Chapter 6 – Hydrologic Analysis and Conveyance Design

Table of Contents

Tables

Figures

Chapter 6 – Hydrologic Analysis and Conveyance Design

6.1 Purpose, Content, and Organization

This chapter presents the minimum computational standards required for designing flow control and runoff treatment best management practices (BMPs) and stormwater conveyance systems. Section 6.2 addresses hydrologic methodologies required for determining design runoff rates and volumes for flow control and runoff treatment BMPs. Section 6.3 addresses methodologies for analysis and design of conveyance systems. Certain methods are required, as noted, in certain situations. Engineers have some discretion in others. In all instances, the City of Lacey (City) may require more extensive analysis or use of a different methodology if deemed necessary.

6.2 Minimum Computational Standards

The minimum computational standards depend on the type of information required and the size of the drainage area to be analyzed as follows:

- For the purpose of designing flow control BMPs, a calibrated continuous simulation model based on the HSPF or an approved equivalent model (e.g., Western Washington Hydrology Model [WWHM]) must be used. Ecology's approval status for other continuous simulation models is provided in the "Additional Resources" section of the online 2019 Washington State Department of Ecology (Ecology) Manual: <https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm> Flow control BMP design standards and sizing criteria are discussed in detail in Chapter 7. The circumstances under which different methodologies apply are summarized in Table 6.1.

- For the purpose of designing runoff treatment BMPs, a calibrated continuous simulation model based on the HSPF program or an approved equivalent model (e.g., WWHM) must be used to calculate runoff and determine the water quality design flow rates and volumes. Design standards and sizing criteria for runoff treatment BMPs are provided in Chapter 8.

- For conveyance system design, the designer may use an approved continuous simulation model or a single event hydrologic model to determine the peak flow rate. The peak flow rate from a continuous simulation model will vary depending on the time step used in the model. Therefore, the length of the time step must be sufficiently short relative to the time of concentration of the watershed to provide for reasonable conveyance system design flows. For most situations in the City, a 15-minute (maximum) time step will be sufficient for conveyance system design. If the project is in a predominantly urbanized watershed with a time of concentration less than about 15 minutes (roughly 10 acres in size), the conveyance design must either use a 5-minute time step (if available) or use an event-based model for conveyance sizing. Conveyance design is discussed in detail in Section 6.3.

- Ecology has developed the HSPF-based WWHM. By default, WWHM uses rainfall/runoff relationships developed for specific basins in the Puget Sound region to all parts of western Washington.

- Use of other continuous simulation models must receive prior concurrence from the City before being used for BMP design.

Table 6.1. Summary of the Application Design Methodologies.

Method	BMP/Conveyance Designs in Western Washington		
	Treatment	**Flow Control**	**Conveyance**
Continuous Runoff Models: (WWHM or approved alternatives)	Method applies to all BMPs	Method applies throughout Western Washington	Method applies throughout Western Washington
Soil Conservation Service Unit Hydrograph (SCSUH)/ Santa Barbara Urban Hydrograph (SBUH)	Not applicable	Not applicable	Acceptable
Rational Method	Not applicable	Not applicable	Acceptable for certain conveyance design only[a]

[a] Refer to Section 6.2.1.

Where large master-planned developments are proposed, the City may require a basin-specific calibration of HSPF rather than use of the default parameters in the above-referenced models. Basin-specific calibrations may be required for projects that will occupy more than 320 acres.

6.2.1 Discussion of Hydrologic Analysis Methods Used for Runoff Modeling and BMP Design

This section provides a discussion of the methodologies to be used for calculating stormwater runoff from a project site. It includes a discussion of estimating stormwater runoff with single event models, such as the Santa Barbara Urban Hydrograph (SBUH), versus continuous simulation models.

The project engineer shall verify that a particular modeling approach will be acceptable. The project engineer shall provide clear and complete information (e.g., input and output files, annotation of key outputs to highlight and clarify key results and conclusions, and discussion of results) to enable the City to conduct its review. See Chapter 3 for additional submittal details and requirements.

Single Event and Continuous Simulation Runoff Models

A continuous simulation runoff model has considerable advantages over the single event-based methods such as the SCSUH, SBUH, or the rational method. HSPF is a continuous simulation model that is capable of simulating a wider range of hydrologic responses than the single event models. Single event models cannot take into account storm events that may occur just before or just after the single event (the design storm) that is under consideration. In addition, the runoff files generated by the HSPF models are the result of a considerable effort to introduce local parameters and actual rainfall data into the model, and therefore produce better estimations of runoff than the SCSUH, SBUH, or rational methods, which tend to overestimate peak runoff.

A major weakness of the single event model is that it is used to model a 24-hour storm event, which is too short to model longer-term storms in western Washington. The use of a longer-term (e.g., 3- or 7-day storm) is perhaps better suited for western Washington.

Related to the last concern is the fact that single event approaches, such as SBUH, assume that flow control ponds are empty at the start of the design event. Continuous simulation models are able to simulate a continuous long-term record of runoff and soil moisture conditions. They simulate situations where ponds are not empty when another rain event begins.

Finally, single event models do not allow for estimation and analyses of flow durations nor water level fluctuations. Flow durations are necessary for discharges to streams. Estimates of water level fluctuations are necessary for discharges to wetlands and for tracking influent water elevations and bypass quantities to properly size runoff treatment BMPs.

Single Event Storms – Hydrograph

Hydrograph analyses utilize the standard plot of runoff flow versus time for a given single event design storm, thereby allowing the key characteristics of runoff such as peak, volume, and phasing to be considered in the design of stormwater BMPs. All storm event hydrograph methods require input of parameters that describe physical drainage basin characteristics. These parameters provide the basis from which the runoff hydrograph is developed. Because the only application for single event methods in this manual is to size conveyance systems, only a limited discussion of design storms, curve numbers, and calculating peak runoffs are presented in Appendix 6A. If single event methods are used to size temporary and permanent conveyances, the user should reference other texts and software for assistance. Conveyance systems can be designed using unit hydrograph analysis methods for estimating storm runoff rates. All stormwater storage BMPs shall be designed to meet the Core Requirement #7 for frequency and duration control using a continuous simulation model. If the engineer decides to use a single event runoff model for conveyance design, the preferred method is the SBUH method, or the SCSUH method as a second choice. The rational method may be used for conveyance sizing on sites of 25 acres or less that have a time of concentration of less than 100 minutes.

Western Washington Hydrology Model

Since the first version of WWHM was developed and released to public in 2001, the WWHM program has gone through several upgrades incorporating new features and capabilities including low impact development (LID) BMP modeling capability. For example, WWHM2012 includes modeling elements for stormwater LID BMPs. WWHM users should periodically check Ecology's WWHM web page for the latest releases of WWHM, user manuals, and any supplemental instructions. Refer to Volume III, Section 2.2, of the 2019 Ecology Manual for background information on WWHM. Guidance on LID BMP modeling in WWHM can be found in Volume V of the 2019 Ecology Manual.

More information on the WWHM can be found on Ecology's website at: https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Stormwater-manuals/Western-Washington-Hydrology-Model.

Closed Depression Analysis

The analysis of closed depressions requires careful assessment of the existing hydrologic performance in order to evaluate the impacts a proposed project will have. The applicable requirements (Chapter 2, Section 2.1.2, and Chapter 16.54 Lacey Municipal Code [LMC]) should be thoroughly reviewed prior to proceeding with the analysis.

Closed depressions generally facilitate infiltration of runoff. If a closed depression is classified as a wetland, then Core Requirement #8: Wetlands Protection may apply.

An approved continuous simulation model must be used for closed depression analysis and design of mitigation BMPs. If a closed depression is not classified as a wetland, model the ponding area at the bottom of the closed depression as an infiltration pond using an approved continuous simulation hydrologic model.

6.2.2 Guidance for Flow Control Standards

Flow control standards are used to determine whether or not a proposed stormwater BMP will provide a sufficient level of mitigation for the additional runoff from land development.

There are three flow-related standards stated in Chapter 2 of this manual: Core Requirement #5: On-Site Stormwater Management; Core Requirement #7: Flow Control; and Core Requirement #8: Wetlands Protection.

Core Requirement #5 allows the user to demonstrate compliance with the LID Performance Standard of matching developed discharge durations to predeveloped durations for the range of predeveloped discharge rates from 8 percent of the 2-year peak flow to 50 percent of the 2-year peak flow. If the postdevelopment flow duration values exceed any of the predevelopment flow levels between 8 percent and 50 percent of the

2-year predevelopment peak flow values, then the LID Performance Standard has not been met.

Core Requirement #7 specifies that stormwater discharges to streams shall match developed discharge durations to predeveloped durations for the range of predeveloped discharge rates from 50 percent of the 2-year recurrence interval peak flow up to the full 50-year peak flow. (Note that Core Requirement #7 also includes discharge requirements for projects in closed depression areas, discussed in more detail in Section 6.2.1 above, and in Chapter 2.)

- The continuous runoff models compute the predevelopment 2- through 100-year recurrence interval flow values and compute the postdevelopment runoff 2- through 100-year recurrence interval flow values from the outlet of the proposed stormwater BMP.

- The model uses discharge data from the applicable BMP(s) to compare the predevelopment and postdevelopment durations and determines if the flow control standards have been met.

- There are three criteria by which flow duration values are compared:

  1. If the postdevelopment flow duration values exceed any of the predevelopment flow levels between 50 percent and 100 percent of the 2-year recurrence interval predevelopment peak flow values (100 percent threshold) then the flow duration requirement has not been met

  2. If the postdevelopment flow duration values exceed any of the predevelopment flow levels between 100 percent of the 2-year and 100 percent of the 50-year recurrence interval predevelopment peak flow values more than 10 percent of the time (110 percent threshold) then the flow duration requirement has not been met

  3. If more than 50 percent of the flow duration levels exceed the 100 percent threshold then the flow duration requirement has not been met.

Method 2 of Core Requirement #8 specifies that total discharge volume to a wetland must not deviate by more than 20 percent on a daily basis and must not deviate by more than 15 percent on a monthly basis. Flow components feeding the wetland under both pre- and postdevelopment scenarios are assumed to be the sum of the surface, interflow, and groundwater flows from the project site. WWHM2012 includes the capability of modeling flows to wetlands and analyzing the daily and monthly flow deviations (per these requirements). Refer to Core Requirement #8 in Chapter 2 and the 2019 Ecology Manual, Volume I, Appendix I-C for additional requirements related to wetlands.

6.3 Conveyance Design and Analysis

This section presents acceptable methods for the analysis and design of conveyance systems. It also includes sections on hydraulic structures that link the conveyance system to the runoff treatment and flow control BMPs.

This section is separated into the following categories:

- Design and analysis methods (Sections 6.3.1 through 6.3.4)
- Conveyance design (Section 6.3.5 and 6.3.6)
  - Channels
  - Culverts
  - Storm drain system
  - Pipe structures (manholes, catch basins, flow splitters)
  - Outfalls
  - Flow spreaders
  - Private drainage systems

6.3.1 Design Storm Frequency

Ideally, every conveyance system and hydraulic structure would be designed for the largest possible amount of flow that could ever occur. Unfortunately, this would require unusually large structures and would add an unjustifiable cost to the projects; therefore, hydraulic structures are analyzed for a specific storm frequency. When selecting a storm frequency for design purposes, consideration is given to the potential degree of damage to adjacent properties, potential hazard and inconvenience to the public, the number of users, and the initial construction cost of the conveyance system or hydraulic structure. The way in which these factors interrelate can become quite complex.

The design event recurrence interval is related to the probability that such an event will occur in any 1 year. For example, a peak flow having a 25-year recurrence interval has a 4 percent probability of being equaled or exceeded in any future year. A peak flow having a 2-year recurrence interval has a 50 percent probability of being equaled or exceeded in any future year. The greater the recurrence interval is, the lower the probability that the event will occur in any given year.

The design event for each conveyance system category is as follows:

- Conveyance systems shall be designed, at a minimum, to convey the 25-year storm event under fully developed conditions.

- Drains and culverts passing under public roads and arterial streets shall be designed to convey the 25-year storm event under fully developed conditions.

- Culverts for and bridges over natural channels shall be designed to convey the 100-year storm event under fully developed conditions. Culverts and bridges must also be designed to meet fish passage and scour criteria, where applicable.

The City may require an increased level of protection and/or freeboard on a case-by-case basis.

6.3.2 Backwater Analysis

If the City determines that, as a result of the project, runoff for any event up to and including the 100-year, 24-hour storm event would cause damage or interrupt vital services, a backwater (pressure sewer) analysis shall be required. When a backwater calculation is required, the design engineer shall analyze for the 25- and 100-year, 24-hour design storm events.

For the 25-year event, there shall be a minimum of one-half a foot of freeboard between the water surface and the top of any manhole or catch basin.

For the 100-year event, overtopping of the pipe conveyance system may occur; however, the additional flow shall not extend beyond half the lane width of the outside lane of the traveled way and shall not exceed 4 inches in depth at its deepest point. Off-channel storage on private property is allowed with recording of the proper easements (see Section 6.3.4). The additional flow shall be analyzed by open channel flow methods.

A backwater profile analysis computer program such as the King County Backwater (KCBW) computer program by King County Stormwater Services Section is recommended over hand calculations. The subroutine, BPIPE, of King County Backwater may be used for quick computation of backwater profiles, given a range of flows through the existing or proposed pipe system.

6.3.3 Conveyance System Route Design

All pipes shall be located under the pavement flow line or lie outside of the pavement, unless otherwise specified below. Perpendicular crossings and cul-de-sacs are exempted from this requirement. For curved sections only of minor local residential, private roads, and alleys, pipe placement may be located underneath pavement areas, but no closer than 6 feet from the roadway centerline. Pipes under permeable pavement sections will need to ensure flows are prevented from short circuiting through the pipe zone bedding. Location and layout of conveyance piping on roadway retrofit projects will be determined on a case-by-case basis.

New conveyance system alignments that are not in dedicated tracts or right-of-way shall be located in drainage easements that are adjacent and parallel to property lines. The width of the permanent easement must be completely within a single parcel or tract and not split between adjacent properties. Topography and existing conditions are the only conditions under which a drainage easement may be placed not adjacent and parallel to a property line. (Exception: Streams and natural drainage channels cannot be relocated to meet this routing requirement.) Requirements for conveyance system tracts and easements are discussed in Section 6.3.4 below. Refer to Chapter 5 of the City of Lacey *Development Guidelines and Public Works Standards* (DG&PWS) for additional conveyance system requirements.

6.3.4 Easements, Access, and Dedicated Tracts

Natural Channels and Stormwater BMPs

All constructed stormwater BMPs and conveyances and all natural channels (on the project site) used for conveyance of altered flows due to development (including swales, ditches, stream channels, lake shores, wetlands, potholes, estuaries, gullies, ravines, etc.) shall be located within easements or dedicated tracts as required by the City. Easements shall contain the natural features and BMPs and shall allow City access for purposes of inspection, maintenance, repair or replacement, flood control, water quality monitoring, and other activities permitted by law.

All stormwater BMPs such as detention or retention ponds or infiltration systems to be maintained by the City shall be located in separate tracts dedicated to the City. Conveyance systems can be in easements. Stormwater BMPs shall not be located in dedicated public road right-of-way areas, with the exception of City and highway BMPs.

Stormwater BMPs that are designed to function as multi-use recreational facilities shall be located in separate tracts or in designated open space and shall be privately maintained and owned, unless accepted by and dedicated to the City.

Maintenance Access

A maintenance access road (and easement) must be provided for all manholes, catch basins, vaults, or other underground stormwater BMPs. This requirement does not apply to on-site stormwater management BMPs. A minimum 15-foot-wide access easement shall be provided to the BMPs from a public street or right-of-way. Access easements shall be surfaced with a minimum 12-foot width of crushed rock, or other approved surface to allow year-round equipment access to the BMP. See also Chapter 7, Section 7.5.1, for pond access and other detention BMP requirements.

Maintenance shall be through an access easement or dedicated tract. Drainage structures for conveyance without vehicular access must be channeled.

Access to Conveyance Systems

All publicly and privately maintained conveyance systems shall be located in dedicated tracts, drainage easements, or public rights-of-way in accordance with this manual. Exception: roof downspout, minor yard, and footing drains unless they serve other adjacent properties.

Conveyance systems to be maintained and operated by the City must be located in a dedicated tract or drainage easement granted to the City. Any new conveyance system located on private property designed to convey drainage from other private properties must be located in a private drainage easement granted to the contributors of stormwater to the systems to convey surface and stormwater and to permit access for maintenance or replacement in the case of failure.

All drainage tracts and easements, public and private, must have a minimum width of 15 feet. In addition, all pipes and channels must be located within the tract, easement, or rights-of-way so that each pipe face or top edge of channel is no closer than 5 feet from its adjacent easement boundary. Pipes greater than 5 feet in diameter and channels with top widths greater than 5 feet shall be placed in easements adjusted accordingly, so as to meet the required dimensions from the boundaries.

Easement widths as shown in Table 6.2 are minimums for access, inspection, and maintenance of conveyance systems.

Table 6.2. Minimum Easement Widths for Conveyance Systems for Access, Inspection, and Maintenance.

Conveyance Width	Easement Width
Channels ≤ 30 feet wide	Channel Width + 15 feet from top, one side
Channels > 30 feet wide	Channel Width + 15 feet from top, both sides
Pipes/Outfalls ≤ 36 inches	15 feet centered on pipe
Pipes/Outfalls > 36 inches but ≤ 60 inches	20 feet centered on pipe[a]
Pipes/Outfalls > 60 inches	30 feet centered on pipe[a]

[a] The City may allow flexibility, or require larger easements, depending on site-specific conditions.

6.3.5 Design Methods and Criteria

This section describes methods and criteria for sizing of storm drain pipes, channels, revetments, and other drainage structures in the conveyance system. Setbacks and easements for conveyances are found in Section 6.3.4.

Channels

Channels can be either roadside ditches, grass lined swales, or a combination thereof. Consideration must be given to public safety when designing open conveyances adjacent to traveled ways and when accessible to the public. Where space and topography permit, channels are the preferred means of collecting and conveying stormwater.

Channels shall be designed by one of the following methods (refer to Appendix 6A):

- Manning's Equation (for uniform flow depth, flow velocity, and constant channel cross-section)
- Direct Step Backwater Method (utilizing the energy equation)
- Standard Step Backwater Method (utilizing a computer program).

Velocities must be low enough to prevent channel erosion based on the native soil characteristics or the compacted fill material. For velocities above 5 feet per second, channels shall have either rock-lined bottoms and side slopes to the roadway shoulder top with a minimum thickness of 8 inches or shall be stabilized in a fashion acceptable to the City. Water quality shall not be degraded due to passage through an open conveyance. Channels must be stabilized against erosion in compliance with minimum standards for erosion control set forth in Chapter 5. Table 6.3 provides minimum criteria to prevent damage.

Table 6.3. Design Criteria – Open Channels.

Channel Lining	Maximum Design. Velocity (fps)	Maximum Design Slope H/V	Minimum Filter Blanket (inches)
Vegetation	5	3	NA
Geotextile	Varies[a]	Varies[a]	NA
Lattice Block Paving Systems	12	2	Varies[a]
Quarry Spalls, 18-inch diameter	15[b]	2	4
Hand-placed Riprap, 2-foot thick	12	2	4
Gabions	30	Varies[a]	4
Concrete	30	Design	NA

[a] Per manufacturer's instructions.

[b] See Riprap Design, Journal of Hydraulics, ASCE, July 7, 1989.

[c] See Guide for determining gradation of sand and gravel filters, SMN-1, Soil Conservation Service, 1986.

Channels having a slope less than 6 percent and having peak velocities less than 5 feet per second shall be lined with vegetation. Check dams for erosion and sedimentation control may be used for stepping down channels being used for biofiltration.

Channel side slopes shall not exceed 2:1 for undisturbed ground (cuts) as well as for disturbed ground (embankments). All constructed channels shall be compacted to a minimum 95 percent compaction as verified by a Modified Proctor test. Channel side slopes adjacent to roads shall not exceed 4:1 and must meet all other AASHTO and City road standards.

Channels shall be designed with a minimum freeboard of one-half foot when the design flow is 10 cubic feet per second or less and 1 foot when the design discharge is greater than 10 cubic feet per second.

Culverts

For the purpose of this manual, culverts are single runs of pipe that are open at each end and have no structures such as manholes or catch basins. Approved pipe materials are detailed below in the "Storm Drain System" subsection of Section 6.3.5. Galvanized or aluminized pipe are not permitted in marine environments or where contact with salt water may occur, even infrequently through backwater events.

Flow capacity shall be determined by analyzing inlet and outlet control for headwater depth. Nomographs used for culvert design shall be included in the submitted Drainage Control Plan. Appendix 6B includes several nomographs that may be useful for culvert sizing.

All culverts shall be designed to convey the flows per Section 6.3.1. The maximum design water surface elevation in the conveyance system shall allow for the open conveyance protection requirements outlined in Table 6.4, with no saturation of roadbeds. For culverts that convey streams, the maximum design headwater depth shall be below the culvert crown. Minimum culvert diameters are as follows:

- For cross culverts under public roadways – minimum 18 inches, 12 inches if grade and cover do not allow for 18 inches

- For roadside culverts, including driveway culverts, minimum 12 inches.

- For culverts on private property, minimum 8 inches.

Inlets and outlets shall be protected from erosion by rock lining, riprap, or biostabilization as detailed in Table 6.4.

Table 6.4. Open Conveyance Protection.

Velocity Greater Than (fps)	Velocity Less Than or Equal To (fps)	Protection	Thickness (feet)	Minimum Height Required Above Design Water Surface (feet)
0	5	Grass lining[a]	NA	0.5
5	8	Riprap[a,b]	1	2
8	12	Riprap[c]	2	2
12	20	Slope mattress, gabion, etc.	Varies	1

[a] Bioengineered lining allowed for design flow up to 8 feet per second (fps).

[b] Riprap shall be in accordance with Section 9-13.1 of the WSDOT Standard Specifications.
Riprap shall be a reasonably well-graded assortment of rock with the following gradation:
Maximum stone size 12 inches
Median stone size 8 inches
Minimum stone size 2 inches

[c] Riprap shall be reasonably well graded assortment of rock with the following gradation:
Maximum stone size 24 inches
Median stone size 16 inches
Minimum stone size 4 inches

Note: Riprap sizing governed by side slopes on channel, assumed ~3:1.

Debris and access barriers are required on inlet and outlet ends of all culverts greater than 18 inches in diameter. Culverts greater than 36 inches in diameter within stream corridors are exempt.

Minimum culvert velocity shall be 2 feet per second (fps) and maximum culvert velocity shall be 15 fps. Up to 30 fps may be used with an engineered outlet protection design. The City may waive the minimum requirement in cases where topography and existing drainage systems make it impractical to meet the standard. No maximum velocity for ductile iron or high density polyethylene (HDPE) pipe shall be established but outlet protection shall be provided.

All corrugated polyethylene pipe (CPEP) and polyvinyl chloride (PVC) culverts and pipe systems shall have concrete or rock headwalls at exposed pipe ends.

Bends are not permitted in culvert pipes.

The following minimum cover shall be provided over culverts:

- 2 feet under roads
- 1 foot under roadside applications and on private property, exclusive of roads
- If the minimum cover cannot be provided on a flat site, use ductile iron pipe, and analyze for loadings
- Maximum culvert length: 250 feet
- Minimum separation from other pipes:
    - 6 inches vertical (with bedding) and in accordance with the City of Lacey Wastewater Utility Design criteria
    - 3 feet horizontal.

Trench backfill shall be bank run gravel or suitable native material compacted to 95 percent Modified Proctor test to a depth of 2 feet; 90 percent below 2 feet compacted in 8-inch to 12-inch lifts.

All driveway culverts shall be of sufficient length to provide a minimum 3:1 slope from the edge of the driveway to the bottom of the ditch. Culverts shall have beveled end sections to match the side slope. Shallow fords may be substituted for culverts on residential driveway crossings of swales.

Culverts in stream corridors must meet any fish passage requirements of the Washington Department of Fish and Wildlife (WDFW).

Storm Drain System

Analysis Methods

Two methods of hydraulic analysis using Manning's Equation are used for the analysis of pipe systems. The first method is the Uniform Flow Analysis Method, commonly referred to as the Manning's Equation, and is used for the design of new pipe systems and analysis of existing pipe systems. The second method is the Backwater Analysis Method (see Section 6.3.2) and is used to analyze the capacity of both proposed, and existing, pipe systems.

When using the Manning's Equation for design, each pipe within the system shall be sized and sloped such that its barrel capacity at normal full flow is equal or greater than the required conveyance capacity as identified in Section 6.3.1. Table 6.5 provides the recommended Manning's "n" values for preliminary design for pipe systems. (Note: The "n" values for this method are 15 percent higher in order to account for entrance, exit, junction, and bend head losses.) Manning's "n" values used for final pipe design must be documented in the Drainage Control Plan.

Table 6.5. Recommended Manning's "n" Values for Preliminary Pipe Design.

Type of Pipe Material	Analysis Method: Backwater Flow	Analysis Method: Manning's Equation Flow
A. Concrete pipe and CPEP-smooth interior pipe	0.012	0.014
B. Annular Corrugated Metal Pipe or Pipe Arch:		
1. 2⅔- x ½-inch corrugation (riveted)		
a. Plain or fully coated	0.024	0.028
b. Paved invert (40% of circumference paved):		
(1) Flow full depth	0.018	0.021
(2) Flow 0.8 depth	0.016	0.018
(3) Flow 0.6 depth	0.013	0.015
c. Treatment 5	0.013	0.015
2. 2.3- x 1-inch corrugation	0.027	0.031
3. 3.6- x 2-inch corrugation (field bolted)	0.030	0.035
C. Helical 2⅔- x ½-inch corrugation and CPEP-single wall	0.024	0.028
D. Spiral rib metal pipe and PVC pipe	0.011	0.013
E. Ductile iron pipe cement lined	0.012	0.014
F. High density polyethylene pipe (butt fused only)	0.009	0.009

Nomographs may also be used for sizing the pipes. For pipes flowing partially full, the actual velocity may be estimated from engineering nomographs by calculating Q_{full} and V_{full} and using the ratio of Q_{design}/Q_{full} to find V and d (depth of flow). Appendix 6B includes several nomographs that may be useful for culvert sizing.

Acceptable Pipe Sizes

The minimum diameter in the public right-of-way is 12 inches. Laterals less than 12 inches in diameter must be approved by City staff as supported by situation variables. Storm drain pipe used for private roof/footing/yard drain systems or other on-site stormwater management BMPs can be less than 12-inch diameter and sized according to the application and design standards presented in Section 6.3.6 and Chapter 7.

The SDM Administrator may waive these minima in cases where topography, design flows, and existing drainage systems make it impractical to meet the standard.

Pipe Materials

Refer to Chapter 5 of the DG&PWS for pipe materials specifications.

Pipe Slope and Velocity

The minimum velocity is 2 feet per second at design flow. The City may waive this minimum in cases where topography and existing drainage systems make it impractical to meet the standard. Table 6.6 summarizes minimum pipe slopes based on pipe diameter; however, pipe slopes greater than these are desirable.

Table 6.6. Minimum Pipe Slopes based on Pipe Diameter.

Pipe Diameter (inches)	Minimum Pipe Slope (percent)
8	0.40
10	0.28
12	0.22
14	0.17
15	0.15
16	0.14
18	0.12
21	0.10
24	0.08
27	0.07
30	0.06
36	0.05

Table 6.7 Maximum Pipe Slopes and Velocities.

Pipe Material	Pipe Slope Above Which Pipe Anchors Required and Minimum Anchor Spacing	Maximum Slope Allowed	Maximum. Velocity at Full Flow
Spiral Rib, PVC, CPEP-single wall[a]	20% (1 anchor per 100 LF of pipe)	30%[b]	30 fps
Concrete or CPEP-smooth interior[a]	10% (1 anchor per 50 LF of pipe)	20%[b]	30 fps
Ductile Iron	40% (1 anchor per pipe section)	None	None
HDPE[c]	50% (1 anchor per 100 LF of pipe—cross slope installations only)	None	None

[a] Not allowed in landslide hazard areas.

[b] Maximum slope of 200% allowed for these pipe materials with no joints (one section) with structures at each end and properly grouted.

[c] Butt-fused pipe joints required. Above-ground installation is required on slopes greater than 40% to minimize disturbance to steep slopes.

CPEP = Corrugated high density polyethylene pipe

fps = feet per second

HDPE = High density polyethylene

LF = linear feet

PVC = Polyvinyl chloride pipe

Pipes on Steep Slopes

Steep slopes (greater than 20 percent) shall require all drainage to be piped from the top to the bottom in HDPE pipe (butt-fused) or ductile iron pipe welded or mechanically restrained. They shall not be gasketed, slip fit, or banded. On steep slopes, HDPE pipe may be laid on the surface or in a shallow trench, anchored, protected against sluicing, and hand compacted.

HDPE systems longer than 100 feet must be secured at the upstream end if the slope exceeds 25 percent and the downstream end placed in a 4-foot section of the next larger pipe size. This sliding sleeve connection allows for high thermal expansion/contraction.

Pipe System Layout Criteria

Changes of Pipe Size or Direction

Pipe direction changes or size increases or decreases are allowed only at catch basins and manholes. (On private property, for 4-inch- and 6-inch-diameter pipe, clean-outs at junctions are permissible). This does not apply to detention tanks or vaults.

Downsizing of pipes is only allowed under special conditions (i.e., no hydraulic jump can occur; downstream pipe slope is significantly greater than the upstream slope; velocities remain in the 3 to 8 feet per second range, etc.).

Downsizing of downstream culverts within a closed system with culverts 18-inches in diameter or smaller will not be permitted.

Connections to a pipe system shall be made only at catch basins or manholes. No wyes or tees are allowed, except on private roof/footing/yard drain systems on pipes 8-inches in diameter or less, with cleanouts upstream of each wye or tee. Pipes connecting into a structure shall match crown elevations.

Pipes must be laid true to line and grade with no curves, bends, or deflections in any direction (except for HDPE and Ductile Iron pipe with flanged restrained mechanical joint bends, not greater than 30 degrees, on steep slopes). Curvilinear pipe may be installed in strict accordance with manufacturer’s instructions, which shall be attached to the Drainage Control Plan and shall be available on the job site.

A break in grade or alignment or changes in pipe material shall occur only at catch basins or manholes.

Cover Requirements, Trench Design, Pipe Strength

When calculating pipe loading for pipes over 24 inches in diameter or over 10 feet in depth, submit proof of pipe suitability for the design condition. Assume pipe trench will be opened at 45 degrees to the trench bottom unless trench configuration can be predicted with certainty (e.g., trench boxes will be specified). Refer to Chapter 5 of the DG&PWS for more information on pipe cover requirements.

Trash Racks

Where open channels or ponds discharge into storm drain systems, trash racks are required on all storm drain inlet pipes of 18 inches in diameter or larger. Trash racks must be removable with ordinary hand tools.

Manholes and Catch Basins

Catch basins and inlets shall be placed, to the maximum extent practical, within grass "islands" protected from traffic in off-street parking situations to provide some biofiltration before runoff enters the system. Vegetation surrounding catch basins must be protected from traffic.

For the purposes of this manual, all catch basins, manholes, and connecting pipe sizes shall meet current *Standard Specifications for Road, Bridge, and Municipal Construction* (WSDOT Standard Specifications) and Plans.

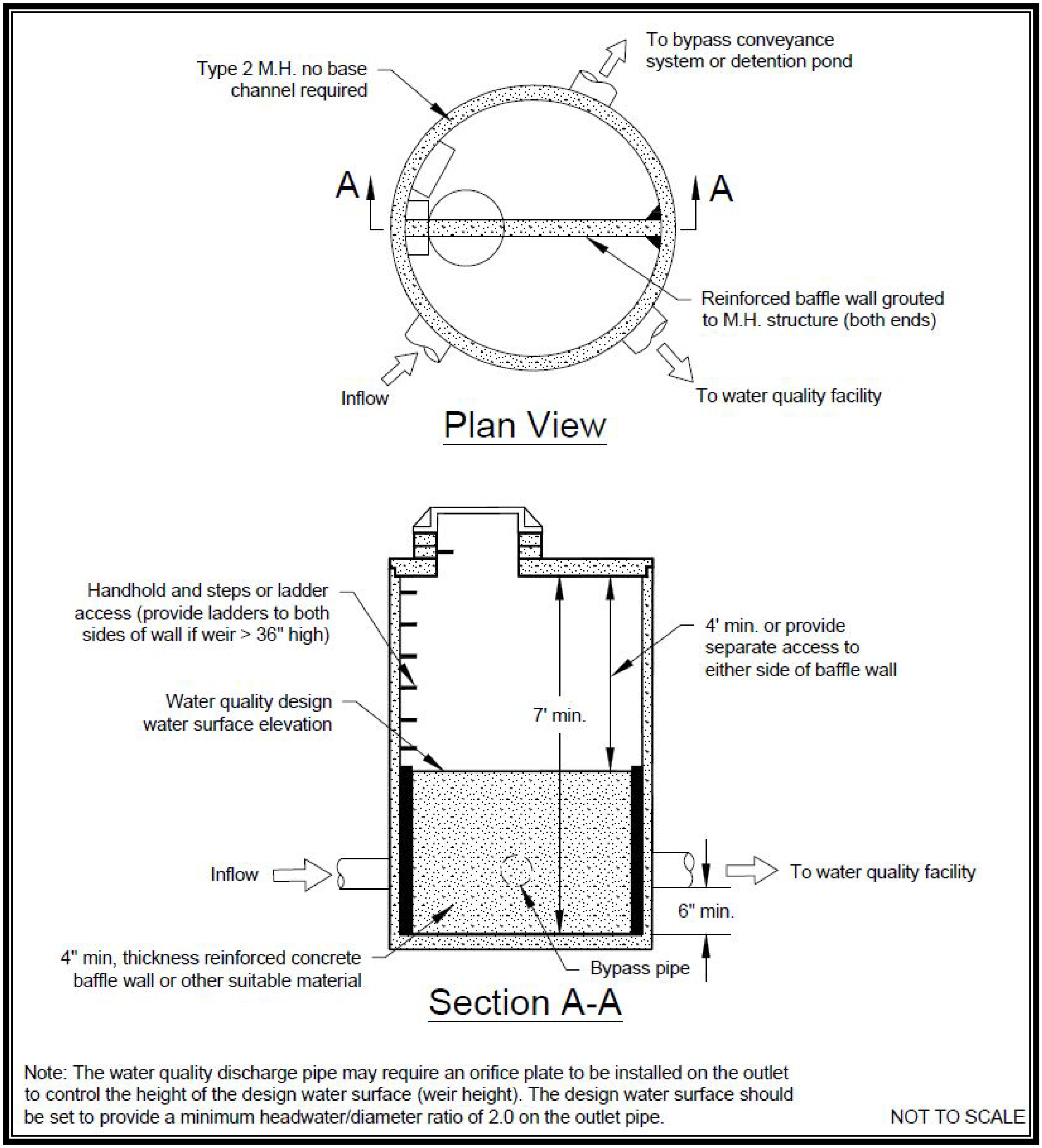
Each catch basin or grated manhole in a storm drain system must have a message pertaining to pollution prevention. Refer to the DG&PWS for details of the applicable standard message.

Flow Splitter Designs

Many runoff treatment BMPs can be designed as flow-through or on-line systems with flows above the water quality design flow or volume simply passing through the BMP at a lower pollutant removal efficiency. However, it is sometimes desirable to restrict flows to runoff treatment BMPs and bypass the remaining higher flows around them through off-line BMPs. This can be accomplished by splitting flows in excess of the water quality design flow upstream of the BMP and diverting higher flows to a bypass pipe or channel. The bypass typically enters a flow control BMP or the downstream receiving drainage system, depending on flow control requirements. In most cases, it is a designer's choice whether runoff treatment BMPs are designed as on-line or off-line; an exception is oil-water separators, which must be designed as off-line.

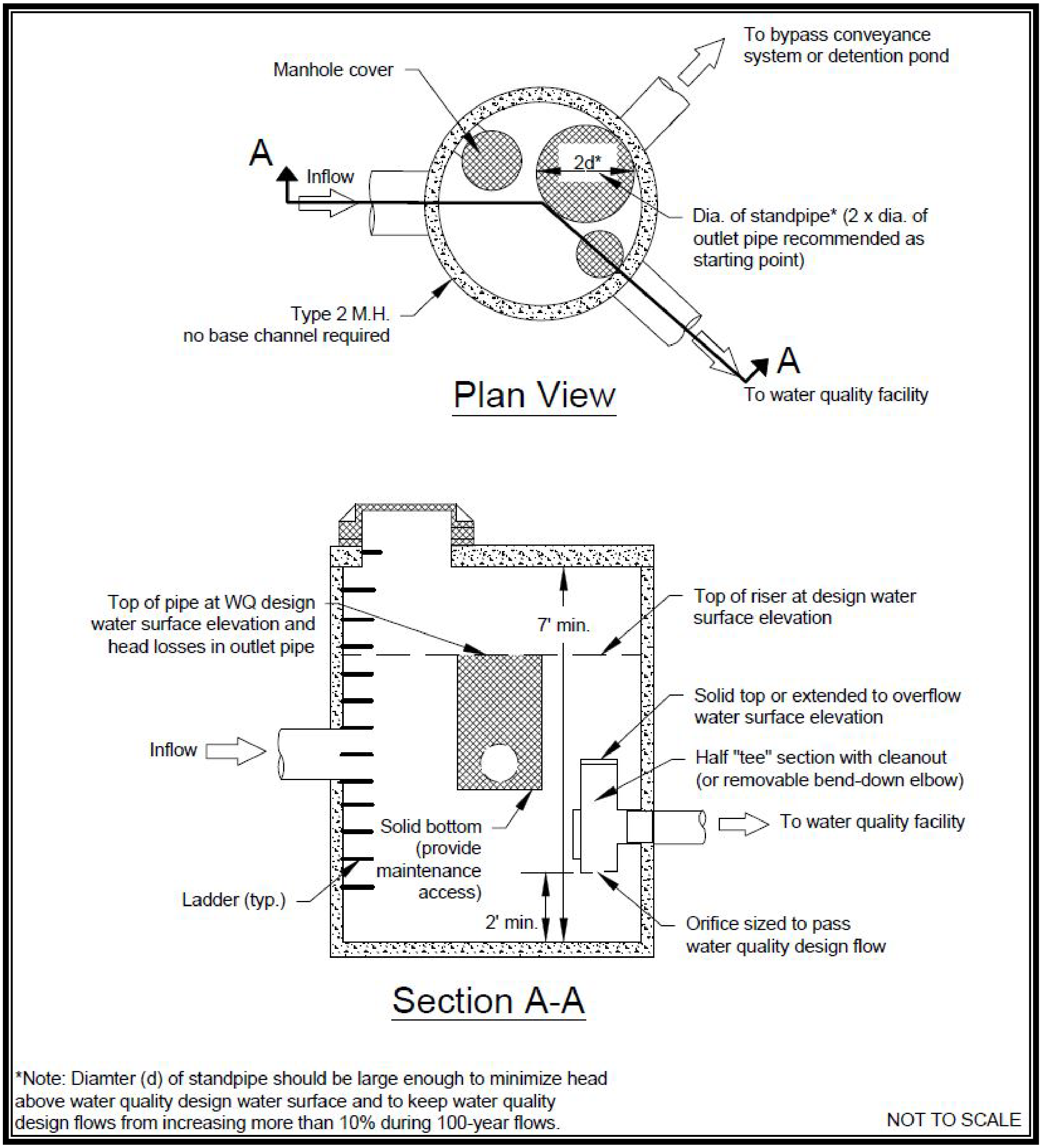
A crucial factor in designing flow splitters is to ensure that low flows are delivered to the runoff treatment BMP up to the water quality design flow rate. Above this rate, additional flows are diverted to the bypass system with minimal increase in head at the flow splitter structure to avoid surcharging the runoff treatment BMP under high flow conditions. Flow splitters may be used for purposes other than diverting flows to runoff treatment BMPs. However, the following discussion is generally focused on using flow splitters in association with runoff treatment BMPs.

Flow splitters are typically manholes or vaults with concrete baffles. In place of baffles, the splitter mechanism may be a half T-section with a solid top and an orifice in the bottom of the T-section. A full T option may also be used as described below in the "General Design Criteria." Two possible design options for flow splitters are shown in Figure 6.1 and Figure 6.2. Other equivalent designs that achieve the result of splitting low flows and diverting higher flows around the BMP are also acceptable.



Source: King County

Figure 6.1. Flow Splitter, Option A.



Source: King County

Figure 6.2. Flow Splitter, Option B.

General Design Recommendations

- Unless otherwise specified, a flow splitter shall be designed to deliver the water quality design flow rate specified to the runoff treatment BMP (see also Chapter 8). Flows modeled using a continuous simulation model should use 15-minute time steps.
- The top of the weir shall be located at the water surface for the design flow. Remaining flows enter the bypass line.
- The maximum head should be minimized for flow in excess of the water quality design flow. Specifically, flow to the runoff treatment BMP at the 100-year water surface shall not increase the design water quality flow by more than 10 percent.
- Either design shown in Figure 6.1 or Figure 6.2, or an equivalent design may be used.
- As an alternative to using a solid top plate in Figure 6.2, a full T-section may be used with the top of the T-section at the 100-year water surface. This alternative would route emergency overflows (if the overflow pipe were plugged) through the runoff treatment BMP rather than back up from the manhole.
- Special applications, such as roads, may require the use of a modified flow splitter. The baffle wall may be fitted with a notch and adjustable weir plate to proportion runoff volumes other than high flows.
- For ponding BMPs, backwater effects must be included in designing the height of the standpipe in the manhole.
- Ladder or step and handhold access must be provided. If the weir wall is higher than 36 inches, two ladders, one to either side of the wall, shall be used.

Materials

- The splitter baffle may be installed in a Type 2 manhole or vault.
- The baffle wall shall be made of reinforced concrete or another suitable material resistant to corrosion and have a minimum 4-inch thickness. The minimum clearance between the top of the baffle wall and the bottom of the manhole cover shall be 4 feet; otherwise, dual access points shall be provided.
- All metal parts must be corrosion resistant. Examples of preferred materials include aluminum, stainless steel, and plastic. Zinc and galvanized materials are discouraged because of aquatic toxicity. Painted metal parts shall not be used because of poor longevity.

Outfalls

All piped discharges to streams, rivers, ponds, lakes, or other open bodies of water are designated outfalls and shall provide for energy dissipation to prevent erosion at or near the point of discharge. Properly designed outfalls are critical to reducing the chance of adverse impacts as the result of concentrated discharges from pipe systems and culverts, both on site and downstream. Outfall systems include rock splash pads, flow dispersal trenches, gabion, or other energy dissipators, and tightline systems. A tightline system is typically a continuous length of pipe used to convey flows down a steep or sensitive slope with appropriate energy dissipation at the discharge end.

General Design Criteria for Outfall Features

All energy dissipation at outfalls shall be designed for peak flows from a 100-year, 24-hour storm event. For outfalls with a maximum flow velocity of less than 10 feet per second, a rock splash pad is acceptable. For velocities equal to or greater than 10 feet per second, an engineered energy dissipator must be provided. See Table 6.8 for a summary of the rock protection requirements at outfalls.

Table 6.8. Rock Protection at Outfalls.

Discharge Velocity at Design Flow (fps)	Required Protection				
	Minimum Dimensions[a]				
	Type	Thickness	Width	Length	Height
0 to 5	Rock lining[b]	1 foot	Diameter + 6 feet	8 feet or 4 x diameter, whichever is greater	Crown + 1 foot
5+ to 10	Riprap[c]	2 feet	Diameter + 6 feet or 3 x diameter, whichever is greater	12 feet or 4 x diameter, whichever is greater	Crown + 1 foot
10+ to 20	Gabion outfall[d]	As required	As required	As required	Crown + 1 foot
20+	Engineered energy dissipator required[e]				

[a] These sizes assume that erosion is dominated by outfall energy. In many cases, sizing will be governed by conditions in the receiving waters.

[b] **Rock lining** shall be quarry spalls with gradation as follows:

Passing 8-inch-square sieve: 100%
Passing 3-inch-square sieve: 40 to 60% maximum
Passing 0.75-inch-square sieve: 0 to 10% maximum

[c] **Riprap** shall be reasonably well graded with gradation as follows:

Maximum stone size: 24 inches (nominal diameter)
Median stone size: 16 inches
Minimum stone size: 4 inches

[d] Gabion outfalls should not be installed in fish bearing streams.

[e] Energy dissipators shall be located above the Ordinary High Water Mark on fish bearing streams.

fps = feet per second

Note: Riprap sizing governed by side slopes on outlet channel is assumed to be approximately 3:1.

Outfalls must be protected against undercutting. Also consider scour, sedimentation, anchor damage, etc. Pipe and fittings materials shall be corrosion resistant such as aluminum, plastic, fiberglass, high density polyethylene, etc. Galvanized or coated steel will not be acceptable.

The following sections provide general design criteria for various types of outfall features.

General Design Criteria to Protect Aquatic Species and Habitat

Outfall structures shall be located where they minimize impacts to fish, shellfish, and their habitats. However, new pipe outfalls can also provide an opportunity for low-cost fish habitat improvements. For example, an alcove of low-velocity water can be created by constructing the pipe outfall and associated energy dissipator back from the stream edge and digging a channel, over widened to the upstream side, from the outfall to the stream (see Figures 6.3 and 6.4). Overwintering juvenile and migrating adult salmonids may use the alcove as shelter during high flows. Potential habitat improvements should be discussed with a WDFW biologist prior to inclusion in design.

Bank stabilization, bioengineering, and habitat features may be required for disturbed areas. Outfalls that discharge to the Puget Sound or a major water body may require tide gates. Contact the City for specific requirements.

Outfalls to streams, wetlands or other waters of the State may be subject to review through the SEPA process, Shorelines Management Act and other applicable regulations. Outfalls also may be subject to hydraulic project permitting requirements of the WDFW, Washington Department of Natural Resources, or the U.S. Army Corps of Engineers, which shall take precedence where more restrictive than those stated herein.

Gabion Outfalls

Gabion outfalls should not be installed in fish bearing streams. One alternative is a four-sided gabion basket located above the Ordinary High Water Mark.

Energy Dissipators

Energy dissipators shall be located above the Ordinary High Water Mark on fish bearing streams.

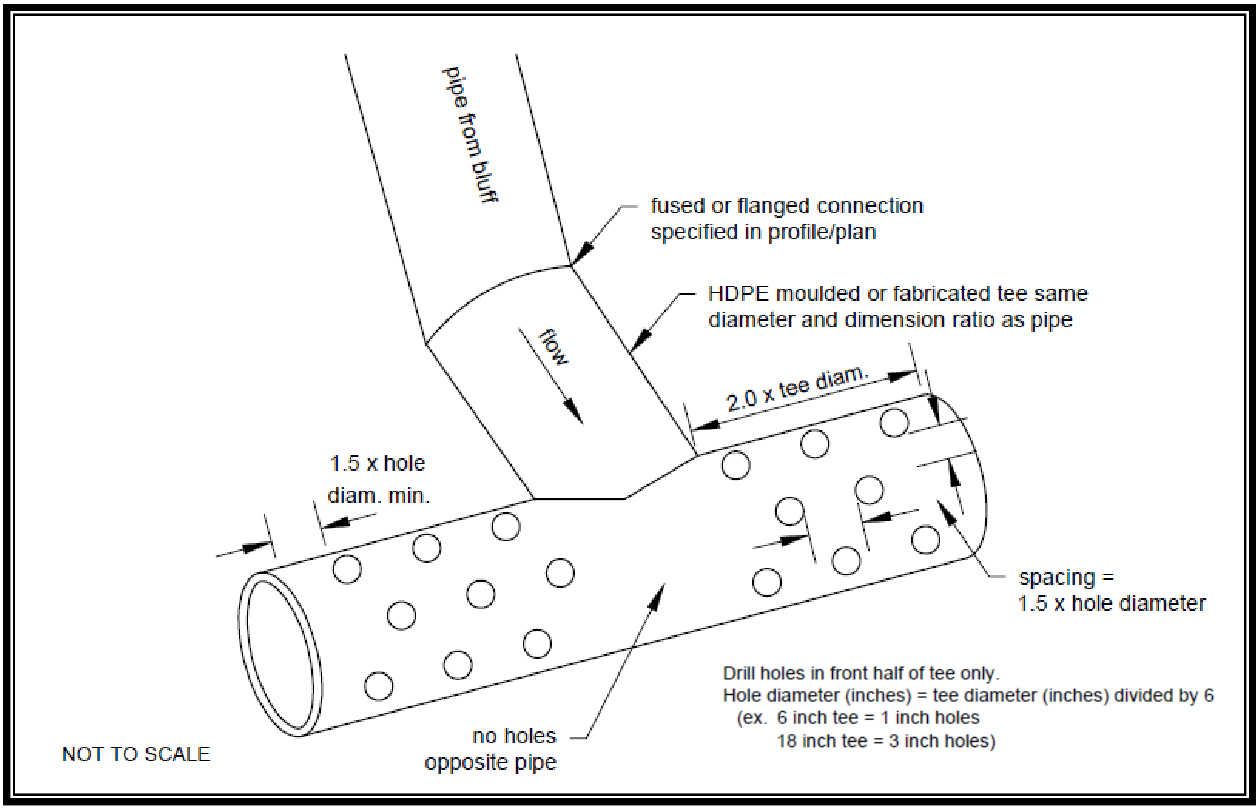
Rock Splash Pad

At a minimum, all outfalls must be provided with a rock splash pad (see Figure 6.5) except as specified below and in Table 6.8.

Flow Dispersal Trench

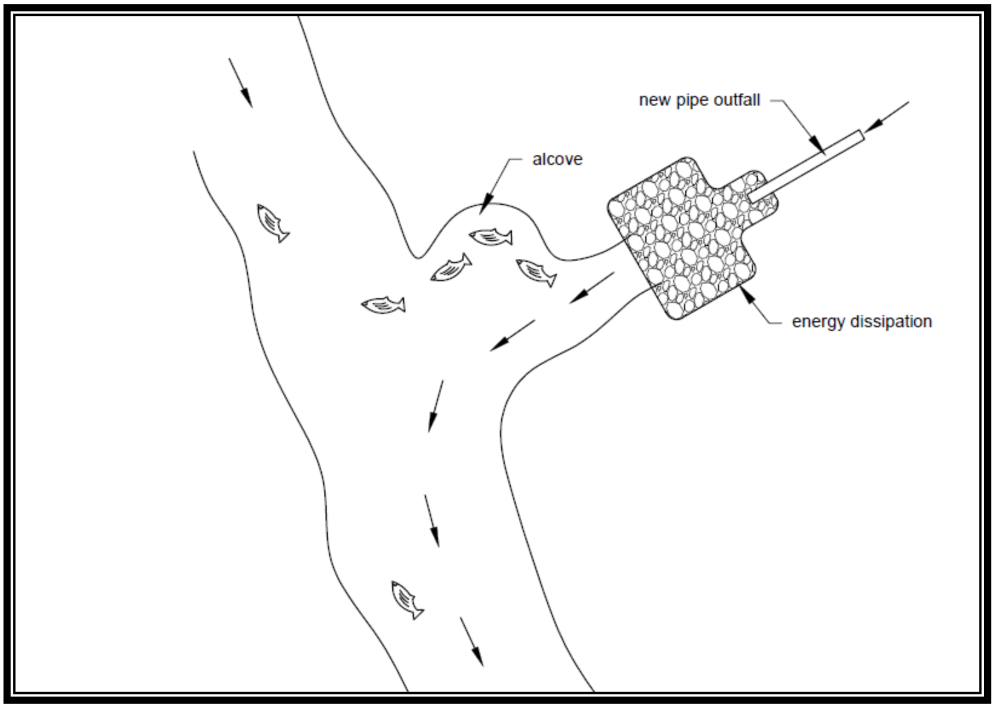
The flow dispersal trenches (see also Figures 6.6 and 6.7) shall only be used when both criteria below are met:

- An outfall is necessary to disperse concentrated flows across uplands where no conveyance system exists, and the natural (existing) discharge is unconcentrated
- The 100-year peak discharge rate is less than or equal to one-half of a cubic foot per second.



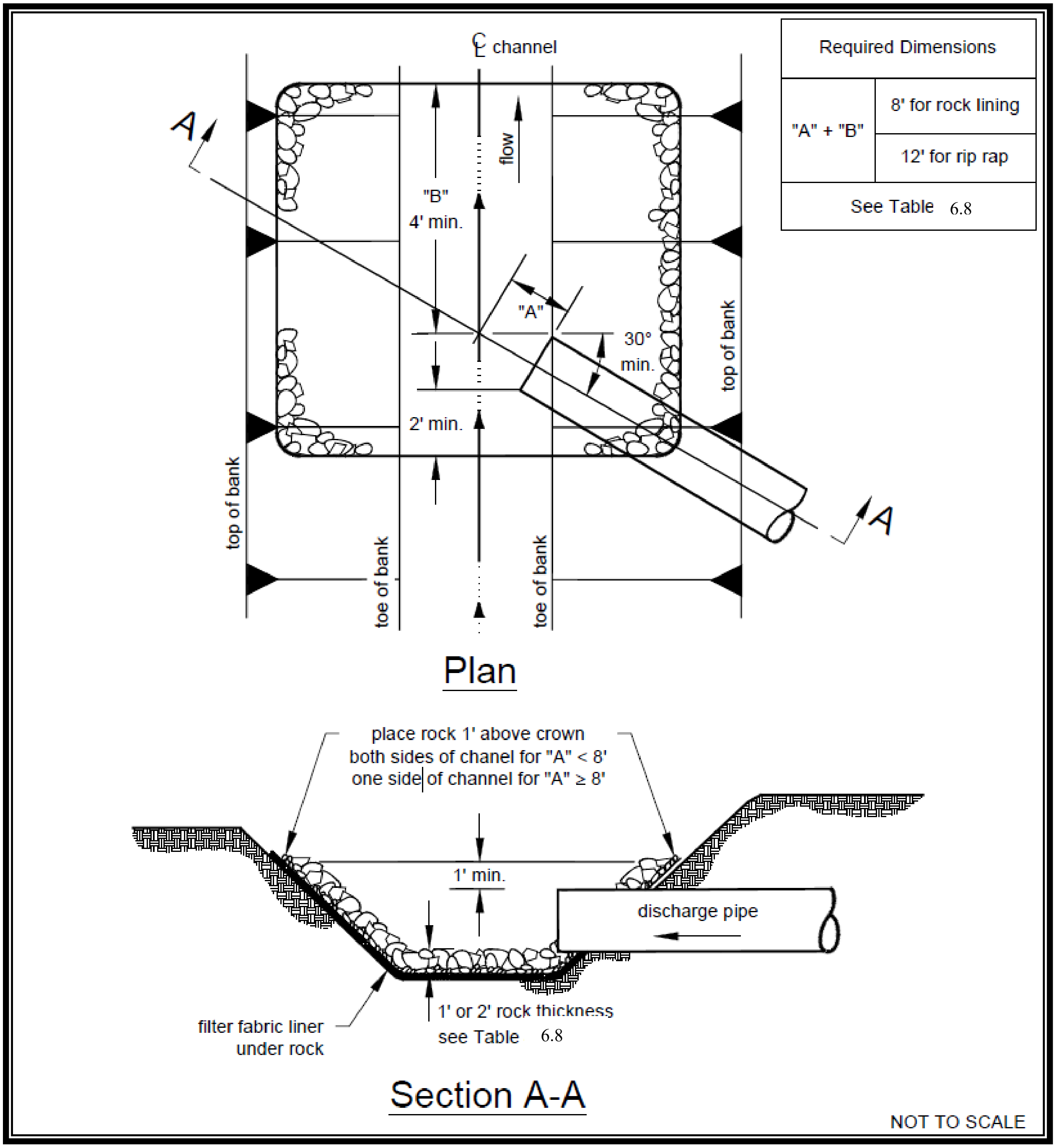
Source: Ecology

Figure 6.3. Diffuser Tee (example of energy-dissipating end feature).



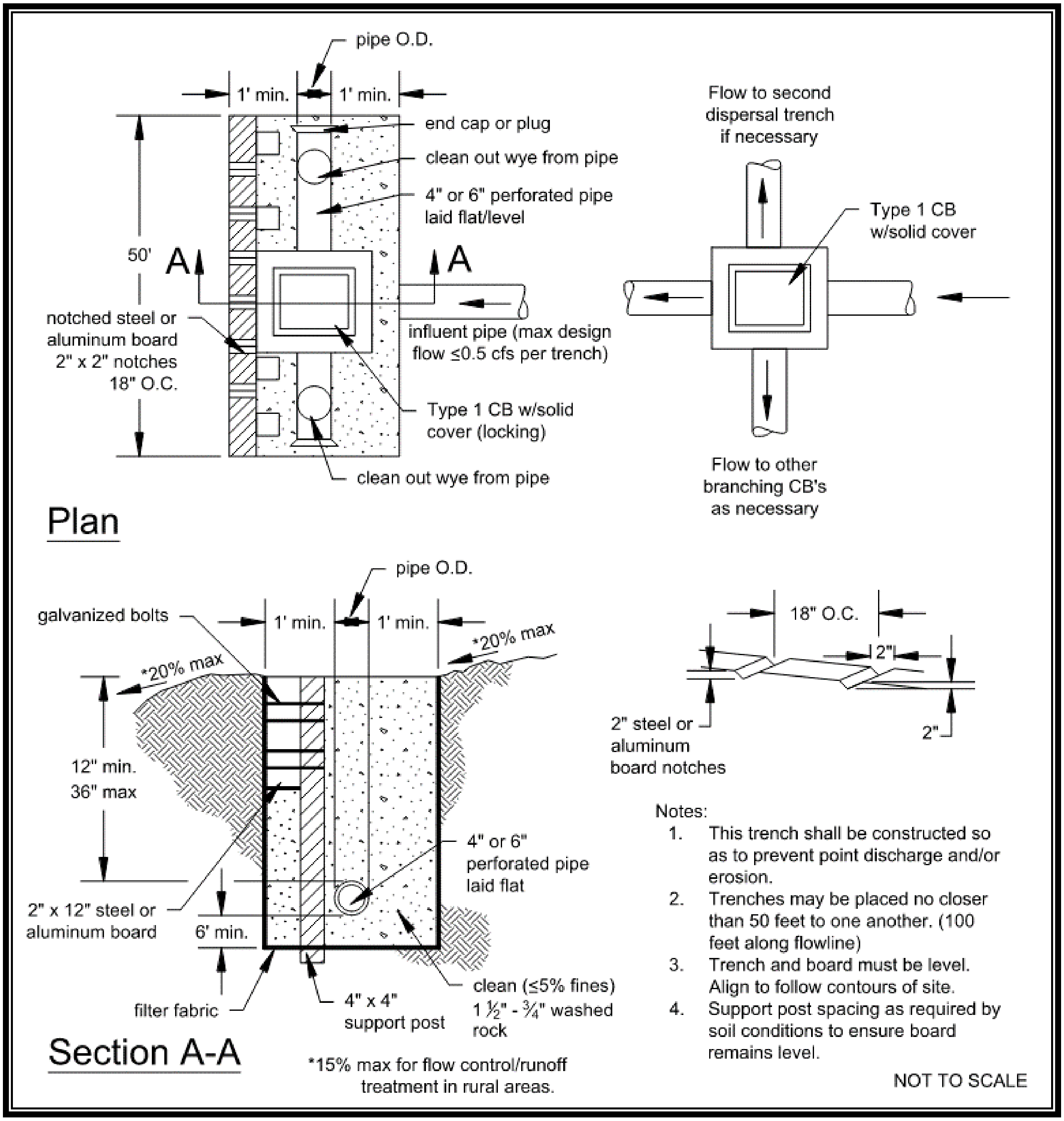
Source: Ecology

Figure 6.4. Fish Habitat Improvement at New Outfalls.



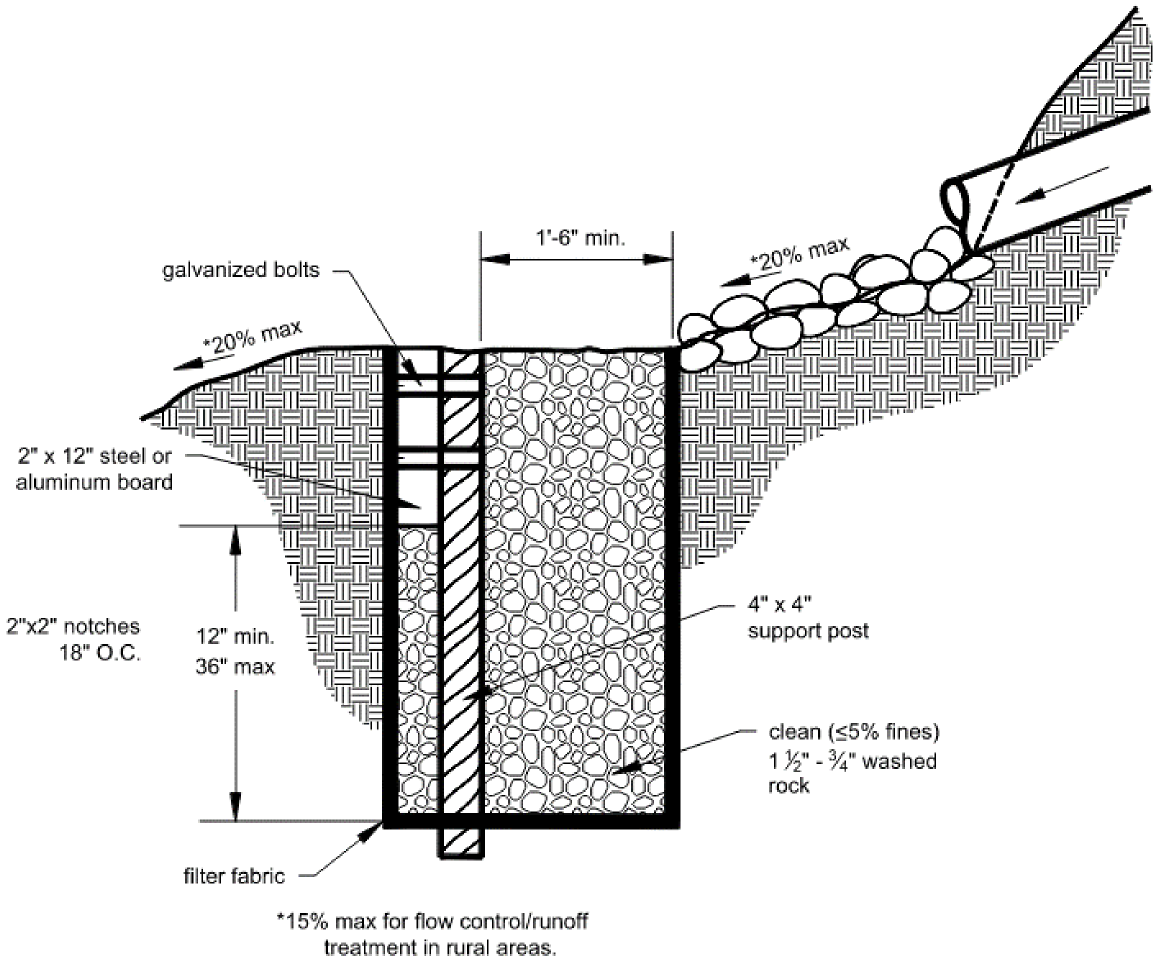
Source: Ecology

Figure 6.5. Pipe/Culvert Outfall Discharge Protection.



Source: Ecology

Figure 6.6. Flow Dispersal Trench.



Section A-A

Notes:

1. This trench shall be constructed so as to prevent point discharge and/or erosion.
2. Trenches may be placed no closer than 50 feet to one another. (100 feet along flowline)
3. Trench and board must be level. Align to follow contours of site.
4. Support post spacing as required by soil conditions to ensure board remains level.

NOT TO SCALE

Source: Ecology

Figure 6.7. Alternative Flow Dispersal Trench.

Tightline Systems

Tightline systems may be needed to prevent aggravation or creation of a downstream erosion problem. The following general design criteria apply to tightline systems:

- Outfall tightlines may be installed in trenches with standard bedding on slopes up to 20 percent. In order to minimize disturbance to slopes greater than 20 percent, it is recommended that tightlines be welded HDPE or restrained joint ductile iron pipe placed at grade with proper pipe anchorage and support.

- Except as indicated above, tightlines or conveyances that traverse the marine intertidal zone and connect to outfalls shall be buried to a depth sufficient to avoid exposure of the line during storm events or future changes in beach elevation. If non-native material is used to bed the tightline, such material shall be covered with at least 3 feet of native bed material or equivalent.

- HDPE pipe tightlines must be designed to address the material limitations, particularly thermal expansion and contraction and pressure design, as specified by the manufacturer. The coefficient of thermal expansion and contraction for solid wall polyethylene pipe (SWPE) is on the order of 0.001 inch per foot per Fahrenheit degree. Sliding sleeve connections shall be used to address this thermal expansion and contraction. These sleeve connections consist of a section of the appropriate length of the next larger size diameter of pipe into which the outfall pipe is fitted. These sleeve connections shall be located as close to the discharge end of the outfall system as is practical.

- Due to the ability of HDPE pipe tightlines to transmit flows of very high energy, special consideration for energy dissipation must be made. Details of a sample gabion mattress energy dissipator have been provided in Figure 6.8. Flows of very high energy will require a specifically engineered energy dissipator structure.

Flow Spreading Options

Flow spreaders function to uniformly spread flows across the inlet of a runoff treatment BMP (e.g., sand filter, biofiltration swale, or filter strip). There are five flow spreader options presented in this section:

- Option A – Anchored plate

- Option B – Concrete sump box

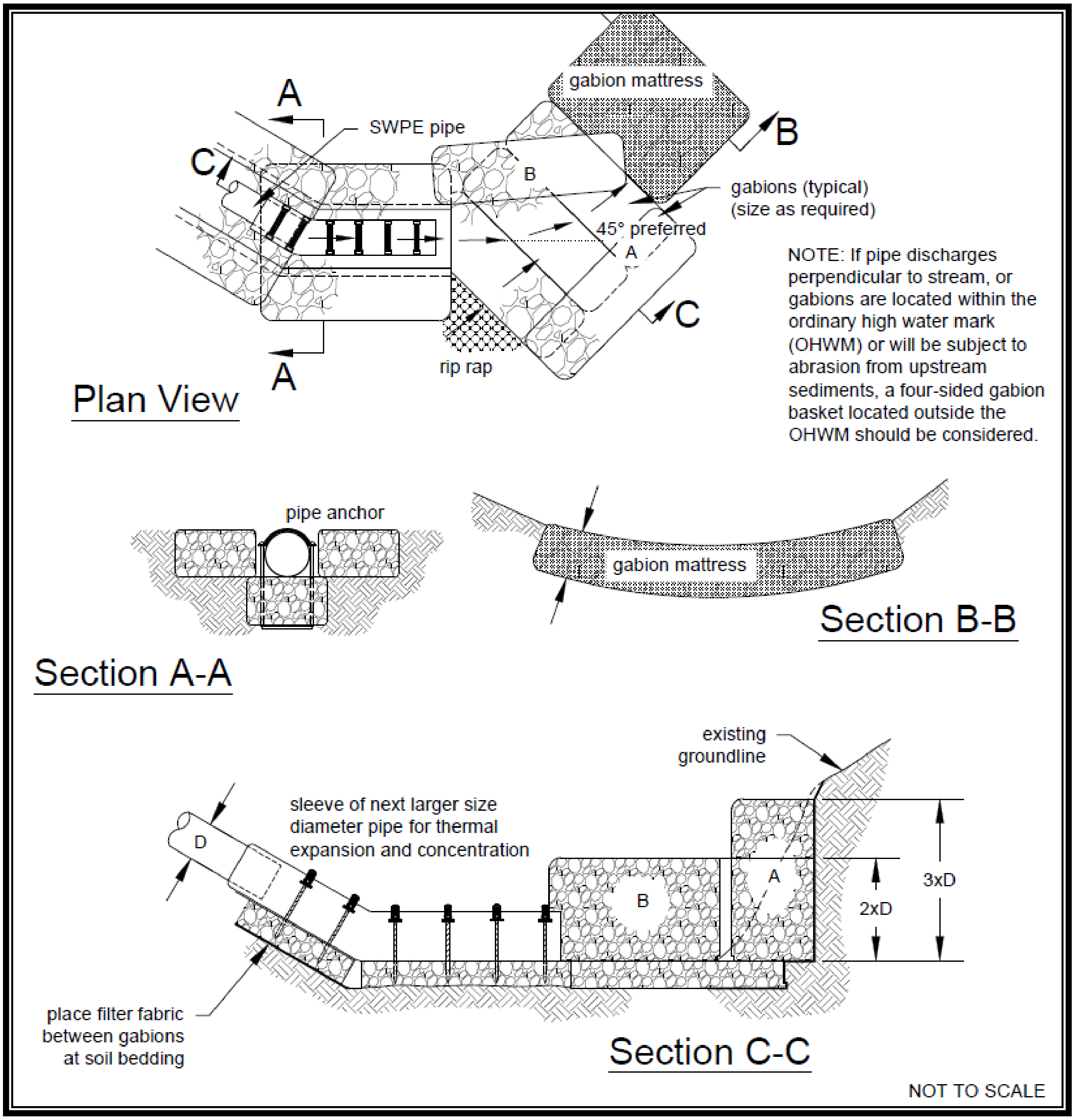
- Option C – Notched curb spreader

- Option D – Through-curb ports

- Option E – Interrupted curb

Options A through C can be used for spreading flows that are concentrated. Any one of these three options can be used when spreading is required by the BMP design criteria. Options A through C can also be used for unconcentrated flows, and in some cases must be used, such as to correct for moderate grade changes along a filter strip.

Options D and E are only for flows that are already unconcentrated and enter a filter strip, bioretention area or continuous inflow biofiltration swale. Other flow spreader options are possible with approval from the City.



Source: Ecology

Figure 6.8. Gabion Outfall Detail.

General Design Criteria

- Where flow enters the flow spreader through a pipe, it is recommended that the pipe be submerged to the extent practical to dissipate energy as much as possible.

- Flow spreaders are difficult to maintain and continue to evenly distribute flow and should not be used on slopes greater than five percent to prevent recombining of downstream flow that can create rills and gullies. Flow spreaders are not to be used in areas accessible by the public as walking on them can alter their flow characteristics.

- For higher inflows (velocities greater than 5 feet per second for the 100-year recurrence interval storm), a Type 1 catch basin shall be positioned in the spreader and the inflow pipe shall enter the catch basin with flows exiting through the top grate. The top of the grate shall be lower than the level spreader plate, or if a notched spreader is used, lower than the bottom of the V-notches.

Option A – Anchored Plate (Figure 6.9)

- An anchored plate flow spreader shall be preceded by a sump having a minimum depth of 8 inches and minimum width of 24 inches. If not otherwise stabilized, the sump area shall be lined to reduce erosion and to provide energy dissipation.

- The top surface of the flow spreader plate shall be level, projecting a minimum of 2 inches above the ground surface of the runoff treatment BMP, or V-notched with notches 6 to 10 inches on center and 1 to 6 inches deep (use shallower notches with closer spacing). Alternative designs may also be used.

- A flow spreader plate shall extend horizontally beyond the bottom width of the BMP to prevent water from eroding the side slope. The horizontal extent shall be such that the bank is protected for all flows up to the 100-year recurrence interval flow or the maximum flow that will enter the runoff treatment BMP.

- Flow spreader plates shall be securely fixed in place.

- Flow spreader plates may be made of either wood, metal, fiberglass reinforced plastic, or other durable material. If wood, pressure treated 4- by 10-inch lumber or landscape timbers are acceptable.

- Anchor posts shall be 4-inch-square concrete, tubular stainless steel, or other material resistant to decay.

Option B – Concrete Sump Box (Figure 6.10)

- The wall of the downstream side of a rectangular concrete sump box shall extend a minimum of 2 inches above the treatment bed. This serves as a weir to spread the flows uniformly across the bed.

- The downstream wall of a sump box shall have “wing walls” at both ends. Side walls and returns shall be slightly higher than the weir so that erosion of the side slope is minimized.

- Concrete for a sump box can be either cast-in-place or precast, but the bottom of the sump shall be reinforced with wire mesh for cast-in-place sumps.

- Sump boxes shall be placed over bases that consists of 4 inches of crushed rock, five-eighths-inch minus to help ensure the sump remains level.

Option C – Notched Curb Spreader (Figure 6.11)

- Notched curb spreader sections shall be made of extruded concrete laid side-by-side and level. Typically, five “teeth” per 4-foot section provide good spacing. The space between adjacent “teeth” forms a V-notch.

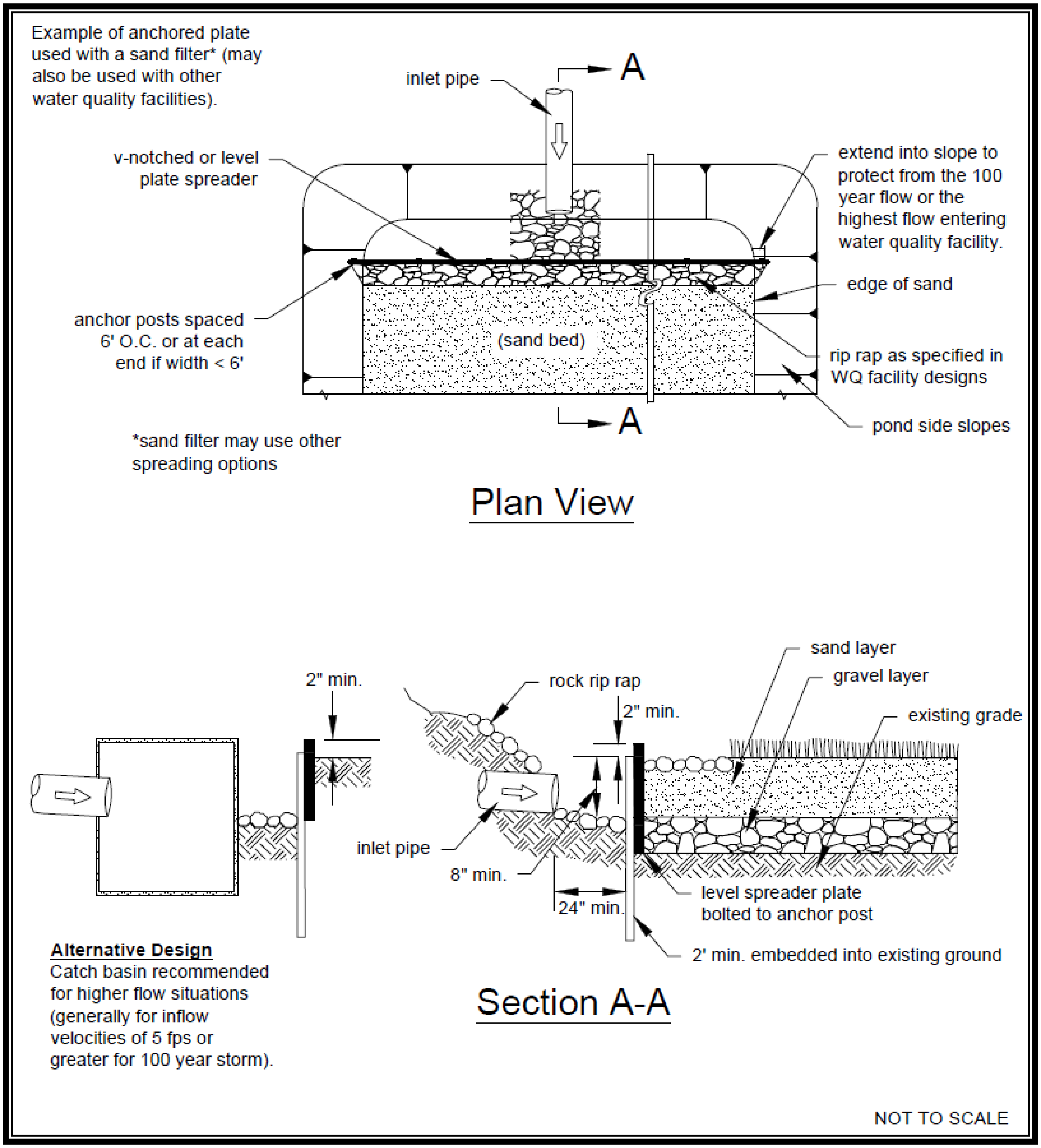
Option D –Through-Curb Ports (Figure 6.12)

- Unconcentrated flows from paved areas entering filter strips, bioretention areas, or continuous inflow biofiltration swales can use curb ports or interrupted curbs (Option E) to allow flows to enter the strip or swale. Curb ports use fabricated openings that allow concrete curbing to be poured or extruded while still providing an opening through the curb to admit water to the runoff treatment BMP.

- Openings in the curb shall be at regular intervals but at least every 6 feet (minimum). The width of each curb port opening shall be a minimum of 11 inches. Approximately 15 percent or more of the curb section length shall be in open ports, and no port shall discharge more than about 10 percent of the flow.

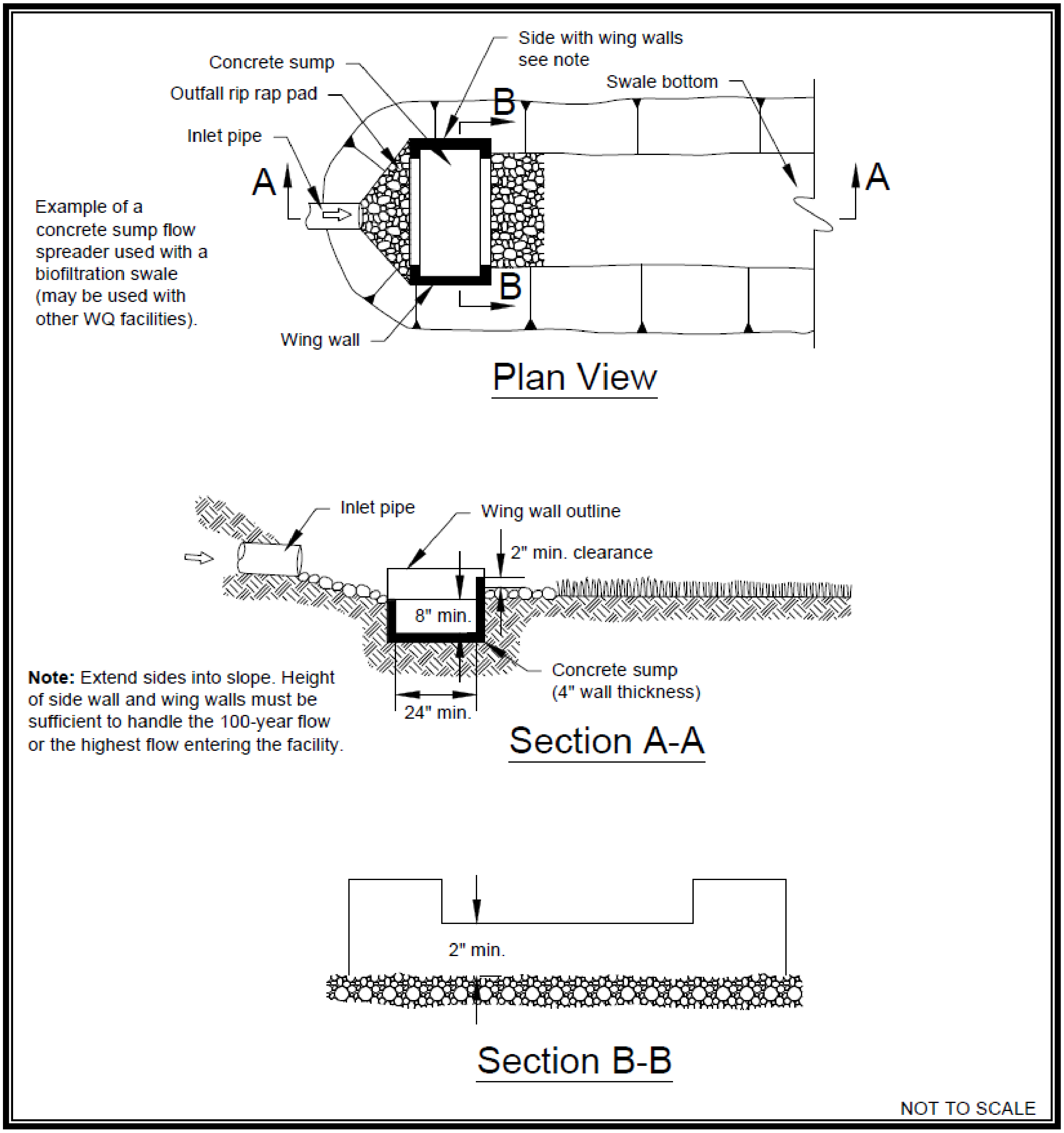
Option E – Interrupted Curb (No Figure)

- Interrupted curbs are sections of curb placed to have gaps spaced at regular intervals along the total width (or length, depending on BMP) of the treatment area. At a minimum, gaps shall be every 6 feet to allow distribution of flows into the runoff treatment BMP before they become too concentrated. The opening shall be a minimum of 2 inches. As a general rule, no opening shall discharge more than 10 percent of the overall flow entering the BMP.



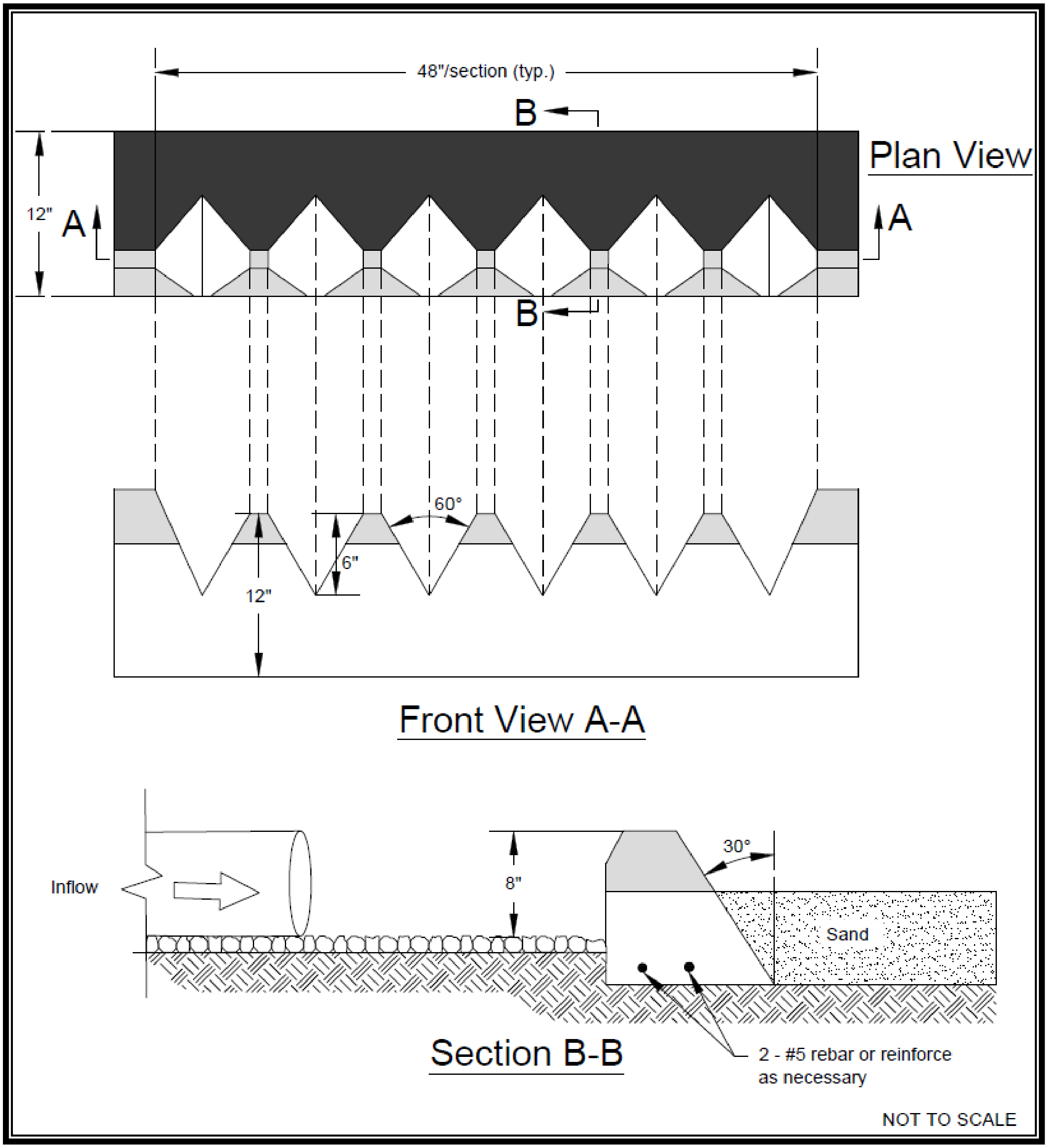
Source: Ecology

Figure 6.9. Flow Spreader Option A: Anchored Plate.



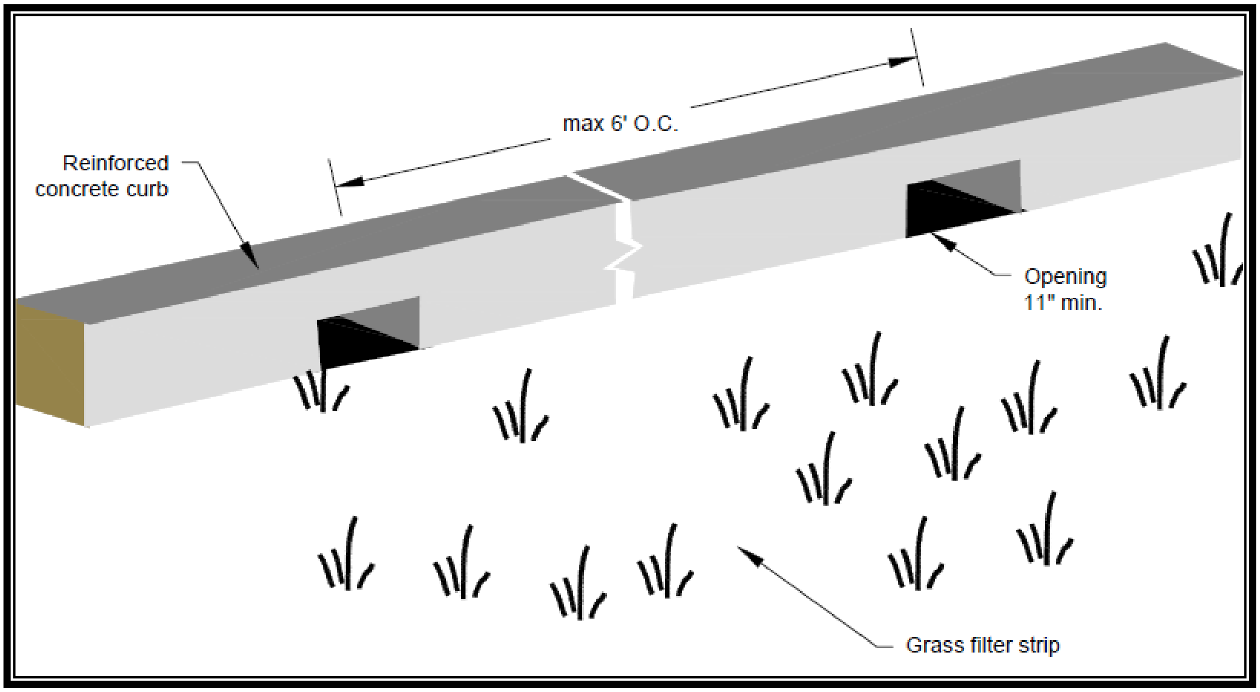
Source: Ecology

Figure 6.10. Flow Spreader Option B: Concrete Sump Box.



Source: Ecology

Figure 6.11. Flow Spreader Option C: Notched Curb Spreader.



Source: Ecology

Figure 6.12. Flow Spreader Option D: Through-Curb Port.

6.3.6 Private Drainage Systems

The engineering analysis for a private drainage system is the same as for a public drainage system. Refer to Section 6.3.5 for conveyance requirements that also apply to private drainage systems.

Private stormwater conveyance piping shall not be located within the public right-of-way. Where soils or other conditions prohibit infiltration on individual parcels (as determined by the City's SDM Administrator), stormwater may be conveyed to the stormwater BMPs associated with the residential or commercial development. In that case, the stormwater conveyance system located in the public right-of-way shall be sized to accommodate the additional stormwater.

Acceptable Pipe Size

The minimum diameter for storm drain pipe on private property is 4 inches. When private stormwater (e.g., roof, lot, or footing drains) cannot be infiltrated on individual lots, the minimum standard piping connection to the public drainage system shall be 8-inch PVC.

Discharge Locations

Stormwater will not be permitted to discharge directly onto public roads or into a public drainage system without the prior approval of the City. Discharges to a public drainage system shall be into a structure such as an inlet, catch basin, manhole, through an approved sidewalk underdrain or curb drain, or into an existing or created public drainage system ditch. Multiple roof drains shall be terminated at a common junction structure outside of the right-of-way (i.e., catch basin or manhole). The connection from the common junction structure to the City's storm drain system shall be through an 8-inch main connecting to a city catch basin or manhole. The 8-inch main used for connection shall begin at the right-of-way, the connection to the catch basin or manhole shall be cored. Concentrated drainage will not be allowed to discharge across sidewalks, curbs, or driveways.

Drainage Stub-Outs

If drainage outlets (stub-outs) are to be provided for each individual lot, the stub-outs shall conform to the requirements outlined below. Note that all applicable core requirements in Chapter 2, in particular Core Requirement #5, must also be addressed for the project site.

- Each outlet shall be suitably located at the lowest elevation on the lot, so as to service all future roof downspouts and footing drains, driveways, yard drains, and any other surface or subsurface drains necessary to render the lots suitable for their intended use. Each outlet shall have free-flowing, positive drainage to an approved stormwater conveyance system or to an approved discharge location.
- Outlets on each lot shall be located with a 5-foot-high, 2- by 4-inch stake marked "storm" or "drain." For stub-outs to a surface drainage, the stub-out shall visibly extend above surface level and be secured to the stake.
- The developer and/or contractor is responsible for coordinating the locations of all stub-out conveyance lines with respect to the utilities (e.g., power, gas, telephone, television).
- All individual stub-outs shall be privately owned and maintained by the property owner including from the property line to the riser on the main line.

Note:
Some pages in this document have been purposely skipped or blank pages inserted so that this document will print correctly when duplexed.

Appendix 6A – Design Aids: Design Storm Precipitation Values, Isopluvial Maps, SCS Curve Numbers, Roughness Coefficients, and Soil Types

6A.1 Single Event Model Guidance

The only approved uses of a single event model are for the sizing of construction BMPs and conveyance systems. Approved continuous simulation models must be used for the design of flow control and runoff treatment BMPs.

6A.1.1 SBUH or SCS Methods

The applicant shall use the western Washington SCS curve numbers, not the SCS national curve numbers. These have been included in Table 6A.5 (Tables 6A.1 through 6A.6 can be found at the end of this section, prior to Figures 6A.1 through 6A.3). Individual curve numbers for a drainage area may be averaged into a "composite" curve number for use in either the SCS or SBUH methods.

NRCS has developed "curve number" values based on soil type and land use. They can be found in "Urban Hydrology for Small Watersheds," Technical Release 55 (TR-55), June 1986, published by the NRCS. The combination of these two factors is called the "soil-cover complex." The soil-cover complexes have been assigned to one of four hydrologic soil groups, according to their runoff characteristics. NRCS has classified over 4,000 soil types into these four soil groups. Table 6A.6 shows the hydrologic soil group of most soils in the City and provides a brief description of the four groups. For details on other soil types refer to the NRCS publication mentioned above (TR-55, 1986).

Isopluvial Maps

Included in this appendix are the 2-, 10-, and 100-year, 24-hour design storm and mean annual precipitation isopluvial maps for Western Washington. These have been taken from NOAA Atlas 2 "Precipitation – Frequency Atlas of the Western United States, Volume IX, Washington. The applicant has the option of using the National Oceanic and Atmospheric Administration (NOAA) isopluvials for design purposes or utilizing the design storm precipitation values listed in Table 6A.1 below. The listed values can be used to an elevation of 650 feet, Mean Sea Level (MSL). Above 650 feet, MSL, the applicant shall use the NOAA isopluvials for selection of the design storm precipitation, unless otherwise approved by the City.

The professional engineer shall use the best engineering judgment in selecting the runoff totals for the project site.

Time of Concentration

Time of concentration is the sum of the travel times for sheet flow, shallow concentrated flow, and channel flow. For lakes and submerged wetlands, the travel time can be determined with storage routing techniques if the stage-storage versus discharge relationship is known, or it may be assumed to be "zero."

Sheet Flow

With sheet flow, the friction value (n_s) (a modified Manning's effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges and rocks; and erosion and transportation of sediment) is used. These n_s values are for very shallow flow depths of about 0.1 foot and are only used for travel lengths up to 300 feet. Table 6A.3 gives Manning's n_s values for sheet flow for various surface conditions.

For sheet flow of up to 300 feet, use Manning's kinematic solution to directly compute T_t.

$$T_t = \frac{0.42\,(n_s L)^{0.8}}{(P_2)^{0.527}(S_o)^{0.4}}$$

Where:

T_t = travel time (min)

n_s = sheet flow Manning's effective roughness coefficient (Table 6A.3)

L = flow length (ft)

P_2 = 2-year, 24-hour rainfall (in)

S_o = slope of hydraulic grade line (land slope, ft/ft)

The maximum allowable distance for sheet flow shall be 300 feet, the remaining overland flow distance shall be shallow concentrated flow until the water reaches a channel.

Shallow Concentrated Flow

After a maximum of 300 feet, sheet flow is assumed to become shallow concentrated flow. The average velocity for this flow can be calculated using the k_s values from Table 6A.3 in which average velocity is a function of watercourse slope and type of channel.

The average velocity of flow, once it has measurable depth, shall be computed using the following equation:

$$V = k \sqrt{s_o}$$

Where:

V = velocity (ft/s)

k = time of concentration velocity factor (ft/s)

S_o = slope of flowpath (ft/ft)

“k” is computed for various land covers and channel characteristics with assumptions made for hydraulic radius using the following rearrangement of Manning’s equation:

$$k = (1.49(R)^{0.667})/n$$

Where:

R = an assumed hydraulic radius

n = Manning’s roughness coefficient for open channel flow (see Table 6A.4

Open Channel Flow

Open channels are assumed to begin where surveyed cross-section information has been obtained, where channels are visible on aerial photographs, or where lines indicating streams appear (in blue) on United States Geological Survey (USGS) quadrangle sheets. The kc values from Table 6A.3 used in the Velocity Equation above or water surface profile information can be used to estimate average flow velocity.

Lakes or Wetlands

This travel time is normally very small and can be assumed as zero. Where significant attenuation may occur due to storage effects, the flows shall be routed using a “level pool routing” technique.

Limitations

The following limitations apply in estimating travel time (T_t).

- Manning’s kinematic solution shall not be used for sheet flow longer than 300 feet.

- In watersheds with storm drains, carefully identify the appropriate hydraulic flow path to estimate Tc.

- Consult a standard hydraulics textbook to determine average velocity in pipes for either pressure or non-pressure flow.

- A culvert or bridge can act as a reservoir outlet if there is significant storage behind it. A hydrograph should be developed to this point and a level pool routing technique used to determine the outflow rating curve through the culvert or bridge.

Design Storm Hyetographs

The standard design hyetograph is the NRCS Type 1A 24-hour rainfall distribution resolved into 10-minute (for conveyance sizing) or 15-minute (for BMP sizing) time intervals, with the design storm values as shown in Table 6A.1 below. Various interpretations of the hyetograph are available and may differ slightly from distributions used in other unit hydrograph-based computer simulations. Other distributions will be accepted with adequate justification and as long as they do not increase the allowable release rates.

Subbasin Delineation

Within an overall drainage basin, it may be necessary to delineate separate subbasins based on similar land uses and/or runoff characteristics or when hydraulically "self-contained" areas are found to exist. When this is necessary, separate hydrographs shall be generated, routed, and recombined, after travel time is considered, into a single hydrograph to represent runoff flows into the conveyance system or flow control or runoff treatment BMP.

Hydrograph Phasing Analysis

Where flows from multiple basins or subbasins having different runoff characteristics and/or travel times combine, the design engineer shall sum the hydrographs after shifting each hydrograph according to its travel time to the discharge location of interest. The resultant hydrograph shall be either routed downstream as required in the downstream analysis or routed through the flow control or runoff treatment BMP.

Estimates of Interception

If interception (the volume of precipitation trapped on vegetation) is modeled, the values shown in Table 6A.2 shall be used as user inputs.

Hydrologic Soil Groups

For purposes of runoff computations using NRCS methods, soils in Lacey have the Hydrologic Soil Group designations as listed in Table 6A.6. The two primary soil associations found in the Lacey area are the Spanaway-Nisqually association and the Alderwood-Everett association (asterisked in Table 6A.6 below).

Table 6A.1. Lacey Design Storm Precipitation Values.

Return Frequency 24-Hour Storm Event (years)	Precipitation (in)
0.5	1.79
2	2.80
5	3.75
10	4.35
25	5.10
50	5.65
100	6.15

Note: The 7-day, 100-year storm volume is 12 inches.

Table 6A.2. Interception Values for Various Land Covers.

Land Cover	Interception (inches)
Heavy Forest	0.15
Light Open Forest	0.12
Pasture and Shrubs	0.10
Lawn	0.05
Bare Ground	0.03
Pavement	0.02

Note: Values shown are about 1/2 of those for dry antecedent conditions found in references.

Table 6A.3. "n" and "k" Values Used in Time Calculations for Hydrographs.	
"n" Sheet Flow Equation Manning's Values (for the initial 300 ft. of travel)	**n_s[a]**
Smooth surfaces (concrete, asphalt, gravel, or bare hand packed soil)	0.011
Fallow fields or loose soil surface (no residue)	0.05
Cultivated soil with residue cover (s≤ 0.20 ft/ft)	0.06
Cultivated soil with residue cover (s> 0.20 ft/ft)	0.17
Short prairie grass and lawns	0.15
Dense grasses	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods or forest with light underbrush	0.40
Woods or forest with dense underbrush	0.80
Shallow Concentrated Flow (After the initial 300 ft. of sheet flow, R = 0.1)	**k_s**
1. Forest with heavy ground litter and meadows (n = 0.10)	3
2. Brushy ground with some trees (n = 0.060)	5
3. Fallow or minimum tillage cultivation (n = 0.040)	8
4. High grass (n = 0.035)	9
5. Short grass, pasture, and lawns (n = 0.030)	11
6. Nearly bare ground (n = 0.025)	13
7. Paved and gravel areas (n = 0.012)	27
Channel Flow (intermittent) (At the beginning of visible channels R = 0.2)	**k_c**
1. Forested swale with heavy ground litter (n = 0.10)	5
2. Forested drainage course/ravine with defined channel bed (n = 0.050)	10
3. Rock-lined waterway (n = 0.035)	15
4. Grassed waterway (n = 0.030)	17
5. Earth-lined waterway (n = 0.025)	20
6. CMP pipe (n = 0.024)	21
7. Concrete pipe (0.012)	42
8. Other waterways and pipe	0.508/n
Channel Flow (Continuous stream, R = 0.4)	**k_c**
9. Meandering stream with some pools (n = 0.040)	20
10. Rock-lined stream (n = 0.035)	23
11. Grass-lined stream (n = 0.030)	27
12. Other streams, man-made channels and pipe	0.807/n[b]

[a] Manning values for sheet flow only, from Overton and Meadows 1976 (See TR-55, 1986).
"k" Values Used in Travel Time/Time of Concentration Calculations.

[b] Determined from Table 6A.3

Source: Washington State Department of Ecology, *Stormwater Management Manual for the Puget Sound Basin*, February 1992.

Table 6A.4. Values of the Roughness Coefficient "n".

Type of Channel and Description	Manning's "n"
A. Constructed Channels	
a. Earth, straight and uniform	
1. Clean, recently completed	0.018
2. Gravel, uniform section, clean	0.025
3. With short grass, few weeds	0.027
b. Earth, winding and sluggish	0.025
1. No vegetation	0.025
2. Grass, some weeds	0.030
3. Dense weeds or aquatic plants in deep channels	0.035
4. Earth bottom and rubble sides	0.030
5. Stony bottom and weedy banks	0.035
6. Cobble bottom and clean sides	0.040
c. Rock lined	
1. Smooth and uniform	0.035
2. Jagged and irregular	0.040
d. Channels not maintained, weeds and brush uncut	
1. Dense weeds, high as flow depth	0.080
2. Clean bottom, brush on sides	0.050
3. Same as above, highest stage of flow	0.070
4. Dense brush, high stage	0.100
B. Natural Streams	
B-1. Minor Streams (top width at flood stage <100 feet)	
a. Streams on plain	
1. Clean, straight, full stage no rifts or deep pools	0.030
2. Same as above, but more stones and weeds	0.035
3. Clean, winding, some pools and shoals	0.040
4. Same as above, but some weeds	0.040
5. Same as 4, but more stones	0.050
6. Sluggish reaches, weedy deep pools	0.070
7. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.100
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages	
1. Bottom: gravel, cobbles, and few boulders	0.040
2. Bottom: cobbles with large boulders	0.050
B-2. Flood Plains	
a. Pasture, no brush	
1. Short grass	0.030
2. High grass	0.035

Table 6A.4 (continued). Values of the Roughness Coefficient "n".	
Type of Channel and Description	**Manning's "n"**
B-2. Flood Plains (continued)	
b. Cultivated areas	
1. No crop	0.030
2. Mature row crops	0.035
3. Mature field crops	0.040
c. Brush	
1. Scattered brush, heavy weeds	0.050
2. Light brush and trees	0.060
3. Medium to dense brush	0.070
4. Heavy, dense brush	0.100
d. Trees	
1. Dense willows, straight	0.150
2. Cleared land with tree stumps, no sprouts	0.040
3. Same as above, but with heavy growth of sprouts	0.060
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.100
5. Same as above, but with flood stage reaching branches	0.120

Source: Washington State Department of Ecology, *Stormwater Management Manual for the Puget Sound Basin*, February 1992.

Table 6A.5. Post-Development Runoff Curve Numbers for Selected Agricultural, Suburban, and Urban Areas.

Cover Type and Hydrologic Condition	Curve Numbers for Hydrologic Soil Group A	B	C	D
Pasture, Grassland, or Range-Continuous Forage for Grazing				
Poor condition (ground cover <50% or heavily grazed with no mulch)	68	79	86	89
Fair condition (ground cover 50% to 75% and not heavily grazed)	49	69	79	84
Good condition (ground cover >75% and lightly or only occasionally grazed)	39	61	74	80
Woods				
Poor (forest litter, small trees, and brush are destroyed by heavy grazing or regular burning)	45	66	77	83
Fair (woods are grazed but not burned, and some forest litter covers the soil)	36	60	73	79
Good (woods are protected from grazing, and litter and brush adequately cover the soil)	30	55	70	77
Open Space (lawns, parks, golf courses, cemeteries, landscaping, etc.)[a]				
Fair condition (grass cover on 50% to 75% of the area)	77	85	90	92
Good condition (grass cover on >75% of the area)	68	80	86	90
Impervious Areas				
Open water bodies: lakes, wetlands, ponds, etc.	100	100	100	100
Paved parking lots, roofs[b] driveways, etc. (excluding right-of-way)	98	98	98	98
Paved	98	98	98	98
Gravel (including right-of-way)	76	85	89	91
Dirt (including right-of-way)	72	82	87	89
Permeable Pavement				
Porous Asphalt, Porous Concrete, or Grid/Lattice Systems (without underlying perforated drain pipes to collect stormwater) (use landscaped area CNs)	77	85	90	92
Paving Blocks (without underlying perforated drain pipes to collect stormwater) (use 50% landscaped area/50% impervious CNs)	87	91	94	96
All Permeable Pavement Types (with underlying perforated drain pipes to collect stormwater) (use impervious area CNs)	98	98	98	98

Table 6A.5 (continued). Post-Development Runoff Curve Numbers for Selected Agricultural, Suburban, and Urban Areas.

Dwelling Unit/Gross Acre (DU/GA)	Average Percent Impervious Area[c,d]	Curve Number
Single-Family Residential[c] (shall only be used for subdivisions >50 acres)		
1.0 DU/GA	15	Separate curve number shall be selected for pervious and impervious portions of the site or basin
1.5 DU/GA	20	
2.0 DU/GA	25	
2.5 DU/GA	30	
3.0 DU/GA	34	
3.5 DU/GA	38	
4.0 DU/GA	42	
4.5 DU/GA	46	
5.0 DU/GA	48	
5.5 DU/GA	50	
6.0 DU/GA	52	
6.5 DU/GA	54	
7.0 DU/GA	56	
7.5 DU/GA	58	
PUDs, condos, apartments, commercial businesses, industrial areas and subdivisions <50 acres		
% impervious must be computed		Separate curve numbers shall be selected for pervious and impervious portions of the site
For a more detailed and complete description of land use curve numbers refer to Chapter 2 of the Natural Resources Conservation Service Technical Release No. 55 (210-VI-TR-55, Second Ed., June 1986).		

[a] Composite Curve Numbers may be computed for other combinations of open space cover type.

[b] Where roof runoff and driveway runoff are infiltrated or dispersed according to the requirements in Chapter 7, Section 7.4.10: Roof Downspout Controls, the average percent impervious area may be adjusted in accordance with the procedure described under “Modeling and Sizing.”

[c] Assumes roof and driveway runoff is directed into street/storm drain system.

[d] All the remaining pervious area (lawn) are considered to be in good condition for these curve numbers.

Sources: Natural Resources Conservation Service, Technical Release No. 55, *Urban Hydrology for Small Watersheds*, June 1986; Washington State Department of Ecology, *Stormwater Management Manual for Western Washington*, 2019.

Table 6A.6. Hydrologic Soil Group (HSG) of Soils in Lacey and Vicinity.

Soil	HSG	SCS Map Symbol #	Soil	HSG	SCS Map Symbol #	Soil	HSG	SCS Map Symbol #
Alderwood*	C		Hydraquents	D		Puyallup	B	89
Baldhill	B	5–8	Indianola*	A	46–48	Rainier	C	
Baumgard	B		Jonas	B		Raught	B	
Bellingham*	D		Kapowsin*	C/D		Riverwash	variable	
Boistfort	B		Katula	C		Salkum	B	
Bunker	B		Lates	C		Scamman	D	
Cagey*	C	20	Mal	C		Schneider	B	
Cathcart	B		Mashel	B		Semiahmoo	D	
Centralia	B		Maytown	C		Shalcar	D	
Chehalis	B		McKenna*	D		Skipopa*	D	
Delphi	D		Melbourne	B		Spana*	D	
Dupont	D		Mukilteo*	C/D		Spanaway*	A/B	110–114
Dystric Xero. Xerochrepts	C		Newberg	B	71, 72	Sultan	C	115
Eld	B		Nisqually*	B	73, 74	Tacoma	D	
Everett*	A	32–35	Norma*	C/D		Tenino	C	117–119
Everson	D		Olympic	B		Tisch	D	
Galvin	D		Pheeney	C		Vailton	B	
Giles*	B		Pilchuck	C	84	Wilkeson	B	
Godfrey	D		Pits, gravel	N/A	85	Xerorthents	C	
Grove	C	42	Prather	C		Yelm*	C	
Hoogdal*	C		Puget	D				

A = (Low runoff potential) Soils having low runoff potential and high infiltration rates, even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (greater than 0.30 in/hr.).

B = (Moderately low runoff potential). Soils having moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15 to 0.3 in/hr.).

C = (Moderately high runoff potential). Soils having low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine textures. These soils have a low rate of water transmission (0.05 to 0.15 in/hr.).

D = (High runoff potential). Soils having high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a hardpan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0 to 0.05 in/hr.).

N/A = Not Applicable

Notes:

1. Soils with * are commonly found in the Lacey area.
2. Soils with SCS Map Symbol numbers are found in Category I Critical Aquifer Recharge Areas (per Section 14.36.070 LMC).
3. HSG classifications, as defined by the NRCS (formerly Soil Conservation Service).
4. Where field infiltration tests indicate a measured (initial) infiltration rate less than 0.30 in/hr, continuous simulation model users may model the site as a C soil if needed to meet Core Requirement #5 (LID Performance Standard).

Sources: Soil Conservation Service, *Soil Survey of Thurston County, Washington*, 1990; Natural Resources Conservation Service, Technical Release No. 55, *Urban Hydrology for Small Watersheds*, June 1986.

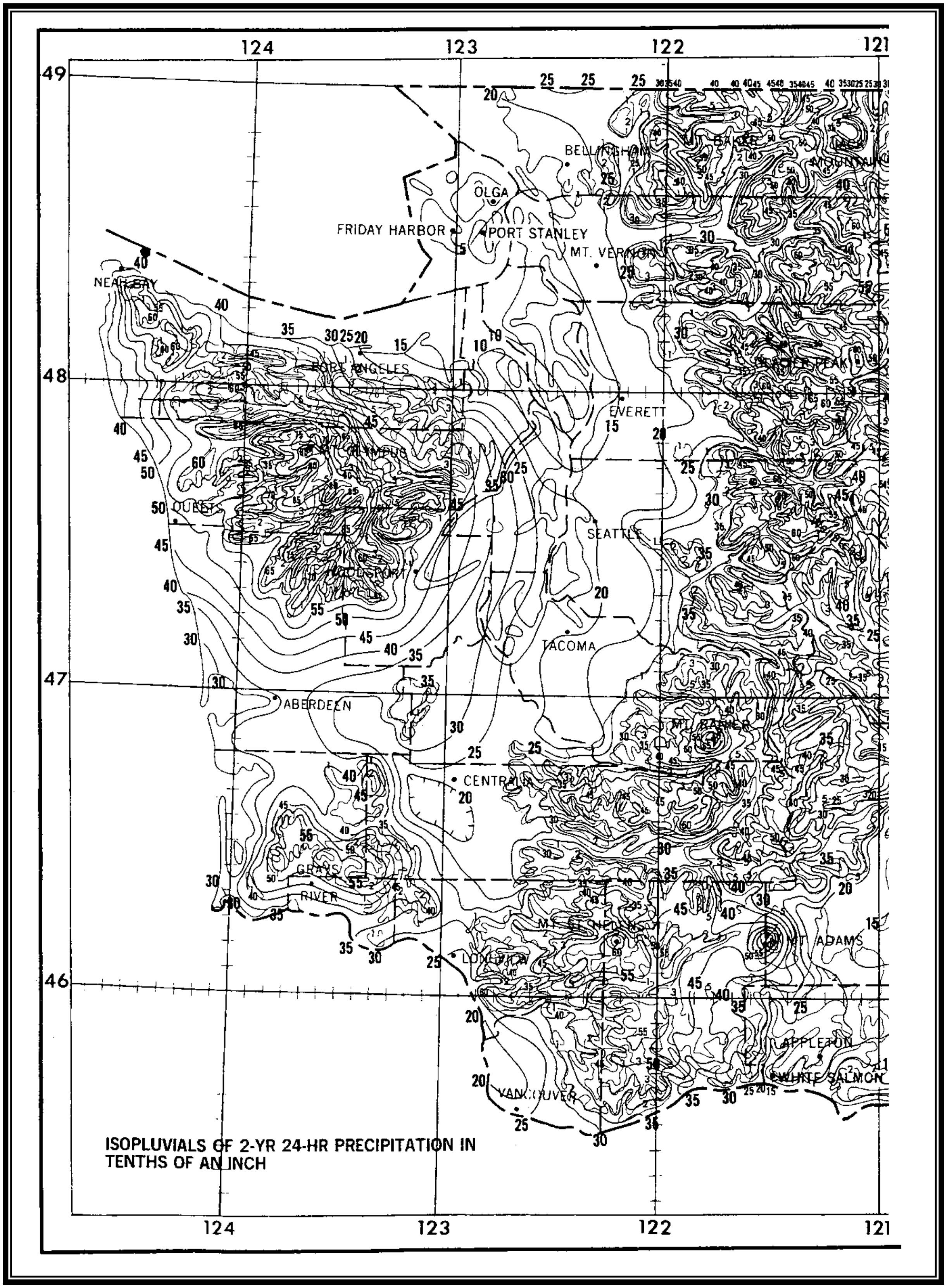


Figure 6A.1. Western Washington Isopluvial 2-Year, 24-Hour.

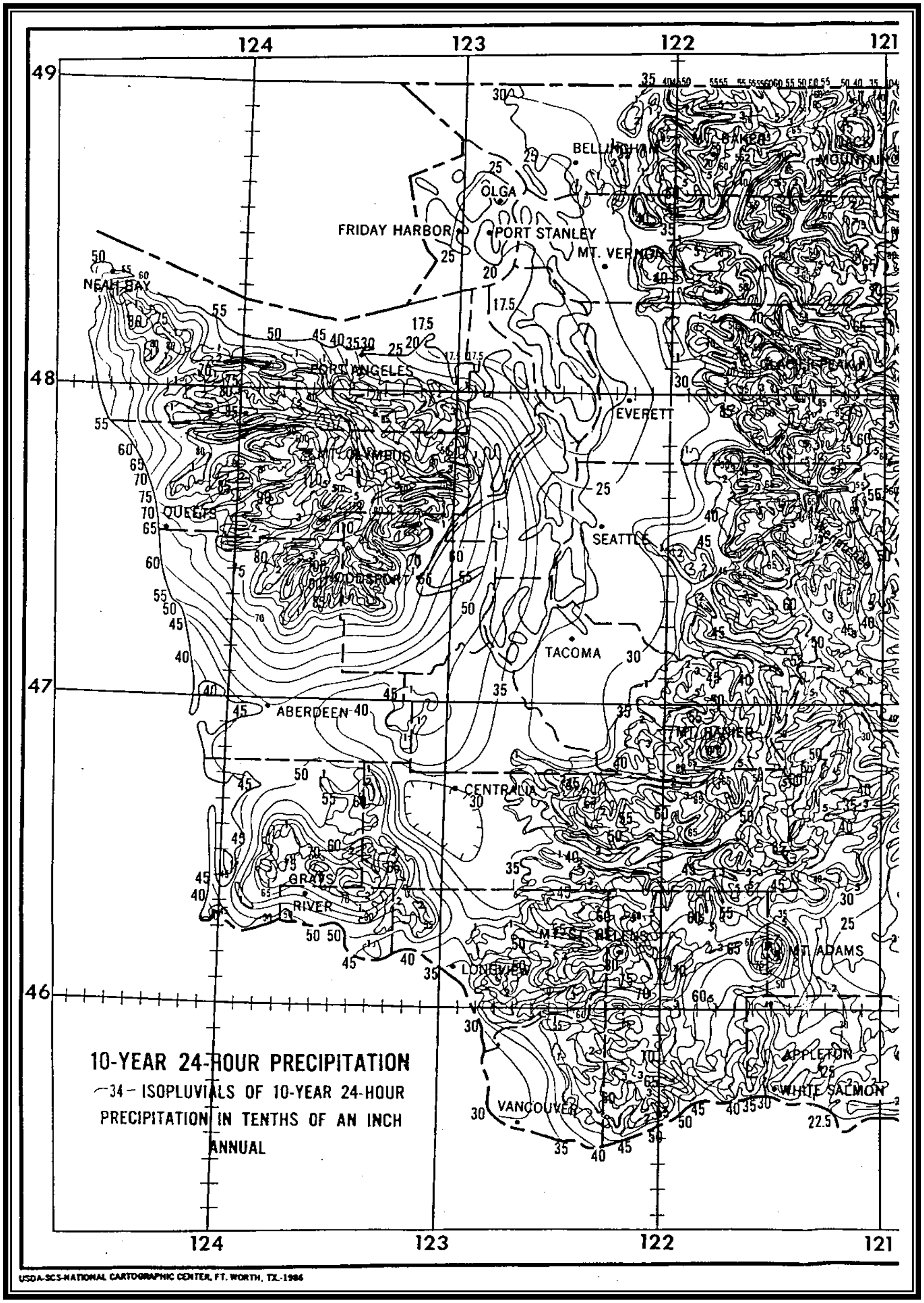


Figure 6A.2. Western Washington Isopluvial 10-Year, 24-Hour.

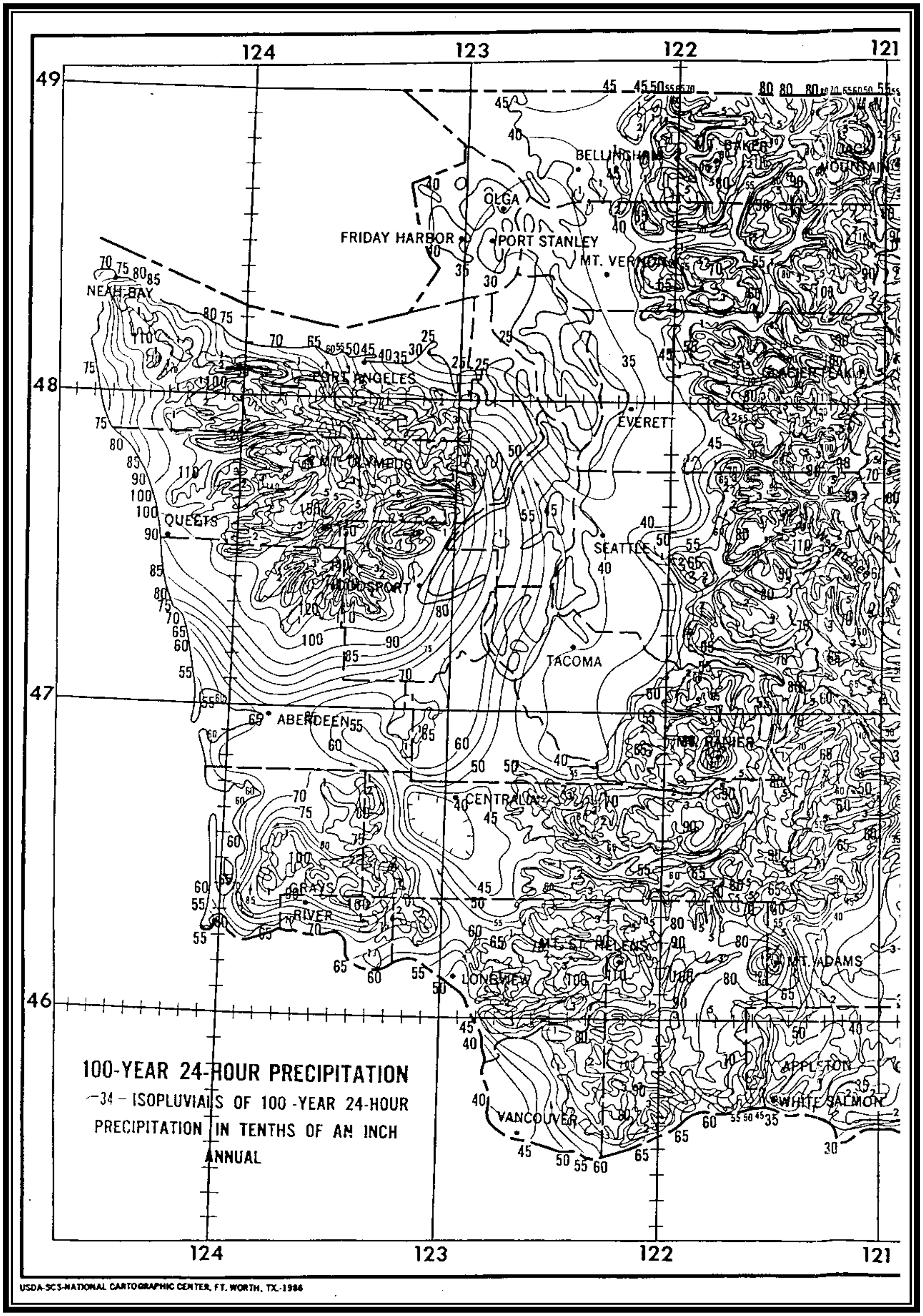


Figure 6A.3. Western Washington Isopluvial 100-Year, 24-Hour.

Appendix 6B – Nomographs for Various Culvert Sizing Needs

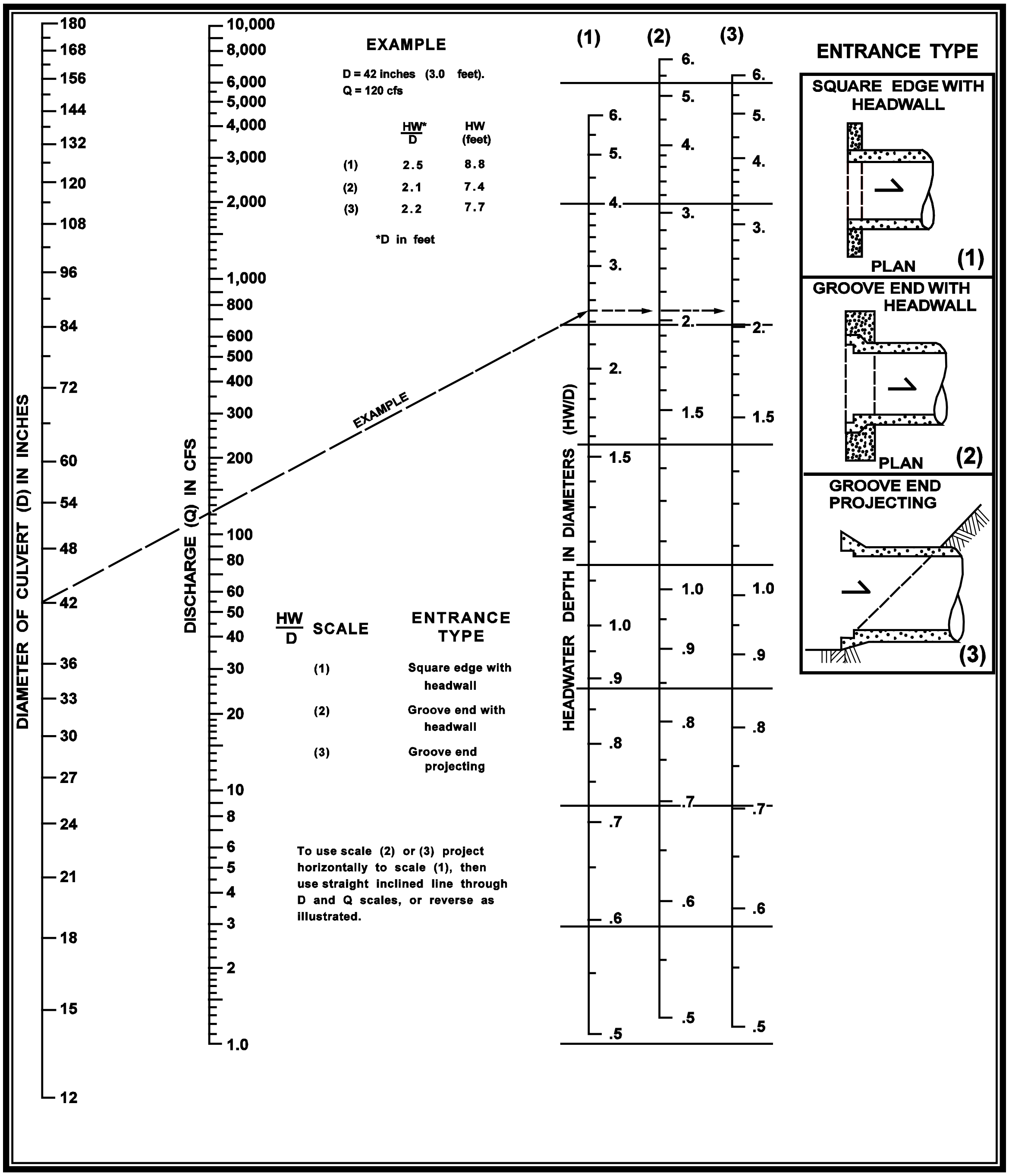


Figure 6B.1. Headwater Depth for Smooth Interior Pipe Culverts with Inlet Control.

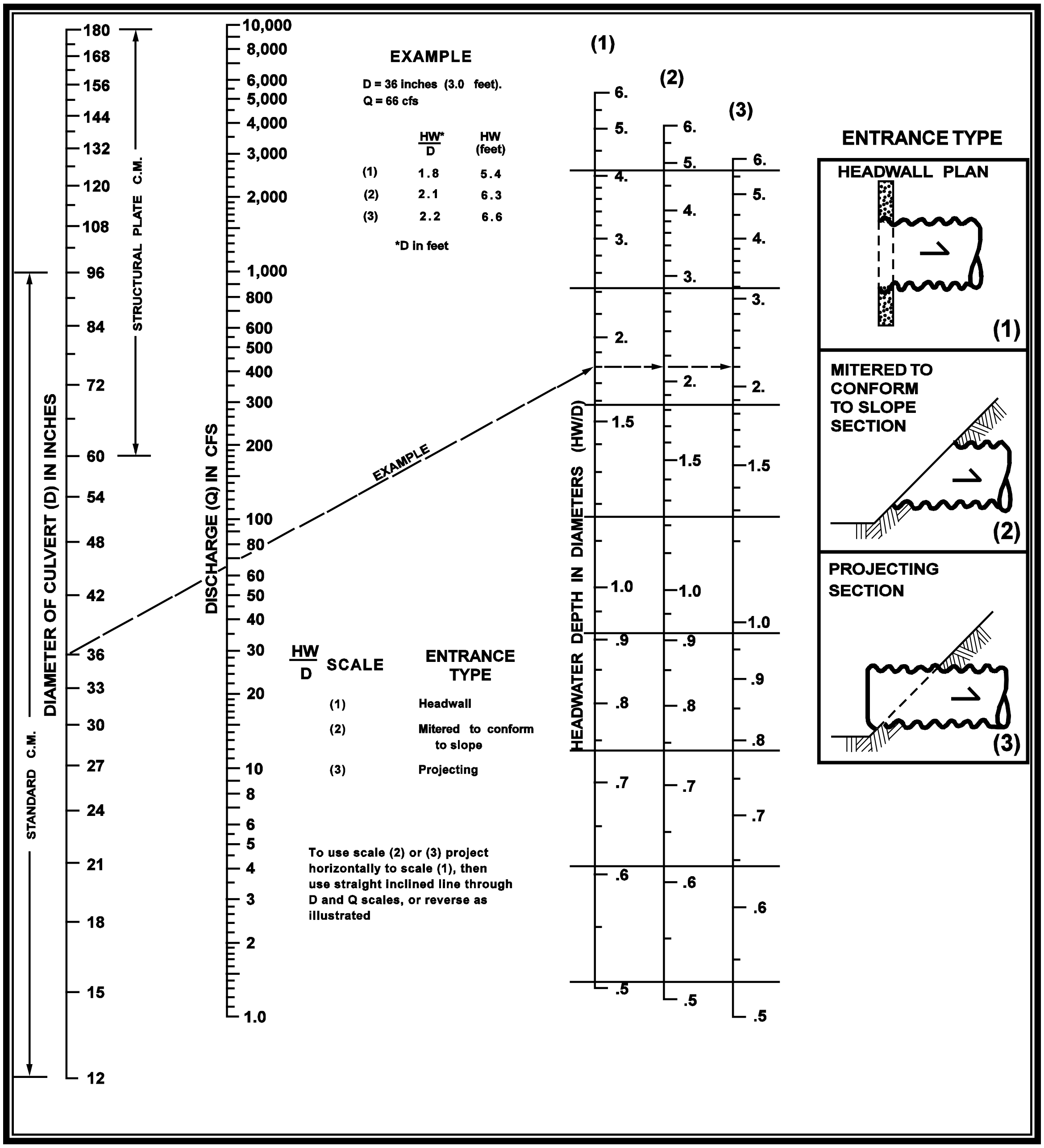
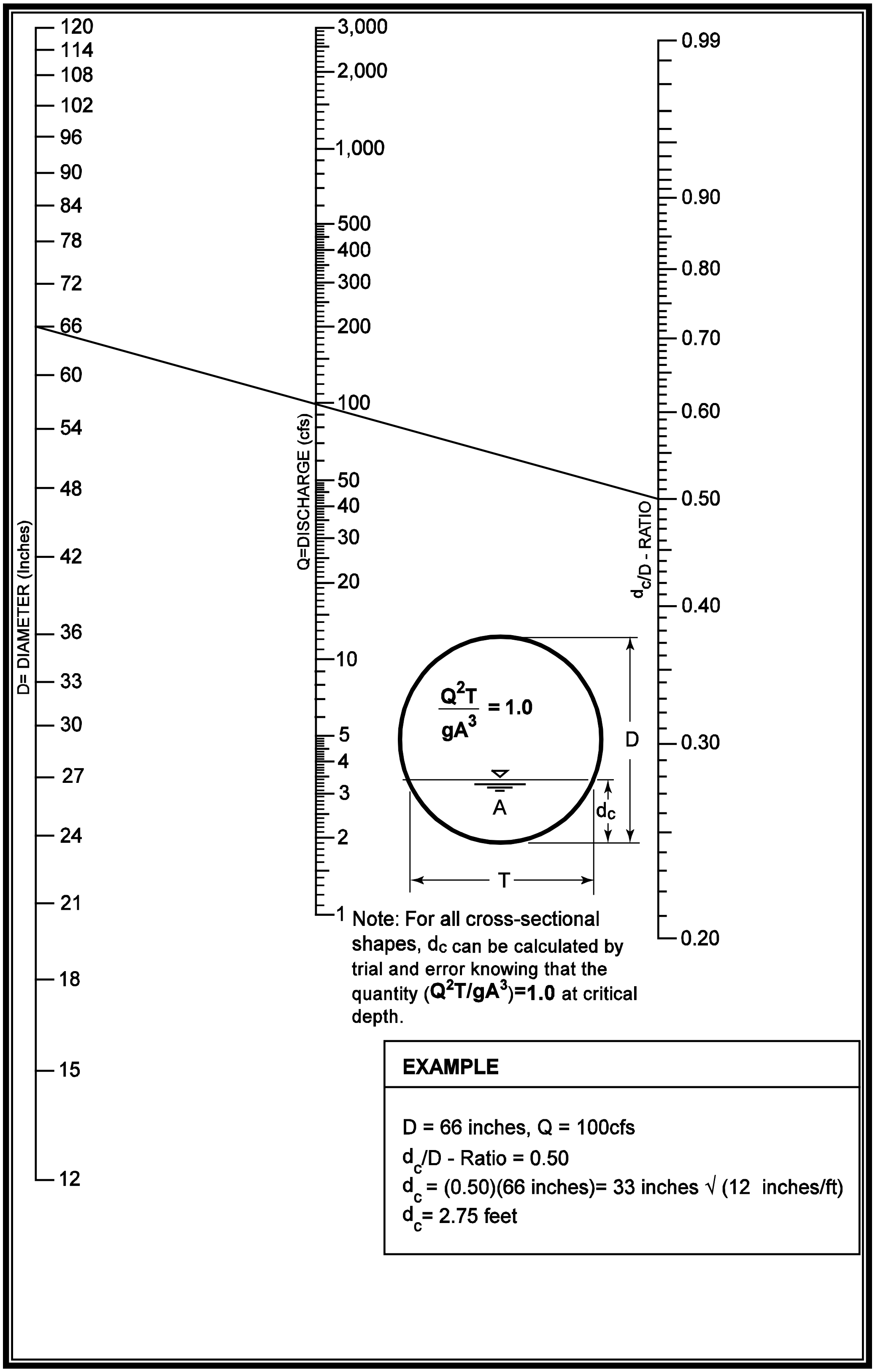


Figure 6B.2. Headwater Depth for Corrugated Pipe Culverts with Inlet Control.



Note: For all cross-sectional shapes, d_c can be calculated by trial and error knowing that the quantity (**Q^2T/gA^3)=1.0** at critical depth.

EXAMPLE
D = 66 inches, Q = 100cfs d_c/D - Ratio = 0.50 d_c = (0.50)(66 inches)= 33 inches √ (12 inches/ft) d_c= 2.75 feet

Figure 6B.3. Critical Depth of Flow for Circular Culverts.

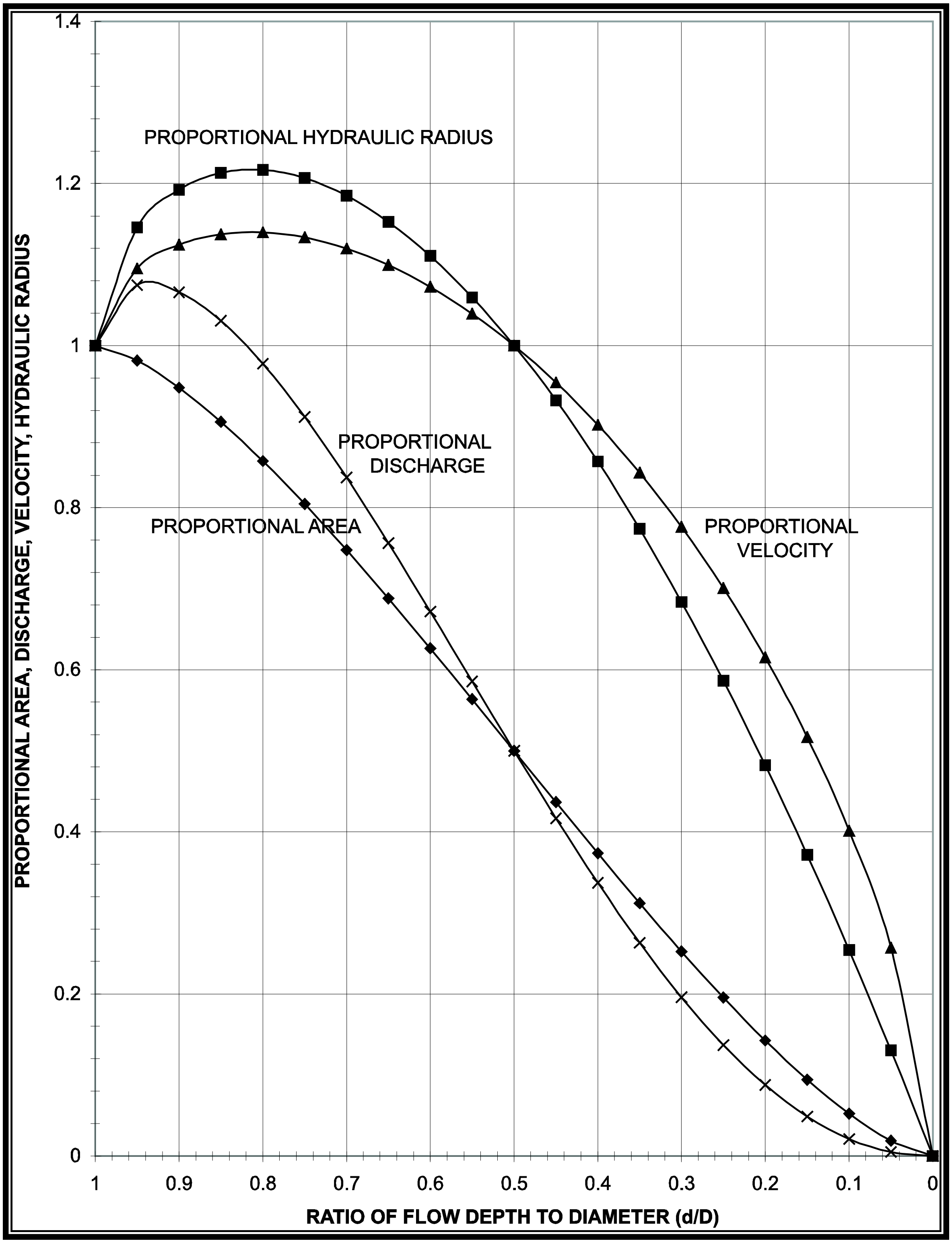


Figure 6B.4. Circular Channel Ratios.