# Chapter 6
# DRAINAGE

## *Introduction*

The NHDOT *Manual on Drainage Design for Highways*, referred to as the “Drainage Manual” *(1)*, is the approved guide for designing New Hampshire highway drainage facilities. This chapter includes a minimum of duplication from that manual plus general information useful to the designer.

Drainage involves the hydraulic analysis, selection of drainage structures, and identification of Best Management Practices (BMPs) for temporary/permanent Erosion & Sediment Control measures, along with Water Quality Management and Pollutant Loading. These procedures, hydraulic tables and charts are addressed extensively in State/Federal manuals that are not included in this chapter. This chapter will focus on the Department’s guidelines and standard practices.

The NHDOT is strongly committed to prevent erosion and sedimentation from occurring and to protect water and other natural resources. See Appendix 6-1 for the policy statement.

## *Responsibility*

*Coordination*

The Bureau of Bridge Design and the Bureau of Highway Design, through the use of in-house and Consultant designers, share the responsibility for designing drainage. The separation of the responsibility is based upon size of the drainage structure. Bridge Design is responsible for structures 10 ft (3.0 m) and over in span along with the structural analysis for concrete box structures regardless of size. Structures less than 10 ft (3.0 m) in span are designed by Highway Design.

Special drainage structures, detention basins, vegetated treatment swales, energy dissipators, hydraulic inlets and the like are designed by the Bureau of Highway Design and coordinated with Bridge Design, as appropriate.

The highway and bridge designers should request assistance from more experienced designers if the highway drainage is complex or includes unusual drainage design elements.

*Survey and Field Information*

The Bureau of Highway Design will provide roadway plans including layouts, typical sections and profiles to the Bureau of Bridge Design to perform their work. Bridge Design will assemble other necessary information.

The designer should evaluate the following list of drainage concerns on their initial field review of the project to determine how much of this information is required and if additional field information is needed:

- Drainage area(s) / type(s) of ground cover;
- Condition of existing closed drainage system;
- Water mark elevations at existing drainage structures;
- Description of culvert structure - condition, type, and diameter;
- Description of channels upstream & downstream of structures including condition, bottom/sideslope characteristics, profile, typical section, and water marks and/or depth of water if encountered;
- Review existing contours to determine drainage flow paths and erosion areas;
- Identify seasonal flooded areas, wetlands, and excessive ground water (i.e. seeping backslopes/spring eruptions);
- Identify existing underground utilities;
- Identify septic systems and wells; and,
- Check with Maintenance District(s) for history of drainage problems in the area.

Flood information, flood plain maps, photogrammetry, aerial photography, USGS topographic maps, storms of record and old project plans are usually on file in either Highway Design (Records Section and Hydraulics Section), Bridge Design or in Planning and Community Assistance for mapping and graphics. County soils maps are also available in the Bureau of Environment that may be used in the hydrologic analysis of watershed areas.

*Permits*

The New Hampshire Wetlands Bureau (NHWB) - Wetlands Permits are required for all work affecting and/or within their jurisdictional areas adjacent to or within natural watercourses and wetlands. Early in the design process, the Bureau of Environment will make that permit determination on a project-by-project basis. For application procedures, the Designer should refer to the Department's *Permit Process Manual for NH Wetlands Bureau Permits (2)* and coordinate with the Bureau of Environment for guidance, review and distribution. The permit application process should begin immediately after the Slope and Drain plan stage. Permit applications for larger projects are processed with the Environmental Impact Statement (EIS) or the Environmental Assessment (EA) and may be granted before, or at the time of, the Public Hearing.

U.S. Army Corps of Engineers (ACOE) Permits are required for all work affecting natural watercourses and wetlands. Implemented June 1, 1992, the ACOE has issued to the State of New Hampshire a State Program General Permit (SPGP). Under this program, the ACOE grants the NHWB permission to act on their behalf for certain projects, with a follow-up concurrence notice from the ACOE. The ACOE, however, retains the right to require a project to go through their Individual Permit process. This decision is usually determined through the Bureau of Environment's Natural Resource Agencies (monthly) Coordination Meeting.

If an ACOE Individual Permit is required, coordination with the Bureau of Environment is necessary to develop the application. Both applications (ACOE & NHWB) are processed at the same time. To eliminate the duplication of effort, plans from the Individual Permit Application may be used in the NHWB Permit application. The Bureau of Environment will process all permits and applications in coordination with the Bureau that initiated the request.

The Individual Permit Application must be submitted early to the Bureau of Environment to provide sufficient review time prior to distribution. The time to obtain an ACOE Individual Permit ranges from 3 months to 1 year depending on the type of wetland impacts on the project and the complexity of the project. The Bureau of Environment can provide an estimated time frame to receive the Permit.

Since October 1, 1992, the NHDOT has been required to obtain the Environmental Protection Agency's (EPA) National Pollutant Discharge Elimination System (NPDES) Permit, with the Department of Environmental Services having NPDES delegated authority. The NPDES Permit regulates storm water discharges in an effort to control and reduce non-point source pollution. Under this permit program, projects with an area of disturbance greater than 5 acres (2.02 hectares) or more were required to obtain this NPDES permit. The disturbance area is determined by the overall project limits. On July 1, 2003, the EPA reissued the NPDES Storm Water Construction General Permit (CGP) for Storm Water Discharge. The reissued CGP now covers construction sites one acre (0.405 hectares) or more in size. The permit contains conditions to protect endangered species and historic properties, and requires the development and implementation of a Storm Water Pollution Prevention Plan (SWPPP). The EPA's regulations require that the Contractor (with control of the day to day operations on the construction site) secure this permit. If the project falls under the above criteria, a "Special Attention" will be included in the contract Proposal alerting the Contractor that the NPDES permit is required. This Special Attention advises of the Contractor's responsibilities to implement the Best Management Practices to control pollutants for those storm water discharges.

The Department's lead designer will assist the Contractor in the application process for the Permit by providing information from the design phase. An Informational Sheet that provides this data will be included with the Special Attention. The Specifications Engineer can provide details of the Informational Sheet and Guidelines.

## *Guidelines and Procedures*

These guidelines and procedures include Storm Frequency for Design; Runoff Computations; Designs of Culverts, Storm Sewers, Ditches, Slope Drainage and Underdrains; and, Storm-water Management, Erosion & Sediment Control and Water Quality/ Pollutant Loading issues.

In addition to the guidelines describing elements of drainage design, the designer should be aware of the following general concerns:

- Drainage items, on the average, can account for 20 to 30 percent of the cost of highway construction (which includes stormwater management and protective measures).
- Inadequate drainage design can cause premature failure of the road, damage to property, environmental impacts, injuries, and possible litigation. Proper attention to the control of stormwater at outlets is critical.

- Erosion control and runoff pollutant removal is a major factor in determining the success of a design.
- Water rights are often the subject of legal disputes. Natural streams should be preserved and not diverted. In addition, downstream effects of all outlets must be evaluated.
- Coordination with appropriate agencies is mandatory including, but not necessarily limited to:
  - U.S. Army Corps of Engineers
  - New Hampshire Department of Environmental Services
  - New Hampshire Wetlands Bureau
  - New Hampshire Fish & Game Department (NHF&G)
- The designer is responsible for the drainage design. Use the Drainage Manual as the approved reference.
- Maintenance concerns

## *Runoff Computations*

Procedures for developing runoff computations and design storm frequencies are explained in the Drainage Manual.

*Storm Design Frequency*

The frequency of the design year storm has no relationship to the design year of the highway improvement. The design year development of the watershed area will be considered in the runoff computations.

Rainfall is classified by probability of occurrence, commonly called 2, 10, 25, 50, or 100-year frequency storms. A 100-year storm has 1:100 probability, or a 1 percent chance of occurring in any particular year. A 50-year storm has a 2 percent chance of occurring in any particular year. Hence, a 25, 10, or 2-year storm has a 4 percent, 10 percent, or 50 percent chance, respectively, of occurring in any particular year. This designation is to classify heavy rainfall events, but it does not mean a 100-year storm will occur only once, or if at all, in 100 years.

The intensity of a storm is measured in in/hr (mm/hr). The intensity of a 50-year storm will be greater than the intensity of a 10-year storm in the same location. The intensity of a storm will vary with its duration, other factors being similar. The average rate of rainfall for a storm 10 minutes long will be greater than the average rate of rainfall for a storm 1 hour long of the same frequency.

Conceptual drainage design must be performed during the preliminary (Pre-Public Hearing) design stage. Design frequency criteria affects the size of culverts and, along with the required minimum cover, may affect the roadway profile. Design Frequency is therefore an important control. Provisions for stormwater runoff treatment areas (e.g., vegetated treatment swales, sedimentation/ detention basins, gravel wetlands, infiltration trenches/ basins) must also be considered in the preliminary design stage. This may require an initial analysis of existing soil type and groundwater conditions to determine the feasibility of BMP types in assessing water quality and pollutant loading issues. The Engineering Report should mention where drainage is a control factor. Final design of projects requires documentation for all culverts. Computation methods are shown in the Drainage Manual.

*Detention Basins for Peak Flow Control*

There are conditions when it is desirable to detain the runoff before it enters a culvert, storm sewer or stream. One of the most common controls requires that post-development peak flows do not exceed pre-development flows for one or more design storm frequencies. The detention basin is the most widely used measure for controlling peak discharge. A detention basin is sometimes used to store stormwater runoff until the outlet pipe can release it, or until the receiving watercourse can accommodate it, similar to a flood control dam.

One reason to consider using a detention basin is to limit the rate and volume of water released downstream. This provides a side benefit of reducing the size of the downstream pipes and structures. As an example, a safe headwater upstream from a highway may dictate the use of a 36 in (900 mm) diameter pipe. However, a detention basin could provide temporary storage until a 12 in (300 mm) pipe will empty the basin after the storm.

Detention basins should be fully drained within 24 to 40 hours after the storm. If they are in urban areas or could be classified as an attractive nuisance or safety concern, they should be enclosed with a fence or be designed as an underground system.

Other considerations include the cost of the land and effect on the environment. Thorough studies must be made of the comparative costs. In some cases, alternate drainage designs with variations can achieve the storage requirements with less cost and environmental impact.

All hydraulic characteristics of the system should be considered. The basic tools for the design of a detention pond are the Inflow Hydrograph (unit-hydrograph; the watershed rainfall-surface runoff relationship plot that indicates “Discharge versus Time”), the pond Stage-Discharge and Stage-Storage relationship. These three components are necessary to establish the pond storm containment and rate of desirable outflow (Inflow-Storage = Release Rate). The Soil Conservation Service (SCS) “Technical Release 20, Computer Program for Project Formulation, Hydrology” (TR-20) is a computer program that computes direct runoff from a rainstorm, generates flood hydrographs from surface runoff, and routes flow through channel reaches and reservoirs. TR-55, “Urban Hydrology for Small Watersheds”*(6)* is another model developed by the SCS that provides simplified procedures for estimating runoff in small watersheds. These are the preferred methods to be used to design a detention basin for a 24-hour storm event. In selecting the appropriate procedure, consider the scope and complexity of the problem, the available data, and the acceptable precision.

Detention basins are typically designed with a principal and emergency spillway. The principal spillway is designed to pass the (pre-development) peak rate of runoff from a minimum 10-yr design storm frequency. Drawdown orifices are provided to pass the (pre-development) peak rate of runoff from the 2-yr design storm. The emergency spillway is designed to pass the 50-yr design storm with a 1 ft (0.3 m) minimum freeboard. Detention basins should also be evaluated for the 100-yr design storm in sensitive areas (where significant impacts to downstream properties could occur in the event of flooding or breaching of the system) and in areas within, and adjacent to, a regulatory floodway/ floodplain.

Sedimentation basins may also be considered for design. The purpose of sedimentation basins is to collect sediment or other waterborne pollutants. They are intended for temporary use during construction, but should be designed using the same criteria as for detention basins.

## Storm Sewers

*Control of Flow*

Within urban areas, storm-water runoff collected in the roadway normally will be controlled with curb and gutter sections and will discharge through a storm sewer system.

Urban-area drainage systems should limit the water ponding along the curb line and behind the curbs to amounts that will minimize interference with traffic or damage to property. This is accomplished by placing catch basins, or drop inlets immediately upgrade of major driveways, at low points, and at intervals determined by gutter flow and (grate) inlet capacity. Care must be exercised to provide adequate grate capacity, as urban areas tend to have relatively high amounts of impervious surfaces and short runoff times.

Minimum pipe sizes to be used for various conditions are given in the Drainage Manual. The designer should check with the municipality (if appropriate) for storm frequency, minimum pipe size and strength requirements if the maintenance responsibility is not to be assumed by the NHDOT.

*Runoff Discharge Tabulation*

Orderly tabulation of the runoff discharge computation is essential to facilitate the storm sewer design. Sample worksheet forms are provided in the Drainage Manual.

*Sizing Storm Sewers*

Refer to the charts from the Drainage Manual, after tabulating the discharges, to determine the pipe size necessary. Storm sewer line gradients should be generally similar to the roadway grade. The same size pipe will run until the cumulative discharge approaches the pipe capacity during the design year storm. When an abrupt reduction in gradient is encountered, an increase of more than one pipe size may be required. Never reduce the pipe size when an abrupt increase in gradient is encountered.

The hydraulic gradient is the line of elevations to which the water would rise in successive piezometer tubes along a storm-sewer run. Differences in elevations for the water surfaces in the successive tubes represent the friction loss for that length of storm sewer. The friction slope is the slope of the line between the water surfaces.

The storm sewer run will not be under pressure if it is placed on a calculated friction slope corresponding to a certain quantity of water, cross section, and the pipe's roughness factor. The resultant hydraulic gradient will be parallel to and at an elevation equal to or lower than the top of the pipe. This is the desirable condition. Small head losses at inlets and manholes may be disregarded if the structures are properly designed.

There may be reason to place the storm sewer run on a slope less than friction slope. In that case, the hydraulic gradient would be steeper than the slope of the storm-sewer run. Depending on the elevation of the hydraulic gradient at the downstream end of the run, it is possible to have the hydraulic gradient rise above the top of the pipe, creating pressure on the storm sewer system until the hydraulic gradient at some point upstream is once again at or below the top of the pipe.

A hydraulic grade line is the actual water surface elevation within the storm sewer system for a given design year storm.

The following design procedures will minimize the hydraulic gradient within the closed drainage system:

- Select the slope and pipe sizes so that the slope is equal to or greater than the friction slope.
- Align the top of successive pipes at changes in size (rather than inverts being aligned).
- Design the outlet above the surface of the water at the point of discharge.

In cases where a pipe discharges against a head or when it is desired to check the storm sewer system against larger than design floods, it will be necessary to compute the hydraulic grade line of the entire storm system. Begin with the tailwater (TW) elevation at the storm sewer outfall and move upstream the length of the storm sewer. For every run, compute the friction loss and plot the elevation of the total head at each manhole and inlet.

If the hydraulic grade line elevation for the 10-year design storm is greater than 1 ft (0.3 m) below the top of any manhole or basin grate, the storm sewer system is satisfactory and provides some measure of fluctuation. If it rises above these points, surcharging (overflow) may occur through the manhole covers and basin grates. Pipe sizes or gradients should be increased to eliminate surcharging within the structures.

A hydraulic gradient must have an original base elevation above the outlet tailwater elevation.

Most drainage design manuals and drainage software describe hydraulic grade line computations.

*Ponding Limits on Roadway*

Water flow along the curb line should be confined to a width and depth that will not affect traffic flow. The ponding (spread) width will have a corresponding depth and the quantity of water carried will depend on the curb line profile, roughness coefficient, roadway cross slope, inlet spacing and capacity.

Unless otherwise directed, the recommended limit of ponding is within the paved shoulders 8 ft (2.4 m) to 10 ft (3.0 m) wide. In sections with no paved shoulders or paved shoulders less than 8 ft (2.4 m) wide, ponding limits must not encroach beyond one-half the traveled way in either direction of travel.

Charts in the Drainage Manual (open channel series) are used for curb line and median capacity design. Given the restraints on ponding limits, determination can be made of the allowable accumulated runoff discharge that the curb line can accommodate. This, with the basin's grate capacity, will indicate the required spacing of inlets.

Catch basins must be placed at the low point of sag vertical curves. Although particularly important in curbed applications, these structures should also be considered on shoulders without curb to accommodate drainage resulting from "snow curb" conditions. Flanker basins should be evaluated in curbed applications to minimize ponding effects and to provide additional protection should the inlet at the sag location become clogged.

Catch basins should also be placed on curbed roadways just upslope of the "zero" section in superelevation transitions from normal crown to full bank (high side). This is to minimize sheet flow across the paved surface.

*Catch Basins and Drop Inlets*

Drop inlets do not have sumps and are used to pick up flow from the roadway surface with no contributing pipe inletting into the structure (commonly used for slope pipe applications). However, catch basins that do have sumps are most frequently used since the sump provides storage for sediment. The maximum pipe size entering or leaving a standard 4 ft (1.2 m) diameter catch basin, drop inlet or manhole is a 30 in (750 mm) diameter CMP or 24 in (600 mm) diameter RCP. Larger pipes will require a larger structure (refer to the Drainage Manual for sizing requirements). When designing a structure with multiple inlet pipes, or skewed pipes, consider the recommended core hole diameter for each pipe to determine the required structure size. To protect the sidewalls of a catch basin or drop inlet (not type D) from salt deterioration, the Department uses a polyethylene insert within the cone area of the structure.

Curbed, median islands greater than 6 ft (2.0 m) wide should be designed to avoid sheet flow onto the adjacent paved surface. This will require appropriate grading of the island and the placement of median catch basins designed to outlet in a suitable location.

*Selection of Pipe Material*

When designing closed drainage systems and culverts, the designer must specify the type of pipe material to be used. This is based upon hydraulic considerations, as well as ease of installation and cost. Plastic pipe is typically used for drainage systems parallel to the roadway, under shoulders and in ditch lines, across low volume roadways (less than 5000 ADT), and for slope drainage purposes. Reinforced concrete pipe (RCP) is typically used for all other applications. Corrugated aluminized steel pipe may be considered for use to reduce potentially high outlet velocities.

*Underdrain*

The purpose of underdrain is to lower the ground water to provide for a more stable roadbed and side slopes. Frost heaving, seeping backslopes, and spring eruptions are three of the more obvious indications of excessive ground water. Ground water infiltration is generally not significant enough to be considered as part of the storm sewer design in terms of the additional quantity of water contributing to the drainage system. However, known spring and well locations should be identified on the plans. The Geotechnical Report provides recommendations for underdrain locations within the project. There are times, however, when water- bearing formations are not revealed until construction has begun. (See the standard plans for underdrain cover requirements). The selection of the type of pipe for underdrain is the Contractor's option, unless otherwise directed. Underdrain flushing basins should be utilized for maintenance purposes where the underdrain cannot be connected to a catch basin or drain manhole.

**Note:** Specification Section 605 provides information on the types of underdrains approved for use.

# *Culverts*

The design of a culvert begins with the determination of the design discharge to be accommodated. There are drainage computer programs available for culvert design. When a number of culverts are to be designed, the computer method is the most efficient. The culvert's design location must be aligned to minimize impacts to the natural channel wherever possible.

Type, size, strength requirements, location, pipe material, and environmental issues are important elements of culvert design. All are described in more detail on the following pages.

*Type*

The following are the types of culvert pipes that should be selected (in order of preference):

1. Single circular pipe hydraulically efficient for the design Q,
2. Double or two-cell combination circular pipes hydraulically efficient. (More than two cells should not be considered under most circumstances unless reviewed and approved by the Section Chief.)
3. Concrete box culverts (may be required for wildlife habitat and fish passage criteria).
4. Single pipe arch hydraulically efficient for the design Q.

If any of the following conditions are evident, reconsider your first choice.

- Consider upstream debris, which may warrant a trash rack or the use of twin pipes.

- Corrosion potential due to the stream's pH level (if known).
- Deterioration potential of invert due to abrasive or impact bed loads.
- Consider bedding conditions, height of fill or lack of cover. If soil conditions are poor or for any reason disjointing might occur, an aluminized steel pipe with rigid fastened couplings may be the best option.
- Consider difficulty of construction, access, replacement, or temporary drainage needs.

Specification Sections 591 and 603 provide information on the types of culverts and storm sewer pipe approved for use.

*Strength Requirements*

Culverts must be designed for impact loads resulting from minimum cover conditions and for weight of embankment under high fill conditions. Where fill height is 20 ft (6.0 m) or greater, imperfect trench construction must be used as detailed in the Standard Specifications 603.3.6.

The width of the trench must never exceed that specified in the Standard Specifications since pipe load increases with wider trenches.

The Height-of-Cover Tables in the Drainage Manual contain information needed to designate the strength requirements for culverts under various heights of fill. The requirements are based principally on the size and shape of culverts, the amount of cover over the pipe and, in some instances, the class of bedding and type of backfill.

The Standard Specifications provide for two (2) methods of culvert bedding.

- Specification 603.3.2.1 - Bedding for pipes less than 48 in (1200 mm) in diameter.
- Specification 603.3.2.2 - Bedding for pipes 48 in (1200 mm) or more in diameter.

The standard bedding procedure for pipe in bedrock consists of bedding the pipe on a prepared layer of sand at a depth of 12 in (300 mm) and backfilled as defined in the Specifications with the material uniformly compacted.

Refer to Specification 603.3.2.1.1 for bedding for plastic pipe.

Additional information regarding structure excavation can be found under Specification Section 206 that also shows pay limits for culvert excavation.

*Location*

The most desirable hydraulic location is in line with the natural stream, but economically it should be as close to perpendicular to the road as possible.

Wherever possible, culvert installations should be designed to conform as closely as possible to natural drainage channels. The length of pipe should not be compromised. If a skewed alignment is needed to fit a natural watercourse (because relocation is not feasible), then, it should be used. The cost associated with stream relocation, erosion control or damage caused by erosion, environmental effects and channel protection may be more of a construction cost than that of the additional length of pipe required for the skewed installation.

The degree of skew is measured as the angle between the pipe installation and a line perpendicular to the highway centerline. Skewed end structures (headwalls) should be used, matching the skew of the culvert as closely as possible.

The required length of perpendicular culverts is determined by measuring the plotted lengths from the cross sections. For skewed installations, plot the pipe ends on the cross sections matching the proposed side slopes. Transfer the end locations by station and offset to the plan, then scale the skewed length from the plan and adjust for slope as necessary.

The length of pipe culverts should be estimated and recorded to the nearest foot (0.1 meter).

*Environmental Issues*

The area adjacent to the culvert plays a key role in the design/selection of a culvert. The designer needs to be aware of issues such as impacting wetlands, disrupting plant and wildlife habitat, and providing adequate openings for fish passage. These issues normally are identified by the Bureau of Environment early in the design stage and should be coordinated accordingly.

Other considerations include maintaining water quality by preventing erosion and sedimentation downstream. The transport of phosphate-bearing sediments can be detrimental to the waterway. Phosphates can cause a significant increase in algae and other plants. This effect can potentially alter the ecology of the stream. Silt fences and turbidity barriers may be used during construction and should be accounted for in the design process. Turbidity barriers are often used to control sedimentation at drainage pipe outlets into water bodies that are upstream of a public water supply intake and/or that are recreational areas used by swimmers and boaters**.** The designer must also consider stone outlet protection and or velocity reduction to prevent downstream erosion and damage to property.

Outlet protection is a major concern in the culvert design process for water quality issues (high velocities will cause soil erosion and sediment/turbidity in the area downstream), and also for the protection of the surrounding soils and pavement structure. The need for protection will be determined by calculating the exit velocity and checking to ensure that it is lower than the permissible velocity for the composition of the streambed. If stone outlet protection is required, the amount and size of stone will be determined by the discharge, pipe size, and tailwater depth at the outlet.

Culvert inlet protection should also be considered to adequately protect the immediate area around the inlet of a pipe from scour, deterioration, and downstream sedimentation.

*Culvert End Treatments*

There are many types of culvert end treatments. Refer to the Standard Plans for details. It is particularly important that the end treatment does not become a hazard within the clear zone.

*Pipe End Section vs. Header*

Culvert inlets at active waterways (year-round & seasonal streams/brooks) and those culvert outlets under outlet control (tailwater condition) must always have headers. End sections are typically used at culvert inlets/outlets when not operating under headwater or tailwater conditions.

Types of headers and application:

- Concrete headers:
  - Submerged inlets or outlets
  - Active waterways with the potential for ice build up.
  - Salt water areas (special concrete, e.g., microsilica to be used to minimize concrete deterioration)

- Mortar Rubble Masonry (MRM) headers:
  - Areas that are within Public view
  - Areas within Historic Districts
  - Areas where aesthetic appearance should be considered

Type of end sections and application:

- Concrete end section:
  - Pipes that are no greater than 48 in (1200 mm) in diameter
  - Areas that are within Public view
  - Urban areas
  - Areas with abnormally low pH

- Steel end sections:
  - All steel pipes
  - At concrete pipe outlets where a concrete end section or headwall is not used. When used on concrete pipes, the end section shall be sized one size greater than the pipe size (i.e. 15 in (375 mm) RCP pipe uses an 18 in (450 mm) steel end section).

- Aluminum end sections:
  - All aluminum pipes (typically drive pipes & slope pipes which are the Contractor's option)

- Plastic end sections:
  - Sized the same as steel end sections. Although HDPE (High Density Polyethylene) plastic end sections are available, the NHDOT has not used them extensively. With the onset use of plastic pipe, this practice may change, and plastic end sections may be approved for use. Plastic end sections should not be considered in locations that are subject to roadside mowing.

With regard to safety, end sections (24 in (600 mm) or smaller) along the slope are preferred because an errant vehicle can drive across them. Headers may constitute a hazard for the errant vehicle even if outside of the clear zone.

*Remedial Pipe Treatments*

There are situations where, due to environmental, right of way, or physical constraints it is not considered practical to replace an existing pipe that has deteriorated. If the hydraulics allow, it may be possible to insert a structural liner that restores the integrity of the pipe without removing the existing pipe and avoiding many of the associated problems. Also, if hydraulic capacity is the issue but the structural integrity is adequate, then it may be possible to use a technique such as Insiitu Form ® to restore the hydraulic integrity. These are more expensive alternatives to normal drainage installation practices but are appropriate in specific situations.

*Improved Culvert Entrances*

In conditions of inlet control, improved entrance structures can increase efficiency and/or reduce the required culvert size. Improved entrance structures on existing culverts may increase the culvert capacity sufficiently to accommodate increased discharges from land-use development. This treatment is usually considered when the hydraulic conditions are appropriate, the culvert's structure requirements are not diminished, and it proves economically justified compared to culvert replacement.

Improvements at pipe and box culvert entrances include beveled entrance edges and special-design entrance structures. Hydraulic Engineering Circular No. 13, *Hydraulic Design of Improved Inlets for Culverts (7)*, shows design procedures.

When the culvert is operating under outlet control conditions (the culvert barrel restricts the flow) at design discharge, the culvert entrance improvements would be of no advantage. When the culvert is operating under inlet control conditions (the culvert opening permits less flow to enter the culvert than the barrel can carry), entrance improvements should be evaluated. Computer programs for designing improved entrance structures are available.

*Flow Control*

The control of flow is a major concern of the designer. With the considerations necessary for erosion and sediment control and impact to properties, the energy and volume of flow must be controlled to minimize the undesirable effects that would otherwise result.

The preferred area to control the flow is before it outlets the drainage system. Supercritical flows (high velocity, low depth) can be reduced to subcritical flow (low velocity, high depth) by forcing a hydraulic jump within the system. At low velocities, the runoff is not as likely to erode soil and any sediment present will be more likely to settle out than at higher velocities. Some methods by which this may be done is as follows:

1. Pipes with higher roughness coefficients;
2. Flat pipe grades;
3. Energy dissipation within the pipes;
4. Detention basins within the system to meter flow;
5. Elevation drops through drainage structures; and,
6. Increase pipe capacities within the system for use of flow regulators.

The above methods may not be practical in certain situations or may not have the ability to achieve the desired result. If so, flows can be controlled at the outlet by distributing runoff over a wide area to reduce the velocity, using impact structures to physically block free discharge thereby creating an energy loss, or by forcing a hydraulic jump as described above. The following treatments at the outlet are options where slope and area are appropriate:

1. Outlet ditch protection such as stone lining;
2. Rip-rap basins;
3. Rigid boundary energy dissipators;
4. Baffle wall energy dissipators;
5. Stilling wells;
6. Sedimentation basins;
7. Detention/retention basins;
8. Level spreaders;
9. Treatment swales;
10. Stone check dams; and,
11. Outlet onto flat channel grades for increased tailwater.

## *Open Channels and Ditches*

Open watercourses 10 ft (3.0 m) or more in width are called “channels”. If less than 10 ft (3.0 m) in width, they are called “ditches.”

Highway ditches, concave (depressed) medians, gutters and relocated watercourses are treated as open channel flow for design purposes. The Bureau of Bridge Design is responsible for the design of channels in the vicinity of bridges. The Bureau of Highway Design is responsible for most other open channel design.

*Size and Shape*

Trapezoidal channels are usually the most economical.

Under average conditions, side slopes ranging from 2:1 to 3:1 are satisfactory. The side slope of a ditch contiguous with the roadway slope should be a continuation of the normal roadway slope. In areas where mowing will be necessary, the side slopes should be designed at a 4:1 slope or flatter.

*Capacity Computations*

In general, ditches or channels flowing to or from culverts are designed using the same storm frequency, velocity and depth of flow compatible with the culvert. Other (permanent) ditches are usually designed to accommodate a 10-year storm. Temporary ditches are designed to accommodate a 5-year storm. The designer should investigate potential damage from a greater storm for all ditches and channels.

*Alignment and Grade*

Changes in channel alignment should be gradual. The radius of horizontal curvature measured along the centerline of a channel should be at least 3 times the bottom width of a trapezoidal or rectangular channel. The minimum grade to be used is 0.25 percent.

When relocation of a stream becomes necessary, maintain the characteristics of the existing stream, i.e., grade, alignment, and roughness.

*Erosion Protection*

Channel protection may be required to prevent erosion and sediment deposition downstream. The need for ditch or channel protection will be determined by the velocity of flow. Depending on the type of ditch or channel bed, protection may be necessary when permissible velocities for the vegetation and underlying soils are exceeded.

Common practice for control is to use matting with hay mulch, stone lining with geotextile matting and, establishing a good stand of vegetation before much of the contributing site is cleared. Such measures provide slope protection where practices such as silt fence, hay bales, stone check dams, log check dams, and well-established, dense vegetation provide flow reduction and sediment filtering. These are only a few of the possibilities available for channel protection. More elaborate and costly protection may be required for higher velocities.

Refer to the Drainage Manual and other State/Federal manuals for Best Management Practices to determine the extent and type of protection to be used. Check the permissible velocity and roughness coefficient for the various types of protection.

*Median Drainage*

Adequate drainage, for medians between widely separated roadways in excess of 90 ft (27 m), is generally provided by culverts under the roadway. With narrow medians, it is usually necessary to provide intermittent catch basins, ideally located coincident with the culverts. However, separate median drain outlets should be included where needed.

Median drains must be placed at the low point of sag vertical curves. The reach in either direction is critical for sag inlets. Special care must be used to limit ponding.

*Median Drain Spacing*

For divided roadway sections with graded medians, median drains should be spaced to result in no greater than 12 in (300 mm) depth of flow for the 10-year rainfall. Although the median ditch may have a greater capacity on steeper grades, drain spacing distances should be coordinated with culverts.

## Erosion Control

Temporary and Permanent erosion and sediment control measures and their criteria are discussed in the Drainage Manual.

The designer should be familiar with the various Best Management Practices (BMP's) for temporary and permanent applications. Coordination with the Bureau of Construction is necessary to provide for the project's Storm Water Pollution Prevention Plan and Water Quality Protection. During the preliminary design stage, prior to the Public Hearing, BMP's and water quality issues need to be addressed so that adequate Right-of-Way is acquired to implement the BMP's for that site. Under the final design stage, permanent BMP's are shown on the plans, included in the estimate, and discussed in the Prosecution of Work. Temporary BMP's (during construction) are the responsibility of the Contractor and are covered in the contract under Item 645.7 – Storm Water Pollution Prevention Plan, Item 645.71 – Monitoring SWPPP and Erosion and Sediment Control, and Item 699 - Temporary Project Water Pollution Control. However, the designer must anticipate temporary BMP requirements, and whether items within the contract can address those needs for temporary erosion and sediment control use. The purpose of Items 645.7 & 645.71 is to develop a Storm Water Pollution Prevention Plan for the project and implement a monitoring program during construction.

Items provided for use in implementing temporary and permanent BMP measures include the following:

Item. 585.3 - Stone Fill, Class C
Item 593.1XX* -Geotextile, Subsurface Drainage
Item 593.2XX* -Geotextile, Separation
Item 593.3XX* - Geotextile, Stabilization
Item 645.11 - Mulch
Item 645.2 - Matting for Erosion Control
Item 645.21 – Slope Stabilization (2:1 or Flatter)
Item 645.22 – Slope Stabilization (Steeper than 2:1)
Item 645.23 – Channel Stabilization (Low Velocity)
Item 645.24 – Channel Stabilization (High Velocity)
Item 645.3 – Erosion Stone
Item 645.51 - Hay Bales for Temporary Erosion Control
Item 645.52 – Rye grass for Temporary Erosion Control
Item 645.531 - Silt Fence
Item(s) 646.1 & 646.11 - Turf Establishment with Mulch
Item 699. - Temporary Project Water Pollution Control

(* XX denotes placeholders for the classification of the geotextile strength and structure, respectively)

## *Water Quality*

Preserving the quality of receiving waters for stormwater runoff is an increasingly important factor in drainage design. This is accomplished by trapping, or filtering, all non-point source pollution (contaminants that are washed across land and road surfaces by rain and snowmelt). A variety of BMP's have been developed to remove pollutants from runoff. Each has a different level of effectiveness for the site and type of pollutants present in the runoff. This section includes a list of some commonly used practices. The structural BMP's should be designed in accordance with NHDES guidelines for pollutant loading analyses.

*Vegetated filter strips* - vegetated panels on gradual to moderate slopes that treat sheet flow by reducing runoff velocity, thereby allowing the vegetative lining to remove contaminants from runoff. Naturally covered areas may be used if adequate and uniform vegetation is present. Filter strips should be wide enough for thorough treatment and flow must be distributed equally to prevent runoff from concentrating and forming rills.

*Level spreaders* - flat (0% grade) outlet trenches (6 in (150 mm) deep) *(13)* that are constructed to change concentrated pipe or channel flow into sheet flow. The runoff is released over the lip of the spreader as a thin, evenly distributed layer onto an erosion-resistant vegetated slope for treatment. The spreader is vegetated for erosion control purposes and treatment occurs when the flow exits the spreader.

*Sediment basins* – basins that are effective for settling material from stormwater runoff and releasing water at a controlled rate so not to cause disturbance to waterways downstream. Sediment basins are for temporary use during construction and require periodic cleaning (the sediment volume should never exceed one-half of the original storage volume). The sediment removed from the basin must not be discarded adjacent to a waterway or flood plain or where it will erode from the site.

Pollutant reduction is achieved by treating a prescribed amount of stormwater runoff commonly referred to as the "first flush" or the Water Quality Volume (WQV). The following Best Management Practices are used to address water quality treatment and pollutant removal.

*Wet Ponds (Stormwater ponds, Wet Retention Ponds, and Wet Extended Detention Ponds)* - Ponds/ basins that are designed to have a permanent pool of standing water. The permanent pool prevents the re-suspension of sediments from previous storms. Treatment occurs through the settlement of particles and biological uptake of nutrients within the pond. Peak flow/ flood control is achieved by providing additional storage above the level of the permanent pool.

*Stormwater Wetlands* - Constructed wetlands are among the most effective treatment measures for removing pollutants. These wetlands are designed to replicate the water quality improvements of natural wetlands and also provide habitat and aesthetic benefits. Stormwater wetlands differ from stormwater ponds by incorporating wetland vegetation as a major treatment component. Constructed wetlands remove pollutants through sedimentation, adsorption, and filtration. There are several variations of the stormwater wetland (Shallow Marsh, Extended Detention Wetland, Pocket Wetlands) that differ in the relative amounts of shallow and deep pools within the system.

*Infiltration Measures (Infiltration Basin, Infiltration Trench, Permeable Pavement, Dry Wells)* - Practices designed to collect and infiltrate surface runoff into the soil. Infiltration measures have a high level of pollutant removal efficiency and also provide for groundwater recharge. The bottom of the basin/ trench should be a minimum of 3 ft (1.0 m) above the seasonal high water table/ bedrock to provide for adequate infiltration. The underlying soil should have a permeability rate between 0.15 in (4.0 mm) and 5.0 in (125 mm) per hour *(13)* (the design should incorporate a safety factor of 2 when applying the permeability rate). Infiltration measures should not be used in groundwater protection areas when collecting surface runoff from "high load" manufacturing and industrial areas.

*Filtering Practices* – These practices include surface filters, underground filters and submerged gravel wetlands that collect stormwater runoff and provide treatment through a filter media such as sand, organic material or crushed stone. The filtered stormwater is then returned to the drainage system or infiltrates into the surrounding soil. Filtering practices typically utilize a pretreatment or sediment chamber in advance of the filter bed to settle out solids and to minimize clogging.

*Vegetated treatment swales* – trapezoidal or parabolic channels that are constructed with dense vegetation for filtering out pollutants from runoff and increasing infiltration. Treatment swales are most effective when the vegetative lining and channel geometry (cross-section and slope**)** reduces the flow depth to a maximum of 4 in (100 mm) and results in a residence time of greater than 9 minutes at the water quality flow (peak flow rate associated with the water quality volume) *(13)***.** If this result can be accomplished by utilizing a naturally vegetated channel, the additional cost and impact of a constructed swale may not be necessary. This is especially important near a waterway, where fertilizer required for new vegetation can wash into the receiving water body as a pollutant. Selection of an appropriate Manning's roughness coefficient, or a vegetal retardance factor, is important in the design of treatment swales. This is directly related to the average length of vegetation and is used to calculate the flow velocity and capacity of the swale.

*Extended dry detention basins*- Basins that provide for first flush treatment through outlets designed to detain stormwater over a minimum period of time (24 hours) to allow for settlement of particles and associated pollutants. The basins may also be utilized for peak flow/ flood control. Extended dry detention basins are not designed with a permanent pool of water and, as a result, do not provide for significant soluble pollutant removal. Alternative stormwater treatment practices should be evaluated if pollutant removal efficiency is a primary consideration.

The references listed at the end of this chapter provide more detailed information relative to the application and design of the previously described, and additional, BMP's. A variety of manufactured products have been created for additional water quality protection or can be used when land is not available for vegetated BMP's, or a basin for treatment is not practical. Such technologies include oil/water separators and detention/infiltration chambers.

All treatment techniques may require regular maintenance. No treatment alternative should be used in lieu of proper erosion control measures, i.e., stone outlet protection, energy dissipators, rip-rap basins, and good construction planning, but shall be implemented to achieve protection of the abutting natural waterways. Drainage outlets and land grading should divert flow so as not to overtax any treatment facility.

Selection of a BMP may be highly dependent upon breeding issues associated with nuisance insects (e.g. mosquitoes). Water quality measures that sustain a pool of standing water for a period exceeding 5 days *(10)* may not be an appropriate choice in urban locations.

## References:


1. New Hampshire Department of Transportation, *Manual on Drainage Design for Highways,* Revision Date: April 1998.

2. New Hampshire Department of Transportation (NHDOT - Bureau of Environment), *Permit Process Manual for NH Wetlands Bureau Permits, NHDOT, 7 Hazen Drive, Concord, N. H.,* October 1998.

3. New Hampshire Department of Environmental Services and Rockingham County Conservation District, *Stormwater Management and Erosion and Sediment Control Handbook for Urban and Developing Areas in New Hampshire*, August 1992.

4. State of New Hampshire Department of Environmental Services, *Best Management Practices for Urban Stormwater Runoff*, January 1996.

5. United States Environmental Protection Agency (EPA), *National Pollutant Discharge Elimination System (NPDES) National Menu of Best Management Practices for Stormwater,* last updated February 2, 2007.

6. United States Department of Agriculture, Soil Conservation Service, *Technical Release 55, Urban Hydrology for Small Watersheds,* June 1986.

7. Federal Highway Administration (FHWA), *Hydraulic Design of Improved Inlets for Culverts, FHWA Washington, D.C.,* November 1972.

8. *Culvert Design, A Training Course Based on Hydraulic Design Series No. 5, Publication No. FHWA HI-99-001,* February 2000.

9. *Design and Implementation of Erosion and Sediment Control, Reference Manual, FHWA Course Number 134054,* November 2001.

10. *2004 Connecticut Stormwater Quality Manual.*

11. *Maryland Stormwater Design Manual* (October 2000).

12. Vermont Agency of Natural Resources, *The Vermont Stormwater Management Manual, Volume 1 – Stormwater Treatment Standards,* April 2002.

13. New Hampshire Department of Environmental Services (NHDES), *Interim Guidance for the Design of Structural Stormwater Best Management Practices Needed to Achieve Results of Pollutant Loading Analyses,* May 24, 2007.


# *APPENDICES*

6-1 Erosion & Sedimentation Control and Stormwater Management Policy