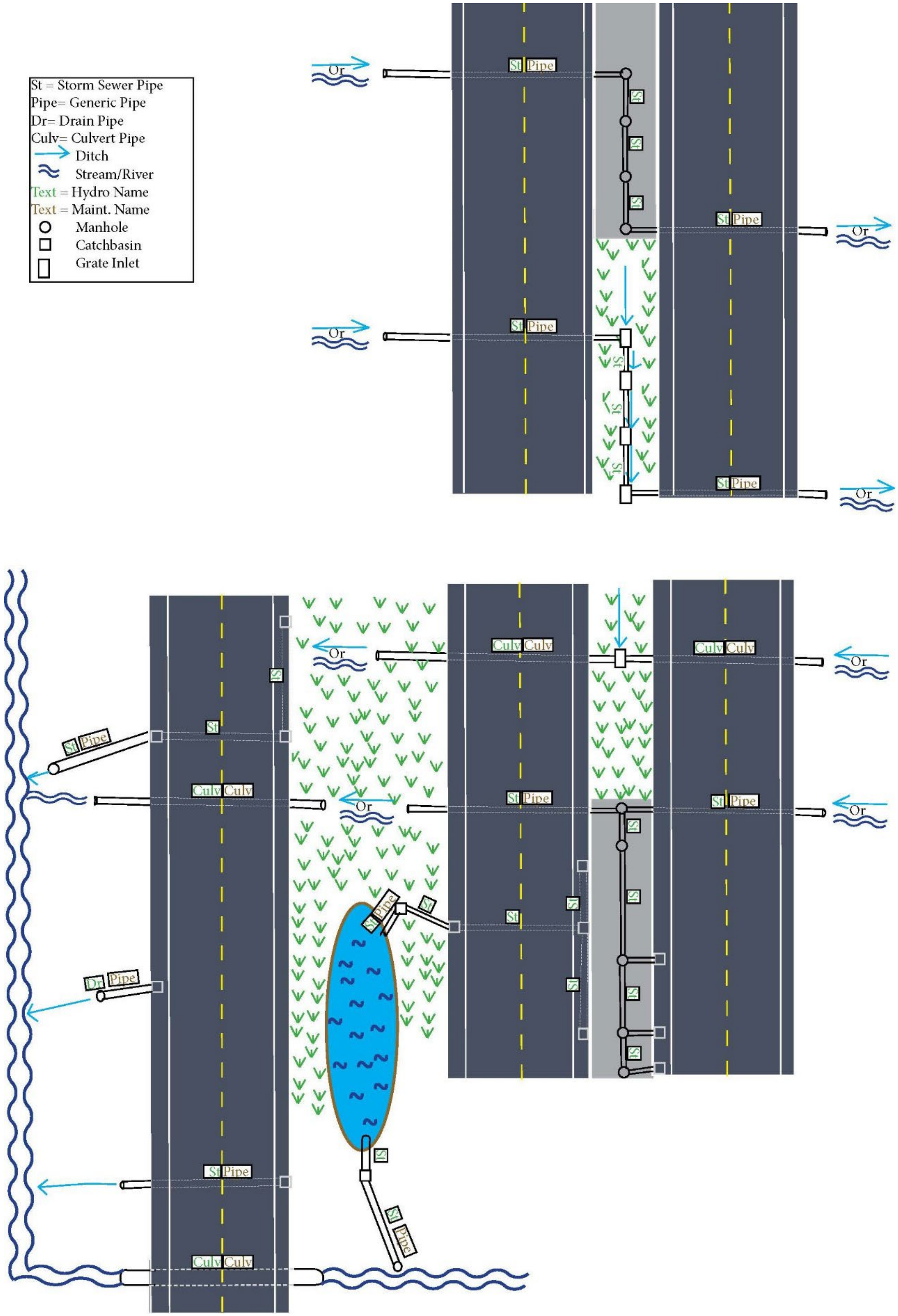
Chapter 6 Storm Sewer

6-1 Introduction

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); the data and process required to document the design (Section 6-3); methods, tools, and concepts to help develop designs (Section 6-4 through Section 6-6); and pipe materials used for storm sewers (Section 6-8). It also includes a discussion of drywells (Section 6-7) and subsurface drainage (Section 6-9).

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 6-4, 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 special flood hazard areas (SFHAs)
- Section 7-4.4.5 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 Design Criteria

Along with determining the required pipe sizes for flow conveyance and the HGL, storm sewer system design should 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) should 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 should 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 should 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 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 should 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 6-8 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*.

6-3 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 should be submitted and recommendations on how it should be organized.

6-4 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 designer must calculate them using hand calculations, per Section 6-6 and HEC-22, or use computer software per Section 6-5. The 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.

6-5 Storm Sewer Design: Computer Analysis

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

6-6 Hydraulic Grade Line

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 should 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

H_f = Friction loss in pipe noted

H_e = Entrance head loss at structure noted

H_{ex} = Exit head loss at structure noted

H_b = Bend head loss at structure noted

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 due to 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.

6-7 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 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*.

6-8 Pipe Materials for Storm Sewers

When designing a storm sewer network, 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.

6-9 Subsurface Drainage

Subsurface drainage is provided for control of groundwater encountered at highway locations. Groundwater, as distinguished from capillary water, is free water occurring in a zone of saturation below the ground surface. The subsurface discharge depends on the effective hydraulic head and on the permeability, depth, slope, thickness, and extent of the aquifer. Sometimes subsurface flow could be significant, especially when the roadway is located next to a big hillside. Subsurface flow must be thoroughly investigated and taken into account during the design.

The solution of subsurface drainage problems often calls for specialized knowledge of geology and the application of soil mechanics. The PEO should work directly with the RHE as subsurface conditions are determined and recommendations are made for design in the soils report.

Subsurface drainage can be intercepted with underdrain pipe or gravel trench with underdrain pipe included, which is sized by similar methods used to design storm sewer pipe. When an underdrain is installed for seepage control in cuts or side hills or lowering the groundwater table for proper subgrade drainage, the design method used to size storm sewers should be followed. The only difference is that the flow used for the calculations is the predicted infiltration from groundwater into the system instead of flow entering the system from roadway drainage. When subsurface drainage is connected to a storm sewer system, the invert of the underdrain pipe shall be placed above the operating water level in the storm sewer. This is to prevent flooding of the underdrain system, which would defeat its purpose. Additional guidance will be provided in future revisions to the *Hydraulics Manual*.