Chapter 6 Storm Sewer, Drain Pipe, Underdrain Pipe

6-1 Introduction

This chapter discusses the design criteria for storm sewers, drain pipe, and underdrain pipes. This chapter also briefly describes the potential design impacts on these types of pipes because of Complete Streets, and includes a discussion of drywells (Section 6-5).

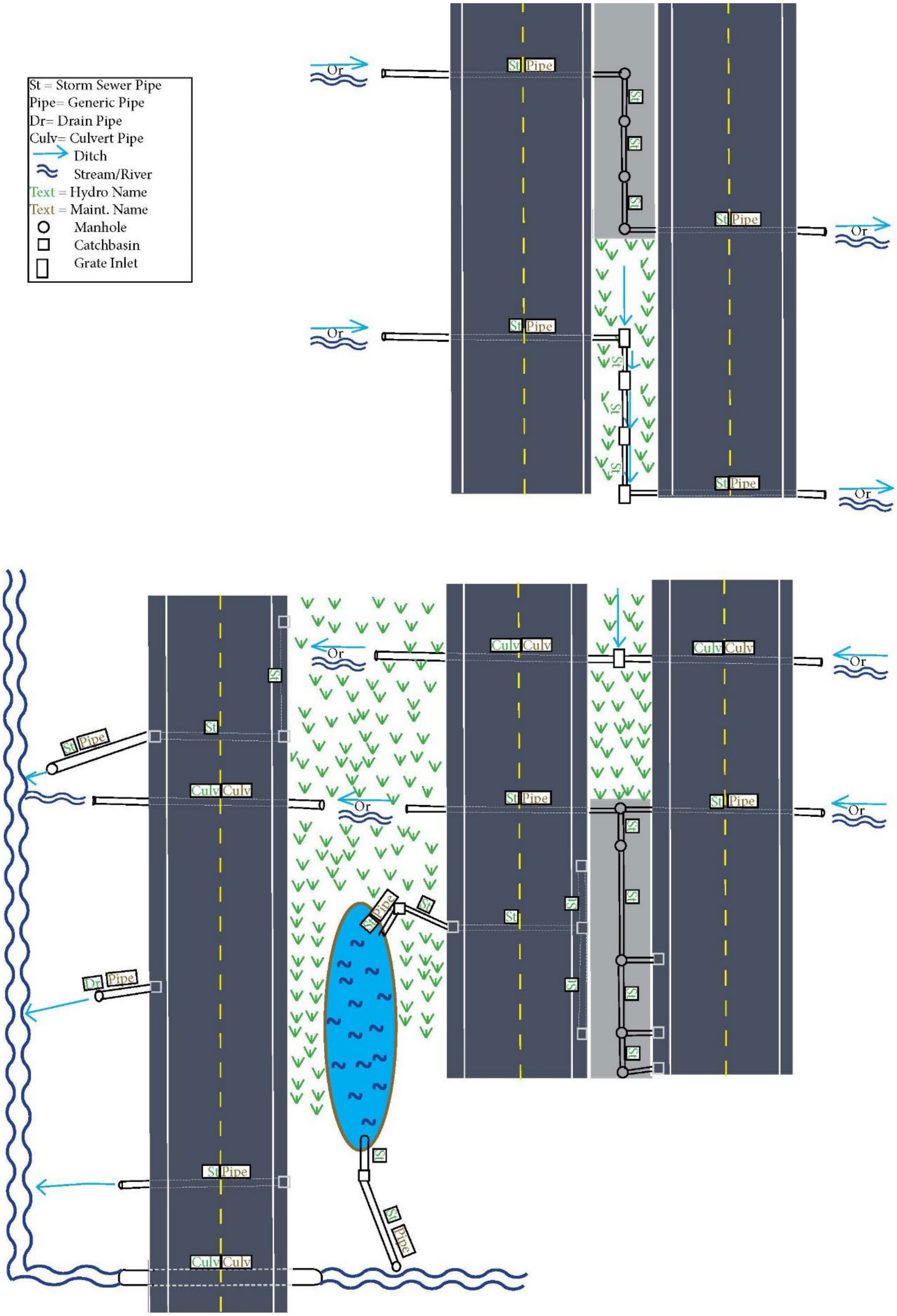
Implementing new Complete Streets and other active transportation design roadway features may require additional design considerations for storm sewers, drain pipes, and under drain pipes. A given project may need to move storm sewers to accommodate share use paths and bike lanes. Another scenario might require an existing run of storm sewer to be moved to the outside edge of pavement which would include the new shared use path or bike lane. The same types of adjustments may be needed for drain pipes and under drain pipe.

6-2 Storm Sewer

A storm sewer is a pipe network that conveys surface drainage from a surface inlet or through a manhole to an outlet location. This chapter discusses the criteria for designing storm sewers (Section 6-2.1); the data and process required to document the design (Section 6-2.2); and methods, tools, and concepts to help develop designs (Section 6-2.3 through Section 6-2.5).

Storm sewers are generally defined as closed-pipe networks connecting two or more inlets; see Figure 6-1. Typical storm sewer networks consist of laterals that discharge into a trunk line. The trunk line then receives the discharge and conveys it to an outlet location. For clarification on the difference between storm sewer and culvert configurations see Figure 6-1. See Section 8-2.4 for pipe testing requirements.

Figure 6-1 Storm Sewer Configurations



All storm sewer design shall be based on the design criteria outlined in Section 6-2, which includes limits for runoff rates, pipe flow capacity, hydraulic grade line (HGL), soil characteristics, pipe strength, potential construction problems, and potential runoff treatment issues. Runoff is calculated using the Rational Method or the SBUH Method; see Chapter 1 and Chapter 2 for further discussion. Based on the runoff rate, the pipe velocity is calculated using Manning's equation, which relates the pipe capacity to the pipe diameter, slope, and roughness. The preference is to have the HGL below the pipe crown. After sizing the pipe, verify that the HGL is below all rim elevations. A storm sewer design may be performed by hand calculations, as described in Section 6-2.3, or by computer program, as described in Section 6-5.

All storm sewer design shall consider climate resilience when determining required pipe sizes for flow conveyance; these factors include the following:

- Storm surges
- 24-hour peak precipitation (100-year event)
- Tidally influenced zones
- Sea level rise
- FEMA SFHAs
- Section 7-4.5.5 of WSDOT *Hydraulics Manual*
- Wildfires
- Landslides
- Sediment transportation
- Chronic events
- Population migration
- Future land use changes
- Heat waves

Additional guidance on pipe sizing with respect to climate resilience will be provided in future revisions to the *Hydraulics Manual*.

6-2.1 *Storm Sewer Design Criteria*

Along with determining the required pipe sizes for flow conveyance and the HGL, storm sewer system design shall consider the following guidelines:

- **Soil conditions:** Soil with adequate bearing capacity must be present to interact with the pipes and support the load imparted by them. Surface and subsurface drainage must be provided to ensure stable soil conditions. Soil resistivity and pH must also be known so that the proper pipe material will be used. Section 8-5 contains further guidance.

- **Structure spacing and capacity:** Design guidelines for inlet spacing and capacity are detailed in Chapter 5. Structures (catch basins, grate inlets, and manholes) shall be placed at all breaks in grade and horizontal alignment. The desired pipe run length between structures is 150 feet and shall not exceed 300 feet for pipes less than 48 inches in diameter and 500 feet for pipes greater than 48 inches in diameter. When grades are flat, pipes are small, or there could be debris issues, the PEO should reduce the spacing. The RHE and local WSDOT Maintenance Office shall be consulted for final determination on maximum spacing requirements. For minimum clearance between culverts and utilities, PEOs shall consult the RHE for guidance.
- **Existing systems:** Criteria for repair and/or replacement of existing systems be provided in future revisions to the *Hydraulics Manual*. Until then, contact the RHE for guidance when working with existing systems, and refer to Chapter 8 for guidance on trenchless pipe repair methods.
- **Future expansion:** If a storm sewer system may be expanded in the future, provision for the expansion shall be incorporated into the current design. Additionally, prior to expanding an existing system, the existing system shall be inspected for structural integrity and hydraulic capacity using the Rational Method.
- **Velocity:** The design velocity for storm sewers shall be between 3 and 10 ft/s. This velocity is calculated using Manning's equation, under full flow conditions even if the pipe is flowing only partially full with the design storm. The minimum slope required to achieve these velocities is summarized in Table 6-1.

  When flows drop below 3 ft/s, pipes can clog because of siltation. Flows can be designed to as low as 2.5 ft/s with justification in the hydraulic report. As the flow approaches (and exceeds) 10 ft/s, PEOs shall consult the RHE for abrasion design guidance.

Table 6-1 Minimum Storm Sewer Slopes

Pipe Diameter (in)	Minimum Slope (ft/ft)	
N = 0.013	**2.5 ft/s**	**3.0 ft/s**
12	0.003	0.0044
15	0.0023	0.0032
18	0.0018	0.0025
24	0.0012	0.0017

- **Pipe elevations at structures**: Pipe crowns differing in diameter, branch, or trunk lines shall be at the same elevation when entering structures. For pipes of the same diameter where a lateral is placed so the flow is directed against the main flow through the manhole or catch basin, the lateral invert must be raised to match the crown of the inlet pipe. Matching the crown elevation of the pipes will prevent backflow in the smaller pipe. (A crown is defined as the highest point of the internal surface of the transverse cross section of a pipe.) It is also generally acceptable to have the crown elevation of the upstream pipe in the structure be higher than the crown elevation of the downstream pipe in the same structure. Invert elevations of pipe draining a structure shall not be higher than any pipe discharging flow into the same structure unless a stilling structure is an intentional part of the storm sewer design.

- **Minimum pipe diameter:** The minimum pipe inside diameter for all storm sewer systems shall be 12 inches. If partially replacing or modifying an existing storm sewer system, the new or added storm sewer shall have at least the same diameter as the existing storm sewer even if the hydraulic analysis shows a smaller-diameter storm sewer would meet hydraulic design requirements in that location. If an existing culvert is replaced and converted to a configuration that would classify it as a storm sewer, coordinate with the RHE on the pipe sizing.
- **Structure constraints:** During the storm sewer layout design, PEOs shall also consider the physical constraints of the structure. Specifically:
    - **Diameter:** Verify the maximum allowable pipe diameter into a drainage structure prior to design. *Standard Plans* for drainage structures have pipe allowances clearly stated in tables for various pipe materials.
    - **Angle:** Verify that the layout is constructible with respect to the angle between pipes entering or exiting a structure before finalizing the storm sewer layout. That is, to maintain structural integrity minimum clearance requirements must be met depending on the pipe diameter. PEOs can verify the minimum pipe angle with the Pipe Angle Calculation Worksheet.
- **Pipe material**: Storm sewers shall be designed to include all Schedule A pipe options, unless specific site constraints limit options (see Section 6-6 for further discussion).
- **Increase in profile grade:** In cases where the roadway or ground profile grades increase downstream along a storm sewer, a smaller-diameter pipe may be sufficient to carry the flow at the steeper grade. However, because of maintenance concerns, WSDOT design practices do not allow pipe diameters to decrease in downstream runs. Consideration could be given to running the entire length of pipe at a grade steep enough to allow use of the smaller-diameter pipe. Although this will necessitate deeper trenches, the trenches will be narrower for the smaller pipe and therefore the excavation may not substantially increase. A cost analysis is required to determine whether the savings in pipe costs will offset the cost of any extra structure excavation.
- **Discharge location:** A discharge location is where stormwater from WSDOT highways is conveyed off of the ROW by pipe, ditch, or other constructed conveyance. Additional considerations for discharge locations include energy dissipators and tidal gates. Energy dissipators prevent erosion at the discharge location. Based on the outlet velocity at the discharge location, the PEO shall install energy dissipation per Section 3-4.7. Installation of tide gates may be necessary when the discharge location is in a tidal area; consult the RHE for further guidance.
- **Location:** Wide medians usually offer the most desirable storm sewer location. In the absence of a wide median, a location beyond the pavement edge on state ROW or easement is preferable. When a storm sewer is placed beyond the pavement edge, a

one-trunk system with connecting laterals shall be used instead of running two separate trunk lines down each side of the road.

- **Confined space and structure depths:** PEOs shall consult the local WSDOT Maintenance Office and RHE to ensure that structures can be adequately maintained.

Additional guidance will be provided in future revisions to the *Hydraulics Manual*.

6-2.2 *Storm Sewer Data for Hydraulic Reports*

Storm sewer system design requires that data be collected and documented in an organized fashion. Hydraulic reports shall include all related calculations, whether performed by hand or computer. See Chapter 1 for guidelines on what information shall be submitted and recommendations on how it shall be organized.

6-2.3 *Storm Sewer Design: Manual Calculations*

Manual calculations and spreadsheet calculations for storm sewer design are suitable only for pipe runs that do not include tailwater conditions or system losses that affect the capacity of the pipe. Project design teams shall consult the RHE prior to beginning design to determine if manual and spreadsheet calculations are acceptable for the project storm sewer design.

Storm sewer design is accomplished in two parts: (1) determine the pipe capacity and (2) evaluate the HGL. See the Storm Sewer Pipe Sizing Spreadsheet to determine the pipe capacity of the storm sewer system.

The Storm Sewer Pipe Sizing Spreadsheet does not currently calculate the HGL at each structure. The hydraulic designer must calculate them using hand calculations, per Section 6-2.5 and HEC-22, or use computer software per Section 6-2.4. The hydraulic designer shall consult with the RHE prior to design to determine if manual and spreadsheet HGL calculations are acceptable for the project storm sewer design.

6-2.4 *Storm Sewer Design: Computer Analysis*

Several computer programs are commercially available for storm sewer design. Refer to Chapter 1 for WSDOT-approved software.

6-2.5 *Storm Sewer Hydraulic Grade Line Analysis*

The HGL shall be designed so there is air space between the top of water and the inside of the pipe. In this condition, the flow is operating as gravity flow, and the HGL is the WSEL traveling through the storm sewer system. If the HGL becomes higher than the crown elevation of the pipe, the system will start to operate under pressure flow. If the system is operating under pressure flow, the WSEL in the catch basin/manhole needs to be calculated to verify that the WSEL is below the rim (top) elevation. When the WSEL exceeds the rim elevation, water will discharge through the inlet and cause severe traffic safety problems. Fortunately, if the storm sewer pipes were designed as discussed in the previous sections, then the HGL will only become higher than the catch basin/manhole rim elevation when energy losses become significant or if the cover over a storm sewer is low (less than 5 feet). During the non-storm events (not raining), the HGL must be zero or at the same elevation as the pipe invert; no standing water inside the pipe would be allowed during non-storm events.

Regardless of the design conditions, the HGL shall be evaluated when energy loss becomes significant. Possible significant energy loss situations include high flow velocities through the system (greater than 6.6 ft/s), pipes installed under low cover at flat gradients, inlet and outlet pipes forming a sharp angle at structures, and multiple flows entering a structure.

The HGL can be calculated only after the storm sewer system has been designed. When computer models are used to determine the storm sewer capacity, the model will generally evaluate the HGL. The remainder of this section provides the details for how the analysis is performed.

The HGL is calculated beginning at the most downstream point of the storm sewer outlet and ending at the most upstream point. To start the analysis, the WSEL at the storm sewer outlet must be known. Refer to Chapter 3 for an explanation on calculating WSELs at the downstream end of a pipe (the tailwater is calculated the same for the storm sewer outlet and culverts). Once the tailwater/pond elevation is known, the energy loss (usually called head loss) from friction is calculated for the most downstream run of pipe and the applicable minor losses are calculated for the first structure upstream of the storm sewer outlet. Head losses are added to the WSEL at the storm sewer outlet to obtain the WSEL at the first upstream structure (also the HGL at that structure, assuming that velocities are zero in the structure). The head losses are then calculated for the next upstream run of pipe and structure and are added to the WSEL of the first structure to obtain the WSEL of the second upstream structure.

This process is repeated until the HGL has been computed for each structure. The flow in most storm sewers is subcritical; however, if any pipe is flowing supercritical, the HGL calculations are restarted at the structure on the upstream end of the pipe flowing supercritical. (Chapter 4 contains an explanation of subcritical and supercritical flow.)

The HGL calculation process is represented in Equation 6-1:

$$\begin{aligned}
\mathrm{WSEL_{J1}} &= \mathrm{WSEL_{OUTFALL}} + \mathrm{H_{f1}} + \mathrm{H_{e1}} + \mathrm{H_{ex1}} + \mathrm{H_{b1}} + \mathrm{H_{m1}} \\
\mathrm{WSEL_{J2}} &= \mathrm{WSEL_{J1}} + \mathrm{H_{f2}} + \mathrm{H_{e2}} + \mathrm{H_{ex2}} + \mathrm{H_{b2}} + \mathrm{H_{m2}} \\
\mathrm{WSEL_{Jn+1}} &= \mathrm{WSEL_{Jn}} + \mathrm{H_{fn+1}} + \mathrm{H_{en+1}} + \mathrm{H_{exn+1}} + \mathrm{H_{bn+1}} + \mathrm{H_{mn+1}}
\end{aligned} \tag{6-1}$$

Where:

WSEL = Water surface elevation at structure noted

$\mathrm{H_f}$ = Friction loss in pipe noted

$\mathrm{H_e}$ = Entrance head loss at structure noted

$\mathrm{H_{ex}}$ = Exit head loss at structure noted

$\mathrm{H_b}$ = Bend head loss at structure noted

$\mathrm{H_m}$ = Multiple flow head loss at structure noted

If the HGL is lower than the rim elevation of the manhole or catch basin, the design is acceptable. If the HGL is higher than the rim elevation, flow will exit the storm sewer and the design is unacceptable. The most common way to lower the HGL below the rim elevation is to lower the pipe inverts for one or more storm sewer runs or increase the pipe diameter. The HGL shall be designed so that regular maintenance inspections may be achieved without pumping.

Head loss because of friction is a result of the kinetic energy lost as the flow passes through the pipe. The rougher the pipe surface is, the greater the head loss is going to be. Refer to HEC-22 to calculate head loss from friction. Note that for all storm sewer pipes 24 inches or less in diameter, Manning's n shall be 0.013.

6-3 Drain Pipe

In a highway setting, a drain pipe is defined as the single pipe that is connected to a single inlet but the pipe does not cross under the majority of the width of the highway or ramp. The pipe typically is in the roadway shoulder or edge of the traveled way if there is no roadway shoulder. If one pipe is connected to an inlet that is connected to another downstream pipe, then the pipes in this system would not be drain pipes. This configuration is either a storm sewer or culvert pipe. See Figure 6-1 for an illustration of a drain pipe. For other slope or groundwater applications for drain pipe, see Section 8-2.1. The design of a drain pipe follows the same methods for storm sewer design. The inlet associated with the drain pipe would also follow the inlet spacing design in Chapter 5. Drain pipes shall have outlet protection if they are discharging to a slope.

6-4 Underdrain Pipe

In a highway setting, an underdrain pipe can be used to drain groundwater or subsurface flow and turn it into surface runoff. Groundwater, as distinguished from capillary water, is free water occurring in a zone of saturation below the ground surface. If an underdrain pipe was installed in an area to drain groundwater, the discharge flow rate from the underdrain pipe depends on many variables that span both hydraulic and geotechnical disciplines. These variables may include the effective hydraulic head over the underdrain pipe, the permeability of the soil layer where the underdrain pipe is installed and any soil layer(s) above the underdrain pipe, the slope of the underdrain pipe, the gradient of the groundwater, and the area and volume of the groundwater layer being drained by the underdrain pipe. Sometimes the underdrain flow rate could be significant, especially when the roadway is located next to a big hillside that has visible seeps or springs. Any underdrain pipe flow rate must be thoroughly investigated and included in the project's drainage design. The PEO shall work directly with the RHE and RME to determine the necessary steps and actions needed to determine the discharge rate from an underdrain pipe installation. This may require significant engineering analysis and time.

The design of an underdrain pipe follows the same methods for storm sewer design. The only difference is that the flow rate used for the calculations is the predicted flow rate from groundwater into the underdrain pipe instead of flow entering the system from roadway drainage. When an underdrain pipe is connected to a storm sewer system, the invert of the underdrain pipe shall be placed at or above the top of pipe inside elevation in the storm sewer system. This is to prevent flooding of the underdrain pipe.

There are two distinct methods for estimating the amount of flow in an underdrain pipe. One method to get a site-specific predicted underdrain flow rate requires the PEO to work with the RHE and RME (and maybe HQ Geotechnical Office). This method may require extensive geotechnical investigations, computer modeling, and a stamped geotechnical report. The second method for estimating the amount of flow in an underdrain pipe is to assume full flow from the underdrain pipe based on the underdrain pipe diameter.

Underdrain pipes that convert groundwater or subsurface flows into surface flows need to be included in the project's drainage design. Increased surface flows from underdrain pipes to the stormwater drainage system need to be designed for and included in the conveyance calculations and possibly the stormwater BMP designs. The increased surface flow from the underdrain pipe shall be discussed in the project's downstream analysis. In some cases, the increased surface flows may need flow control stormwater mitigation. The PEO shall consult with the RHE when installing, removing, or modifying underdrain pipes within the project. Underdrain pipes shall have outlet protection if they are discharging to a slope. Underdrain pipes shall not drain water from natural wetlands, constructed stormwater treatment wetlands, or other treatment BMPs unless specified in the BMP design guidelines in the *Highway Runoff Manual*.

Additional guidance will be provided in future revisions to the *Hydraulics Manual*.

6-5 Drywells

Prior to specifying a drywell in a design, PEOs shall consult the *Highway Runoff Manual* for additional guidance and design criteria. Drywells are considered underground injection control wells and are required to be registered with Ecology per Washington Administrative Code (WAC) 173-218. Refer to the *Highway Runoff Manual*. Additionally, stormwater must be treated prior to discharging into a drywell using a BMP described in the *Highway Runoff Manual*. Finally, all drywells shall be sized following the design criteria outlined in the *Highway Runoff Manual*.

6-6 Pipe Materials for Storm Sewers, Drain Pipe, and Underdrain Pipe

The PEO shall review Chapter 8 (for pipe materials) and the list of acceptable pipe material (schedule pipe) in the *Standard Specifications*.

Storm sewer pipe is subject to some use restrictions, which are detailed in Section 8-2.4.

Pipe flow capacity depends on the roughness coefficient, which is a function of pipe material and manufacturing method. Fortunately, most storm sewer pipes are 24-inch diameter or less and studies have shown that most common schedule pipe materials of this size range have a similar roughness coefficient. For calculations, the PEO shall use a roughness coefficient of 0.013 when all 24-inch-diameter schedule pipes and smaller are acceptable. For calculations during the preliminary design and when the pipe materials have not been determined, the PEO shall use a roughness coefficient of 0.013 for schedule pipes

24 inches in diameter or smaller. For larger-diameter pipes, the PEO shall calculate the required pipe size using the largest Manning's roughness coefficient for all the acceptable schedule pipe values in Table 4-1. In the event that a single pipe alternative has been selected, the PEO shall design the required pipe size using the applicable Manning's roughness coefficient for that material listed in Table 4-1.

In estimating the quantity of structural excavation for design purposes at any location where alternative pipes are involved, estimate the quantity of structural excavation based on concrete pipe because it has the largest outside diameter.