

7. DRAINAGE DESIGN

Practices and Procedures

7-1 GENERAL

While the basic principles of hydrology and hydraulics are universal, a number of distinct subdisciplines are in effect at the MaineDOT including design of drainage ditches, drainage culverts and urban drainage, both roadway and closed systems.

7-1.01 Responsibilities

Highway Designer

Responsible for hydrology and hydraulics for their projects with assistance from the Hydrology & Hydraulics (H&H) engineer. The level of assistance will depend on their experience and the complexity of the project.

Hydrology and Hydraulics Engineer

Assists and oversees the highway designer's hydrologic and hydraulic design. This will include assisting with the delineation of the larger drainage basins, layout design and the design of non-typical drainage features.

Hydrologist (Environmental Office)

Designs the structures related to streams and assists the highway designer and H&H engineer with layout of these structures.

Stormwater Engineer (Environmental Office)

Designs required post-construction stormwater treatment systems and assists the highway designer with the layout and details of these systems. Cooperates with the H&H Engineer to integrate the stormwater treatment system into the main drainage system.

7-1.02 Drainage Summary Documentation

The highway designer shall complete the Drainage Summary with assistance from the H&H engineer.

Drainage Summary Form

A drainage summary will include

1. A brief description of the project, it's site characteristics and the drainage characteristics, as well as areas that have unusual hydrologic or hydraulic characteristics.
2. A brief description of how the data was obtained.
3. Maps of the drainage areas and closed system runs.
4. Summary Report - A short summary concisely summarizing the important hydraulic characteristics of each site.

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5. Completed Excel Hydrology and Closed System workbooks containing the pertinent hydrologic and hydraulic information or other information used to obtain flows for the project

7-2 HYDROLOGY

Hydrology - The science concerned with the occurrence, distribution, and circulation of water on the earth (Hydraulic Design Series (HDS) 5). For highway design, the hydrologic analysis is concerned with the delineation of the entire drainage area and the natural and manmade pathways the water follows to the collection point of interest.

7-2.01 Design Return Period

Design flow – Discharge, for a specified Return Period that is selected as the basis for the design or evaluation of a hydraulic structure. (modified from HDS 5 p. xxvi)

Return Period – The average length of time between occurrences in which the value of a random variable (e.g. flood magnitude) is equaled or exceeded. Actual times between occurrences may be longer or shorter, but the return period represents the average interval. The return period is the inverse of the frequency. For example, if the frequency is 0.01 (the one percent) the return period is 100 years. (Hydraulic Engineering Circular (HEC) 17)

The recommended design shall be based on the following return periods:

- For cross culvert diameters < 60 inches, the return period is the 50-year storm.
- For cross culverts > 60 inches, the return period is the 100-year storm. See Design Guidance – Instream culvert sizing and work with the Environmental Office for design.
- For driveway culverts, the return period is the 10-year storm, unless the driveway culvert is part of the main drainage system, then design for the 50-year return period storm.
- For closed systems, the return period is the 10-year storm.

Exceptions to Recommended Design Return Period

Some roads may warrant design to a higher return period, e.g. 100 years. These roads include major arterials that offer few or no detour options and roads that serve significant health, safety and other public facilities. The expectations should be identified on a case-by-case basis in consultation with Region personnel and local officials.

Occasionally, some roads may warrant design to a lower return period, primarily in cases where the design to the recommended return period is too expensive. Such exceptions should be clearly identified and fully documented.

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7.2-02 Calculating Storm Runoff for Use as Design Flow

The calculated peak storm runoff is the estimated maximum flow leaving the drainage area. This maximum flow occurs at a time, T_c , after the initiation of a storm with a rainfall intensity, I . The rainfall intensity is derived from the drainage areas, T_c and the selected Return Period for the point of interest. Essentially, this is the total volume of rainfall falling on a drainage area minus the volumes that are evaporated, infiltrated, and stored. The Rational Method uses the runoff coefficient, C , to capture these losses, C = percent of total flow minus losses. The remaining volume of water is then delivered to the outlet over time yielding a flow distribution curve. Both the Rational Method and the Regression Equations attempt to estimate the peak flow, the maximum on the distribution curve. For design purposes, peak flow is considered the design flow.

Rational Method – Rational Method is used for hydrologic design on small drainage areas and paved surfaces. The best results are obtained when the drainage area is less than 200 acres.

$$Q = CIA$$

- Q = Design flow (ft^3/s) – Flow for a specific return period.
- C = Runoff Coefficient – The percentage of water that flows off a drainage area which is dependent on Land Use, soil type
- I = Rainfall Intensity (in/hr) – A specific intensity storm for a design flow return period and time of concentration (T_c) for the site.
 - o T_c = Time of Concentration (min) – The time required for a uniform rainfall of intensity, I , to produce the peak flow at the point of interest.
- A = Drainage area (acres) – Area that drains towards the point of interest.

See Design Guidance – Hydrology for more information on choosing C and calculating T_c .

USGS Regression Equations – were published by the USGS in cooperation with the MaineDOT hydrology section. These provide the most accurate estimate of flows for undeveloped drainage basins between 0.3 square miles (192 acres) and 12 square miles. These equations are incorporated in the Hydrology Workbook.

$$Q_T = b(A)^a 10^{-w(W)} 10^{c(I)}$$

- Q = Design flow (ft^3/s) – Flow for a specific return period.
- T = Design return period (years)
- b, a, w, c = Coefficients dependent on T value
- A = Drainage area, (acres) – Area that drains towards the point of interest.
- W = Percentage (%) wetlands as determined from National Wetlands Inventory (NWI) maps
- I = Rainfall Intensity (in/hr) of the 24-hour storm for a return period, T .

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Most used Regression equations for the purpose of this document:

$$Q_{10} = 56.754A^{0.823} * 10^{(-0.0242*W)} * 10^{(0.115*I_{24H10Y})}$$

$$Q_{50} = 89.950A^{0.801} * 10^{(-0.0252*W)} * 10^{(0.0865*I_{24H2Y})}$$

$$Q_{100} = 105.925A^{0.793} * 10^{(-0.0256*W)} * 10^{(0.0776*I_{24H1Y})}$$

Sources for Calculating Drainage Areas

- Microstation Contours from survey and imported Lidar DEM files when necessary.
- 2' Lidar Contours on Mapviewer
- [StreamStats](#) for areas greater than 0.5 square miles
- Aerial photographs and other sources as needed

Rainfall-Runoff Modeling

Modeling is primarily used when the storage properties of detention or retention ponds need to be quantified. The Hydrology and Hydraulics engineer for Highway or the Stormwater engineer will perform any modeling necessary.

7-3 OPEN CHANNELS AND DITCHES

7-3.01 Types

The Department uses the following types of open channels and ditches for drainage:

1. Roadside Ditches: These are used adjacent to and parallel with the highway. They remove the storm runoff from the highway section and drain the subbase material.
2. Median Ditches: These are relatively shallow, depressed areas in medians of multilane, divided highways.
3. Berm Ditches: These are provided longitudinally at the top of a cut to intercept runoff from the hillside.
4. Swale Ditches: These are rounded shallow ditches that capture surface runoff.
5. Channels: In general, these refer to naturally occurring pathways for water (e.g., stream channels). Hydraulic design of channels will likely require environmental permitting. Therefore, work in natural channels should always be coordinated with the Environmental Office. The Hydrology and Water Resources Units should be consulted early in the project, before design work begins. Channel design should be executed by a Professional Engineer and/or qualified geomorphologist. Any channel relocation requires an analysis.

Typically, ditches shall be v-shaped and follow existing road grade. Shallow v-ditches, flatter backslopes and rounded swales should be considered to reduce impacts in lawn areas. Shallow

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v-ditches channel surface water when full v-shaped ditches cannot fit and should also be considered at locations restricted by bedrock. Consideration should also be given to how subgrade will drain when shallow ditch options are designed.

7-3.02 Design Criteria

Cross Section

See Design Guidance – Sideslopes and Backslopes

Ditches shall be a minimum of 1 foot below subgrade/sideslope intercept. If the 1-foot dimension is not possible, underdrain should be considered when the ditch intercept matches the subgrade/sideslope intercept.

Ditches are not typically designed for hydraulic capacity, but in certain situations they should be designed for the 10-year return period. See Design Guidance – Open Channel Flow

Minimum Gradients

The desirable gradient is 1.0% or more. The minimum gradient should not be less than 0.5%.

Channel/Ditch Lining

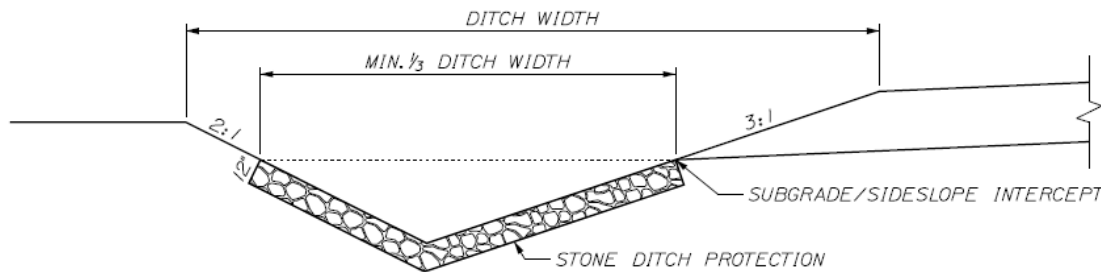
See Channel Linings in the [MaineDOT Best Management Practices for Erosion and Sediment Control](#) (pg 93,119).

- Suggested treatments based on channel slopes
 - 0%-4% - Temporary Erosion Control Blanket
 - shall be placed from the subgrade/sideslope intercept to a point on the backslope that is at the same elevation
 - 4%-6% - Temporary Erosion Control Blanket or Stone Ditch Protection based on input from the H&H engineer.
 - >6% - Use Riprap and add check dams as needed
 - Check dams appropriate when flow velocity is high. Will require hydraulic design.

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Stone ditch protection shall be 12 inches in depth and shall be placed from the subgrade/sideslope intercept to a point on the backslope that is at the same elevation. The minimum width should be one-third of the width at the top of the ditch.



Riprap shall be 18 inches in depth and shall be placed from the subgrade/sideslope intercept to a point on the backslope that is at the same elevation. The minimum width should be one-third of the width at the top of the ditch.

7-3.03 Post-Construction Stormwater Treatment

The Environmental Office Surface Water Quality Unit reviews the MaineDOT projects under development and flags the ones requiring post-construction stormwater treatment to comply with the “Memorandum of Agreement (MOA) for Stormwater Management between MaineDOT, Maine Turnpike Authority (MTA), and DEP” and/or “General Permit for the Discharge of Stormwater from MaineDOT and MTA Municipal Separate Stormwater Sewer Systems (MS4)”, know as the TS4 GP, using ProjEx. The Stormwater Engineer designs the post-construction stormwater treatment measures and prepares the related special provisions and estimated quantities. The Stormwater Engineer designs the stormwater treatment system in consultation with/and agreement by DEP Bureau of Land Resources stormwater engineering team. The Stormwater Engineer assists the Highway Designer with the layout and details of the stormwater treatment system. The Stormwater Engineer cooperates with H&H Engineer to integrate the stormwater treatment system into the main drainage system. The stormwater treatment systems designed by the consulting engineers are reviewed by the Stormwater Engineer to determine their compliance with MOA and/or TS4 GP.

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7-4 CULVERTS

7-4.01 Physical Characteristics

Culvert Materials

For culvert pipes, there are three options:

1. Option I: Any one of the following may be used:
 - a. corrugated steel, metallic (zinc or aluminum) coated pipe
 - b. reinforced concrete pipe
 - c. corrugated polyethylene pipe
 - d. any metal pipe allowed under Option III
2. Option III: Any one of the following may be used:
 - a. corrugated aluminum alloy pipe
 - b. polyvinylchloride (PVC) pipe (12 in (300 mm) and 15 in (375 mm) diameters only)
 - c. polymer-precoated galvanized corrugated steel pipe
 - d. polypropylene pipe
 - e. reinforced concrete pipe
 - f. corrugated polyethylene pipe
3. Reinforced Concrete Pipe (RCP)

The types of culvert material recommended for various site locations are:

1. Reinforced Concrete Pipe (RCP): See Design Guidance – Reinforced Concrete Pipe.
 - a. RCP class is based on the loads the culvert is expected to carry
 - b. For RCP class and maximum fill heights see [ACPA Fill Height Tables](#) for type 3 bedding – classes III, IV, V should be considered
2. Option I: Use under driveways.
3. Option III: Use unless the criteria in Nos. 1 or 2 apply.

Culvert Shapes

Use circular pipes wherever possible. Pipe arches or elliptical pipes may be used where there are clearance problems, restrictive room for headwater, etc.

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Minimum Size

The minimum sizes of culvert for maintenance purposes are as follows:

Driveways: Use minimum 15-inch diameter pipe.

Cross Culverts: Use minimum 18-inch diameter pipe.

Smaller sizes can be used but must be analyzed for capacity.

Segment Length

See the Section 603 items in Estimating Guidance.

Minimum Cover (Design)

Desirably, the pipe will be placed with a cover of at least 2 feet from the subgrade. The minimum cover for any type of pipe is 1 foot below the subgrade.

Spacing Between Multiple Pipes

The minimum spacing allowed between multiple pipes is as follows:

1. Up to 36-inch pipe: minimum 18-inch spacing recommended.
2. 36-inch – 72-inch pipe: spacing will be equal to the radius of the larger pipe.
3. Larger than 72-inch pipe: 36-inch spacing is recommended.

Minimum Slope

Except where the pipe is used as an equalizer, a minimum slope of 0.5% (0.005 ft/ft) should be used for any type of culvert at any site.

7-4.02 Hydraulic Design of Culverts

The analysis of the culvert capacity is accomplished using the Federal Highway culvert analysis program, HY8.

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Design Criteria

Design for $\frac{H_W}{D} \leq 1.5$ at Q50 unless culvert is considered instream then follow Design Guidance - Instream Culvert Sizing.

For ease of comparison during design, the headwater to diameter ratio is used. Headwater to diameter ratio $\frac{H_W}{D}$ is the dimensionless version of head or the inlet water level. The inlet water level during the design flow will be controlled by the peak flow and the size and geometry of the culvert. This ratio allows the comparison of pipes of various sizes. For example, a $\frac{H_W}{D}$ value of 1.5 for a 4' diameter pipe would be a 6' water depth, while a 2' diameter pipe would have a 3' water depth.

For shallow pipes, the water should not reach the subgrade of the pavement section and the base of the subgrade should be at least one foot above the top of the pipe. In certain cases, the pipe size required to pass the design flow will be too large to fit below subgrade. In these situations, pipe arches and elliptical pipes may be possible. Contact the H&H Engineer for assistance.

See Design Guidance – Culvert Hydraulics

7-5 PAVEMENT DRAINAGE & CLOSED SYSTEM DESIGN

7-5.01 Drainage Structures

Catch Basins

A catch basin conveys stormwater into the subsurface storm drain system. It typically includes a grate and/or curb inlet at ground surface where stormwater enters the catch basin and a cylindrical subsurface structure that provides connections to the underground drain system. This structure is often called the “catch basin”, separate from the surface inlet. The depth of the catch basin below the outlet pipe invert acts as a sump to capture sediment, debris and associated pollutants. Catch basins act as pretreatment for other treatment practices by capturing large sediments. The performance of catch basins at removing sediment and other pollutants depends on the design of the catch basin (e.g., the size of the sump), and routine maintenance to retain the storage available in the sump to capture sediment.

The following provides selection criteria for the types of catch basins presented in the Standard Details:

- Type A: use with Type 1 Granite Curb
- Type B: use with any curb type or without curb

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- Type A or B Portland: for use in the City of Portland or when requested by the municipality and with agreement from the Department
- Type F: use on lawns, other areas outside the roadway or roadway areas where a Type A or B basin is not practical – minimum basin depth of 4 feet.

The following provides selection criteria for catch basin shapes:

- Shape 1: standard basin with 2-foot cone
- Shape 5: offset basin with 4-foot or 2-foot cone – must specify
- Flat top: limited use for shallow drainage with input from Construction Support

Grates shall be cascade in all areas unless there is a project specific need for a different type. Solid grates can be used for catch basins that act as junctions for drainage. Beehive grates can be used in areas outside of the pavement for drainage.

Manholes

Manholes shall be used for utility purposes only. See the [Standard Details](#) for shapes and tops.

Catch Basin Inlet Location

The following applies to the location of catch basins:

1. For inlet spacing guidelines, see Design Guidance – Catch Basin Placement.
2. If the location, according to the hydraulic analysis, falls within an intersection, driveway entrance area, curb-cut ramp, or pedestrian crosswalk, the catch basin should be placed on the high side of the feature.
3. Catch basins should be placed to capture the side street flow before it reaches the major highway
4. On super-elevated curves, catch basins should be placed to prevent water from sheeting across the roadway.
5. Areas where drive bumps are necessary to maintain gutter flow and prevent water from draining down driveways towards buildings; bump heights provide limited gutter capacity. If the water depth at the curb is greater than the bump height a catch basin should be provided on the high side of the drive.
6. Where granite curb is proposed, the catch basin should be located in a full-height curb section and not within a terminal curb section.
7. Catch basins should be considered at the grade transition from a steeper slope to a flatter slope near sag vertical curves.
8. At median barriers or raised islands where water collects and flows along them, catch basins should be placed to prevent water from ponding or sheeting across the roadway.

See 4.4.6 of *Hydraulic Engineering Circular (HEC) 22* for more information on placing catch basin inlets.

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Closed Systems

The following applies to closed systems:

1. 6-inch underdrain shall be used as the first section of pipe upgradient of the first inlet. All other sections of pipe shall be no less than 12 inches.
2. Match top elevations of pipes. If pipes are same diameter there should be a minimum difference of 3 inches between invert elevations.
3. Desirably, the pipe will have a cover of at least 2 feet below the subgrade. The minimum cover for any pipe should be 1 foot below subgrade.
4. Pipes that run transversely from catch basin to catch basin shall be non-perforated.
5. Pipes that run longitudinally from catch basin to catch basin may be perforated, with perforations up.
6. Catch basins should have a depth of 8 feet from the top of the grate to the bottom of the basin with a sump of at least 2 feet beneath the lowest pipe invert.
7. Catch basin and manhole outlet pipes should be at least as large as the largest inlet pipe.
8. Average pipe velocity should be between 2ft/s and 10ft/s
9. Pipe should follow profile grade, maintaining a slope of at least 0.003ft/ft (0.3%)
10. In the presence of other underground utilities, potential conflicts should be assessed on the basis of outside pipe diameter
11. Calculations should be performed for smoothline pipe and corrugated pipe

7-5.02 General Design Criteria

Design Criteria

- 10-year return period with storm duration no less than 5 minutes, Q10.
- Rational Method will typically be used for pavement drainage.
- See table 7-5.01 for allowable spread based on highway corridor priority
- The centerline profile on highways and streets with curb should have a minimum gradient of 0.3% (0.003 ft/ft). Desirably, the minimum grade will be 0.5% (0.005 ft/ft). See EI C5 – Maximum Gradient
 - Grades less than 0.5% may cause drainage concerns, the H&H engineer should be involved
 - Note the slope at the gutter is not generally constant, so while the slope at the catch basin can be used to estimate the efficiency, the spread and flow velocity will vary with the slope being strongly influenced by the slope uphill of the basin.
- Normal roadway cross section slope from centerline to curb should be at least 2% (0.02 ft/ft). See EI C4 – Cross Slope

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Table 7-5.01 – Allowable Spread in Travelway

	Priority 1		Priority 2	Priority 3	Priority 4	Priority 5
	Interstates (Including Freeways)	All Other				
Spread in Travelway	Not Permitted	3 feet	3 feet	3 feet	½ driving lane	½ driving lane

7-5.03 Hydraulic Analysis of Closed Systems

Pavement Hydraulics

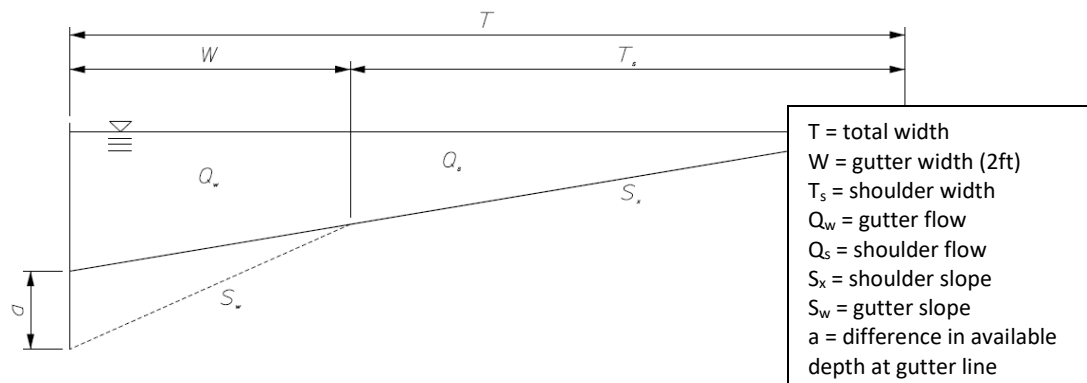
- Curb and gutter flow – Pavement flow that drains towards and combines along the curb.
- Spread – Width of water during a specified storm event measured from the curb and gutter toward the travelway.
- Intercepted flow – Flow that is drained from the curb and gutter by an inlet.
- Bypass flow – Flow that passes over the inlet to continue flowing along the curb.

Flows are based on the pavement drainage area for each proposed catch basin and calculated in the Hydrology Workbook.

The *FHWA Hydraulic Toolbox* can be used to determine the hydraulic characteristics of curb and gutter flow. The FHWA Hydraulic Toolbox Program is a standalone suite of calculators that performs routine hydrologic and hydraulic computations.

The curb and gutter calculator is used to calculate the depth of flow at the gutter line, the width of spread along the roadway, and how much flow will be intercepted by on grade basins. The design flow used is calculated above in the Hydrology Workbook for **surface flow** for a 10-year return storm.

The figure below defines the characteristics of a typical gutter section based on Hydraulic Toolbox definitions



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Things to consider during gutter flow analysis

- Manning's $n = 0.013$ for pavement roughness

See Table 7-4.01 for allowable spread in travelway.

By their nature, closed systems have limited capacity and therefore are designed for the 10-year event instead of the much larger 50-year event. Standard gutters and inlets can only accommodate relatively small flows; pipe capacity may be limited by physical constraints. Offsite flow shall be considered prior to entering the closed drainage system.

Closed System Hydraulics

Closed System Hydraulics is the analysis of how water flows through connected pipes and catch basins to an outfall. This analysis uses Manning's equation at just less than full capacity to size the pipes in the system based on flow as it cumulates through the system.

Manning's Equation

$$Q = AV = \frac{1.49}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

- A = Drainage Area, (ft²)
- V = Velocity, (ft/s)
- n = Manning's Coefficient
- R = Hydraulic Radius, (ft)
- S = Slope, (decimal)

For just full flow in a circular pipe

$$A = \frac{\pi}{4} D^2 \quad \text{Area of a circle}$$

$$P = \pi D \quad \text{Wetted perimeter}$$

$$R = \frac{A}{P} = \frac{D}{4} \quad \text{Hydraulic Radius}$$

The Closed System Workbook can be used to calculate pipe diameters based on Q10 for **surface flow** found using the Hydrology Workbook. HydroCad and other analysis software can be used to calculate flows.

See *Hydraulic Engineering Circular (HEC) 22* or the Closed System workbook for more information on sizing pipes for closed systems.