye (Lolium multiflorum)	A	C	M	G	D/M	X			X								X

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Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
Winter Rye (Secale cereale)	A	C	T	G	D/M	X			X								X
FORBS AND LEGUMES																	
Illinois Bundleflower (Desmanthus illinoensis)	P	W	M	G/BR	M	X	X		X					X			
Purple Coneflower (Echinacea purpurea)	P	W	M	P	M	X	X		X					X	X	X	
Leadplant (Amorpha canescens)	P	W	M	B	M	X	X		X					X	X	X	
Showy Goldenrod (Solidago speciosa)	P	W	T	Y	M	X	X		X	X				X	X	X	
Maximillian Sunflower (Helianthus maximillianii)	P	W	T	Y	M	X	X		X	X				X	X	X	
Prairie Blazingstar (Liatris pycnostachya)	P	W	M	P/R	M	X	X		X	X				X	X	X	
Black-eyed Susan (Rudbekia hirta)	A/P	W	M	Y	M	X	X		X	X				X	X	X	
Purple Prairie Clover (Dalea purpurea)	P	W	M	P	M	X	X		X	X				X	X	X	
Common Dayflower (Commelina communis)	P	W	S	B	M	X	X		X	X				X	X	X	
Cut-leaf Coneflower (Rudbeckia laciniata)	P	W	T	Y	D/M	X	X		X	X				X	X	X	
Shrubby Cinquefoil (Potentilla fruticosa)	P	W	S	Y	M	X	X		X	X				X	X	X	

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Wild False Indigo (Baptisia alba var. macrophylla)	P	W	M/T	W/Y	M	X	X		X	X				X	X	X	
Showy Tick Trefoil (Desmodium canadense)	P	W	S/M	P	M/D	X	X		X	X				X	X	X	
Showy Sunflower (Helianthus lateriflorus)	A/P	W	T	Y	D/M	X	X		X	X				X	X	X	
False Sunflower (Heliopsis helianthoides)	P	W	M	Y	D/M	X	X		X					X	X	X	
Rough Blazing Star (Liatris aspera)	P	W	M	P/R	D/M	X	X		X					X	X	X	
Joe Pyeweed (Eupatorium maculatum)	P	W	M	P	M/W	X	X	X	X					X	X	X	
Boneset (Eupatorium perfoliatum)	P	W	T	W	W			X						X	X	X	
Sneezeweed (Helenium autumnale)	P	W	S	Y	M/W	X	X	X	X					X	X	X	
Prairie Cinquefoil (Potentilla arguta)	P	W	S	Y	D/M	X	X		X					X	X	X	
Heart-leaved Alexander (Zizia aptera)	P	W	S	Y	D/M	X	X		X					X	X	X	
Swamp Milkweed (Asclepias incarnata)	P	W	T	P/PK	M/W	X	X	X	X					X	X	X	
Marsh Aster (Aster puniceus)	P	W	M/T	W/Y	W			X						X	X	X	
Great Blue Lobelia (Lobelia siphilitica)	P	W	M	B	M/W	X	X	X	X					X	X	X	

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Common Water Horehound (Lycopus americanus)	P	W	S	W	W		X	X						X	X	X	
Common Mountain Mint (Pycnanthemum virginianum)	P	W	M	W	M/W	X	X	X	X					X	X	X	
Cup Plant (Silphium perfoliatum)	P	W	T	Y	M/W	X	X	X	X					X	X	X	
Purple Meadow Rue (Thalictrum dasycarpum)	P	W	M	P	M/W	X	X	X	X					X	X	X	
Blue Vervain (Verbena hastata)	P	W	S	P/B	M/W	X	X	X	X					X	X	X	
Canada Anemone (Anemone canadensis)	P	W	S	W	M/W	X	X	X	X					X	X	X	
Cream Gentian (Gentiana alba)	P	W	M	W	D/M	X	X		X					X	X	X	
Showy Evening Primrose (Oenothera speciosa)	P	W	S	W	D/M	X	X		X					X	X	X	
Indian Blanket (Gaillardia pulchella)	A	W	S	R/Y	D/M	X	X		X					X	X	X	
Nodding Onion (Allium cernuum)	P	C	S	PK	D/M	X	X		X					X	X	X	
Cream False Indigo (Baptisia bracteata)	P	W	S	W	D/M	X	X		X					X	X	X	
White Prairie Clover (Dalea candida)	P	C	S	W	D/M	X	X		X					X	X	X	

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Golden Alexanders (Zizia aurea)	P	W	M	Y	M/W	X	X	X	X					X	X	X	
Sky Blue Aster (Aster azureus)	P	W	M	B	D/M	X	X		X					X	X	X	
Blue Wild Indigo (Baptisia australis)	P	W	M	B	D/M	X	X	X	X					X	X	X	
Wild Bergamot (Monarda fistulosa)	P	W	M/T	P/B	D/M	X	X		X					X	X	X	
Smooth Penstemon (Penstemon digitalis)	P	W	M	W	M/W	X	X	X	X					X	X	X	
Ohio Spiderwort (Tradescantia ohiensis)	P	W	M	B	D/M/W	X	X	X	X					X	X	X	
Slender Mountain Mint (Pycanthemum tenuifolium)	P	W	S	W	D/M	X	X		X					X	X	X	
Wild Columbine (Aquilegia canadensis)	P	W	M	R	D/M	X	X		X					X	X	X	
False Solomon's Seal (Smilacina racemosa)	P	W	S/M	W	D/M	X	X		X					X	X	X	
Hoary Vervain (Verbena stricta)	P	W	M	P/PK	D/M	X	X		X					X	X	X	
Common Milkweed (Asclepias syriaca)	P	W	M	PK	M	X	X	X	X					X	X	X	
Partridge Pea (Cassia fasciculata)	A	W	S	Y	D/M	X	X		X					X	X	X	

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Bush Clover (Lespedeza capitata)	P	W	M	B	D/M	X	X		X					X	X	X	
Compass Plant (Silphium laciniatum)	P	W	T	Y	D/M	X	X		X					X	X	X	
Stiff Goldenrod (Solidago rigida)	P	W	M/T	Y	D/M	X	X		X	X				X	X	X	
Buttererfly Milkweed (Asclepias tuberosa)	P	W	M	OR	D/M	X	X		X	X				X	X	X	
Whorled Milkweed (Asclepias verticillata)	P	W	S	W	D/M	X	X		X	X				X	X	X	
Smooth Blue Aster (Aster laevis)	P	W	M	P/B	D/M	X	X		X	X				X	X	X	
Western Sunflower (Helianthus occidentalis)	P	W	M	Y	D/M	X	X		X	X				X	X	X	
Spotted Berfgamot (Monarda punctata)	P	W	M	Y/P	D	X	X		X	X							
Yellow Coneflower (Ratibida pinnata)	P	W	M	Y	D/M	X	X		X	X				X	X	X	
New England Aster (Aster novae-angliae)	P	W	M/T	B	M/W	X	X		X	X				X	X	X	
Thimbleweed (Anemone cylindrica)	P	W	S	G	D/M	X	X		X	X				X	X	X	
Heath Aster (Aster ericoides)	P	W	S/M	W	D/M	X	X		X	X				X	X	X	

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Silky Aster (Aster sericeus)	P	W	S	P/B	D	X	X		X	X							
New Jersey Tea (Ceanothus americanus)	P	W	S/M	G/BR	D/M	X	X		X	X				X	X	X	
Alum Root (Heuchera richardsonii)	P	W	S	GR	D/M	X	X		X	X				X	X	X	
Prairie Smoke (Geum triflorum)	P	W	S	R	D/M	X	X		X	X				X	X	X	
Wild Lupine (Lupinus perennis)	P	W	S	B	D	X	X		X	X							
Large Flowered Beard Tongue (Penstemon grandiflorus)	P	W	M	P/B	D	X	X		X	X							
Downy Phlox (Phlox pilosa)	P	W	S	PK	D/M	X	X		X	X				X	X	X	
Blue-eyed Grass (Sisyrinchium campestre)	P	W	S	B	D	X	X		X	X							
Old Field Goldenrod (Solidago nemoralis)	P	W	S	Y	D	X	X		X	X							
Riddell's Goldenrod (Solidago riddellii)	P	W	S/M	Y	M/W	X	X	X	X	X				X	X	X	
Flowering Spurge (Euphorbia corollata)	P	W	S	W	D/M	X	X		X	X				X	X	X	
Prairie Spiderwort (Tradescantia bracteata)	P	W	S	B	D/M	X	X		X	X				X	X	X	

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WETLAND SPECIES																	
Blueflag (Iris virginica)	P	W	S/M	B	M/W			X						X	X	X	
Arrowhead (Sagitaria fasciculate & latifolia)	P	W	S/M	W	M/W									X	X	X	
Needle Spikerush (Eleocharis acicularis)	P	W	S	BR	M/W			X						X	X	X	
Rice Cutgrass (Leersia oryzoides)	P	W	S	GR	M/W			X						X	X	X	
Bulrush var. Olney's (Scirpus americanus)	P	W	T	GR	M/W			X						X	X	X	
Common Spikerush (Eleocharis acicularis)	P	W	S	BR	M/W			X						X	X	X	
Cardinal Flower (Lobelia cardinalis)	P	W	M	R	M/W			X						X	X	X	
White Water Lilly (Nymphaea odorata)	P	W	S	W	W									X		X	
Wild Calamus (Acorus calamus)	P	W	M	W	W			X						X	X	X	
Bottlebrush Sedge (Carex hystricina)	P	W	M	BR	M/W			X						X	X	X	
Pointed Broom Sedge (Carex scoparia)	P	W	M	BR	M/W			X						X	X	X	
Dark Green Rush (Scirpus atrovirens)	P	W	M	GR	M/R			X						X	X	X	

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Wool Grass (Scirpus cyperinus)	P	W	M	GR	M/W			X						X	X	X	
Great Bulrush (Scirpus validus creber)	P	W	T	GR	M/W			X						X	X	X	
Common Spike Rush (Juncus effusus)	P	W	S	BR	M/W			X						X	X	X	
Wood Sedge (Carex rosea)	P	W	S	GR	M/W	X								X		X	
Smartweed (Polygonum spp.)	P	W	S/T	BR	M/W			X						X	X	X	
Angelica (Angelica atropurpurea)	P	W	M	GR/W	M/W			X						X	X	X	
Water Hemlock (Cicuta maculata)	P	W	T	Y	W									X	X	X	
Barnyard Grass (Echinochloa crusgalli)	P	W	M	GR	M/W			X						X	X	X	X
Fowl Manna Grass (Glyceria striata)	P	W	M/T	GR	W			X						X	X	X	
Germander, Wood Sage (Teucrium canadense)	P	W	M	W/P	M	X										X	
Woodland Sedge (Carex blanda)	P	W	S/M	GR	M	X										X	
Pen Sedge (Carex pensylvanica)	P	W	S/M	GR	M			X						X	X	X	

APPENDIX D

TABLE D-1 RECOMMENDED PLANT MATERIALS FOR BMPs

Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
Woodland Sedge (Carex sparganioides)	P	W	S/M	GR	M			X						X	X	X	
Winged Loosestrife (Lythrum alatum)	P	W	S	B/P	W			X						X	X	X	
Common Bur Reed (Sparganium eurycarpum)	P	W	M/T	BR	W			X						X	X	X	
Iron Weed (Vernonia fasciculata)	P	W	M	R/PK	M/W									X	X	X	
Culver's Root (Veronicastrum virginicum)	P	W	M/T	W	M/W			X						X	X	X	
Blue Joint Grass (Calamagrostis canadensis)	P	W	M/T	GR/Y	M/W			X						X	X	X	
TREES																	
Sycamore (Platanus occidentalis)					M/W	X								X		X	
Hackberry (Celtis occidentalis)					D/M	X								X		X	
Shagbark Hickory (Carya ovata)					D/M	X											
Red bud (Cercis canadensis)					D/M	X								X		X	
Black Cherry (Prunus serotina)					D/M	X								X		X	
White Oak (Quercus alta)					D	X										X	

APPENDIX D

TABLE D-1 RECOMMENDED PLANT MATERIALS FOR BMPs

Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
Black Walnut (Juglans nigra)					D/M	X										X	
Eastern Red Cedar (Juniperus virginiana)					D/M/S	X								X		X	
Red Maple (Acer rubrum)					M/W/S	X								X		X	
Bur Oak (Quercus macrocarpa)					M/S	X								X		X	
Eastern Cottonwood (Populus deltoides)					D/M/S	X		X						X		X	
River Birch (Betula nigra)					M/W	X		X						X	X	X	
Hazelnut (Corylus americana)					D/M	X								X		X	
Pin Oak (Quercus palustris)					M/W/S	X		X						X		X	
Red Elm (Ulmus rubra)					D/M	X								X		X	
Green Ash (Fraxinus pennsylvanica subintegerrima)					M/W	X								X	X	X	
Red Oak (Quercus rubra)					D/M	X								X		X	
Basswood (Tilia americana)					D/M	X								X		X	

APPENDIX D

TABLE D-1 RECOMMENDED PLANT MATERIALS FOR BMPs

Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
Boxelder (Acer negundo)					M/S	X		X						X		X	
SHRUBS AND VINES																	
Streamco Willow (Salix purpurea)				GR/Y	M/W	X		X						X	X	X	
Sandbar Willow (Salix exigua)				GR/Y	M/X	X		X						X	X	X	
Rough-leaved Dogwood (Cornus drumondii)				W	D/M	X	X		X	X				X	X	X	
Coralberry (Symphocarpus orbiculatus)				PK	D/M	X	X		X	X				X	X	X	
Wild Plum (Prunus americana)				W	D/M	X	X		X	X				X		X	
Elderberry (Sambucus canadensis)				W	M	X	X	X	X	X				X		X	
Flame-leaf Sumac (Rhus glabra)				R	D/M	X	X		X	X				X		X	
Red-osier Dogwood (Cornus stolonifera)				W	D/M	X	X	X	X	X				X		X	
Chokecherry (Prunus virginiana)				W	D	X	X		X					X			
Common Buckthorn (Rhamnus cathartica)				Y	D	X	X		X	X				X		X	
Button Bush (Cephalanthus occidentalis)				w	M/W			X						X	X	X	
Gray Dogwood (Cornus racemosa)				W	D/M	X	X		X	X				X		X	

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APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
GRASSES											
Prairie Cordgrass (Spartina pectinata)	P	W	T	G/BG	Sl	Sun	M/W			M/S	
Switchgrass (Panicum virgatum)	P	W	T	G	Di, Dr	Sun	D-M	5+	10	M/S	Dense habitat cover, stands up through winter, soil tolerent
Western Wheatgrass (Pascopyrum smithii)	P	C	M	G/YG	Dr, Sl, Alkaline	Sun	M-D		8-10	M/S	Best in fine-grained soils that collect runoff.
Indian Grass (Sorghatrum nutans)	P	W	T	G	Dr	Sun	M-W		6-10 #/Ac	D/M	Deep, moist soils
Big Bluestem (Andropogon gerardii)	P	W	T	G	Dr	Sun	D-W	5.4-6.2	10-12	M	
Little Bluestem (Schizachyrium scoparium)	P	W	M	BG/G	Dr	Sun	D-M	5.4-6.2	Wildlife:6-10 10-12	D/M	Not for clay/damp soils Turns crimson in fall.
Side Oats Grama (Bouteloua curtipendula)	P	W	M	P/G		Sun	D-M		6-10	D/M	
Canada Wildrye (Elymus canadensis)	P	C	M/T	G	Mod-Dr	Sun	D-M		15	D/M	Does not do well in sandy soil Good soil erosion control
Virginia Wildrye (Elymus virginicus)	P	C	M	G	Dr	p-Sh	M		10-12	M	Grows on moist, woodland soils Not as dr tol as Canada Wildrye
Buffalograss (Buchloe dactyloides)	P	W	S	BG/G	Dr	Sun to p-Sh	D-M		5#/1000 SF	D/M/S	clays and loams, rarely sands tends to establish dominance
Redtop * (Agrostis gigantea)	P	C	T	R/G			W-M		15	D/M/S	Acidic or clayey, not for limestone areas; allergen
Bermuda * (Cynodon dactylon)	P	W	S	G	Dr, Sl, acidic	Sun	M-D	5-8	35	D/M/S	Tropical: some varieties developed for cooler temperatures
Blue Grama (Bouteloua gracilis)	P	W	S	BG	Dr	Sun	D		10	D	Cannot tolerate shade from taller plants
Hairy Grama (Bouteloua hirsuta)	P	W	S	BG	Dr	Sun to p-Sh	D			D	Well drained rocky soils, particularly limestone and granite

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
Alta or Kentucky 31 Fescue * (Festuca elatior var. arund.)	P	C	S	G	Dr, Mod-Di	Sun to p-Sh	D-M		7-10#/1000SF	D/M/S	
Kentucky Bluegrass * (Poa pratensis)	P	C	S	BG		Sun	M		2#/1000 SF	D/M	
Perennial Ryegrass * (Lolium perenne var. derby)	P	C	M	G		Sun to p-Sh	M			D/M	Lawn varieties not suitable for forage; needs irrigation.
Red Creeping Fescue * (Festuca rubra)	P	C	S	G/R	Dr, mod-Sl	Sun to p-Sh				D/M	Generally hardy, soil tolerant
Prairie Dropseed (Sporobolus heterolepis)	P	W	M	G	Dr	Sun	D-M			D/M	Establish by sodding; well drained soil; fragrant seedhead
Saltgrass (Distichlis stricta)	P	W	S	G	Sl	Sun	M	alkaline		M/S	Brackish marshes, saline, alkaline soils that are poorly drained.
Vine Mesquite (Panicum obtusum)	P	W	S	G		Sun to p-Sh	M	4.8-7.0	6	M/S	Moist areas in arid environments with short, mild winters.
Timothy * (Phleum pratense)	P	C	M	G					8-10	M	Allergen
Bottlebrush Grass Hystrix patula (Elymus hystrix)	P	C	M	G		p-Sh	D-M		7-10	M	Prefers well drained soils light to medium shade
Woodland Brome Bromus pubescens	P	C	M	G		p-Sh				M	
Seed Oats (Avena sativa)	A	C	T	G/BG	wet/heavy soil	Sun	D-M		cover: 30	D/M	Seed rate for crop: 90-100 #/Ac Cold sensitive
Annual Rye (Lolium multiflorum)	A	C	M	G		Sun to p-Sh	M		Spring: 5 Fall: 15	D/M	Better with p-Sh in hot south; not heat/drought tolerant
Winter Rye (Secale cereale)	A	C	T	G	cold tolerant to -40F	Sun to p-Sh	M		3 #/ 1000 SF	D/M	Better with p-Sh in hot south; not heat/drought tolerant

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
FORBS AND LEGUMES											
Illinois Bundleflower (Desmanthus illinoensis)	P	W	M	G/BR	Dr, Cold	Sun	D-M		13	M	Prefers clay soils
Purple Coneflower (Echinacea purpurea)	P	W	M	P	Dr, Cold to 10F	Sun	M		12	M	Herb
Leadplant (Amorpha canescens)	P	W	M	B		Sun to p-Sh	D-M			M	Well drained sandy/gravelly soils South and East slopes
Showy Goldenrod (Solidago speciosa)	P	W	T	Y		Sun	D-M			M	Prefers sandy loam
Maximillian Sunflower (Helianthus maximillianii)	P	W	T	Y		Sun	M		5	M	
Prairie Blazingstar (Liatris pycnostachya)	P	W	M	P/R		Sun	M		2	M	
Black-eyed Susan (Rudbekia hirta)	A/P	W	M	Y		Sun	M		2	M	
Purple Prairie Clover (Dalea purpurea)	P	W	M	P	Dr, heat	Sun	D-M		3-8	M	slopes, roadsides, meadows well drained soils
Common Dayflower * (Commelina communis)	P	W	S	B		Sh	W			M	Considered invasive plant in KY and VI. Flowers for only 1 day
Cut-leaf Coneflower (Rudbeckia laciniata)	P	W	T	Y	Dr	Sun to p-Sh	M-W	4.5-7.0		D/M	well drained soil
Shrubby Cinquefoil (Potentilla fruticosa)	P	W	S/M	Y	Dr, cold	Sun	M-W			M	Well-drained; pond/marsh edges and calcareous fens
Wild False Indigo (Baptisia alba var. macrophylla)	P	W	M/T	W/Y		Sun	D-M			M	Toxic alkaloids cause cattle poisoning
Showy Tick Trefoil (Desmodium canadense)	P	W	S/M	P		Sun	D-M			M/D	Prefers clay or loam
Showy Sunflower (Helianthus lateriflorus)	A/P	W	T	Y		Sun to p-Sh	D-M			D/M	Sandy loam

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
False Sunflower (Heliopsis helianthoides)	P	W	M	Y	Dr	Sun to p-Sh	D-M			D/M	Best in well drained moist soils near woods. Long blooming
Rough Blazing Star (Liatris aspera)	P	W	M	P/R		Sun to p-Sh	D-M	acidic		D/M	Sandy loams
Joe Pyeweed (Eupatorium maculatum)	P	W	M	P		Sun to p-Sh	M			M/W	Moist meadows, ditches, water or swamp edges
Boneset (Eupatorium perfoliatum)	P	W	T	W		Sun to p-Sh	W-M			W	Damp to wet streams, low meadows. Herb
Sneezeweed (Helenium autumnale)	P	W	S/M	Y		Sun to p-Sh	M-W			M/W	Misnamed, not an allergen
Prairie Cinquefoil (Potentilla arguta)	P	W	S/M	Y	Dr	Sun to p-Sh	D-M			D/M	well-drained, sandy loam to open rocky areas
Heart-leaved Alexander (Zizia aptera)	P	W	S/M	Y		Sun to p-Sh	M			D/M	Grows in well drained soils in woods, thickets, glades, and prairies.
Swamp Milkweed (Asclepias incarnata)	P	W	T	P/PK		Sun to p-Sh	W-M			M/W	Wet, marshy areas with clayey, peaty soils
Marsh Aster (Aster puniceus)	P	W	M/T	W/Y		Sun to p-Sh	W			W	
Great Blue Lobelia (Lobelia siphilitica)	P	W	M	B		Sun to p-Sh	M-W			M/W	
Common Water Horehound (Lycopus americanus)	P	W	S	W		Sun	M-W			W	
Common Mountain Mint (Pycnanthemum virginianum)	P	W	M	W		Sun to p-Sh	W-M			M/W	Misnomer, not mountainous
Cup Plant (Silphium perfoliatum)	P	W	T	Y		Sun to p-Sh	M-W			M/W	Prefers clay or loam
Purple Meadow Rue (Thalictrum dasycarpum)	P	W	M	P		Sun	M-W			M/W	

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
Blue Vervain (Verbena hastata)	P	W	S	P/B		Sun	M-W			M/W	Moist stream/pond edges
Canada Anemone (Anemone canadensis)	P	W	S	W		Sun to p-Sh	M-W	to slt. acidic		M/W	Damp roadside ditches
Cream Gentian (Gentiana alba)	P	W	M	W		Sun to p-Sh	D-M			D/M	mesic black soils; rare plant
Showy Evening Primrose (Oenothera speciosa)	P	W	S	W		Sun	D		1	D/M	Rocky soils and waste areas
Indian Blanket (Gaillardia pulchella)	A	W	S	R/Y	Dr	Sun	D		10	D/M	Thrives in hot, sunny, dry conditions
Nodding Onion (Allium cernuum)	P	C	S	PK		Sun to p-Sh	M			D/M	
Cream False Indigo (Baptisia bracteata)	P	W	S	W		Sun to p-Sh	D-M			D/M	Prefers sand and loam slow growing/long lived
White Prairie Clover (Dalea candida)	P	C	S	W		Sun to p-Sh	D-M			D/M	sandy loam
Golden Alexanders (Zizia aurea)	P	W	M	Y		Sun to p-Sh	M-W			M/W	
Sky Blue Aster (Aster azureus)	P	W	M	B	Dr	Sun to p-Sh	D-M			D/M	sandy loam
Blue Wild Indigo (Baptisia australis)	P	W	M	B		Sun	D-M			D/M	Prefers rocky soil that isn't too alkaline.
Wild Bergamot (Monarda fistulosa)	P	W	M/T	P/B		Sun to p-Sh	D-M	Neutral		D/M	Well drained, sandy loam
Smooth Penstemon (Penstemon digitalis)	P	W	M	W		Sun to p-Sh	M			M/W	loves clay
Ohio Spiderwort (Tradescantia ohiensis)	P	W	M	B		Sun to p-Sh	D-M			D/M/W	Dormant in summer

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
Slender Mountain Mint (Pycanthemum tenuifolium)	P	W	S	W		Sun	D-M			D/M	
Wild Columbine (Aquilegia canadensis)	P	W	M	R		Sun to Shade	D-M			D/M	Sandy loam
False Solomon's Seal (Smilacina racemosa)	P	W	S/M	W		Shade	M			D/M	Moist, shady forest floor
Hoary Vervain (Verbena stricta)	P	W	M	P/PK	Dr	Sun	D-M			D/M	Dry, sandy soils and well drained loamy soils
Common Milkweed (Asclepias syriaca)	P	W	M	PK		Sun to p-Sh	M			M	Host for Monarch Butterfly Poisonous to animals
Partridge Pea (Cassia fasciculata)	A	W	S	Y		Sun	D-M		13	D/M	Soil stabilization/reclamation Sandy loam
Bush Clover (Lespedeza capitata)	P	W	M	B	Dr	Sun	D-M			D/M	Middle to dry prairie Sandy loam
Compass Plant (Silphium laciniatum)	P	W	T	Y	Dr	Sun	M-D			D/M	Leaves point North/South
Stiff Goldenrod (Solidago rigida)	P	W	M/T	Y	Dr	Sun	M-D			D/M	Not an allergen
Butterfly Milkweed (Asclepias tuberosa)	P	W	M	OR		Sun	M-D	acidic		D/M	Host for Monarch Butterfly; toxic to animals; dry, sandy/rocky soils
Whorled Milkweed (Asclepias verticillata)	P	W	S	W		Sun	D-M			D/M	Dry, calcareous soils and rocky hillsides
Smooth Blue Aster (Aster laevis)	P	W	M	P/B	Dr	Sun to p-Sh	M-D			D/M	Sandy loams
Western Sunflower (Helianthus occidentalis)	P	W	M	Y		Sun	D-M			D/M	Poor, dry, sandy soils Not recommended for clay
Spotted Bergamot (Monarda punctata)	P	W	M	Y/P	Dr	Sun to p-Sh	M			D	Sandy soil

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
Yellow Coneflower (Ratibida pinnata)	P	W	M	Y	Dr, flood, heat, cold	Sun to p-Sh	D-M			D/M	Thrives in dry sandy soils and in raw clay
New England Aster (Aster novae-angliae)	P	W	M/T	B		Sun	M		2	M/W	
Thimbleweed (Anemone cylindrica)	P	W	S	G		Sun to p-Sh	M-D			D/M	Sandy, loamy, gritty soils Foliage is toxic
Heath Aster (Aster ericoides)	P	W	S/M	W	Dr	Sun	D-M			D/M	Dry or well drained soils
Silky Aster (Aster sericeus)	P	W	S	P/B	Dr	Sun	D-M			D	Dry, open uplands Associate with limestone soils
New Jersey Tea (Ceanothus americanus)	P	W	S/M	G/BR		Sun to p-Sh	D-M			D/M	Sand/loam. Used as a tea.
Alum Root (Heuchera richardsonii)	P	W	S	GR		Sun to p-Sh	D-M			D/M	Prefers full sun in northern range but partial sun further south.
Prairie Smoke (Geum triflorum)	P	W	S	R		Sun	D-M			D/M	Found in pine forests at 6,000 to 9,500 foot elevations
Wild Lupine (Lupinus perennis)	P	W	S	B		Sun to p-Sh	Dry			D	Endangered Karner Blue Butterfly (Great Lakes area) depends on plant.
Large Flowered Beard Tongue (Penstemon grandiflorus)	P	W	M	P/B		Sun	Dry			D	Very sandy soils
Downy Phlox (Phlox pilosa)	P	W	S	PK		Sun to p-Sh	M-W			D/M	Woods and meadows
Blue-eyed Grass (Sisyrinchium campestre)	P	W	S	B		Sun	M-D			D	
Old Field Goldenrod (Solidago nemoralis)	P	W	S	Y		Sun to p-Sh	M-D			D	
Riddell's Goldenrod (Solidago riddellii)	P	W	S/M	Y		Sun	W-M			M/W	Wet seeps on prairies

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
Flowering Spurge (Euphorbia corollata)	P	W	S/M	W	Dr	Sun	M-D			D/M	
Prairie Spiderwort (Tradescantia bracteata)	P	W	S	B		Sun	M-D			D/M	Sandy, rocky prairie soils
WETLAND SPECIES											
Blueflag (Iris virginica)	P	W	S/M	B		Sun to p-Sh	M-W	acidic boggy		M/W	Light shade in south part of range, marshes
Arrowhead (Sagitaria latifolia)	P	W	S/M	W		Sun to p-Sh	M-W			M/W	Water edges, shallow water
Needle Spikerush (Eleocharis acicularis)	P	W	S/M	BR		Sun	M-W			M/W	Erosion control Water edges, shallow water
Rice Cutgrass (Leersia oryzoides)	P	W	S	GR		Sun	Wet			M/W	
Bulrush var. Olney's (Scirpus americanus)	P	W	T	GR		Sun	Wet			M/W	Calcareous fens water edges, wet meadows
Common Spikerush (Eleocharis palustris)	P	W	S	BR		Sun to p-Sh	M-W			M/W	Shallow water and marshes
Cardinal Flower (Lobelia cardinalis)	P	W	M	R		Sun to p-Sh	M	to slt. acidic		M/W	Attracts hummingbirds Moist but not saturated soils
White Water Lilly (Nymphaea odorata)	P	W	S	W		Sun	Aquatic			W	Forms dense patches; can cause problems if not controlled
Wild Calamus (Acorus calamus)	P	W	M	W		Sun to p-Sh	Aquatic			W	Around edges of stream. Herb: stimulant, psychadelic
Bottlebrush Sedge (Carex hystricina)	P	W	M	BR		Sun	Wet to Aquatic			M/W	Shallow marshes, bogs, peat soil
Pointed Broom Sedge (Carex scoparia)	P	W	M	BR		Sun	Wet to Aquatic			M/W	Peat soil

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
Dark Green Rush (Scirpus atrovirens)	P	W	M	GR		Sun	Wet to Aquatic			M/R	Marshes, wet meadows, peats, mucks, clay, sand
Wool Grass (Scirpus cyperinus)	P	W	M/T	GR		Sun to p-Sh	Wet			M/W	peat, sand
Great Bulrush (Scirpus validus creber)	P	W	T	GR	Dr	p-Sh	Wet to Aquatic			M/W	Shallow water or saturated soils
Common Rush (Juncus effusus)	P	W	S	BR	Dr	Sun	M-W			M/W	Very hardy, withstands flloding
Wood Sedge (Carex rosea)	P	W	S	GR		Sun to p-Sh	M-W			M/W	forests
Smartweed (Polygonum spp.)	P	W	S/T	BR		Sun	Aquatic			M/W	Wetland varities around water edges and marshes
Angelica (Angelica atropurpurea)	P	W	M	GR/W		Sun	M-W			M/W	Moist, swampy woodlands
Water Hemlock (Cicuta maculata)	P	W	T	Y		Sun	Wet			W	Most violently poisonous plant in N.Amer. Resembles edible plants.
Barnyard Grass * (Echinochloa crusgalli)	P	W	M	GR		Sun	W-D			M/W	Removes 80% soil nitrogen causes crop failure, poisons cattle
Fowl Manna Grass (Glyceria striata)	P	W	M/T	GR		Sun	M-W			W	
Germander, Wood Sage (Teucrium canadense)	P	W	M	W/P		Sun to p-Sh	M			M	Thickets and moist sites along water bodies
Woodland Sedge (Carex blanda)	P	W	S/M	GR		Sun to p-Sh	D-M-W			M	Swamps to dry woodlands Wet woods along streams
Pennsylvania Sedge (Carex pensylvanica)	P	W	S/M	GR		Shade to Sun	D-M			M	Forests and open meadows, well drained dry soils
Woodland Sedge (Carex sparganioides)	P	W	S/M	GR		Shade	D-M			M	Soil stabilization on shady slopes

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
Winged Loosestrife (Lythrum alatum)	P	W	S	B/P		Sun	W-M			W	Swamps and wet meadows, poorly drained soils
Common Bur Reed (Sparganium eurycarpum)	P	W	M/T	BR		Sun	W-A			W	Marshes, wetlands, muddy ditches, pools of shallow water
Iron Weed (Vernonia fasciculata)	P	W	M	R/PK		Sun to	M-W			M/W	Damp soils, wet prairies
Culver's Root (Veronicastrum virginicum)	P	W	M/T	W		Sun to p-Sh	M			M/W	Thickets, prairies, moist, well drained soils
Blue Joint Grass (Calamagrostis canadensis)	P	W	M/T	GR/Y	mod-Sl	Sun	W	as low as 3.5		M/W	Very common, widespread. Moist, moderately well drained soils
TREES											
Sycamore (Platanus occidentalis)	P		90'	R	Dr, wet	Sun	M			M/W	Urban uses, soil tolerant
Hackberry (Celtis occidentalis)	P		45-80'	G	Dr, Sl	Sun to p-Sh	M			D/M	Bark easily damaged, ice damage Urban uses, soil tolerant
Shagbark Hickory (Carya ovata)	P		60-80'	G		Sun to p-Sh	M			D/M	Ornamental not general use; Nut-fall problem. Well drained soil
Red bud (Cercis canadensis)	P		30	Pk/P		Sun to p-Sh	M			D/M	Fast growth/short lived. Soil tolerant. Partial sun in hot areas.
Black Cherry (Prunus serotina)	P		60-90'	W	Dr	Sun to p-Sh	M	acidic to alkaline		D/M	Staining and pits cause problems on walks/pavement.
White Oak (Quercus alta)	P		60-100'	Br	Mod-Dr	Sun to p-Sh	M	acidic		D	Slow growth. Not adapted to dry fairly soil tolerant, well drained
Black Walnut (Juglans nigra)	P		70' +	-	Dr	Sun	M			D/M	Open, sunny area with moist, rich soil Nut-fall problem. Well drained soil
Eastern Red Cedar (Juniperus virginiana)	P		50'	G/Y	Dr, mod-Sl	Sun to p-Sh	M-D			D/M/S	Urban uses, windbreaks, screens Doesn't like continuous moisture

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
Red Maple (Acer rubrum)	P		40-75'	R		Sun to p-Sh	W			M/W/S	Use local seed source. Tree shorter in south. Avoid alkaline soil
Bur Oak (Quercus macrocarpa)	P		70-90'	Br	Dr, Sl	Sun	M			M/S	Soil tolerant
Eastern Cottonwood (Populus deltoides)	P		70-90'	-	Dr	Sun	M			D/M/S	Fast growth, floodplains, soft wood separate male/female trees
River Birch (Betula nigra)	P		50' +	Br	Flood, low soil Oxygen	Sun to p-Sh	M	Requires acidic		M/W	Short lived (30-40 years)
Hazelnut (Corylus americana)	P		10-15'	Br		Sun to p-Sh	M			D/M	Fast growth; best in rich, moist, well drained soils
Pin Oak (Quercus palustris)	P		50-75'	Br	wet, urban	Sun	M	acidic		M/W/S	Not recommended for limestone (alkaline conditions)
Red Elm (Ulmus rubra)	P		80'	G	Dutch Elm disease	Sun to p-Sh	M-W			D/M	Fast growth, less flood tolerant than Amer. Elm., Drier sites if limestone
Green Ash (Fraxinus pennsylvanica subintegerrima)	P		60'	G	mod-Sl	Sun	D-M-W			M/W	Prefers moist but is adaptable. Urban uses, fast growth.
Red Oak (Quercus rubra)	P		70'	Br	Dr	Sun	D-M	below 7.5		D/M	Common to north and east slopes Well drained soils
Basswood (Tilia americana)	P		50'	Y	mod-Dr	Sun to p-Sh	M	acidic to slt. Alkaline		D/M	Attracts honey bees; low branches may require pruning.
Boxelder (Acer negundo)	P		50'	W	Dr, mod-Sl	Sun to p-Sh	M			M/S	Fast growth/short lived, weak wood, disease/decay, stream banks.
SHRUBS AND VINES											
Streamco Willow * (Salix purpurea)	P		15'	GR/Y		Sun	W			M/W	Fast rooting, erosion control Doesn't like shade
Sandbar Willow (Salix exigua)	P	C	18'	GR/Y	Dr	Sun	W			M/X	Sandbars, mud flats, stream banks. thickets, soil stabilization

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Plant Species	Life Cycle	Season	Growth Height	Color of Flower	Resistance or Tolerance	Light	Moisture	pH	Rate (Pounds/Acre unless specifed)	Site Tolerance	Remarks
Rough-leaved Dogwood (Cornus drumondii)	P	C	20'	W	Dr	Sun to p-Sh	M			D/M	Well drained, moist soils
Coralberry (Symphocarpus orbiculatus)	P	W	6'	PK			D			D/M	Dry sand along streams, in woods field edges, and prairies.
Wild Plum (Prunus americana)	P	C	20-30'	W	Dr	Sun	D-M			D/M	Short lived found in thickets, old fields
Elderberry (Sambucus canadensis)	P	W	12'	W			M			M	Rich bottom/upland soils on steams
Flame-leaf Sumac (Rhus glabra)	P	C	15'	R						D/M	Open uplands, sandy soils
Red-osier Dogwood (Cornus stolonifera)	P		3-19'	W	flood, cold	Sun to p-Sh	W-M	5.5-7.0		D/M	Good screen, windbreak (generally a northern plant)
Chokecherry (Prunus virginiana)	P		6-10'	W	Dr		M			D	Bank stabilization, windbreaks Moist, well drained soils
Common Buckthorn * (Rhamnus cathartica)	P		22'	Y		Sun to p-Sh	D-W			D	Aggressive invasive, crowds out native plants. Soil tolerant
Button Bush (Cephalanthus occidentalis)	P	W	15'	w		Sun to p-Sh	M			M/W	Swamps, water edges
Gray Dogwood (Cornus racemosa)	P		15'	W		Sun to p-Sh	M-W			D/M	Prairie and stream bed invasive May need to control spread

APPENDIX D

TABLE D-2 PLANT RECOMMENDATIONS

Table Notes:

Life Cycle: A-Annual, B-Biennial, P-Perennial

Season: C-Cool, W-Warm

Growth Height: S - < 2 ft, M - 2-4 ft, T - > 4 ft. Tree and shrub heights are given.

Color of Flower: B-Blue, BG-Blue Green, Br-Brown, G-Green, Or-Orange, P-Purple, Pk-Pink, R-Red, W-White, Y-Yellow

Site Tolerance:D-Dry, M-Moist, S-Salt, W-Wet

Resistance or Tolerance: Dr-drought resistance, Mod-moderate drought tolerance, Di-drought intoloerent, Sl-salt tolerant

* Introduced plant, not native to North America

Planting Rate Specification - Pounds of Seeds per Acre

Certified Seed for Grasses, Sedges and Forbs: Specify "Pounds of PLS" (Pure Live Seed) per Acre

Non-Certified Seed for Grasses, Sedges and Forbs: Specify "Pounds of BS" (Bulk Seed) per Acre

Planting Rate - Number of Live Plants:

Wetland Species: Maximum number of stems per Acre (2 x 2 ft spacing) = 10,890 per Acre

Shrubs: Maximum spacing per Acre (6 x 6 ft spacing) = 1210 per Acre

Grees: Maximum spacing per Acre (10 x 10 ft spacing) = 726 per Acre

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APPENDIX F
TABLES AND FIGURES

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TABLES

TABLE 2.2.2.2

NRCS RUNOFF COEFFICIENTS

Runoff curve numbers for urban areas[1]					
Cover description		**Curve numbers for hydrologic soil group**			
Cover type and hydrologic condition	**Average percent impervious area**[2]	**A**	**B**	**C**	**D**
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses,cementeries etc.)[3]					
Poor condition (grass cover<50%)		**68**	**79**	**86**	**89**
Fair (grass cover 50%-75%)		**49**	**69**	**79**	**84**
Good (grass cover>75%)		**30**	**61**	**74**	**80**
Impervious areas					
Pavement, roof, etc.		**98**	**98**	**98**	**98**
Streets and roads					
Paved w/ curb (excluding right-of-way)		**98**	**98**	**98**	**98**
Paved w/ roadside swale (including right-of-way)		**83**	**89**	**92**	**93**
Gravel (including right-of-way)		**76**	**85**	**89**	**91**
Dirt (including right-of-way)		**72**	**82**	**87**	**89**
Urban Districts					
Commercial and business	**85**	**89**	**92**	**94**	**95**
Industrial	**72**	**81**	**88**	**91**	**93**
Residential districts by avg. lot size					
1/8 acre or less	**65**	**77**	**85**	**90**	**92**
1/4 acre	**38**	**61**	**75**	**83**	**87**
1/3 acre	**30**	**57**	**72**	**81**	**86**
1/2 acre	**25**	**54**	**79**	**80**	**85**
1 acre	**20**	**51**	**68**	**79**	**84**
2 acre	**12**	**46**	**65**	**77**	**82**
Developing urban areas					
Newly graded areas					
(pervious areas only, no vegetation)[4]		**77**	**86**	**91**	**94**

From USDA, TR-55, Urban Hydrology for Small Watersheds, 1986

[1]Average runoff condition, and Ia=0.2S.

[2]The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious are considered equivalent to open space in good hydrologic condition. CN's for other combination of conditions may be computed as shown in TR-55, 1986—Figure 2-3 or 2-4.

[3]CN's shown are equivalent to those of pasture. Composite DN's may be computed for other combinations of open space cover type.

[4]Composite CN's to use for the design of temporary measures during grading and construction should be computed as shown in TR-55, 1986—Figure 2-3 or 2-4.

TABLE 2.2.2.2 Continued

Runoff curve numbers for undeveloped areas[1]					
		Curve numbers for hydrologic soil group			
Cover description	**Hydrologic Condition**	**A**	**B**	**C**	**D**
Pasture, grassland or range-continuos grazing[2]	**Poor**	**68**	**79**	**86**	**89**
	Fair	**49**	**69**	**79**	**84**
	Good	**39**	**61**	**74**	**80**
Meadow-continous grass, protected from grazing, generally mowed for hay.		**30**	**58**	**71**	**78**
Brush-brush/weed/grass mix with brush the major element[3]	**Poor**	**48**	**67**	**77**	**83**
	Fair	**35**	**56**	**70**	**77**
	Good	**30[4]**	**48**	**65**	**73**
Woods-grass combination (orchard or tree farm)[5]	**Poor**	**57**	**73**	**82**	**86**
	Fair	**43**	**65**	**76**	**82**
	Poor	**32**	**58**	**72**	**79**
Woods[6]	**Poor**	**45**	**66**	**77**	**83**
	Fair	**36**	**60**	**73**	**79**
	Good	**30[4]**	**55**	**70**	**77**
Farmsteads-buildings, lanes, driveways, and surrounding lots		**59**	**74**	**82**	**86**

[1]Average runoff condition, and I_a=0.2S.
[2]Poor: <50% fround cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and not heavily grazed.
[3]Poor: <50% fround cover
Fair: 50 to 75% ground cover
Good: >75% ground cover
[4]Actual curve number is less than 30; use CN = 30 for runoff computations.
[5]CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.
[6]Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Table 3.1.1.1

MANNING'S ROUGHNESS COEFFICIENT

Type of Channel	n
Closed Conduits	
Reinforced Concrete Pipe (RCPs)	0.013
Reinforced Concrete Elliptical Pipe	0.013
Corrugated Metal Pipe (CMPs):	
2⅔ x ½in. Annular or Helical Corrugations unpaved - plain	0.024
2⅔ x ½in. Annular or Helical Corrugations paved invert	0.021
3x1 in. Annular or Helical Corrugations unpaved - plain	0.027
3x1 in. Annular or Helical Corrugations paved invert	0.023
6x2 in. Corrugations unpaved - plain	0.033
6x2 in. Corrugations paved invert	0.028
Vitrified Clay Pipe	0.013
Asbestos Cement Pipe	0.012
Open Channels (Lined)	
Gabions	0.025
Concrete	
Trowel Finish	0.013
Float Finish	0.015
Unfinished	0.017
Concrete, bottom float finished, with sides of	
Dressed Stone	0.017
Random Stone	0.020
Cement Rubble masonry	0.025
Dry Rubble or Riprap	0.030
Gravel bottom, side of	
Random Stone	0.023
Riprap	0.033
Grass (Sod)	0.030
Riprap	0.035
Grouted Riprap	0.030
Open Channels (Unlined) Excavated or Dredged	
Earth, straight and uniform	0.027
Earth, winding and sluggish	0.035
Channels, not maintained, weeds & brush uncut	0.090
Natural Stream	
Clean stream, straight	0.030
Stream with pools, sluggish reaches, heavy underbrush	0.100
Flood Plains	
Grass, no brush	0.030
With some brush	0.090
Street Curbing	0.014

Table 3.1.1.2

HEAD LOSS (so-called minor loss) COEFFICIENT k

Condition $\left(Loss = k\,\dfrac{v^2}{2g} \right)$	k
Manhole, junction boxes and inlets with shaped inverts*:	
Thru flow	0.15
Junction	0.4
Contraction transition	0.1
Expansion transition	0.2
90 degree bend	0.4
45 degree and less bends	0.3
Culvert inlets:	
Pipe, Concrete	
Projecting from fill, socket end (grove end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove end)	0.2
Square edge	0.5
Round (radius=1/12D)	0.2
Mitered to conform to fill slope	0.7
Standard end section	0.5
Beveled edges, 33.7º or 45º bevels	0.2
Side or slope-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
Standard end section	0.5
Beveled edges, 33.7º or 45º bevels	0.2
Side or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dim. or beveled edges on 3 sides	0.2
Wingwalls at 30º to 75º to barrel	
Square edged at crown	0.4
Crown edge rounded to radius of 1/12 barrel dimension or beveled top edge	0.2
Wingwalls at 10º to 25º to barrel - square edged at crown	0.5
Wingwalls parallel (extension of sides) - square edged at crown	0.7
Side or slope-tapered inlet	0.2

***Note:** When 50 percent or more of the discharge enters the structure from the surface, "k" shall be 1.0.

Table 5.1.4.1
CRITICAL SHEAR STRESSES FOR CHANNEL MATERIALS
(Solely for use in stream assessments as described in Chapter 5.1.4.
Not to be used as allowable shear stresses for design)

	psf
<u>Granular Material</u>	
Boulders (100 cm)	20.295
Boulders (75 cm)	15.222
Boulders (50 cm)	10.148
Boulders (25.6 cm)	5.196
Rip Rap	3.132
Cobbles (6.4 cm)	1.299
Cobbles and shingles	1.100
Cobbles and shingles, **clear water**	0.910
Coarse sand (1mm)	0.015
Coarse sand (1mm)	0.015
Coarse gravel, noncolloidal (GW), **clear water**	0.300
Coarse gravel, noncolloidal, (GW)	0.670
Gravel (2cm)	0.406
Fine gravel	0.320
Fine gravel, **clear water**	0.075
Fine sand (0.125 mm)	0.002
Fine sand (0.125 mm) (SP)	0.002
Fine sand (SW), (SP), colloidal	0.075
Fine sand, colloidal, (SW), (SP), **clear water**	0.027
Graded loam to cobbles, noncolloidal (GM)	0.660
Graded loam to cobbles, noncolloidal,(GM), **clear water**	0.380
Graded silts to cobbles, colloidal (GC)	0.800
Graded silts to cobbles, colloidal, (GC), **clear water**	0.430
<u>Fine Grained</u>	
Resistant cohesive (CL), (CH)	1.044
Stiff clay, very colloidal, (CL)	0.460
Stiff clay, very colloidal, (CL), **clear water**	0.260
Moderate cohesive (ML-CL)	0.104
Ordinary firm loam (CL-ML)	0.150
Ordinary firm loam, (CL-ML), **clear water**	0.075
Alluvial silts, colloidal (CL-ML)	0.460
Alluvial silts, colloidal,(CL-ML), **clear water**	0.260
Alluvial silts, noncolloidal (ML)	0.150
Alluvial silts, noncolloidal, (ML), **clear water**	0.048
Sandy loam, noncolloidal (ML)	0.075

Table 5.1.4.1
CRITICAL SHEAR STRESSES FOR CHANNEL MATERIALS
(Solely for use in stream assessments as described in Chapter 5.1.4.
Not to be used as allowable shear stresses for design)

Sandy loam, noncolloidal, (ML), **clear water**	0.037
Silt loam, noncolloidal (ML)	0.110
Silt loam, noncolloidal, (ML), **clear water**	0.048
Shales and hardpans	0.67
<u>Others</u>	
Jute net	0.46
Plant cuttings	2.09
Well established dense vegetation to the normal low water	2.16
Geotextile (synthetic)	3.01
Large Woody Debris	3.13

Note: For non-cohesive soils, the table values are based on spherical particles and Shield equation, as follows: $\tau_c = \Theta(\gamma_s - \gamma)$ D where γ_s is the specific weight of sediment (165 pcf), γ is specific weight of water, D is the reference particle size, and Θ is the Shield's parameter (0.06 for gravel to cobble, 0.044 for sand). For cohesive soils the values are based on limited testing as reported in Chow (1988) and USDA (2001).

Project: ____

Stream Name and Location: ________________________________

Evaluated by: _____________Firm: ____________ Date:________

Table 5.1.4.2 **CHANNEL CONDITION SCORING MATRIX** (adapted from Johnson, et al 1999)						
Stability Indicator	**Good (1)**	**Fair (2)**	**Poor (3)**	**Score (S)**	**Weight (W)**	**Rating S*W= (R)**
Bank soil texture and coherence	cohesive materials, clay (CL), silty clay (CL-ML), massive limestone, continuous concrete, clay loam (ML-CL), silty clay loam (ML-CL), thinly bed limestone	sandy clay (SC), sandy loam (SM), fractured thinly bedded limestone	non-cohesive materials, shale in bank, (SM), (SP), (SW), (GC), (GM), (GP), (GW)		0.6	
Average bank slope angle	slopes ≤ 2:1 on one or occasionally both banks	slopes up to1.7:1 (60˚) common on one or both banks	bank slopes over 60˚ on one or both banks		0.6	
Average bank height	less than 6 feet	greater than 6 and less than 15 feet	greater than 15 feet		0.8	
Vegetative bank protection	wide to medium band of woody vegetation with 70-90% plant density and cover. Majority are hardwood, deciduous trees with well-developed understory layer, minimal root exposure	narrow bank of woody vegetation, poor species diversity, 50-70% plant density, most vegetation on top of bank and not extending onto bank slope, some trees leaning over bank, root exposure common	thin or no band of woody vegetation, poor health, monoculture, many trees leaning over bank, extensive root exposure, turf grass to edge of bank		0.8	
Bank cutting	little to some evident along channel bends and at prominent constrictions, some raw banks up to 4 foot	Significant and frequent. Cut banks 4 feet high. Root mat overhangs common.	Almost continuous cut banks, some over 4 feet high. Undercut trees with sod-rootmat overhangs common. Bank failures frequent		0.4	

Table 5.1.4.2
CHANNEL CONDITION SCORING MATRIX
(adapted from Johnson, et al 1999)

Stability Indicator	**Good (1)**	**Fair (2)**	**Poor (3)**	**Score (S)**	**Weight (W)**	**Rating S*W= (R)**
Mass wasting	little to some evidence of slight or infrequent mass wasting, past events healed over with vegetation. Channel width relatively uniform with only slight scalloping	Evidence of frequent and significant mass wasting events. Indications that higher flows aggravated undercutting and bank wasting. Channel width irregular with bank scalloping evident	Frequent and extensive mass wasting evident. Tension cracks, massive undercutting and bank slumping are considerable. Highly irregular channel width.		0.8	
Bar development	narrow relative to stream width at low flow, well-consolidated, vegetated and composed of coarse bed material to slight recent growth of bar as indicated by absence of vegetation on part of bar	Bar widths wide relative to stream width with freshly deposited sand to small cobbles with sparse vegetation	Bar widths greater than ½ the stream width at low flow. Bars are composed of extensive deposits of finer bed material with little vegetation		0.6	
Debris jam potential	slight – small amounts of debris in channel. Small jams could form	moderate – noticeable debris of all sizes present	significant – moderate to heavy accumulations of debris apparent		0.2	
Obstructions, flow deflectors (walls, bluffs) and sediment traps	negligible to few or small obstructions present causing secondary currents and minor bank and bottom erosion but no major influence on meander bend	moderately frequent and occasionally unstable obstructions, noticeable erosion of channel. Considerable sediment accumulation behind obstructions	frequent and unstable causing continual shift of sediment and flow		0.2	
Channel bed material consolidation and armoring	massive competent to thinly bed limestone, continuous concrete, hard clay,	shale in bed, soft silty clay, little consolidation of particles, no apparent overlap, moderate %	silt, weathered, thinly bedded, fractured shale, high slaking potential, very poorly		0.8	

Table 5.1.4.2 CHANNEL CONDITION SCORING MATRIX (adapted from Johnson, et al 1999)						
Stability Indicator	**Good (1)**	**Fair (2)**	**Poor (3)**	**Score (S)**	**Weight (W)**	**Rating S*W= (R)**
	moderately consolidated with some overlapping. Assorted sizes of particles, tightly packed and overlapped, possibly imbricated. Small % of particles < 4mm	of particles < 4mm	consolidated, high % of material < 4mm			
Sinuosity	1.2 ≤ Sinuosity ≤ 1.4	1.1<Sinuosity <1.2	Sinuosity <1.1		0.8	
Ratio of radius of curvature to channel width	$3 \leq R_c/W_b \leq 5$	$2 < R_c/W_b < 3$, $5 < R_c/W_b < 7$	$2 > R_c/W_b$, $R_c /Wb > 7$		0.8	
Ratio of pool-riffle spacing to channel width at elevation of 2-year flow	$4 \leq Length/W_b < 8$	$3 \leq Length/W_b < 4$, $8 < Length/W_b \leq 9$	$3 > Length/W_b$, Length/Wb > 9, unless long pool or run because of geologic influence		0.8	
Percentage of channel constriction	< 25%	26-50%	> 50%		0.8	
Sediment movement	little to no loose sediment	scour and/or deposition, some loose sediment	near continuous scour and/or deposition and/or loose sediment		0.8	

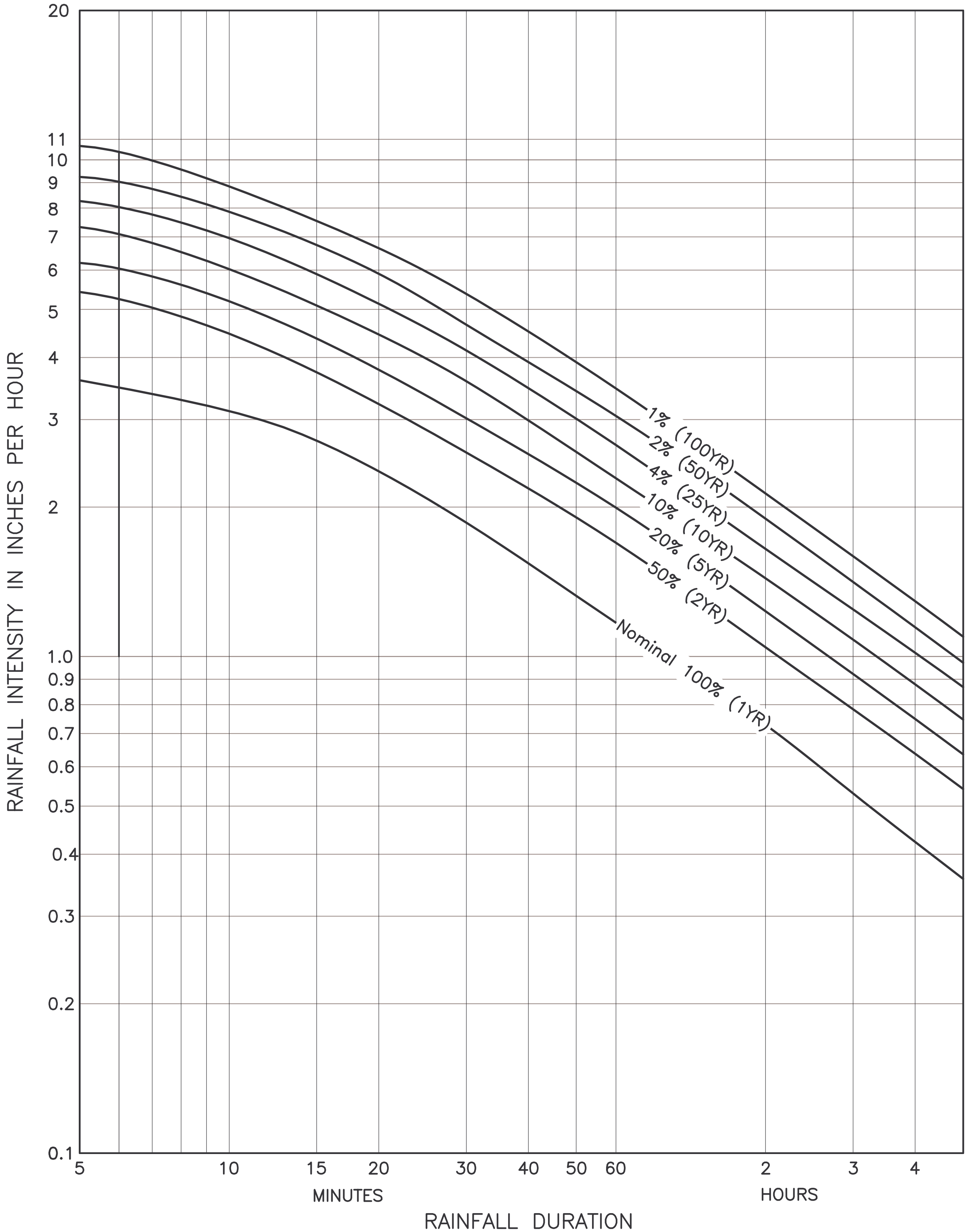
TOTAL ____

Table 5.2.7.1
Permissible Shear Stresses for Lining Material

Lining Category	Lining Type	lb/ft^2
General	Erosion Control Blankets	1.55-2.35
	Turf-Reinforced Matrix (TRMs):	------------------------
	Unvegetated:	3.0
	Vegetated:	8.0
	Geosynthetic Materials	3.01
	Cellular Containment	8.1
	Woven Paper Net	0.15
	Jut Net	0.45
	Fiberglass Roving:	------------------------
	Single	0.60
	Double	0.85
	Straw With Net	1.45
	Curled Wood Mat	1.55
	Synthetic Mat	2.00
Vegetative	Class A (see Table 5606-2)	3.70
	Class B (see Table 5606-2)	2.10
	Class C (see Table 5606-2)	1.00
	Class D (see Table 5606-2)	0.60
	Class E (see Table 5606-2)	0.35
Gravel Riprap	25 mm	0.33
	50 mm	0.67
Rock Riprap	150 mm	2.00
	300 mm	4.00
Bare Soil	Non-Cohesive	See Figure 5606-2
	Cohesive	See Figure 5606-3

FIGURES

FIGURE 2.2.1.1
RAINFALL/INTENSITY/DURATION FREQUENCY CURVES



Lines 1% through 50% are from TP40, 1961
Line Nominal 100% is from Bulletin 71, 1992 RAINFALL DURATION

Figure 2.2.1.2

OVERLAND FLOW (INLET TIME) NOMOGRAPH

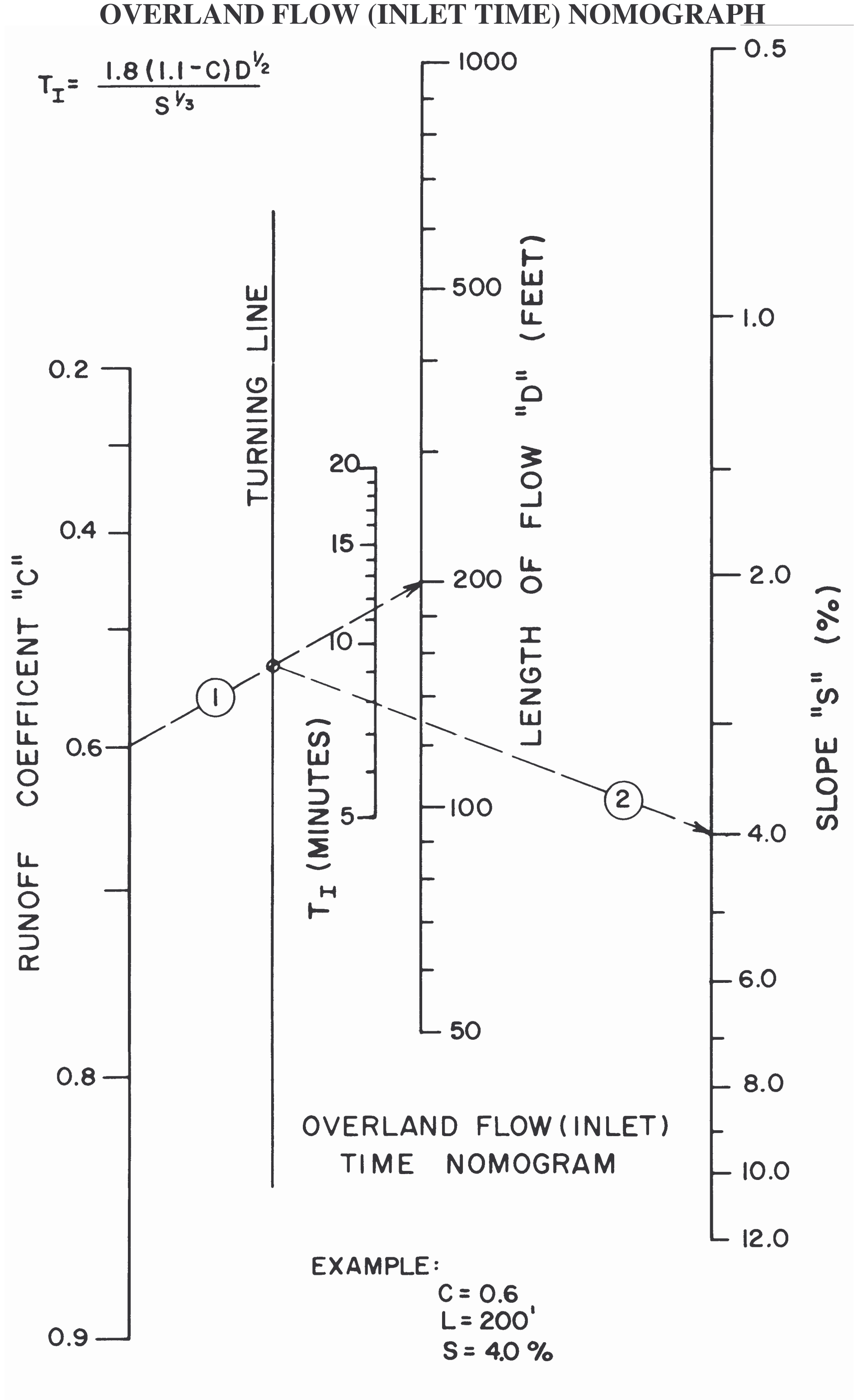
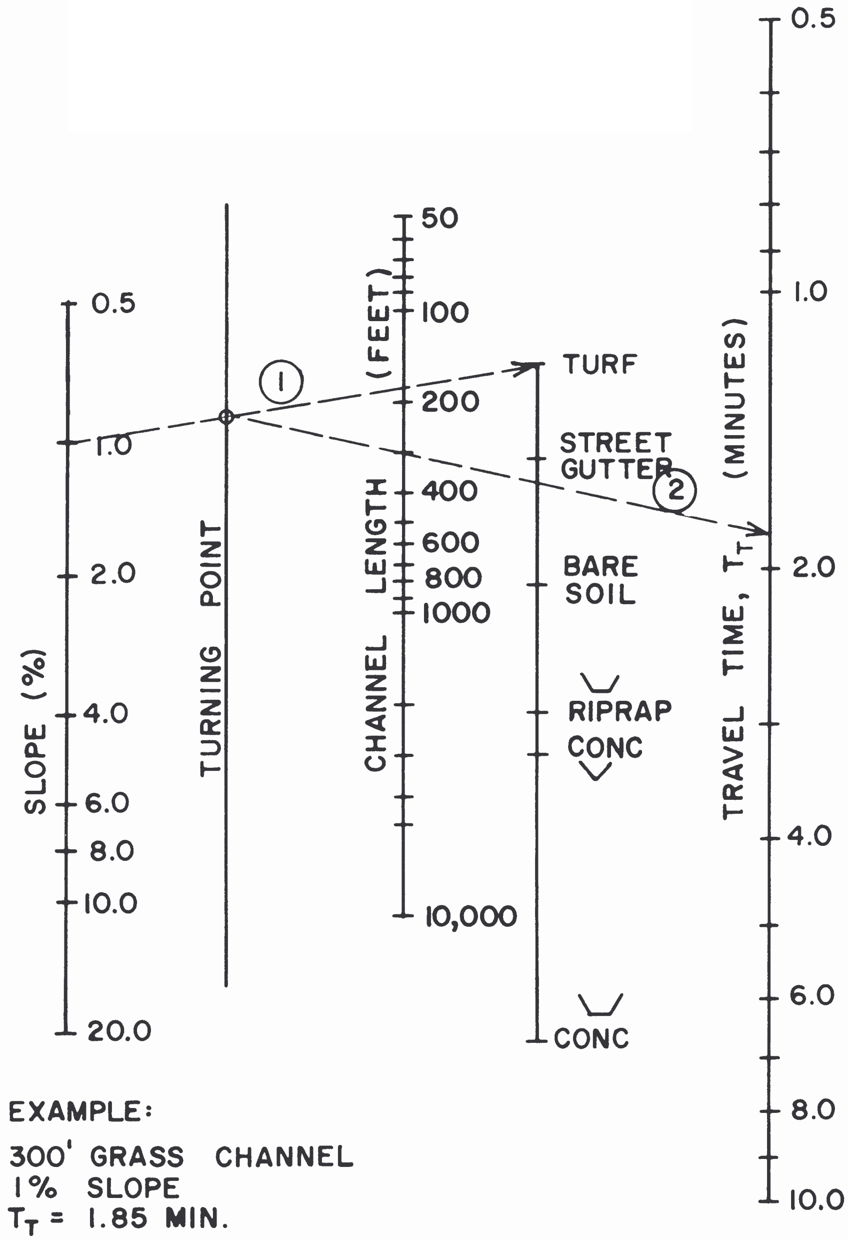


Figure 2.2.1.3

CHANNEL TIME FLOW NOMOGRAPH

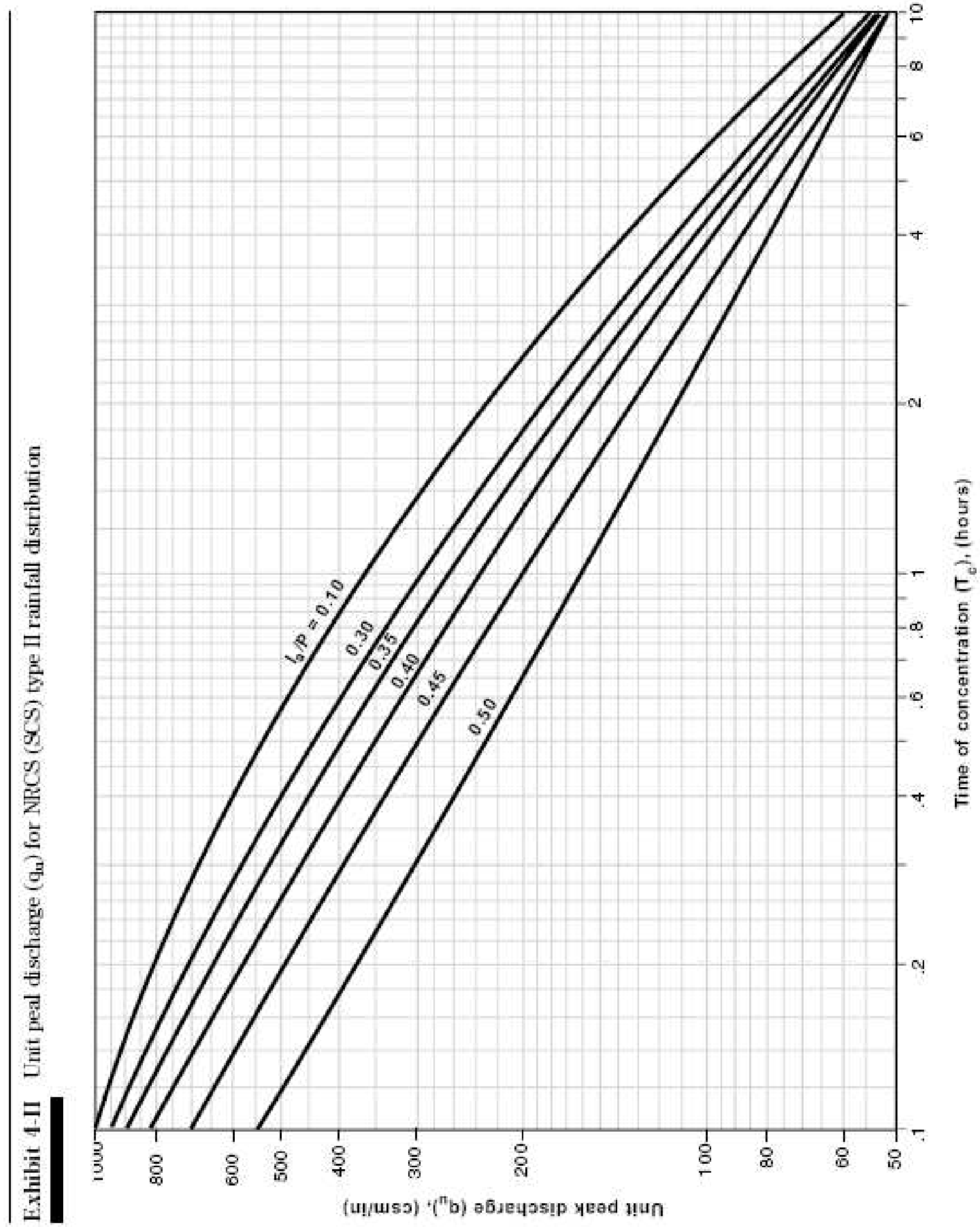


(1) Connect Slope & Channel Condition to locate point on Turning Line

(2) Extend line from Turning Line through Channel Length, Read T_T

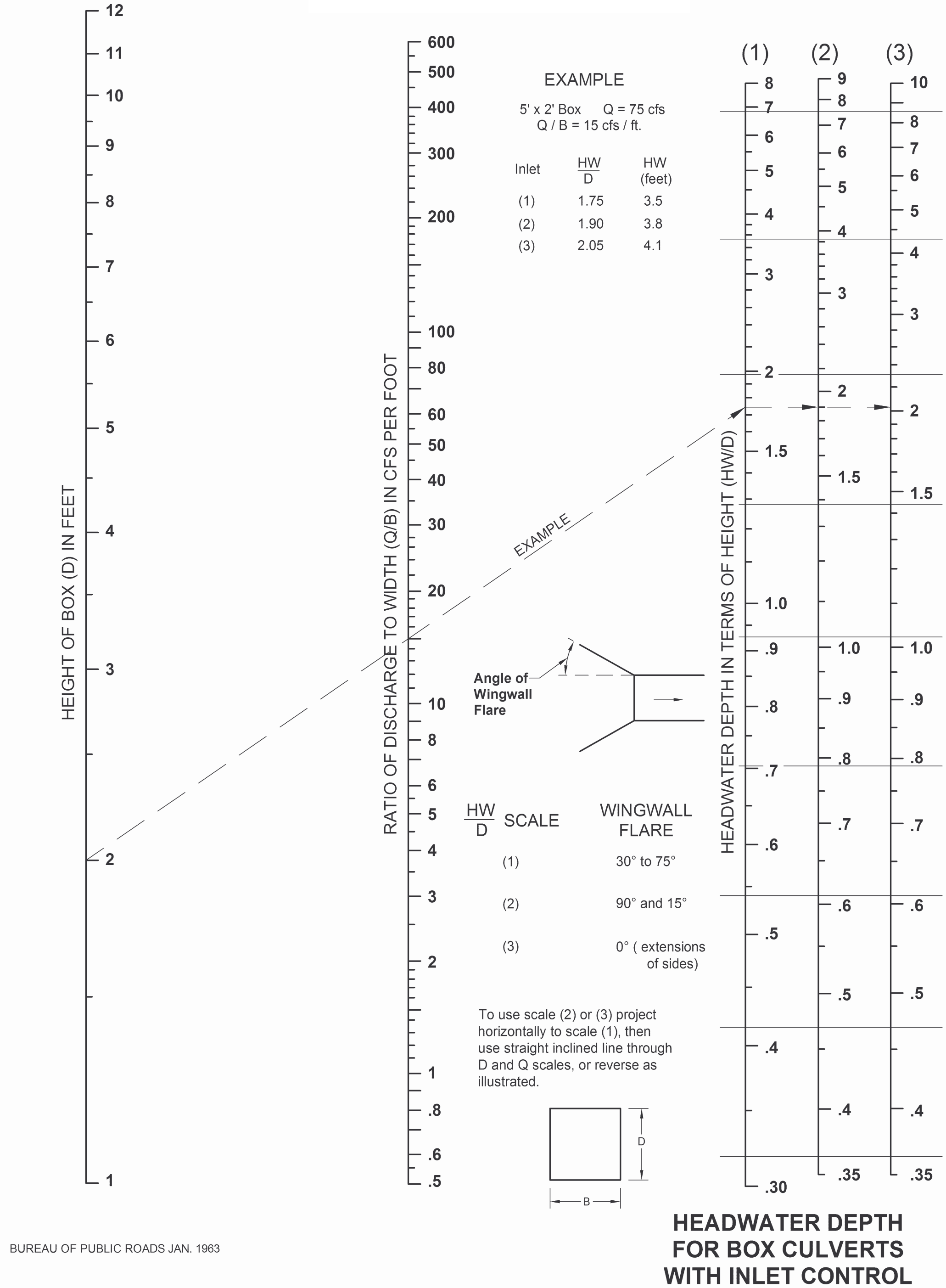
Figure 2.3.1

UNIT PEAK DISCHARGE IN CFS/SQUARE MILE/INCH OF RUNOFF



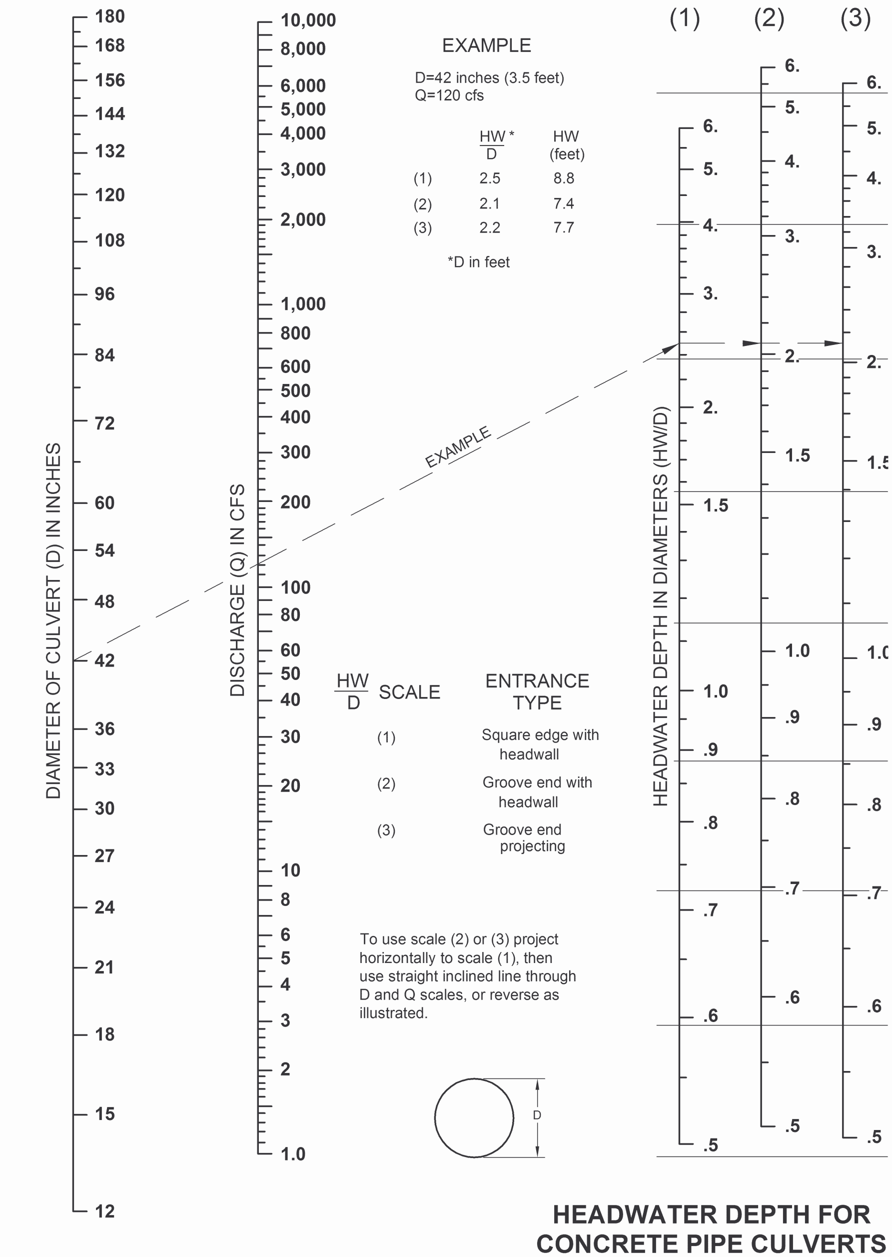
From USDA, TR-55, Urban Hydrology for Small Watersheds, 1986

Figure 3.1.2.1



HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

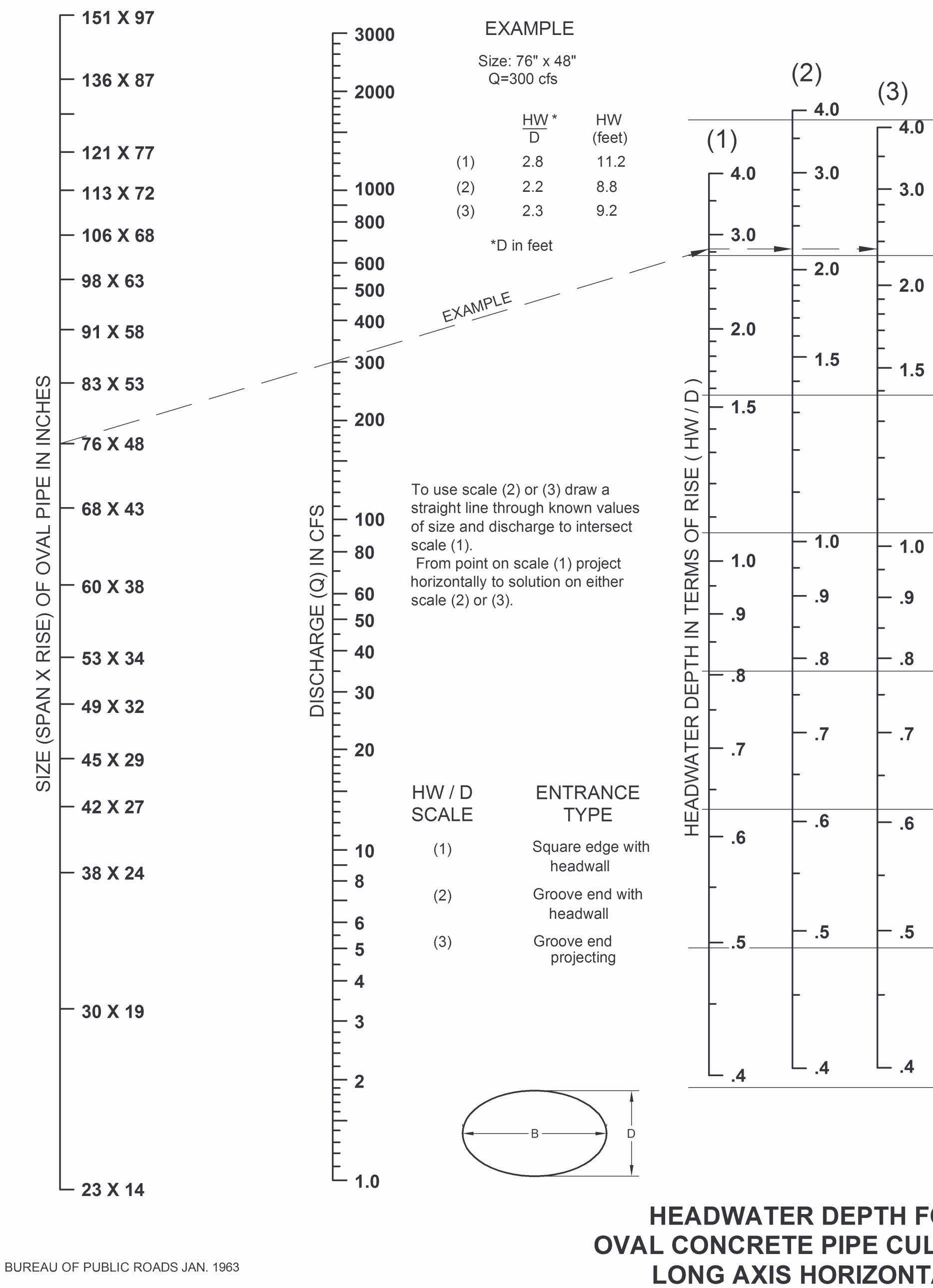
Figure 3.1.2.2



HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

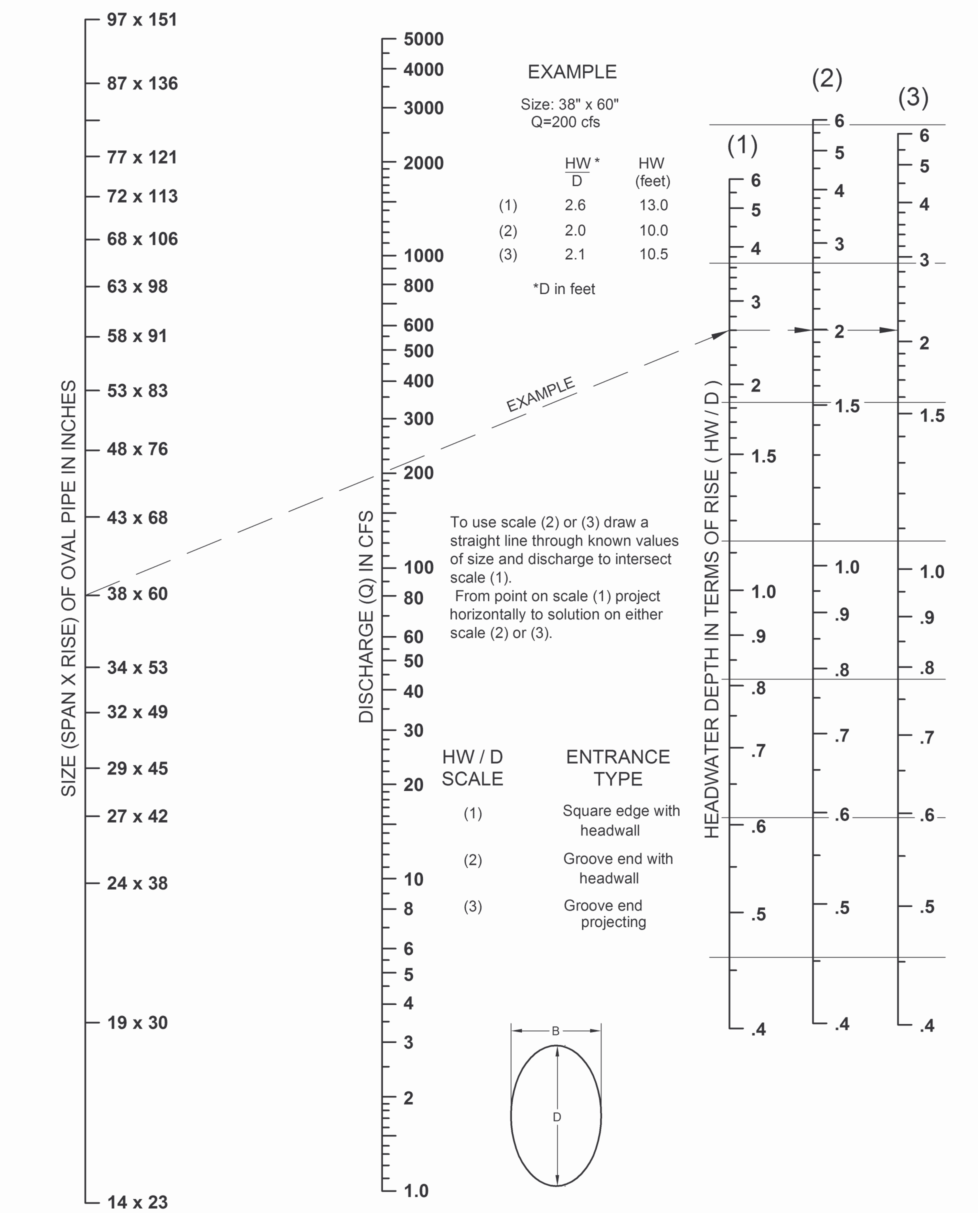
BUREAU OF PUBLIC ROADS JAN. 1963
HEADWATER SCALES 2 & 3 REVISED MAY 1964

Figure 3.1.2.3



HEADWATER DEPTH FOR OVAL CONCRETE PIPE CULVERTS LONG AXIS HORIZONTAL WITH INLET CONTROL

Figure 3.1.2.4



BUREAU OF PUBLIC ROADS JAN. 1963

HEADWATER DEPTH FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS VERTICAL
WITH INLET CONTROL

Figure 3.1.2.5

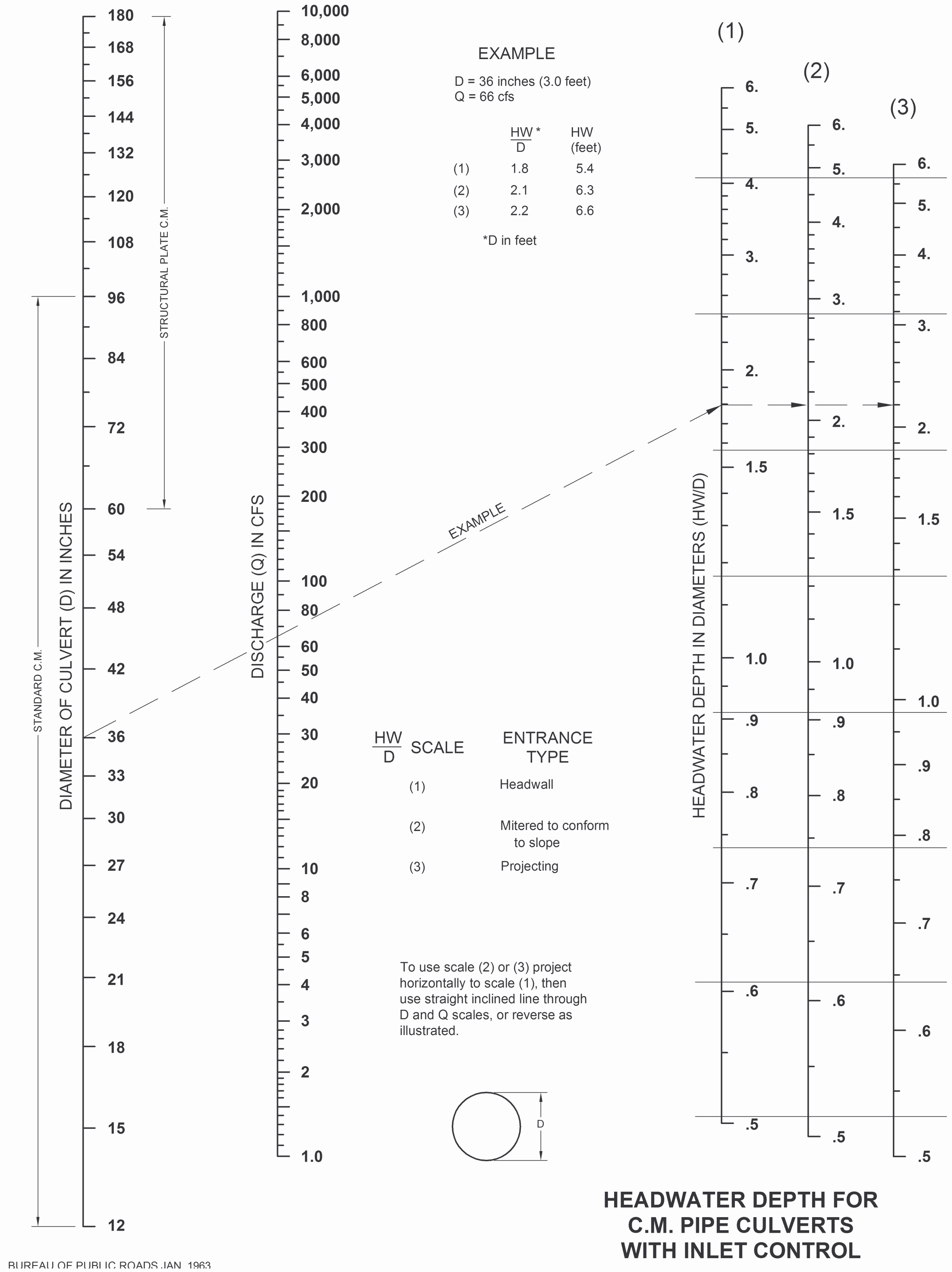
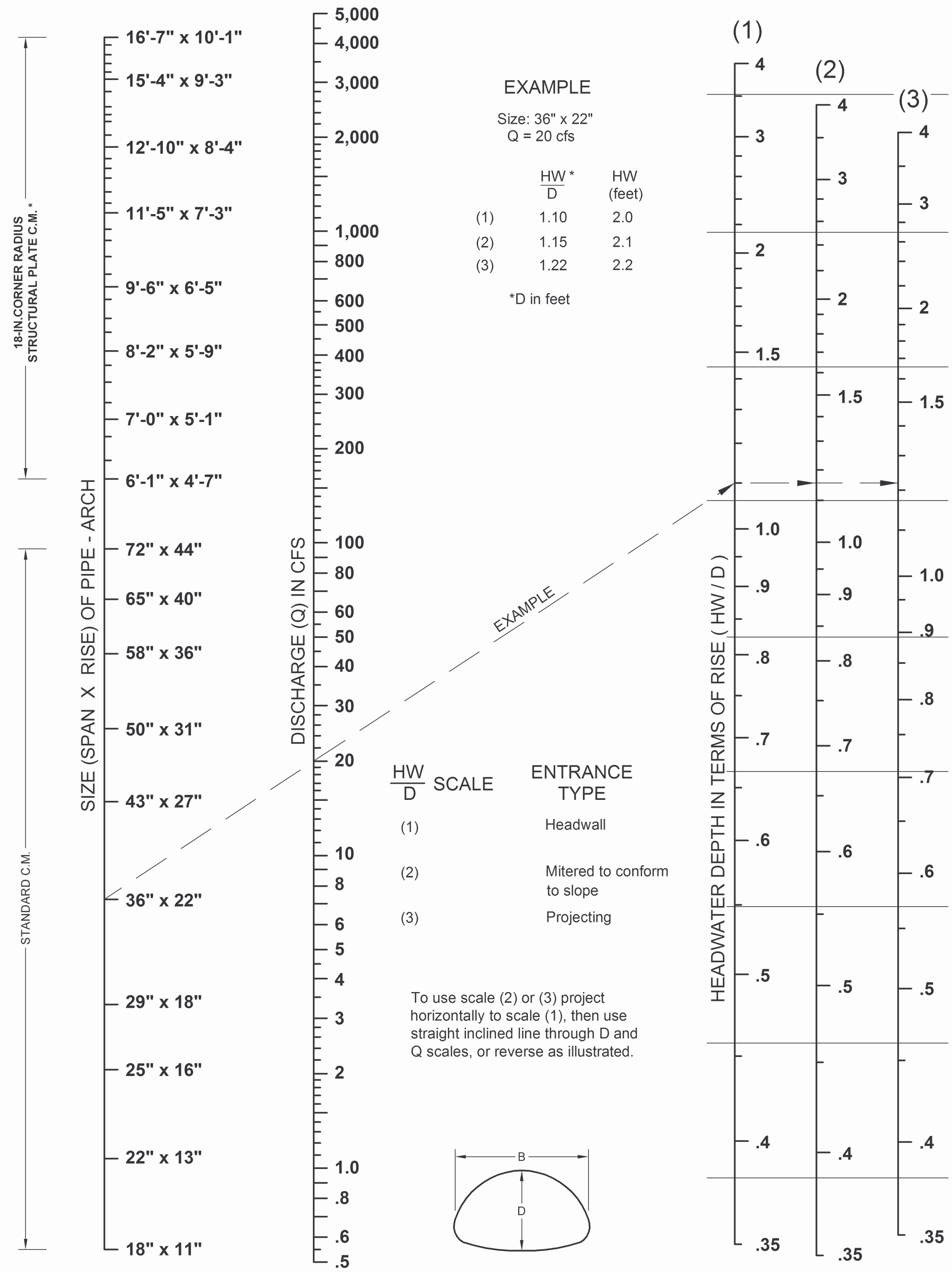

EXAMPLE
D = 36 inches (3.0 feet)
Q = 66 cfs
HW*/D HW (feet)
(1) 1.8 5.4
(2) 2.1 6.3
(3) 2.2 6.6
*D in feet
DIAMETER OF CULVERT (D) IN INCHES
STANDARD C.M.
STRUCTURAL PLATE C.M.
DISCHARGE (Q) IN CFS
HEADWATER DEPTH IN DIAMETERS (HW/D)
EXAMPLE
HW/D SCALE ENTRANCE TYPE
(1) Headwall
(2) Mitered to conform to slope
(3) Projecting
To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.
D
HEADWATER DEPTH FOR C.M. PIPE CULVERTS WITH INLET CONTROL
BUREAU OF PUBLIC ROADS JAN. 1963

Figure 3.1.2.6

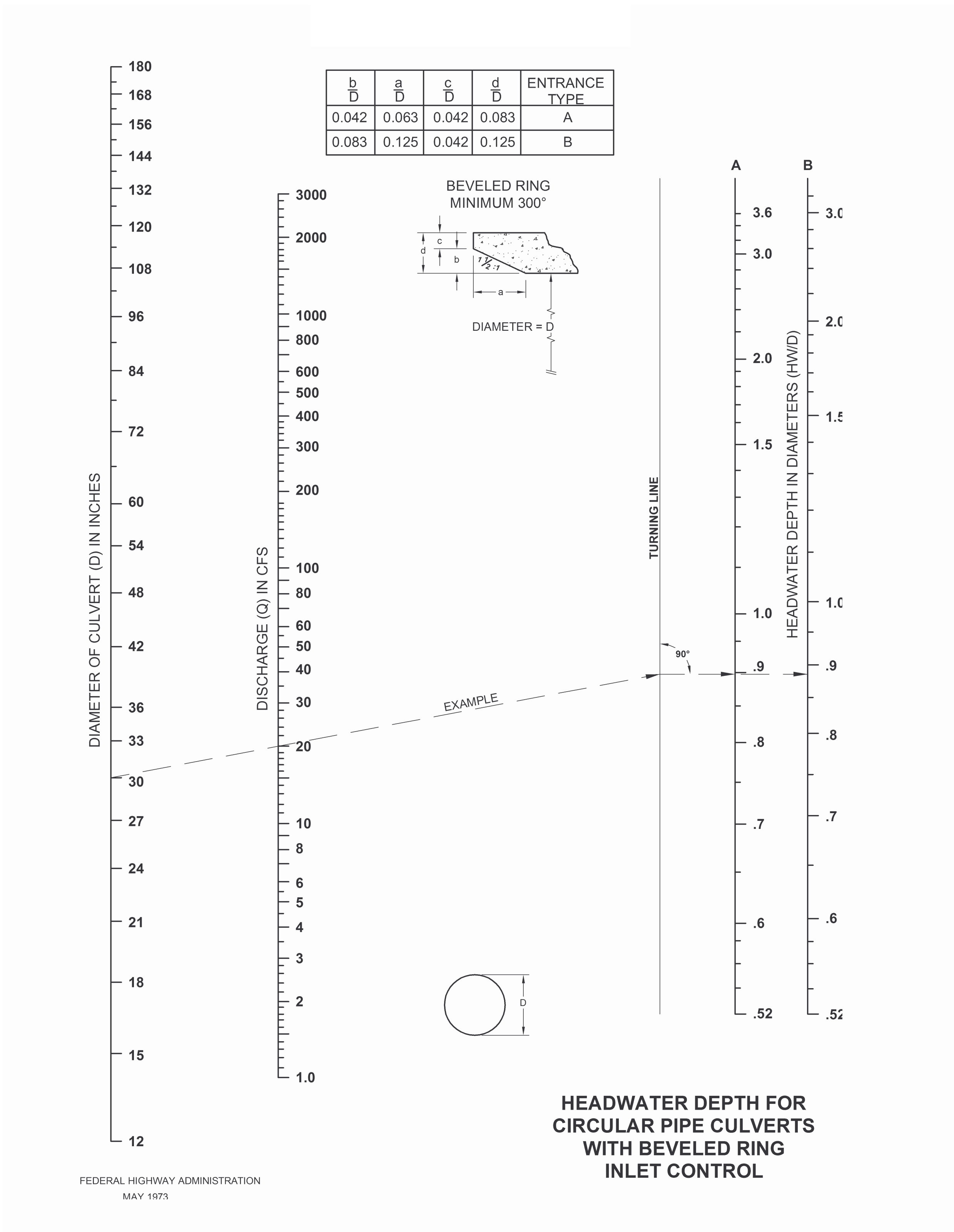


* ADDITIONAL SIZES NOT DIMENSIONED ARE LISTED IN FABRICATOR'S CATALOG

BUREAU OF PUBLIC ROADS JAN. 1963

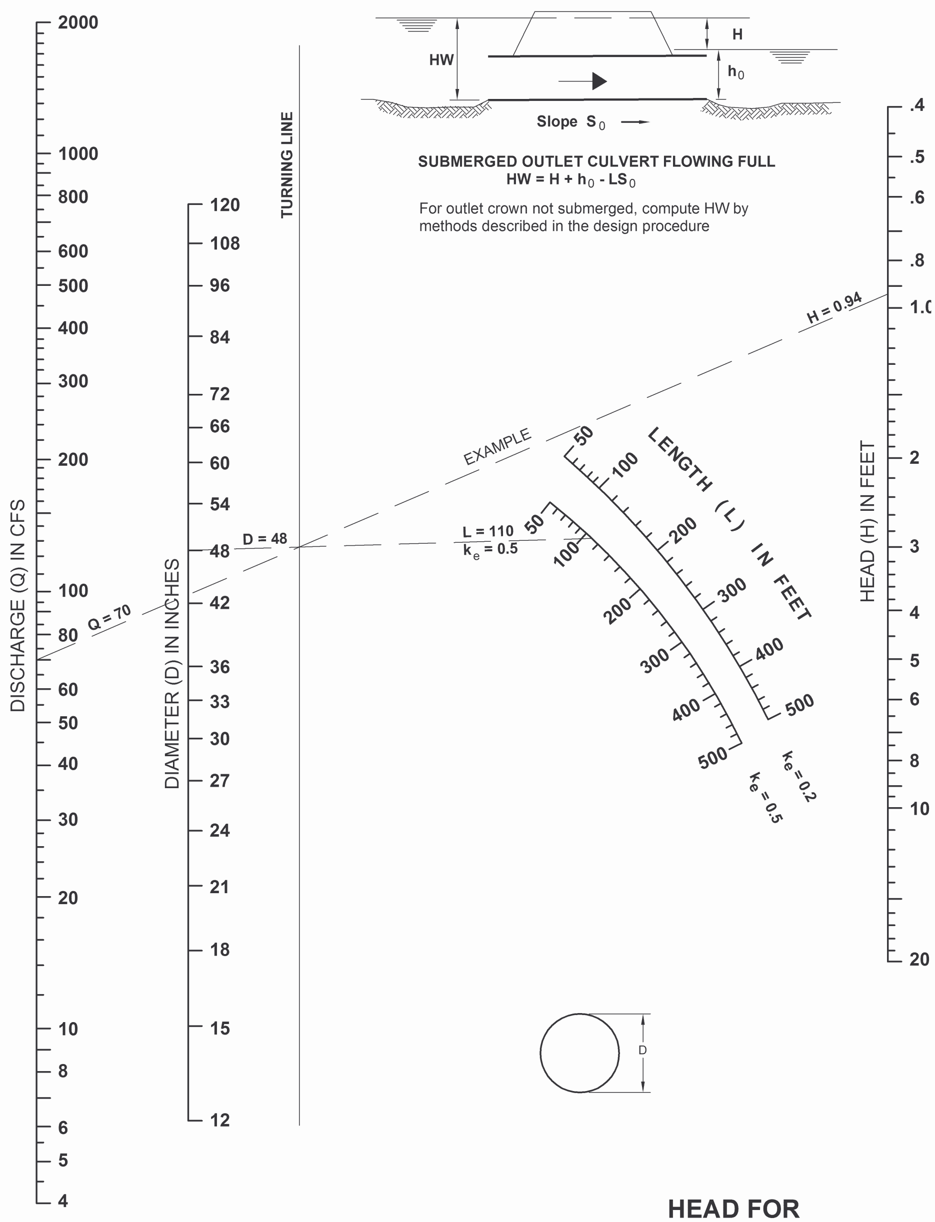
HEADWATER DEPTH FOR C. M. PIPE - ARCH CULVERTS WITH INLET CONTROL

Figure 3.1.2.7



b/D | a/D | c/D | d/D | ENTRANCE TYPE
0.042 | 0.063 | 0.042 | 0.083 | A
0.083 | 0.125 | 0.042 | 0.125 | B
BEVELED RING
MINIMUM 300°
DIAMETER = D
DIAMETER OF CULVERT (D) IN INCHES
180
168
156
144
132
120
108
96
84
72
60
54
48
42
36
33
30
27
24
21
18
15
12
DISCHARGE (Q) IN CFS
3000
2000
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1.0
EXAMPLE
TURNING LINE
90°
A
B
HEADWATER DEPTH IN DIAMETERS (HW/D)
3.6
3.0
2.0
1.5
1.0
.9
.8
.7
.6
.52
D
HEADWATER DEPTH FOR
CIRCULAR PIPE CULVERTS
WITH BEVELED RING
INLET CONTROL
FEDERAL HIGHWAY ADMINISTRATION
MAY 1973

Figure 3.1.2.8



HEAD FOR
CONCRETE PIPE CULVERTS
FLOWING FULL
n=0.012

BUREAU OF PUBLIC ROADS JAN. 1963

Figure 3.1.2.9

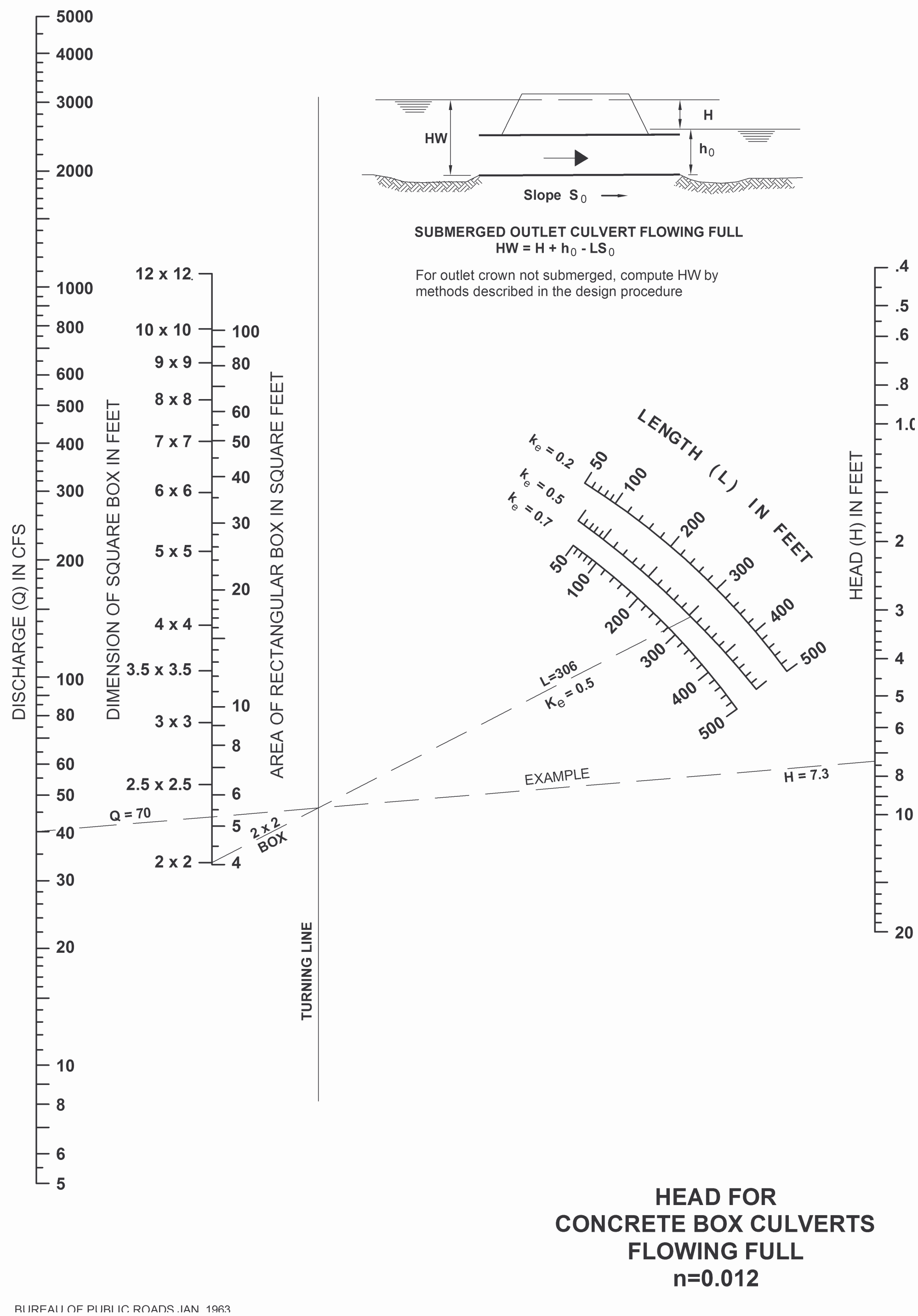
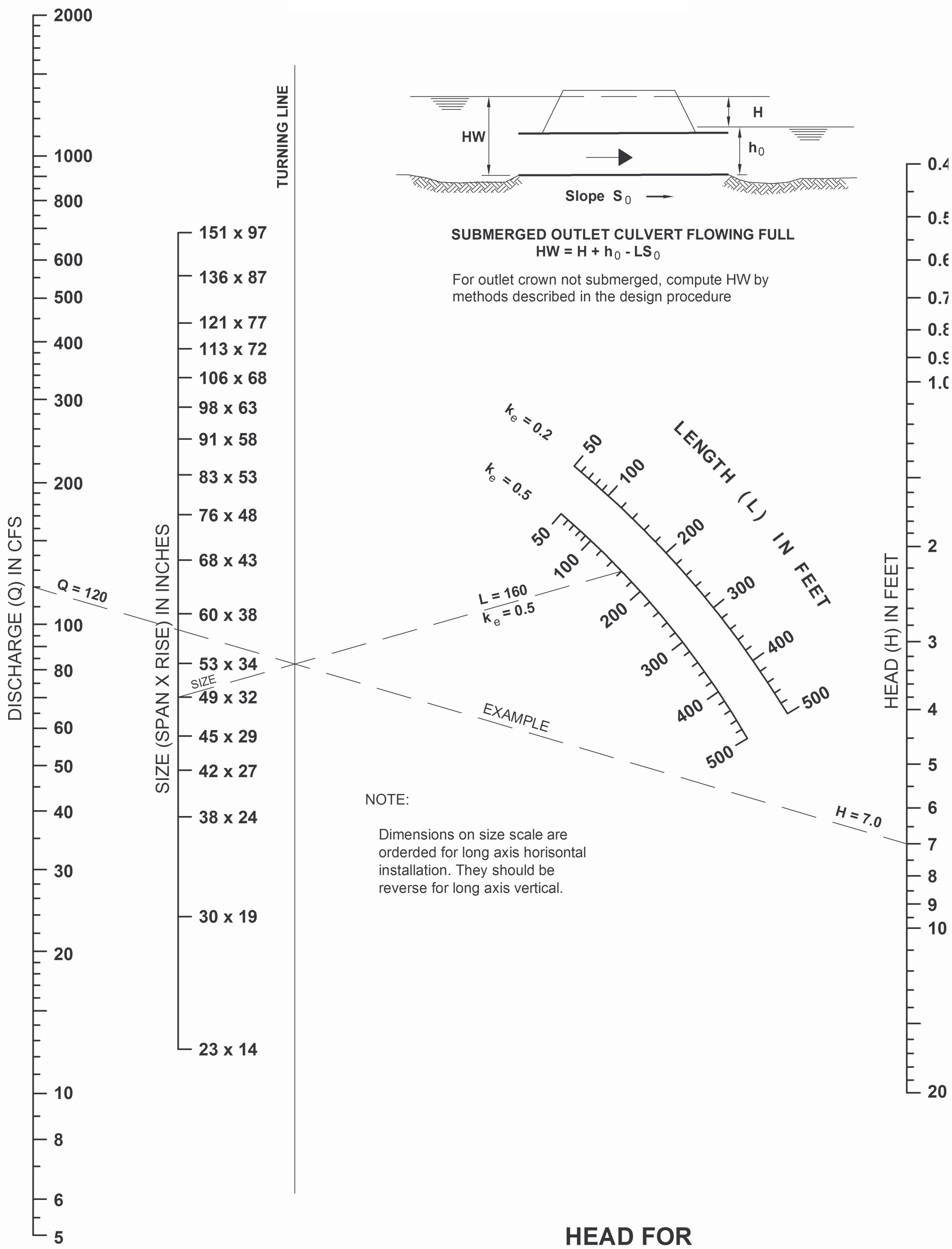

SUBMERGED OUTLET CULVERT FLOWING FULL
HW = H + h0 - LS0
For outlet crown not submerged, compute HW by methods described in the design procedure
HW
H
h0
Slope S0
DISCHARGE (Q) IN CFS
DIMENSION OF SQUARE BOX IN FEET
AREA OF RECTANGULAR BOX IN SQUARE FEET
TURNING LINE
LENGTH (L) IN FEET
HEAD (H) IN FEET
ke = 0.2
ke = 0.5
ke = 0.7
L=306
Ke = 0.5
Q = 70
2 x 2 BOX
EXAMPLE
H = 7.3
HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
n=0.012
BUREAU OF PUBLIC ROADS JAN. 1963

Figure 3.1.2.10



HEAD FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS HORIZONTAL OR VERTICAL
FLOWING FULL
n=0.012

BUREAU OF PUBLIC ROADS JAN. 1963

Figure 3.1.2.11

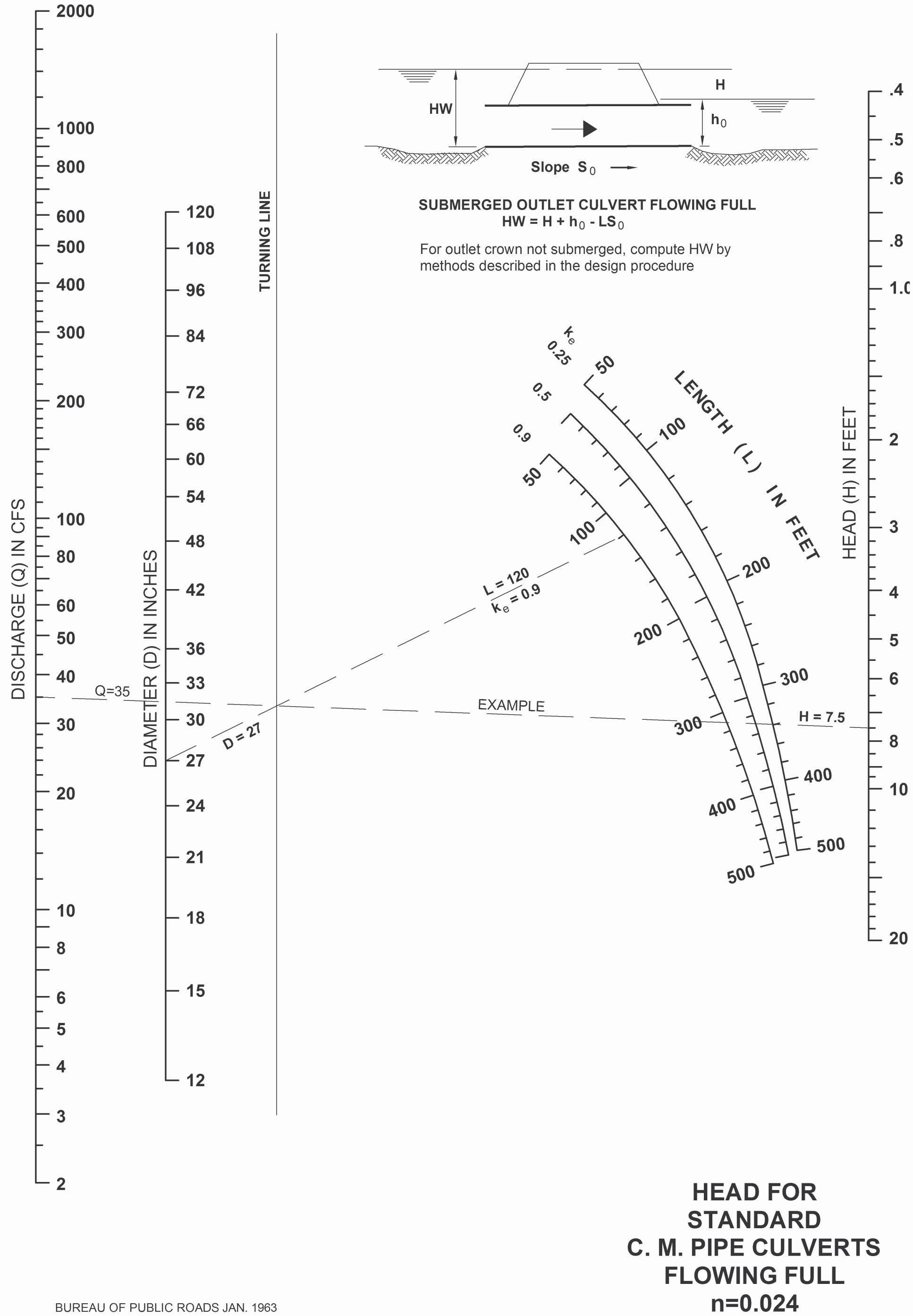
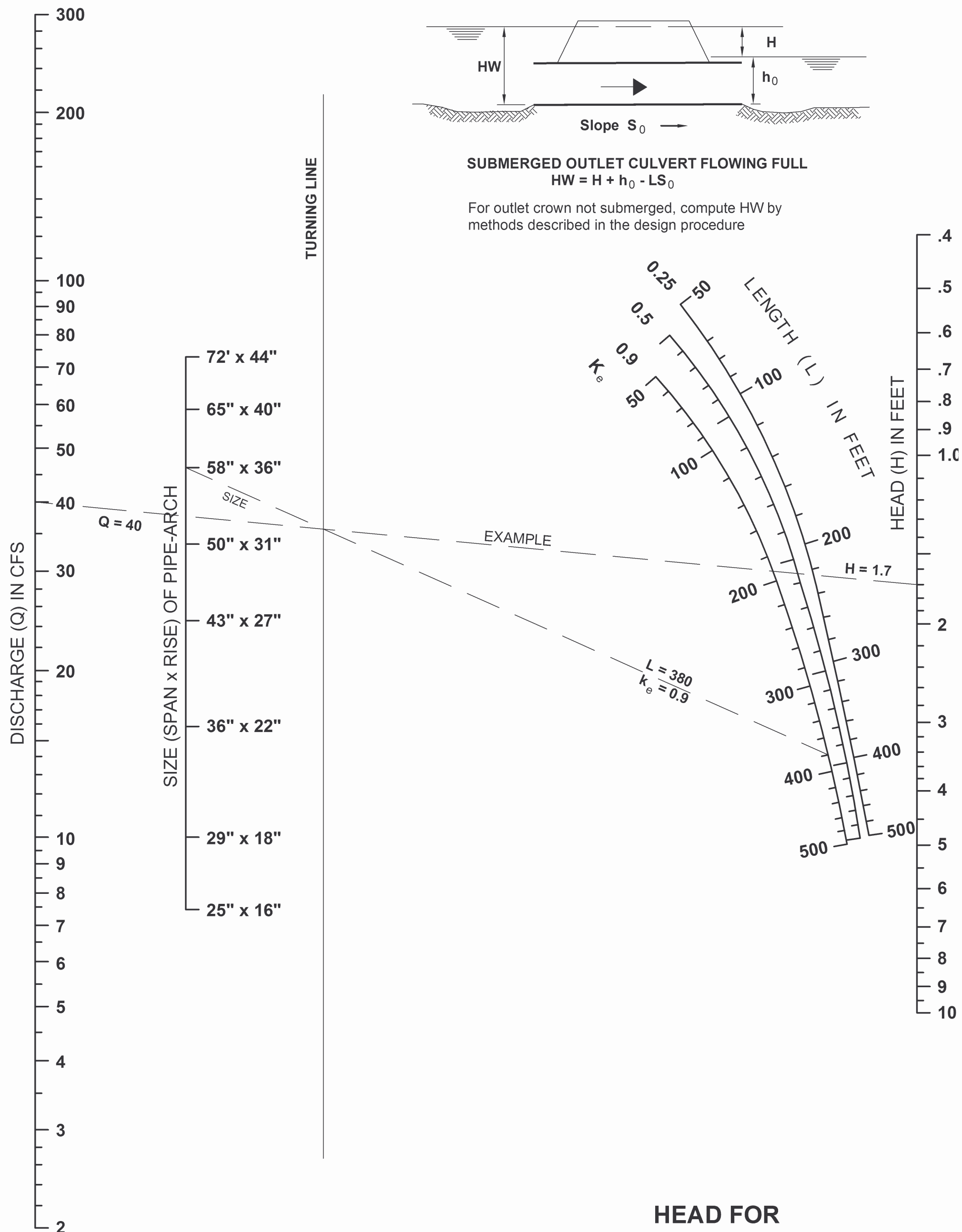


Figure 3.1.2.12



HEAD FOR STANDARD C.M. PIPE-ARCH CULVERTS FLOWING FULL n=0.024

BUREAU OF PUBLIC ROADS JAN. 1963

Figure 3.1.2.13

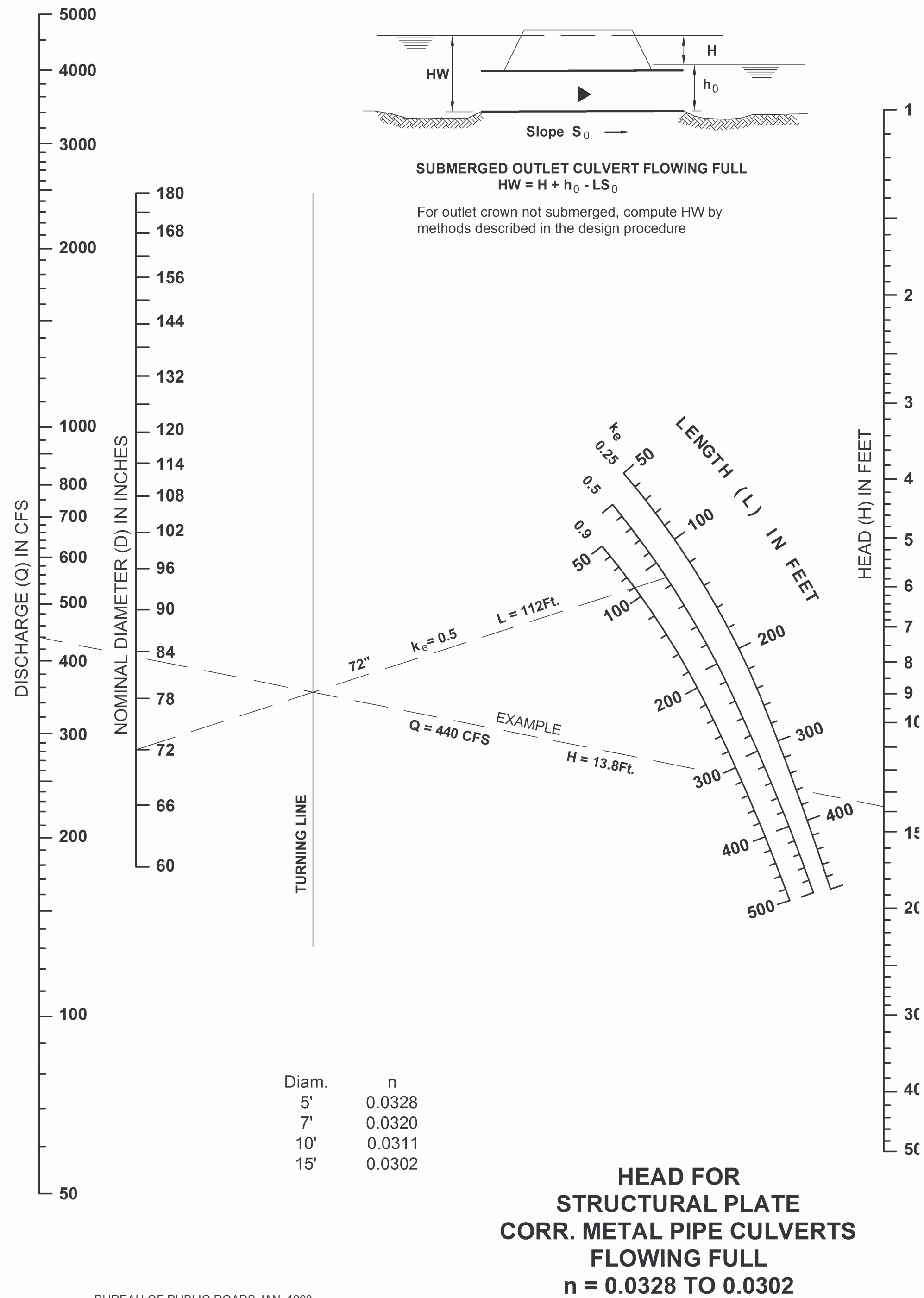


Figure 3.1.2.14

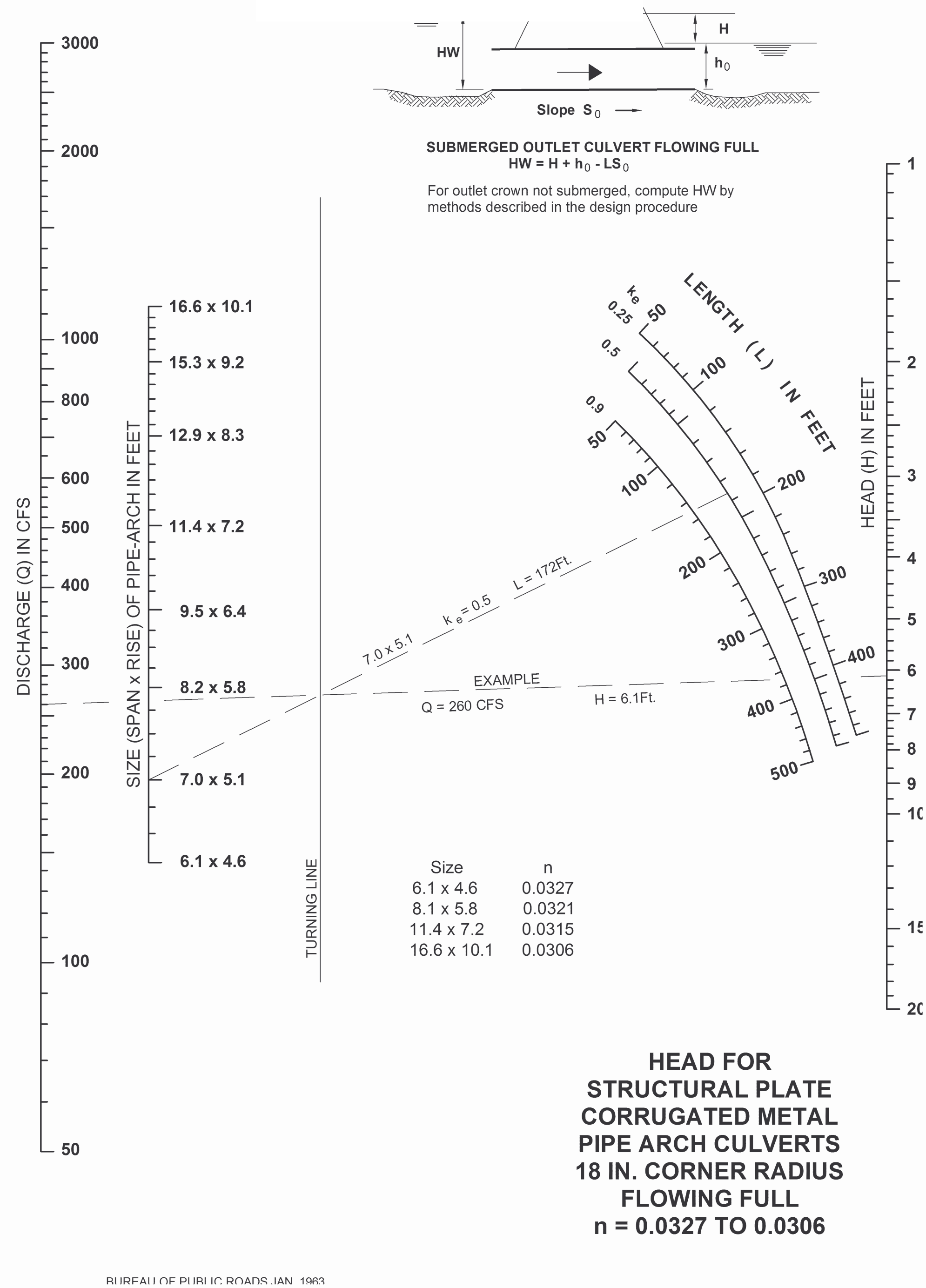
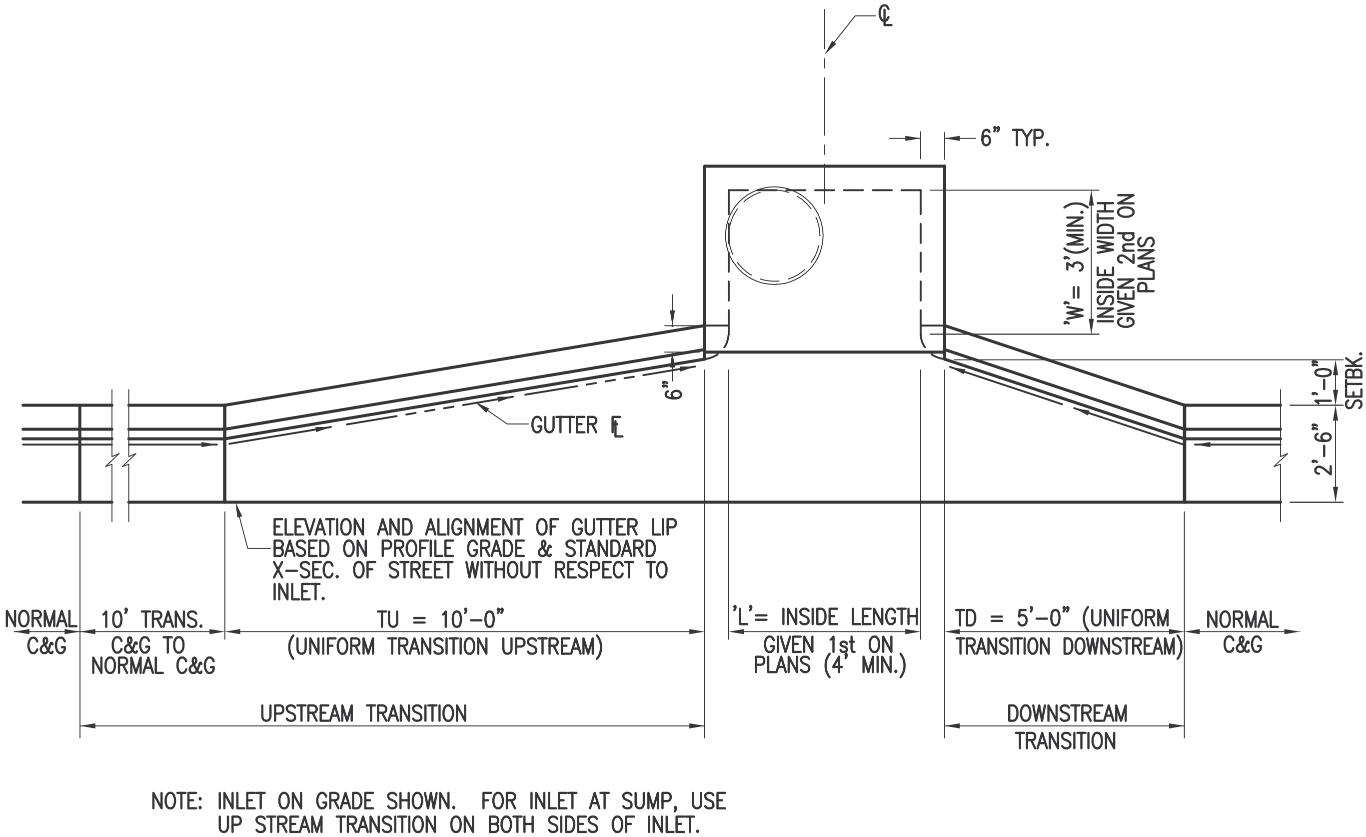
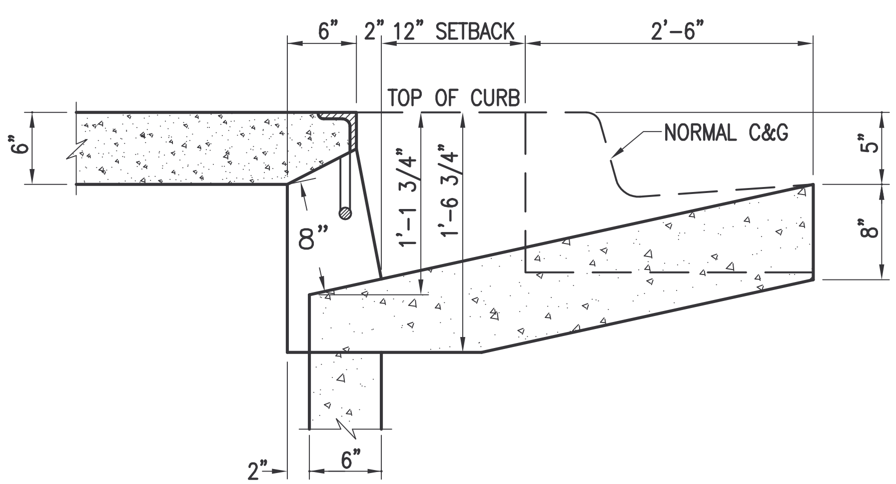


Figure 4.3.2.1
Type M Inlet



PLAN



THROAT DETAIL

Figure 4.3.3.1

THEORETICAL INLET CAPACITY

4'-0" LONG DEPRESSED CURB OPENING INLET

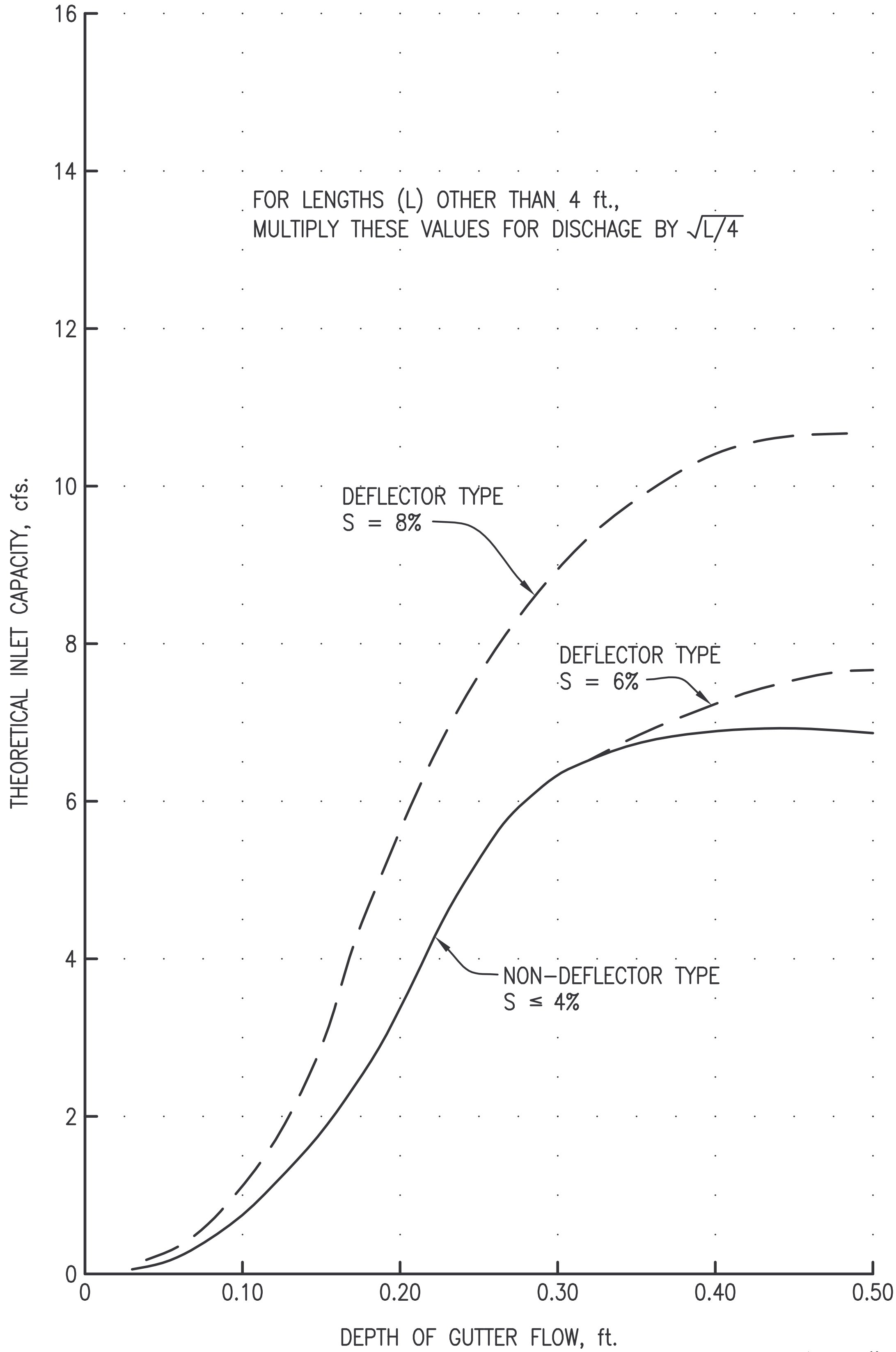
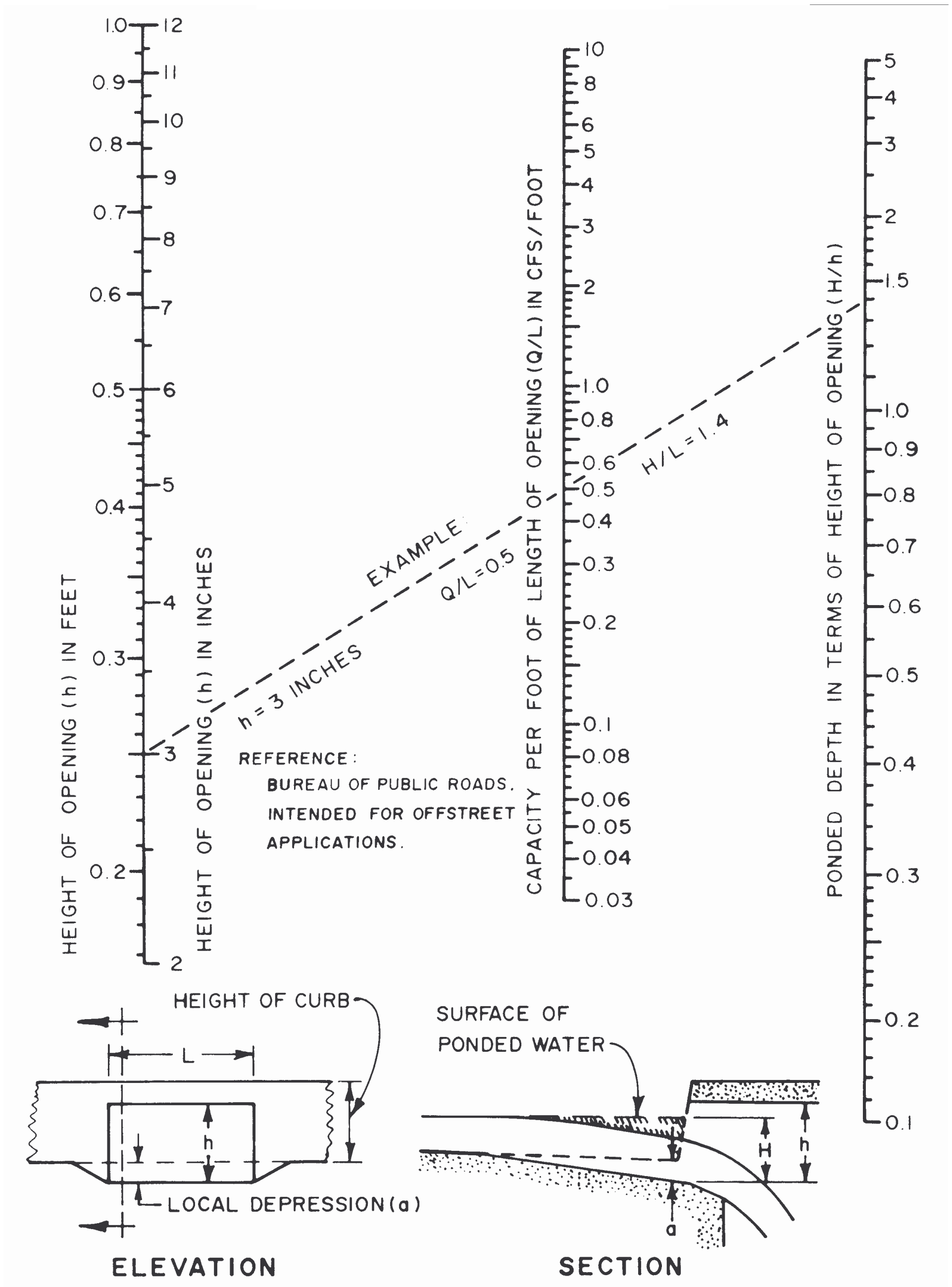


Figure 4.3.3.2



CAPACITY OF CURB OPENING INLET
AT LOW POINT IN GRADE.

Figure 4.4.1.1

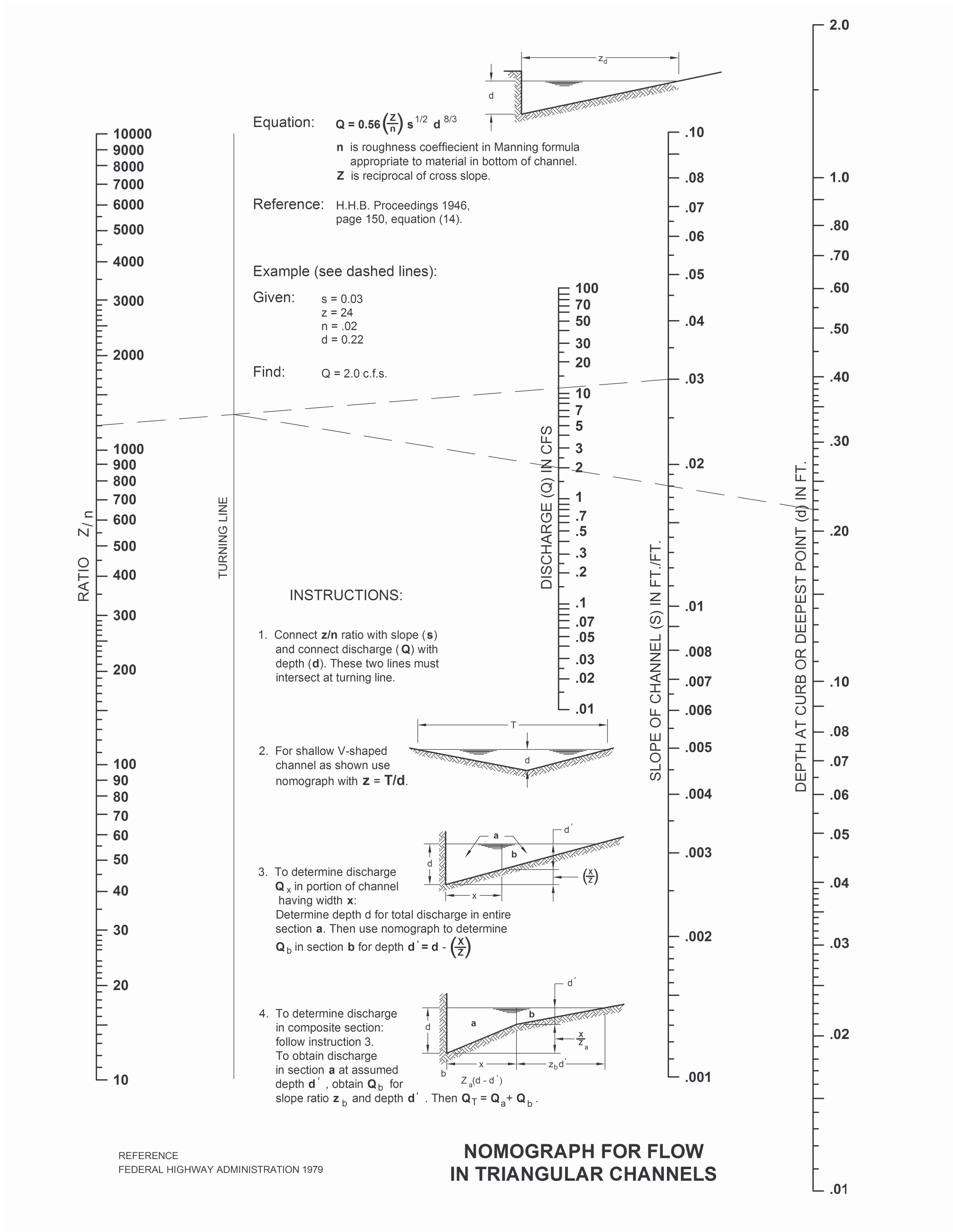
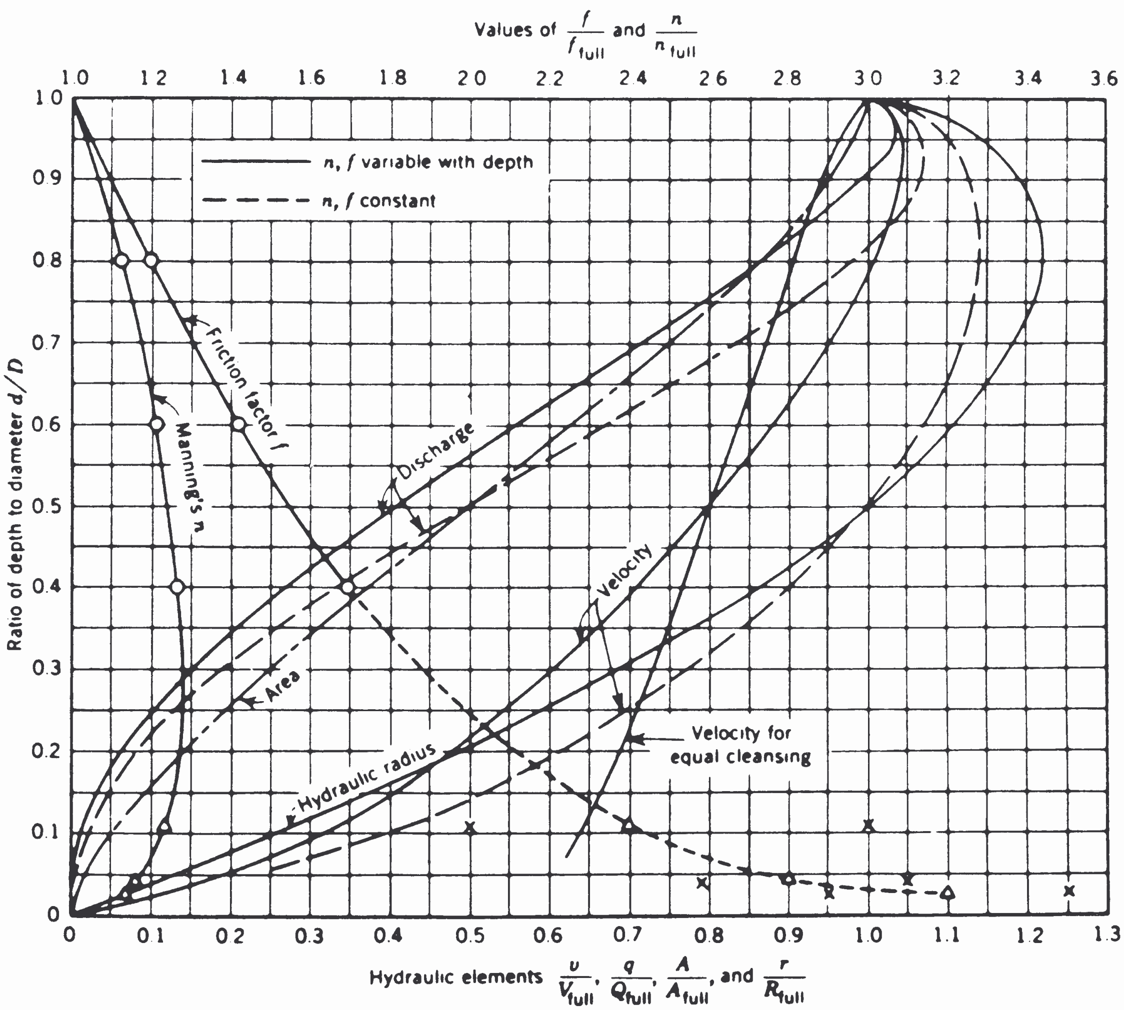

Equation: $Q = 0.56\left(\frac{Z}{n}\right) s^{1/2} d^{8/3}$
n is roughness coeffiecient in Manning formula appropriate to material in bottom of channel.
Z is reciprocal of cross slope.
Reference: H.H.B. Proceedings 1946, page 150, equation (14).
Example (see dashed lines):
Given: s = 0.03
z = 24
n = .02
d = 0.22
Find: Q = 2.0 c.f.s.
RATIO Z/n
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
TURNING LINE
DISCHARGE (Q) IN CFS
100
70
50
30
20
10
7
5
3
2
1
.7
.5
.3
.2
.1
.07
.05
.03
.02
.01
SLOPE OF CHANNEL (S) IN FT./FT.
.10
.08
.07
.06
.05
.04
.03
.02
.01
.008
.007
.006
.005
.004
.003
.002
.001
DEPTH AT CURB OR DEEPEST POINT (d) IN FT.
2.0
1.0
.80
.70
.60
.50
.40
.30
.20
.10
.08
.07
.06
.05
.04
.03
.02
.01
INSTRUCTIONS:
1. Connect z/n ratio with slope (s) and connect discharge (Q) with depth (d). These two lines must intersect at turning line.
2. For shallow V-shaped channel as shown use nomograph with z = T/d.
3. To determine discharge Q_x in portion of channel having width x: Determine depth d for total discharge in entire section a. Then use nomograph to determine Q_b in section b for depth $d' = d - \left(\frac{x}{z}\right)$
4. To determine discharge in composite section: follow instruction 3. To obtain discharge in section a at assumed depth d', obtain Q_b for slope ratio z_b and depth d'. Then $Q_T = Q_a + Q_b$.
REFERENCE
FEDERAL HIGHWAY ADMINISTRATION 1979
NOMOGRAPH FOR FLOW
IN TRIANGULAR CHANNELS

Figure 4.6.2.1



v	=	Actual velocity of flow (fps)	A	=	Area occupied by flow ($ft.^2$)
V_{full}	=	Velocity flowing full (fps)	A_{full}	=	Area of pipe ($ft.^2$)
q	=	Actual quantity of flow (cfs)	r	=	Actual hydraulic radius (ft.)
Q_{full}	=	Capacity flowing full (cfs)	R_{full}	=	Hydraulic radius of full pipe (ft.)

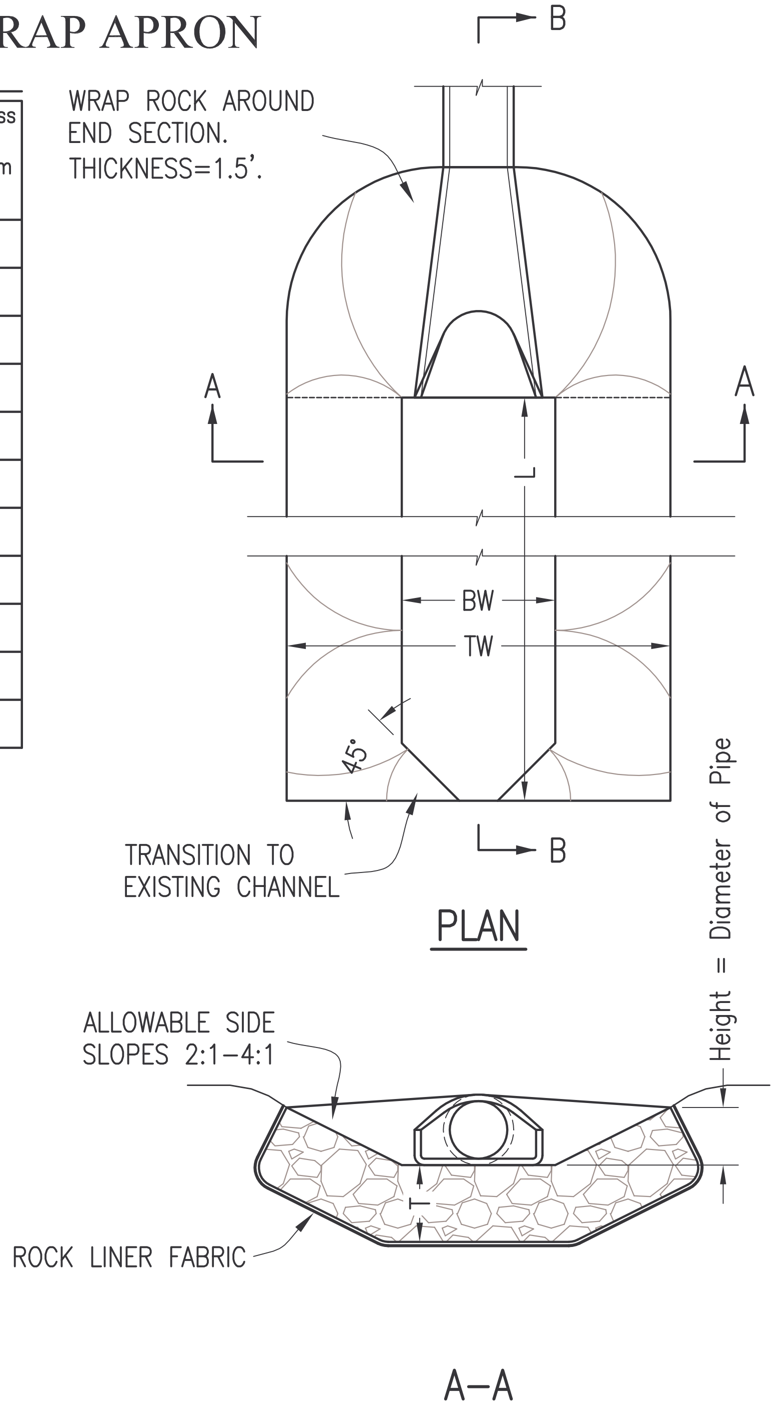
HYDRAULIC ELEMENTS OF CIRCULAR CONDUITS (2)

Figure 4.6.4.1
RIP RAP APRON

Pipe Size (in)	Maximum Pipe Slope (%)	Length L (ft)	Bottom Width BW Minimum (ft)	Top Width TW Minimum (ft)	Thickness T Minimum (ft)
12	3.50	12	4	8	2
15	2.60	15	4	9	2
18	2.00	16	4	10	2
24	1.70	20	4	12	2
30	1.40	24	6	16	2
36	1.00	28	6	18	2
42	0.80	32	6	20	3
48	0.65	36	6	22	3
54	0.55	40	8	26	3
60	0.45	44	8	28	3
72	0.40	48	8	32	3

Rip rap to be MoDOT Type I: 50% of particles greater than or equal to 1 foot in diamenter. Rock must be angular, hard and durable.

Rock Liner Fabric shall consist of a non-woven polypropylene type fabrice: Amoco 4553 or SI Geosolutions Geotex 801 or approved equal. Alternatively, an 8 inch bed of well graded sand and gravel with gravel up to 3" is acceptable.



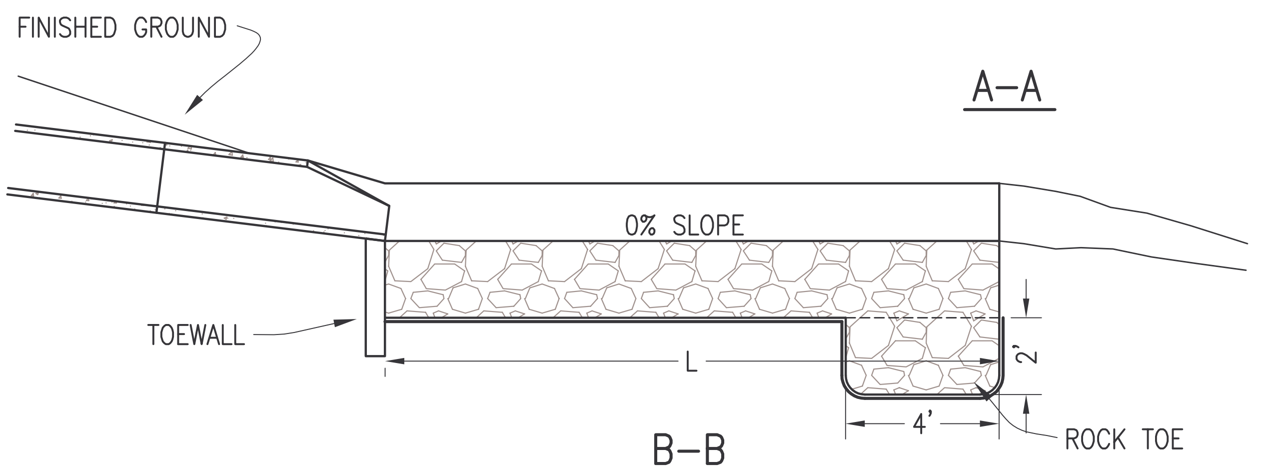


Figure 5.1.4.1A: **Natural Channel Assessment**

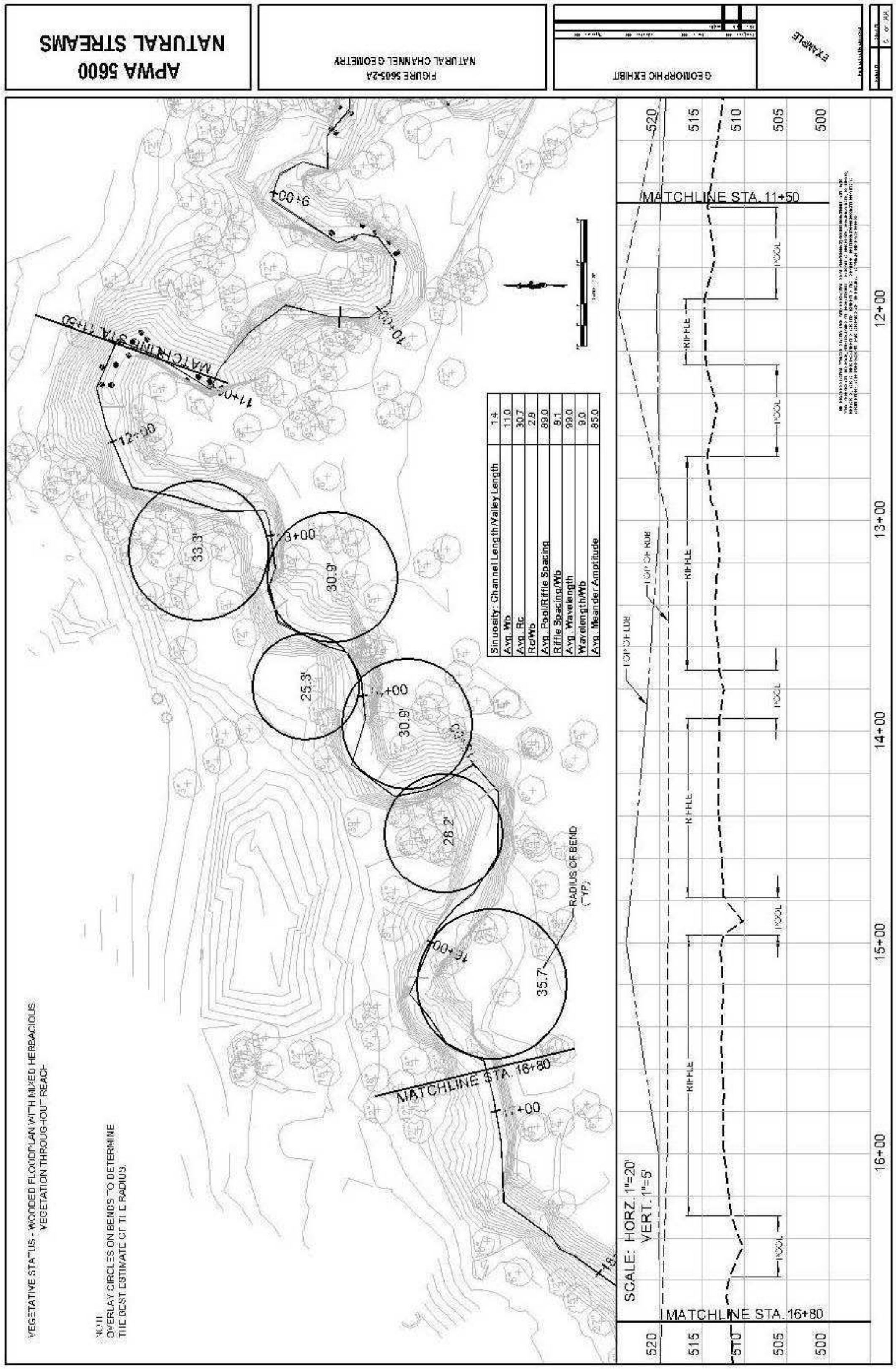


Figure 5.1.4.1B: Natural Channel

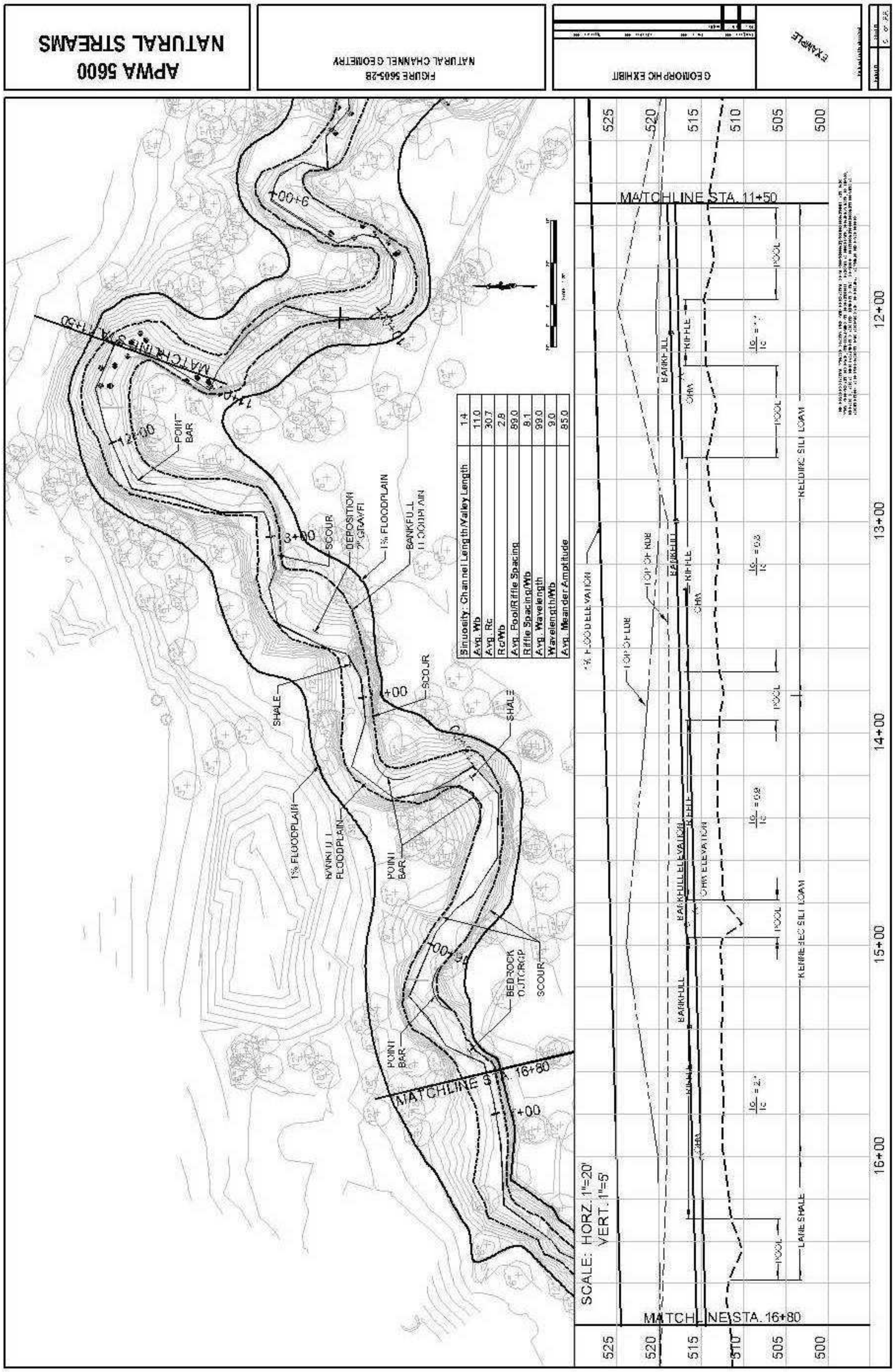


Figure 5.1.4.2

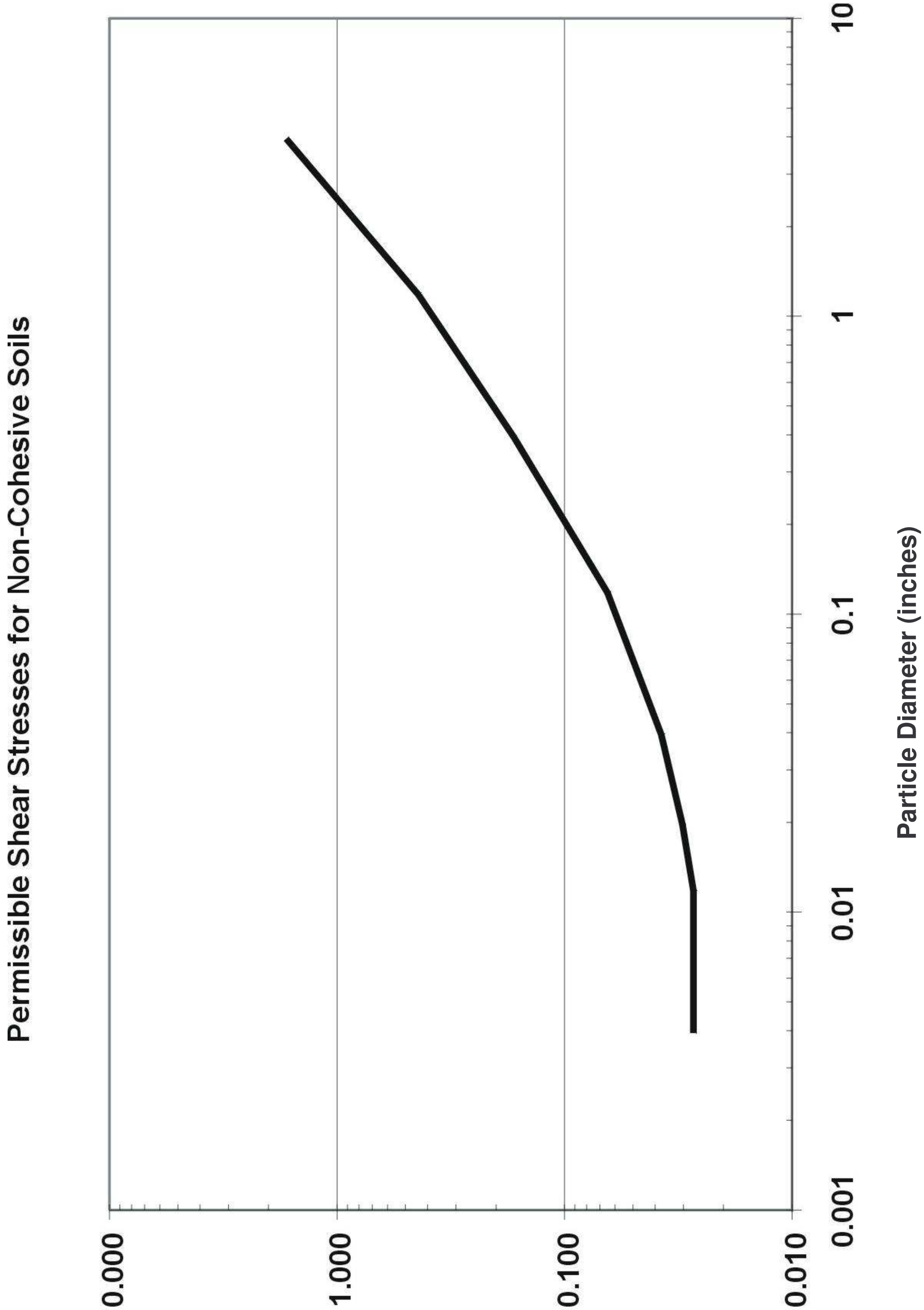

Permissible Shear Stresses for Non-Cohesive Soils
tp (lbs/ft2)
10.000
1.000
0.100
0.010
0.001
0.01
0.1
1
10
Particle Diameter (inches)

Figure 5.1.4.3

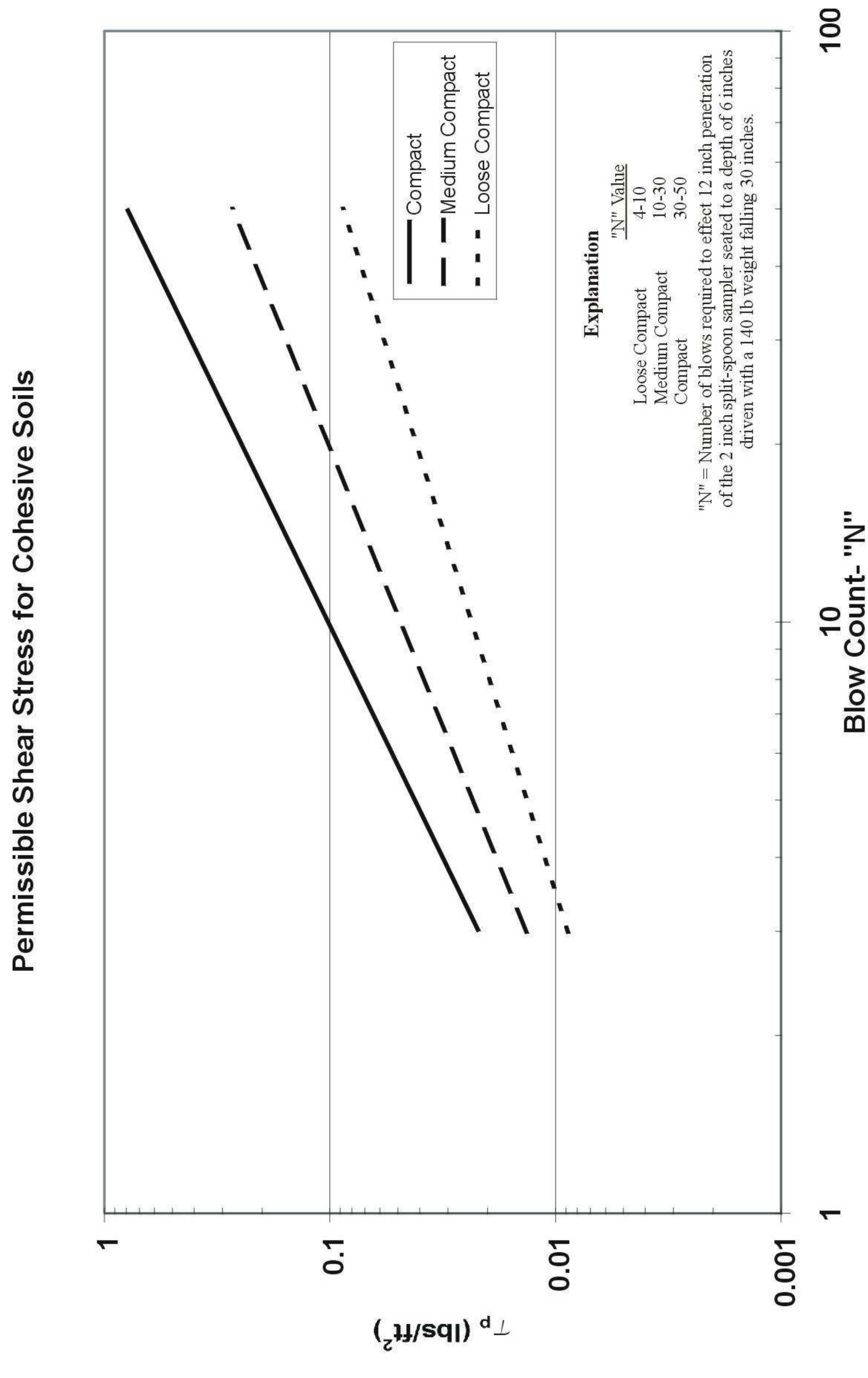
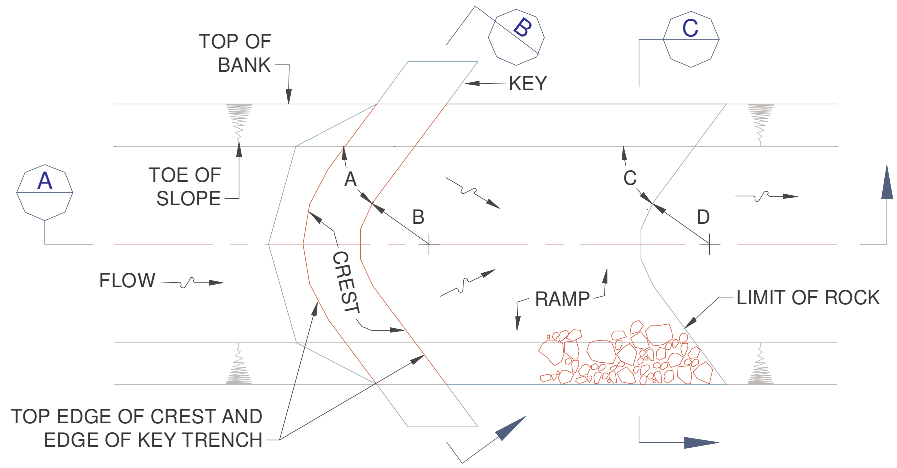
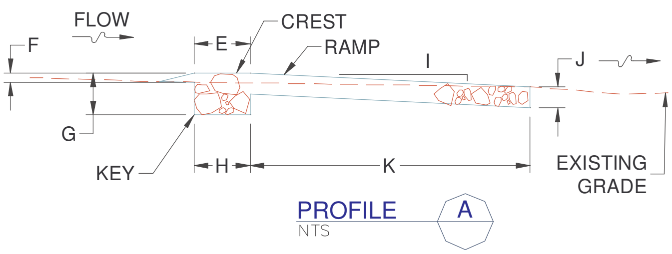
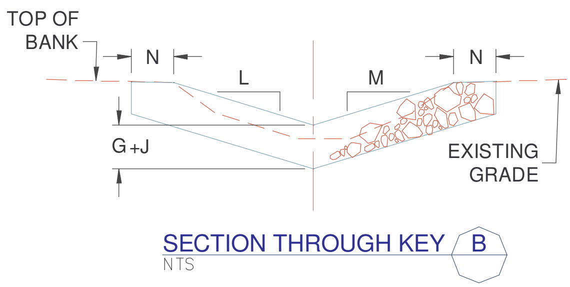

Permissible Shear Stress for Cohesive Soils
Compact
Medium Compact
Loose Compact
Explanation
"N" Value
Loose Compact 4-10
Medium Compact 10-30
Compact 30-50
"N" = Number of blows required to effect 12 inch penetration of the 2 inch split-spoon sampler seated to a depth of 6 inches driven with a 140 lb weight falling 30 inches.
1
0.1
0.01
0.001
τp (lbs/ft²)
1
10
100
Blow Count- "N"

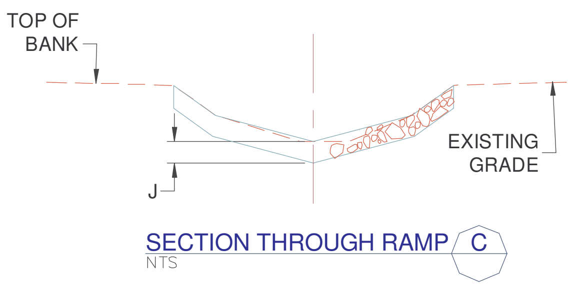
Figure 5.1.8.1: Grade Control Structure







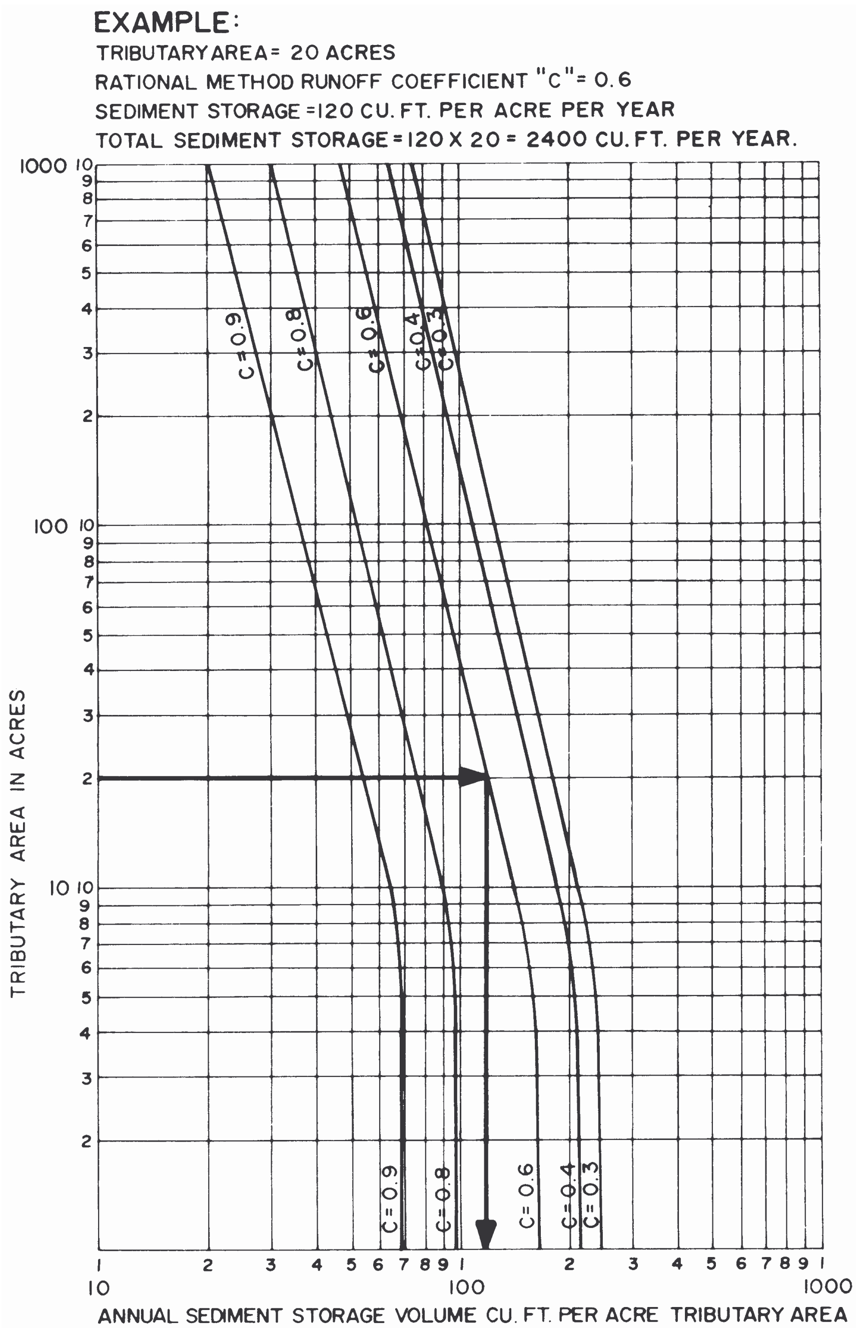
A	STREAM BANK ANGLE (50°< A < 80°)
B	CREST RADIUS
C	TAIL ANGLE(50° < A < 80°)
D	END OF RAMP RADIUS
E	CREST WIDTH
F	CREST HEIGHT
G	KEY THICKNESS ≧ 1.5 D_{90}
H	KEY WIDTH ≧ 1.5 D_{90}
I	RAMP GRADE 20H:1V
J	RAMP THICKNESS ≧ 1.5 D_{100}
K	RAMP LENGTH
L	CREST SIDE SLOPE
M	CREST SIDE SLOPE
N	EMBANKMENT KEY



Notes

1. The depth of key trench shall be a minimum of 1.5 D_{90}. The crest shall slope downward from the stream bank to the center of the structure to focus the flow to the channel center. The tail ramp is generally sloped at 20 horizontal to 1 vertical and dissipates energy gradually over it length. The upstream face is not perpendicular to the flow but has an upstream oriented "V" or arch shape in plan form.
2. For item A, Stream Bank Angle, and item C Tail Angle, the lower end of the range should be used for softer soils.
3. For items L and M, crest angle, the typical range is 5 to 1 to 10 to 1.

Figure 6.5.1



ANNUAL SEDIMENT STORAGE

Figure 7.3.1
Calculation Form A

Project: Calculated By: Checked By: Date:

Area Name:			Overland Flow Hydrology								Gutter and Inlet Hydraulics						
Area No.	To Inlet No.	Inlet Type	Ground Slope S	Length of Overland Flow L	Time of Concen- tration Tc	Runoff Coeff. C	Area A	Per Cent Imper- viousness CA	Rainfall Intensity i	Runoff Qr	Gutter Flow Qg	Gutter Slope Sg	Width of Gutter Flow W	Depth of Gutter Flow Yg	Theoret. Inlet Capacity Q	Design Inlet Capacity k Qi	Inlet Bypass Flow q
			ft/ft	ft	min		acres	acres	in/hr	cfs	cfs	ft/ft	ft	ft	cfs	cfs	cfs

Figure 7.3.2

Calculation Form B

Project:

Calculated By:

Checked By:

Date:

Area Name:		Storm Drain Hydraulics														
Area NO.	Manhole or Junction NO.	Time of Concen-tration Tc	Percent Imperviousness CA Added	Cumul.	Rainfall Intensity i	Runoff Q	Storm Drain Length L	Storm Drain Slope S	Storm Drain Diameter D	Capacity Flowing Full Qf	Velocity Flowing Full Vf	Time in Storm Drain t	Head-Losses hL	Manhole or Junction Invert Elevation Upstm	Downstm	Ground Surface Elev. @ Manhole
		min	acres	acres	in/hr	cfs	ft	ft/ft	in	cfs	fps	min	ft	ft	ft	ft

Figure 7.3.3
Calculation Form C

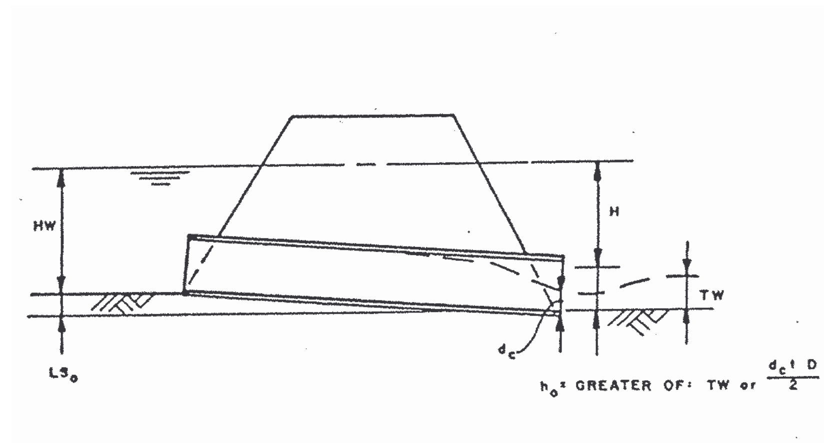
Project:

Calculated By:

Checked By:

Date:

Hydrology						
Area NO.	Culvert NO.	Percent Imperviousness CA Added	Cumul	Time of Concentration Tc	Rainfall Intensity	Discharge Q
		acres	acres	min	in/hr	cfs



						Inlet Control		Outlet Control								
Culvert NO.	Culvert Type	Discharge Q	Culvert Dimensions Lngth L	Slope So	Dia. D	HW/D	HW	Ke	H	dc	(dc + d)/2	TW	ho	LSo	HW	Remarks
		cfs	ft	ft/ft	in		ft		ft	ft	ft	ft	ft	ft	ft	

Figure 7.3.4

Calculation Form D

Project: ______________________ Calculated By: ______________________

Date: ______________________ Checked By: ______________________

Columbia, Missouri
Storm Drain Calculations
Calculation Form A

Area Name:
Runoff Coefficient Calculations: (Either May Be Used)

Method A

Area NO.	Land Use Category	C

Method B

Area NO.	Surface Characteristics	C

Street Configuration:

Width: ☐ 32' ☐ 38'
☐ 44'
☐ Other, Specify________

Cross Slope: ☐ 4" Para ☐ 5" Para
☐ 6" Para ☐ 2%
☐ Other, Specify:_______

Curb Type: ☐ 6" High Straight Back ☐ Other, Specify: _______

Storm Drain Material: ☐ Concrete Pipe: n = ________
☐ Corrugated Metal Pipe: n = ________
☐ Other, Specify:________________________ n = ________

Rainfall Return Frequency ____________ Years

Figure 7.3.5

Calculation Form E

Open Channel Calculations

	Hydrology							Channel Parameters							
Description	Area NO.	Area A	Runoff Coeff. C	Percent Imperv-iousness	Rainfall Return Frequency	Rainfall Intensity i	Q (total)	Channel Slope	Mannings	Left Side Slope	Right Side Slope	Bottom Width	Depth	Velocity	Capacity Q
		Acres	C	CA	Year	in/hr	cfs	ft/ft	n	X : 1	X : 1	ft	ft	fps	cfs

Project: ____________ Calculated By: ____________ Checked By: ____________ Date: ________