Appendix F Stormwater Conveyance System Design

F.1 Introduction

The focus of this SWMG is to define standards and specifications for design, construction and maintenance of BMPs required to meet stormwater performance objectives. The components and considerations of the accompanying stormwater conveyance system are outlined in this appendix.

F.2 Clearance with Other Utilities

- All proposed and existing utilities crossing or parallel to designed storm sewer systems must be shown on the plan and profile.
- Storm drain and utility crossings must not have be less than a 45-degree angle between them.
- Minimum vertical and horizontal clearances, wall to wall, must be provided between storm drainage lines and other utilities as defined by the District of Columbia Water and Sewer Authority (DC Water). Consult DC Water's Project Design Manual and Green Infrastructure Utility Protection Guidelines, latest additions, for details. Exceptions may be granted by the DC Water on a case-by-case basis when justified.

F.3 Design of Stormwater Conveyance Systems

The Chezy-Manning formula is to be used to compute the system's transport capacities:

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

where:

Q	=	channel flow (cfs)
n	=	Manning's roughness coefficient (Table F.1)
A	=	cross-sectional area of flow (ft^2)
R	=	hydraulic radius (ft)
S	=	channel slope (ft/ft)
Wp	=	wetland perimeter
R	=	A/W_P

Table F.1 Manning's Roughness Coefficient (*n*) Values for Various Channel Materials

Channel Materials	Roughness Coefficient
Concrete pipe and precast culverts	
24 inches and smaller	0.015
27 inches and larger	0.013
Monolithic concrete in boxes, channels	0.015
Corrugated metal	0.022
PVC pipes	0.011
Sodded channel with water depth < 1.5 feet	0.050
Sodded channel with water depth >1.5 feet	0.035
Smooth earth channel or bottom of wide channels with sodded slopes	0.025
Rip-rap channels	0.035

Note: Where drainage systems are composed of more than one of the above channel materials, a composite roughness coefficient must be computed in proportion to the wetted perimeter of the different materials.

Also, the computation for the flow velocity of the channel must use the continuity equation as follows:

$$Q = A \times V$$

where:

V = velocity (ft/s)
A = cross-sectional area of the flow (ft^2)

F.4 Gutters

With uniform cross slope and composite gutter section use the following equation:

$$Q = \frac{0.50}{n} \times S_x^{1.67} \times S^{0.5} \times T^{2.67}$$

where:

Q = flow rate (cfs)
n = Manning's roughness coefficient (Table F.1)
S_x = cross slope (ft/ft)
S = longitudinal slope (ft/ft)
T = width of flow (spread) (ft)

F.5 Inlets

In accordance with the current requirements of the District of Columbia Plumbing Code, all inlets on private or public parcels, but outside the public right-of-way (PROW), must be sized to ensure safe conveyance of stormwater flows exceeding the capacity of the approved on-site stormwater management practices and the designated pervious land cover areas. These stormwater flows must not flow over property lines onto adjacent lots unless these flows run into an existing natural water course. Stormwater inlets in the PROW must be designed in accordance with the current requirements in Chapter 33 of the District of Columbia Department of Transportation Design and Engineering Manual and be approved for use by the District of Columbia Water and Sewer Authority.

F.6 Street Capacity (Spread)

Design of the conveyance of stormwater runoff within the public right-of-way must follow the current requirements in the Design and Engineering Manual of the District of Columbia Department of Transportation. The roadway drainage design criteria for existing streets is a 15-year storm, 5-minute duration, and a maximum spread of 6 feet from the face of the curb (32.3.13 DDOT Design and Engineering Manual 2009). Proposed streets must use AASHTO Chapter VI for their design criteria.

F.7 Manhole and Inlet Energy Losses

The following formulas must be used to calculate headloss:

$$HL = \frac{V_{outlet}^2 - V_r^2}{2g} + SL$$

$$V_r = \frac{Q(V\cos\frac{a}{2})(inlet\,1) + Q(V\cos\frac{a}{2}(inlet\,2) + ...}{Q(outlet)}$$

where:

HL	=	headloss in the structure
V_r	=	resultant velocity
g	=	gravitational acceleration (32.2 ft/s^2)
SL	=	minimum structure loss
a	=	angle between the inlet and outlet pipes (180°)

Table F.2 provides the minimum structure loss for inlets, manholes, and other inlet structures for use in the headloss calculation.

Table F.2 Minimum Structure Loss to Use in Hydraulic Grade Line Calculation

Velocity, V_{outlet} (ft/s)*	Structure Loss, *SL*
2	0.00
3	0.05
4	0.10
5	0.15
6	0.20
6	0.25

* Velocities leaving the structure.

Headloss at the field connection is to be calculated like those structures, eliminating the structure loss. For the angular loss coefficient, cos a/2 is assumed to be 1.

F.8 Open Channels

- Calculations must be provided for all channels, streams, ditches, swales and etc., including a typical section of each reach and a plan view with reach locations. In the case of existing natural streams/swales, a field survey of the stream (swale) cross sections may be required prior to the final approval.
- The final designed channel must provide a 6-inch minimum freeboard above the designated water surface profile of the channel.
- If the base flow exists for a long period of time or velocities are more than five feet per second in earth and sodded channel linings, gabion or rip-rap protection must be provided at the intersection of the inverts and side slopes of the channels unless it can be demonstrated that the final bank and vegetation are sufficiently erosion-resistant to withstand the designed flows, and the channel will stay within the floodplain easement throughout the project life.
- Channel inverts and tops of bank are to be shown in plan and profile views.
- For a designed channel, a cross section view of each configuration must be shown.
- For proposed channels, a final grading plan must be provided.
- The limits of a recorded 100-year floodplain easement or surface water easement sufficient to convey the 100 year flow must be shown.
- The minimum 25-foot horizontal clearance between a residential structure and 100 year floodplain must be indicated in the plan.
- For designed channels, transition at the entrance and outfall is to be clearly shown on the site plan and profile views.

F.9 Pipe Systems

- Individual stormwater traps must be installed on the storm drain branch serving each structural best management practice, or a single trap must be installed in the main storm drain after it leaves the structural best management practice and before it connects with the city's combined sewer. Such traps must be provided with an accessible cleanout. The traps must not be required for storm drains which are connected to a separate storm sewer system.
- The pipe sizes used for any part of the storm drainage system within the public right-of-way must follow District of Columbia Water and Sewer Authority Standard and Specifications. The minimum pipe size to be used for any part of a private storm drainage system must follow the current requirements of the District of Columbia Plumbing Code.
- The material and installation of the storm drain for any part of public storm sewer must follow District of Columbia Water and Sewer Authority Standard and Specifications.
- An alternative overflow path for the 100-year storm is to be shown on the plan view if the path is not directly over the pipe. Where applicable, proposed grading must ensure that overflow will be into attenuation facilities designed to control the 100-year storm.
- A pipe schedule tabulating pipe lengths by diameter and class is to be included on the drawings. Public and private systems must be shown separately.
- Profiles of the proposed storm drains must indicate size, type, and class of pipe, percent grade, existing ground and proposed ground over the proposed system, and invert elevations at both ends of each pipe run. Pipe elevations and grades must be set to avoid hydrostatic surcharge during design conditions. Where hydrostatic surcharge greater than one foot of head cannot be avoided, a rubber gasket pipe is to be specified.

F.10 Culverts

Culverts must be built at the lowest point to pass the water across embankment of pond or highway. Inlet structure must be designed to resist long term erosion and increased hydraulic capacities of culverts. Outlet structures must be designed to protect outlets from future scouring. The following formulas are to be used in computing the culvert:

If the outlet is submerged then the culvert discharge is controlled by the tail water elevation:

$$h = h_e + h_f + h_v$$

where:

h	=	head required to pass given quantity of water through culvert flowing in outlet control with barrel flowing full throughout its length
h_e	=	entrance loss
h_f	=	friction loss
h_v	=	velocity head

and

$$h = k_e\left(\frac{V^2}{2g}\right) + \frac{n^2V^2L}{2.21R^{4/3}} + \frac{V^2}{2g}$$

$$h = \left[k_e + \frac{n^2L}{2.21R^{4/3}} \times 2g + 1\right] \times \left(\frac{V^2}{2g}\right)$$

$$h = \left[k_e + \frac{n^2L}{2.21R^{4/3}} \times 2g + 1\right] \times \left(\frac{8Q^2}{9.87gD^4}\right)$$

where:

k_e	=	entrance loss coefficient = 0.5 for a square-edged entrance entrance loss coefficient = 0.1 for a well-rounded entrance
V	=	mean or average velocity in the culvert barrel (ft/s)
g	=	32.2ft/s^2 (gravitational acceleration)
n	=	Manning's roughness coefficient = 0.012 for concrete pipe
L	=	length of culvert barrel (ft)
R	=	0.25D = hydraulic radius (ft)
Q	=	flow (cfs)
D	=	diameter (ft)

If the normal depth of the culvert is larger than the barrel height, the culvert will flow into a full or partially full pipe. The culvert discharge is controlled by the entrance conditions or entrance control.

$$Q = C_d A(2gh)^{0.5}$$

where:

Q	=	discharge (cfs)
Cd	=	discharge coefficient = 0.62 for square-edged entrance discharge coefficient = 0.1 for well-rounded entrance
A	=	cross sectional area (ft^2)
g	=	32.2ft/s^2 (gravitational acceleration)
h	=	hydrostatic head above the center of the orifice (ft)

If the hydrostatic head is less than 1.2D, the culvert will flow under no pressure as an open channel system.

If the flows are submerged at both ends of the culvert, use Figure F.1.

F.11 Hydraulic Grade Line

A hydraulic grade line (HGL) must be clearly indicated on the system profiles and identified with the initials HGL on the line and identified in the legend key. This grade line must take into consideration pipe and channel friction losses, computing structures losses, tail water conditions and entrance losses. All pipe systems must be designed so that they will operate without building up a surcharged hydrostatic head under design flow conditions. It is recommended that the HGL be no more than 1 foot above the pipe crown. If pipes have a HGL more than 1 foot above the pipe crown, rubber gaskets are required.

If the structural best management practice discharges into a storm sewer or a combined sewer system, a detailed HGL analysis of the system including the receiving system must be submitted with the final stormwater management plans for the 15- and 100-year flow frequencies. If the time characteristics of the HGL are unknown, the designed structural best management practice must be functional under expected minimum and maximum grade lines.

F.12 Manholes and Inlets

- District of Columbia Water and Sewer Authority Standards and Specifications must be used. All structures are to be numbered and listed in the structure schedule and must include type, standard detail number, size, top elevation, slot elevation and locations, and modification notes.
- Access structures must be spaced according to the District of Columbia Water and Sewer Authority Standards and Specifications and the Design and Engineering Manual of the District of Columbia Department of Transportation.
- Where two or more pipes enter a structure maintain a minimum of 9 inches of undisturbed concrete between holes in precast concrete is required to ensure sufficient steel. Consult the District of Columbia Water and Sewer Authority (DC Water) for more specifics.
- A minimum drop of 0.1 foot must be provided through the structure invert.
- Drainage boundary and contours must be shown around each inlet to ensure that positive drainage to the proposed inlet is provided.
- Invert elevations of the pipes entering and leaving the structures must be shown in the profile view.
- Yard or grate inlets must show the 15-year and 100-year ponding limits (if applicable). A depth of not more than two feet is allowed from the throat or grate to the 100-year storm elevation.
- Public street inlets must follow District of Columbia Water and Sewer Authority and District of Columbia Department of Transportation criteria.
- Additional structures are recommended and may be required on steep slopes to reduce excessive pipe depths and/or to provide deliberate drops in the main line to facilitate safe conveyance to a proper outfall discharge point. In order to provide an outfall at a suitable slope (i.e., less than 5 percent slope), drop structures may need to be used to reduce the velocity before discharging on a rip-rap area.
- Curb inlets located on private cul-de-sacs must have a maximum 10 linear feet opening.
- For commercial/industrial areas, inlets must be kept at least five feet away from the driveway aprons.

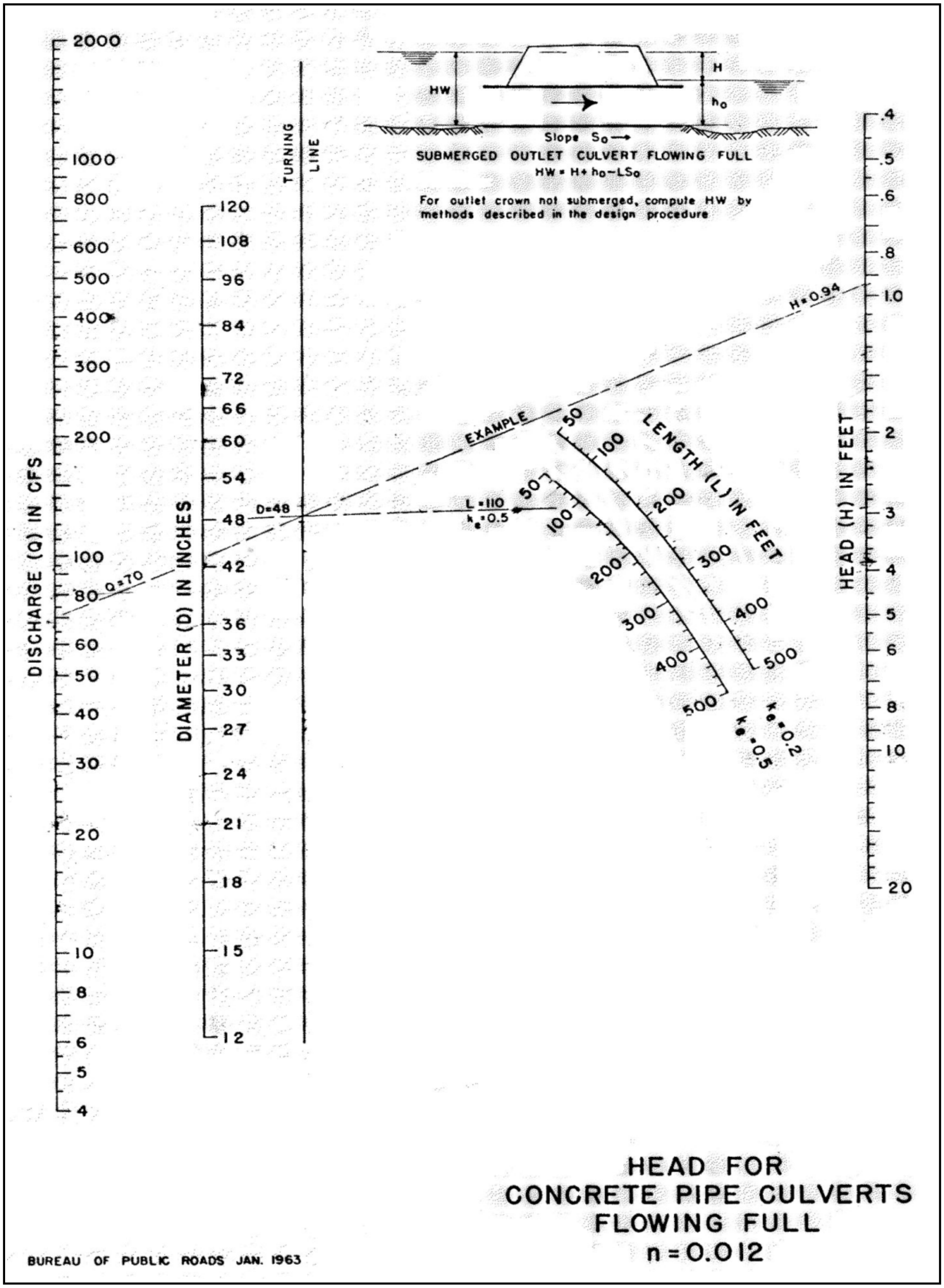

Figure F.1 Typical nomograph for culverts under outlet control.

The determination of the minimum width of a structure based on incoming pipes is based on the following formula:

$$W = \frac{D}{\sin\theta} + \frac{T}{\tan\theta}$$

where:

D	=	pipe diameter (outside)
T	=	inlet wall thickness
W	=	minimum structure width (inside)
θ	=	angle of pipe entering structure