Appendix B

Design of Storm Water Conveyance Systems

B.1 Design of Storm Water Conveyance Systems

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

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

Where: Q = channel flow (cfs)
n = Manning’s roughness coefficient (Table B.1)
A = cross-sectional area of flow (ft^2)
R = hydraulic radius (ft)
S = channel slope (ft/ft)

Table B.1 Manning’s Roughness Coefficient (n) Values for Various Channel Materials

Channel Materials	Roughness Coefficient
Concrete pipe and precast culverts	0.013
Monolithic concrete in boxes, channels	0.015
PVC pipes 24" to 36" 42" and larger	0.011 0.019 0.021
Sodded channel with water depth < 1.5'	0.050
Sodded channel with water depth <1.5'	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 shall use the continuity equation as follows:

$$Q = A * V$$

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

1) For Gutters:

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

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

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

2) For Inlets:

All inlets shall be sized to intercept a minimum of 70% of incoming flow.

3) Street Capacity (Spread):

Water shall not cross the centerline of the street or exceed the width or depth permitted by the District of Columbia Department of Public Works, Bureau of Transportation Construction Services, Design and Engineering Division.

4) Manhole and Inlet Energy Losses:

The following formulas shall be used to calculate headloss:

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

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

Where: HL = headloss in the structure

V_r = resultant velocity
g = 32.2ft/sec^2 (gravitational acceleration)
SL = minimum structure loss
a = (180^0 - angle between the inlet & outlet pipes)

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

Table B.2 Minimum Structure Loss to Use in HGL Calculation

Velocity (ft/sec)*	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.

5) Open Channels:

- Calculations shall 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 shall provide 6" 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 shall 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 shall be shown.

- For proposed channels, a final grading plan shall be provided.

- The limits of a recorded 100-year floodplain easement or surface water easement sufficient to convey the 100 year flow shall be shown.

- The minimum 25' horizontal clearance between a residential structure and 100 year floodplain shall 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.

6) Pipe Systems:

- Individual storm water traps shall be installed on the storm drain branch serving each storm water management facility, or a single trap shall be installed in the main storm drain after it leaves the storm water management facility and before it connects with the city's combined sewer. Such traps shall be provided with an accessible cleanout. The traps shall not be required for storm drains which are connected to a separate storm sewer system.

- All pipes are to be made of reinforced concrete pipe (RCP) unless otherwise specified and approved by the District reviewing authority(s).

- The minimum pipe size to be used for any part of the public storm drainage system shall be 15" in diameter. The minimum pipe size to be used for any part of a private storm drainage system shall 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 shall follow District of Columbia DPW Standard & Specifications, Section 02730.

- The minimum pipe size and material to be used for any part of private storm drain shall follow the current District of Columbia Plumbing Code.

- 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 shall 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 are to be separated.

- Profiles of the proposed storm drains shall 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 shall 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.

7) Culverts:

- Culverts shall be built at the lowest point to pass the water across embankment of pond or highway. Inlet structure shall be designed to resist long term erosion and increased hydraulic capacities of culverts. Outlet structures shall 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

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

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

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

Where: k_e = entrance loss coefficient = 0.5 for a square edged entrance
k_e = entrance loss coefficient = 0.1 for a well rounded entrance
V = mean or average velocity in the culvert barrel (ft/sec)
g = 32.2ft/sec^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.

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

Where: Q = discharge (cfs)
C_d = discharge coefficient = 0.62 for square-edged entrance
C_d = discharge coefficient = 0.1 for well-rounded entrance
A = cross sectional area (ft^2)
g = 32.2ft/sec^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 B.1.

8) Hydraulic Gradient:

- A hydraulic gradient shall be drawn in color on the system profiles. This gradient shall take into consideration pipe and channel friction losses, computing structures losses, tail water conditions and entrance losses. All pipe systems shall be designed so that they will operate without building up a surcharged hydrostatic head under design flow conditions. The HGL should 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 shall be required.

- If the storm water management facility discharges into a storm sewer or a combined sewer system, a detailed hydraulic gradient analysis of the system including the receiving system must be submitted with the final storm water management plans for the 15 and 100-year flow frequencies. If the time characteristics of the hydraulic gradient are unknown, the designed storm water management facility shall be functional under expected minimum and maximum gradients.

9) Manholes and Inlets:

- District of Columbia DPW structures shall be used. All structures are to be numbered and listed in the structure schedule and shall include type, standard detail number, size, top elevation, slot elevation and locations, and modification notes.

- Access structures shall be spaced as follows:

15"-24" drain	400' max.
27"-42" drain	600' max.
Large than 42"	controlled by site conditions.

- A minimum drop of 0.1 foot shall be provided through the structure invert.

- Drainage boundary and contours are to 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 are to be shown in the profile view.

- Yard or grate inlets shall 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 shall follow District of Columbia DPW criteria.

- Additional structures 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% 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 shall have a maximum 10 linear feet opening.

- Where two or more pipes enter a structure, a minimum of two feet horizontal clearance must be maintained between the pipes connected to the structure at the same elevation.

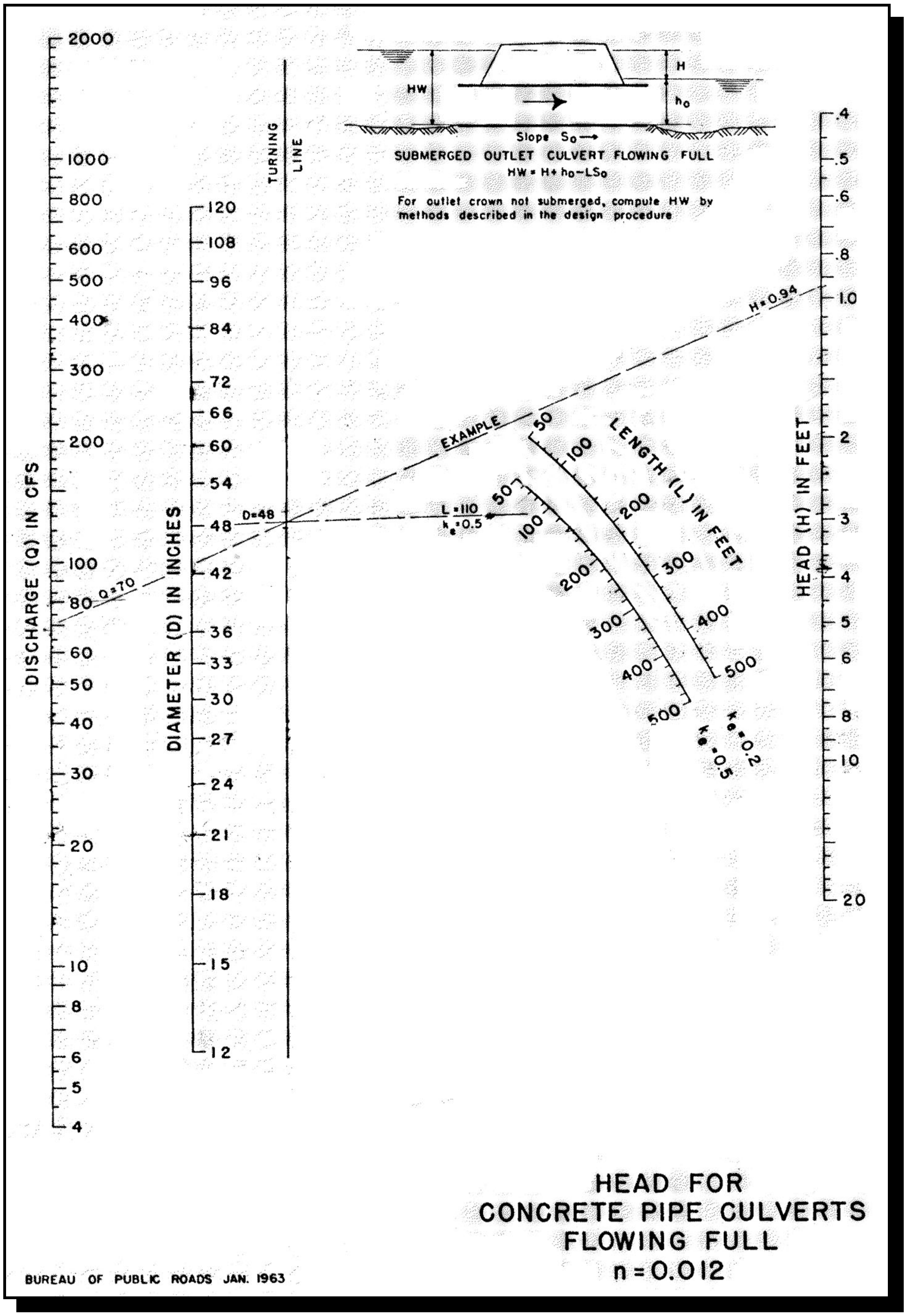

Figure B.1 Typical Nomograph for Culverts Under Outlet Control

- For commercial/industrial areas, inlets should be kept at least five feet away from the driveway aprons.

- 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

10) Clearance With Other Utilities:

- All proposed and existing utilities crossing or parallel to designed storm sewer systems shall be shown on the plan and profile.

- Storm drain and utility crossings shall not have be less than a 45-degree angle between them.

- A minimum vertical clearance of one foot and a minimum horizontal clearance of five feet, wall to wall, shall be provided between storm drainage lines and other utilities. Exceptions may be granted on a case-by-case basis when justified.