CHAPTER 4 ENCLOSED SYSTEMS

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

4.1 General Guidance

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

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

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

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

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

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

4.2 Existing Drainage Systems

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

- They are in sound structural condition.

- Their hydraulic capacity, including surcharge, is equal to or greater than the capacity required by these criteria.

- Easements exist or are dedicated to allow operation and maintenance.

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

4.3 Inlet Design

4.3.1 Type

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

4.3.2 Configuration

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

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

4.3.3 Design Method

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

4.3.4 Location/Spread of flow in streets

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

4.3.5 Spread in streets

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

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

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

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

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

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

4.3.6 Freeboard Requirements

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

4.4 Gutter Flow

4.4.1 Gutter Capacity

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

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

Q = The gutter capacity in cubic feet per second

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

S_O= The longitudinal street grade in feet per foot

D = The depth of flow at curb face in feet

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

A. **Street Grade on Vertical Curves, S_O**

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

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

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

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

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

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

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

4.5 Protection for Streets

4.5.1 Street Crossings

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

TABLE 4.5.1.1
DESIGN STORM CAPACITY FOR STREETS

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

4.5.2 Roadway Overtopping

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

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

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

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

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

where:

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

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

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

4.6 Enclosed Pipe Systems

4.6.1 General Requirements and Guidance

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

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

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

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

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

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

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

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

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

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

4.6.2 Capacity

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

4.6.3 Pressure Flow

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

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

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

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

4.6.4 Outfalls and Energy Dissipation

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4.6.5 Minimum Pipe Slope

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

4.6.6 Velocity Within the System

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

4.6.7 Loading Conditions for Structures

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

4.7 Overflow Provisions

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

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

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

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

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

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

4.8 Easements

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

4.8.1 Permanent

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

4.8.2 Temporary

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

This page intentionally blank.