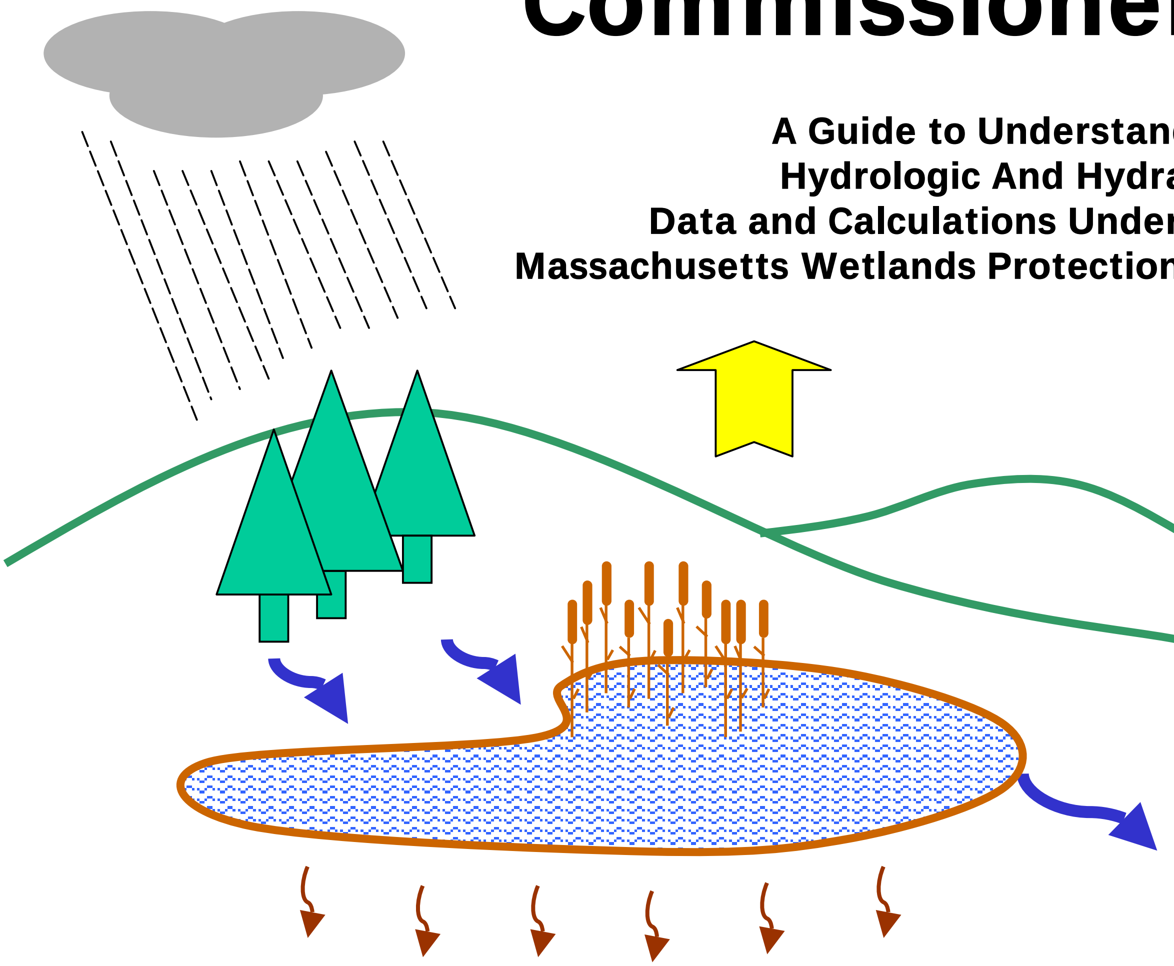
Hydrology Handbook For Conservation Commissioners



A Guide to Understanding Hydrologic And Hydraulic Data and Calculations Under the Massachusetts Wetlands Protection Act

Massachusetts Department of Environmental Protection
Division of Watershed Management
Wetlands and Waterways Program

March 2002

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DEP Guideline No. BRP/DWM/WETG02-1, Approved by: Cynthia Giles, Assistant Commissioner Resource Protection
State Publication No. 18300, Approved by: Philmore Anderson III, State Purchasing Agent

This information is available in alternate formats upon request.
Printed on Recycled Paper

ACKNOWLEDGEMENTS

This handbook was prepared for the Department of Environmental Protection by ENSR International under contract. It replaces the publication entitled *"Basic Hydrologic Calculations for Conservation Commissions: Runoff, Land Subject to Flooding and Flow in Pipes and Channels,"* by Dr. Elizabeth A. Colburn of the Massachusetts Audubon Society, published by the Massachusetts Department of Environmental Quality Engineering (predecessor of the Massachusetts Department of Environmental Protection), 1987.

The Department of Environmental Protection (DEP) acknowledges the contributions of its staff in the preparation of this handbook, especially (in alphabetical order): Michael Abell (NERO), Nancy Baker (NERO), Lois Bruinooge (CERO), Gillian Davies (NERO), Heidi Davis (NERO), Susan Gillan (WERO), Alex Gagnon (Boston), Gary Gonyea (Boston), Elizabeth Kouloheras (SERO), Nancy Lin (Boston), Robert McCollum (WERO), Jeremiah Mew (WERO), Ralph Perkins (NERO), Lisa Rhodes (Boston), Christopher Ross (SERO), Ginny Scarlet (DWM), James Sprague (NERO), Marielle Stone (CERO), Michael Stroman (Boston), and Heidi Zisch (Boston); and also from the Massachusetts Highway Department: Henry Barbaro and Richard Murphy. Special thanks also to former DEP staff Nancy Reed (DEM) and William Selbig (USGS), Massachusetts Association of Conservation Commissions, and National Association of Industrial and Office Properties for their review and input.

DEP acknowledges the contributions of Kristine Clough, Xuan Gao, Caroline Hampton, Stan Humphries, and Amy Schoenfeld of ENSR International; and Sarah Toole of Vanasse Hangen Brustlin, Inc. (VHB).

DEP also wishes to thank the following organizations for granting permission to republish materials included in this document:

Maryland Department of the Environment; and
Northeast Regional Climate Center at Cornell University

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Funding for the preparation and printing of this document (Project Number: 1997-02B/104) was provided by the Massachusetts Department of Environmental Protection, the Massachusetts Environmental Trust, and the U.S. Environmental Protection Agency under Section 104(b)(3) of the Clean Water Act. The contents do not necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

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Effective Date: March 1, 2002 Guideline No. BRP/DWM/WETG02-1

Program Applicability: DEP Wetlands Program and Office of Administrative Appeals, Local Conservation Commissions, Environmental Permitting Consultants, and the General Public

Approved by: [Signed]
Cynthia Giles, Assistant Commissioner
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Supersedes: "Basic Hydrologic Calculations for Conservation Commissioners: Runoff, Land Subject to Flooding and Flow in Pipes and Channels," 1987, Department of Environmental Quality Engineering, Boston, MA.

Copies of the hydrology handbook may be obtained from DEP's WEB site (http://www.mass.gov/dep) or by mail beginning April 2002. For further information, contact Thomas Maguire at (617) 292-5602.

Table of Contents

APPENDICES

List of Tables

List of Figures

Chapter 1: Introduction

This chapter introduces you to "Basic Hydrologic Calculations for Conservation Commissioners". In this chapter, you will find:

- The purpose of the manual;
- The importance of hydrology in protecting statutory interests;
- An overview of the Manual.

1.1 The Purpose of the Manual

The Massachusetts Wetlands Protection Act (WPA) (Massachusetts General Laws, Chapter 131, Section 40), is designed to protect the functions that vegetated wetlands and other wetland resource areas serve in the Commonwealth. The Massachusetts Department of Environmental Protection (MA DEP) has developed a Stormwater Management Policy (issued November 18, 1996) to adopt uniform standards to reduce stormwater impacts through a number of different DEP water-related regulations, including the **WPA.** Hydrology, the study of the movement of water on the earth's surface and in its environment, relates directly or indirectly to the function of each of these resources. As such, it is important for Commissioners to understand the relationships between hydrology and interests protected by the WPA and Stormwater Management Policy.

This manual has been developed to assist Conservation Commissioners in evaluating the hydrologic impacts of proposed activities on wetland function and statutory interests, as well as in evaluating the adequacy and accuracy of hydrologic analyses submitted to the Commission. While Commissioners will not be expected to perform hydrologic calculations themselves, they must possess a basic understanding of hydrologic processes, the assumptions made during hydrologic analyses, and the conditions that must be met for such calculations to be valid. In addition, Commissioners must be able to gage the significance of potential impacts to take the appropriate action.

The information provided in this manual will assist Commissioners in determining what information should be provided in a hydrologic evaluation and report, to allow for adequate evaluation of potential impacts. It will also help Commissioners ask the appropriate questions, to confirm the validity of information submitted for their review.

1.2 The Importance of Hydrology in Protecting Statutory Interests

Site development typically alters the volume, rate, duration, frequency, and pathways of stormwater runoff to wetland resource areas. When evaluating development proposals, Conservation Commissioners need to consider these changes in hydrology.

The resource areas protected under the Wetlands Protection Act and the Stormwater Management Policy are assumed to perform certain critical functions in the environment, such as flood control, storm damage prevention, groundwater recharge, pollutant removal, and provision of wildlife habitat. **Hydrology** plays an important role in each of these functions. Hydrology, which is further described in Chapter 2, deals with the movement of water between the atmosphere, the earth's surface, and its subsurface. When considering wetland resource areas, the study of this movement of water focuses on the **hydrologic regime** of the resource areas. The hydrologic regime (also discussed further in Chapter 2) characterizes the factors that influence the volume of water entering and leaving a resource area. The hydrologic regime also includes the timing, duration, routing, rates, and frequency of flows. Additional site factors governing the hydrologic regime of a resource area include soil conditions, vegetative cover, topography, and groundwater levels.

Proposed development and redevelopment projects have the potential to transform these hydrologic conditions, degrade stormwater quality, and disrupt the hydrologic regime by changing the rate, timing, and volume of flow contributing to a resource area. As a result, development may impact the wetland function and statutory interests. Although it is virtually impossible to replicate pre-development hydrologic conditions on a site, the Conservation Commission should assess the proposed activities under their jurisdiction to determine whether resource areas are sufficiently protected in the post-development site.

1.3 An Overview of the Manual

This manual has been designed to address the key hydrologic issues faced by Conservation Commissioners during the review process. Chapter 2 presents an overview of basic hydrologic concepts as they relate to the regulatory interests protected by the Conservation Commissions. Chapter 3 reviews the typical information and calculations, relevant to the WPA and Stormwater Management Policy, that Commissioners should expect from an applicant when reviewing a submittal for hydrologic impacts. That chapter also discusses the additional resources available to Commissioners for aid in evaluation.

The remainder of the document (Chapters 4-11) provides more detailed discussions of the specific hydrologic issues and calculations that Commissioners may need to consider during a review. Topics include the following:

- Estimation of stormwater runoff volumes and rates[1];
- Basic principles for the design of stormwater conveyance systems;
- Strategies and estimating methods for controlling peak stormwater runoff rates;
- Determination of the Water Quality Volume for compliance with the Stormwater Management Policy;
- Information on the design of recharge systems;
- Procedures used in analyzing floodplain areas, such as Bordering Lands Subject to Flooding (**BLSF's**) and Isolated Lands Subject to Flooding (**ILSF's**);
- Selected hydrologic issues pertaining to Riverfront Areas and Coastal Resource Areas.

*Terms in bold text (such as **hydrology**) may be found in the glossary in Appendix A.*

Appendix A contains a glossary of hydrology related terminology. This glossary may prove helpful to the reader, as he or she explores each of the chapters. Terms that appear in bold font in the text are included in the Glossary.

Additional Appendices contain more detail on some of the calculation and analysis procedures discussed in the main body of the manual.

[1] Under the Stormwater Management Policy, runoff volume and rate should be estimated using SCS (U.S. Soil Conservation Service, now NRCS) methods, assuming the necessary underlying assumptions of the SCS models are satisfied.

Chapter 2:
Fundamentals of Hydrology

This chapter contains basic information about stormwater hydrology. It presents an explanation of:

- Hydrology;
- The "hydrologic cycle";
- Hydrologic regime of wetland resources;
- Hydrologic factors of concern to Conservation Commissioners;

This chapter also refers you to the glossary of terms in Appendix A.

2.1 Hydrology

Hydrology is the study of the circulation of water between the earth and the atmosphere. This endless circulation of water is known as the **hydrologic cycle**. A basic understanding of the hydrologic cycle serves as an essential foundation for understanding the rest of the material presented in this manual. This section presents an overview of the hydrologic cycle, and describes some of its key components.

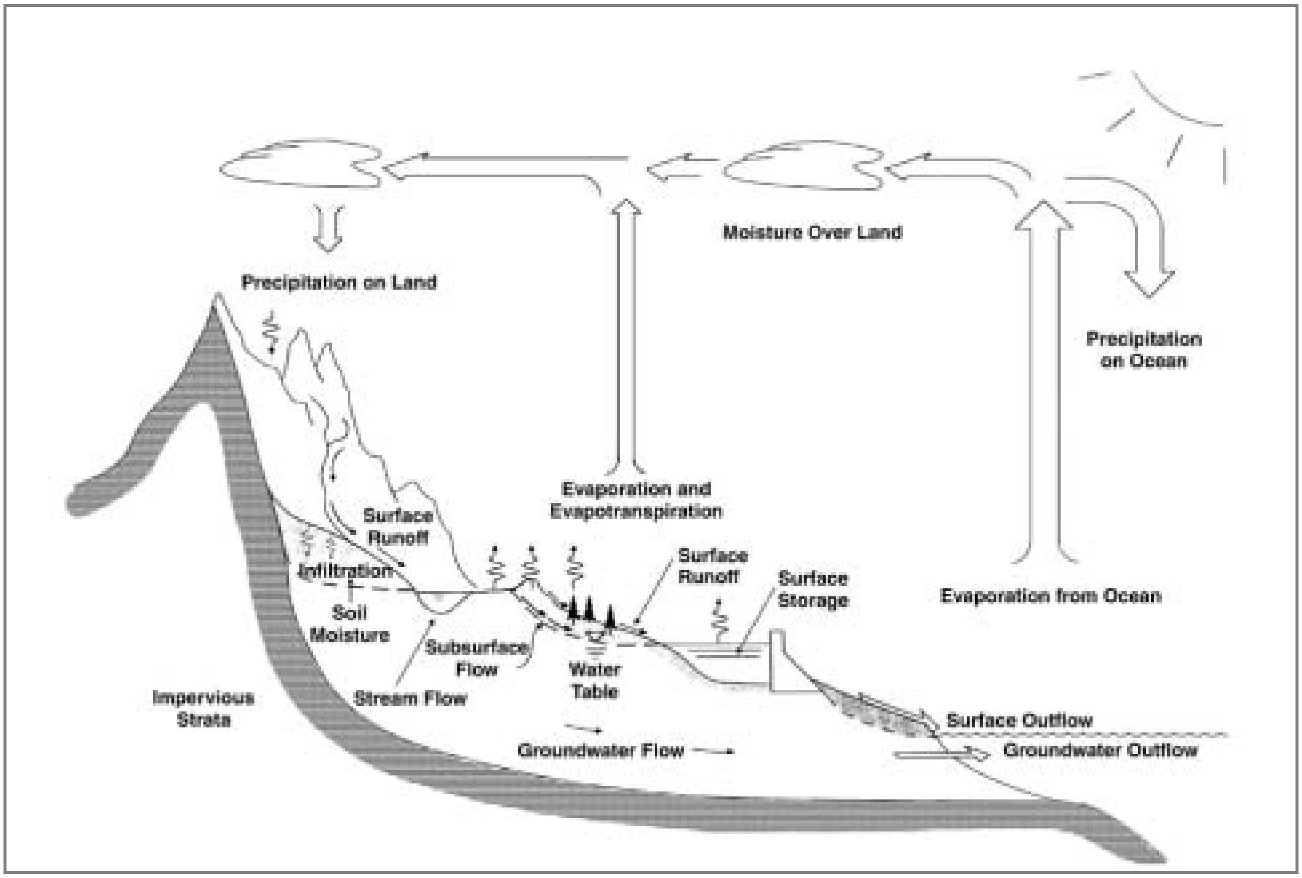
The components of the hydrologic cycle can also be examined at the level of a wetland resource. In this case, we often use the terms "wetland hydrology", "water budget", and "hydrologic regime". Therefore, this Chapter will discuss these concepts, as they pertain to the analysis of water flowing into and out of wetland resources.

In discussing these concepts, the material in this Chapter and later Chapters will focus on some key relationships among precipitation, stormwater runoff, groundwater recharge, and other components of the hydrologic cycle.

2.2 The Hydrologic Cycle

Water is found in the earth's atmosphere, on the earth's surface (surface water), and within its subsurface (groundwater). The hydrologic cycle is the continuous process of water moving among these three general locations. Figure 2-1 depicts the basic components of the hydrologic cycle.

Figure 2-1   The Hydrologic Cycle



Adapted from Chow, 1988

Water, which exists in the atmosphere as water vapor, reaches the earth's surface by **precipitation** (rain, snow, hail, fog). Once on the surface, water moves by the force of gravity, and may follow a number of paths.

As precipitation falls on the ground, some of the water remains on the surfaces of plants, a process known as **interception**. Some of the water is stored in the irregularities and small depressions on the land surface, as **depression storage**. During winter months in temperate climates, some precipitation may be stored on the surface as snow, ice, and frost.

Some of the water that falls as precipitation enters the ground through soil pores, and is called **infiltration**. A portion of this infiltrated water may be stored in the soil, as **soil moisture**. Within the root zone, this soil moisture becomes available for plants. The remainder of the water entering deeper into the ground is referred to as **recharge**, and moves through the soil as **interflow** (unsaturated flow through the soil) or **groundwater flow** (saturated flow through the soil). The zone in which groundwater flow occurs is commonly referred to as the **groundwater table**.

When precipitation exceeds the combined effects of interception, depression storage, and infiltration, the remaining water flows over the surface of the ground as **direct runoff** (also referred to as "excess rainfall"). This runoff flows over the surface to natural channels such as topographic swales, gullies, intermittent streams, perennial streams, and rivers. Some of this water is also stored on the earth's surface in wetland systems, ponds, lakes, reservoirs, and the oceans.

Water beneath the ground surface may also flow to these various water resources through the processes of interflow and groundwater flow. The portion of flow in streams and other water bodies that originates from interflow and groundwater discharge, is generally known as **base flow**.

Water eventually returns to the atmosphere by direct **evaporation** from the surfaces of the land and water bodies. Water also returns to the atmosphere from vegetation by **evapotranspiration**, which is the combined process of evaporation from plant surfaces and the uptake and release of water through the biological process known as transpiration.

This guidance manual deals primarily with surface water flows. The behavior of subsurface flows is treated only to the extent of describing certain important relationships to surface water flows. Similarly, the behavior of water in the atmosphere is considered only to the extent of its effect on inputs to or losses from the surface water system.

With this basic description of the hydrologic cycle, the next section of this chapter considers some basic hydrologic components as they pertain to the "hydrologic regime" of wetland resources.

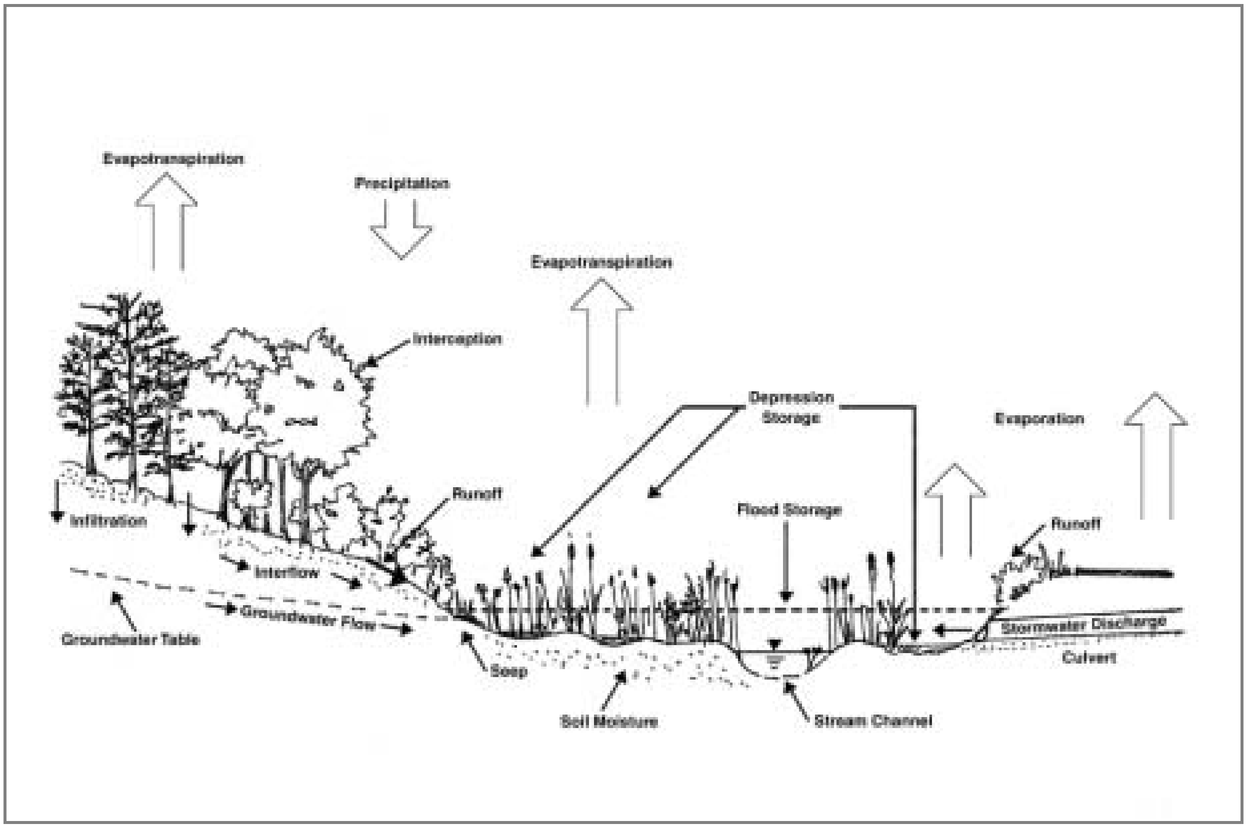
2.3 Hydrologic Regime of Wetland Resources

The Wetlands Protection Regulations make frequent use of the term **hydrologic regime**. This term refers to the relationship of water in its various forms (overland surface water flows, channelized flows, groundwater storage and flows, pond storage, flood storage) within the wetland setting. To describe a wetland resource area's hydrologic regime requires an understanding of how water moves through the wetland, as well as the wetland's geologic setting and biologic character. Moreover, such a description requires an understanding of how this process occurs over time, during the course of individual rainfall events, the progression of the seasons, and the progression of climatic cycles.

Since a full understanding of the "hydrologic regime" also requires knowledge of the wetland's geologic and biologic parameters, this manual will not treat this subject in detail. However, this Chapter will offer some comments on the hydrologic cycle as it relates to understanding the "hydrologic regime".

Figure 2-2 depicts the components of the hydrologic cycle in a wetland resource. For any given wetland or water body, the hydrologic cycle involves a number of sources of water feeding into the wetland (inputs), paths of water leaving the wetland (outputs), and the change over time of the quantity of water within the wetland (storage). The interrelationship of these water quantities is known as the **Water Budget** or the **Water Balance** of the wetland resource.

Figure 2-2 Hydrologic Regime in a Freshwater, Groundwater Discharge Wetland



As seen in Figure 2-2, inputs may include precipitation, overland flow into the wetland, stream flow into the wetland, interflow and groundwater flow into the wetland, and discharge to the wetland from closed drainage systems.

Outputs may include recharge to the groundwater from the wetland, stream flows leaving the wetland, evaporation from standing water and land surfaces within the wetland, and evapotranspiration from wetland vegetation.

Storage within the wetland occurs within the soil (as soil moisture), as ponded water, and as static flood storage.

A water budget (or water balance) is a description of the relationships among these components, and is simply described by the following equation:

Inputs - *Outputs = Change in Storage*

All of these components (inputs, outputs, storage) vary over time. Thus, the water budget must be considered in terms of some unit of time, depending on the analysis. If long term trends are of concern (for instance, the influence on groundwater elevations as a result of recharge), the water budget may be analyzed by a summation of these various inputs, outputs, and changes in storage over an extended time (for instance, over a year). On the other hand, if short-term impacts are of concern (for instance, the influence on wetland flood levels and downstream discharges as a result of a storm event), the water budget must be analyzed over a series of shorter time increments.

Why should the water budget concern Conservation Commissioners? The functions of wetland resource areas are primarily driven by, and sensitive to:

- The presence or absence of water;
- The quantity of water on and beneath the ground surface;
- The rate at which water moves through the resource area; and
- The quality of water.

A change in any one of the inputs, outputs, or storage can result in changes in the other parameters, which in turn can result in altering the wetland. For instance, diverting surface flows away from a wetland resource area can result in a change in vegetation to more drought tolerant species, which can in turn result in an alteration in habitat. Thus, Conservation Commissioners are concerned with the volumes and rates at which water enters and leaves wetlands. They are also concerned with the quality of water entering wetland resource areas, to the extent that quality affects the functions of these resources.

Later chapters of this manual examine key hydrologic factors of the wetland resource area water budget, explaining why each parameter is of concern. The chapters also offer guidance on how Conservation Commissioners can evaluate changes in these hydrologic parameters that can occur as a result of development. The discussion relates the parameters to the Stormwater Management Policy, to facilitate Commissioners' review of applications relative to stormwater management issues.

2.4 Hydrologic Factors of Concern to Conservation Commissioners

Several hydrologic factors can be of key importance to the water balance of wetland resources, and are therefore of particular concern to Conservation Commissioners. These factors are identified in the following discussion, and treated in greater detail in later chapters. The factors include:

Surface Runoff

During a precipitation event, some of the water falling on the earth's surface is retained on vegetative surfaces and in shallow depressions. Some additional water infiltrates into the ground. The remaining water flows over the ground surface as direct runoff (sometimes referred to as "**stormwater runoff**" or simply, "**runoff**").

The **volume of runoff** that will occur on a site during a given rainfall event depends on a number of factors:

- The area of land from which runoff occurs (known as the **watershed**);
- amount of precipitation;
- the duration and intensity (volume per unit of time) at which precipitation falls;
- the soils at and near the land surface; and
- the surface cover (combination of exposed earth, vegetation, pavement and roofs).

The rate at which runoff discharges from a given site is known as the **runoff rate** or **discharge rate.** The **peak rate** of runoff from a given site (also referred to as the peak flow rate, peak runoff rate, or peak discharge rate) is the maximum rate of runoff that occurs during a particular storm event. The rate of runoff depends on the following factors in addition to those affecting runoff volume:

- the roughness of the surface, which is determined by the type of surface cover (type of vegetation, bare ground, pavement);
- the location of the impervious area in the watershed in relation to the point of analysis;
- slope of the ground surface (flatter slopes result in slower rates of flow over the ground, steeper slopes result in faster rates of flow);
- total distance the runoff must travel to the point of analysis.

The development of a previously undeveloped site for another use can alter the physical features affecting runoff. The development of an undeveloped site for an urban land use usually involves the creation of impervious surfaces (pavements and roofs) which have particularly significant effects on the volume and rate of runoff. The primary effects of urban development include:

- *Increase in volume of runoff.* The volume of water available for runoff increases because the impervious area provided by roofs, parking lots, streets, and other impervious surfaces reduces the amount of infiltration that can occur. Note that this increase in runoff volume is directly associated with a decrease in recharge of the groundwater.
- *Increase in runoff rates.* Urban development involves changes in surface cover, and the introduction of channels, curbing, gutters, and storm drainage collection systems. These changes result in hydraulic efficiencies that increase the velocity of runoff as it flows to the watershed outlet. This results in higher peak rates of storm water discharge.

Thus, if a site is under development, alterations in soils, surface cover, and topography can result in changes in the quantities and rates of runoff entering a wetland. Such alterations can change the water budget of a wetland, with resulting changes in wetland functions. Such changes may include:

- increase or decrease in the total volume of water reaching a wetland over an extended period of time, affecting the amount of water available to support aquatic and terrestrial habitat;
- increases in flow volumes during storm events, that result in increased flooding of upland or wetland areas;

- increases in peak flow rates during storm events. Increases in peak rates may result in increased erosion of upland or wetland resource areas, and subsequent deposition of sediment within resource areas;
- changes in patterns of flow, resulting in localized changes in erosion, sedimentation, and surface water storage.

Therefore, Conservation Commissioners need to consider the effects of development on the volumes, peak rates, and patterns of runoff entering wetlands. Chapter 4 discusses the estimation of volumes and rates of runoff, and further explains the significance of these hydrologic parameters. Chapter 5 gives a brief overview of how pipes and channels must be designed to adequately convey runoff from developed sites. Chapter 6 addresses ways to control peak flows, to mimic pre-development conditions to the extent practicable.

Urban development can result in an increase in the volume of runoff in an area, as well as an increase in the peak rate of that runoff. Such alterations can change the water budget of a wetland, thus changing the wetland's functions. Therefore, Conservation Commissioners need to consider the effects of development on the volumes, peak rates, and patterns of runoff entering wetlands.

Groundwater Recharge

When a portion of rainfall infiltrates into the ground surface, some of that water replenishes soil moisture. Some of the water stored or flowing beneath the ground is taken up by vegetation, and returns to the atmosphere by transpiration. Some of the moisture near the ground surface evaporates into the atmosphere. The water that remains after these losses becomes **groundwater recharge**. Groundwater recharge is important for replenishing of aquifers used as water supplies, and for sustaining "base flow". Some of the water moving beneath the surface as unsaturated flow (interflow) and saturated flow (groundwater flow), discharges to wetlands, streams, rivers, ponds, lakes and other water bodies, and sustains the base flow of water supplying those resources. Thus, resource areas and drinking water supplies are dependent on groundwater recharge.

The amount of groundwater recharge depends on the following factors:

- quantity of rainfall;
- the characteristics of the soils (some soils have a high capacity to allow the infiltration of water, and other soils have a very low capacity see Table 2-1);
- surface cover (vegetated surfaces help promote infiltration, whereas impervious surfaces such as pavements and roofs prevent water from penetrating the ground surface);
- the amount of water that may be stored on the surface during a rainfall event (such as depression storage), that remains available for infiltration for a period of time during or after the event.

When a site is developed, alterations of the surface soils and surface cover occur, which in turn can affect the amount of water that can infiltrate the ground. Reduced infiltration can reduce recharge, in turn reducing a source of water supply to wetland resource areas. Conservation Commissioners need to consider development effects on groundwater recharge. Chapter 8 discusses this hydrologic parameter in greater detail.

Table 2-1 Infiltration Rates for Various Soil Textures[2]

Texture Class	NRCS Hydrologic Soil Group	Design Infiltration Rate (inches per hour)
Sand	A	8.27
Loamy Sand	A	2.41
Sandy Loam	B	1.02
Loam	B	0.52
Silt Loam	C	0.27
Sandy Clay Loam	C	0.17
Clay Loam	D	0.09
Silty Clay Loam	D	0.06
Sandy Clay	D	0.05
Silty Clay	D	0.04
Clay	D	0.02

Surface Runoff Water Quality Issues

The activities associated with urban land uses – and in particular with vehicular traffic – result in the generation of pollutants, which accumulate on pavement surfaces, and are carried off by storm water runoff. Land disturbance activities and the increase in peak discharges also result in accelerated erosion of upland areas and stream channels, resulting in greater sediment loads.

The earth's surface has a certain capacity to remove pollutants through natural processes. The hydrologic changes introduced by urban development can alter these processes. For instance, natural infiltration of water into the ground can help remove some pollutants. Reduced infiltration can result in a reduction of this natural function. Changes in the water balance of a wetland resource area can result in alterations in vegetation and the time water is in contact with vegetation. These changes can affect the natural processes of sediment removal and pollutant uptake. Reductions in flows to a particular resource area can reduce the water available to dilute contaminants, resulting in potential impacts on living organisms from the more concentrated contaminants.

In areas with cold water fish habitat, runoff from urban development can result in thermal impacts (runoff from pavements and discharges from detention basins can be much warmer than runoff from natural surfaces).

Stormwater runoff poses concerns relative to the quality of discharges to resource areas. Because of these potential effects, Conservation Commissioners will be concerned with the provisions of measures to address runoff water quality impacts. The Stormwater Management Policy includes

[2] Source: Rawls, Brakensiek and Saxton, 1982. The DEP recharge bulletin (Appendix E) contains further guidance on use of published infiltration information and on-site infiltration testing.

standards to address such impacts. The MA DEP has prepared guidance documents for the design and implementation of measures for treating runoff from urban areas (*Stormwater Management Volume One: Stormwater Policy Handbook*, and *Volume Two: Stormwater Technical Handbook*). These treatment measures are referred to as Best Management Practices (BMPs). Chapter 7 discusses how to estimate the volume of water to use in the design of BMPs, in order to achieve desired annual average treatment objectives stated in the Policy. Chapter 7 also describes how to estimate the overall performance of a system of BMPs.

Stormwater runoff poses concerns relative to the quality of discharges to resource areas. Because of these potential effects, Conservation Commissioners will be concerned with the provisions of measures to address runoff water quality impacts.

Other Related Issues

Conservation Commissions also are concerned with some other issues involving the relationship of wetland resource areas to hydrology. The Wetland Protection Act and associated Regulations provide certain protections for Bordering Land Subject to Flooding (BLSF) and Isolated Land Subject to Flooding (ILSF). Chapter 9 addresses certain hydrologic-related calculations pertaining to these resource areas.

Chapter 10 addresses selected topics pertaining to Riverfront Areas. Chapter 11 offers some discussion relating to Coastal Resource Areas.

2.5 Glossary

A number of terms are commonly used when discussing hydrologic concepts. To help explain this terminology, this manual includes a glossary in Appendix A, defining selected terms. Terms that appear in bold font in the text are included in the Glossary. The authors of this manual encourage the reader to make frequent use of the glossary when exploring the remaining chapters of this manual.

Chapter 3: Reviewing Submittals

This chapter describes key elements of submittals, to enable Conservation Commissioners to review hydrologic calculations. The discussion addresses:

- Types of submittals
- Required site plan data
- The Stormwater Management Form
- Additional calculations and related documentation
- The site visit
- Suggested Outline for Stormwater Management System Reviews
- Sources of Technical Information and Assistance.

3.1 Types of Submittals

Conservation Commissions may be presented with two main types of submittals that might require documentation concerning hydrologic issues. These submittals include the Request for Determination and the Notice of Intent.

Request for Determination of Applicability

The MA DEP issued the Buffer Zone Policy (Policy 99-1) in March, 1999[3]. This policy identifies several criteria for determining whether activities occurring exclusively in the buffer zone are eligible for a Negative Determination of Applicability. The Policy Criterion 3 requires eligible activities to manage stormwater according to standards set by the Department. Thus, qualifying buffer zone activities will need to comply with the Stormwater Management Policy. Therefore, depending on the proposed activity, a Request for Determination of Applicability (RDA) may need to be accompanied by hydrologic data, to document compliance with the Stormwater Management Policy.

Notice of Intent

The Notice of Intent (NOI) submittal package is typically the most extensive with regards to hydrologic considerations. Depending on the size and type of development proposed, the NOI may contain a significant amount of information regarding the existing and proposed hydrologic

[3] A copy of the Buffer Zone Policy can be found at www.state.ma.us/dep/brp/ww/wwpubs.htm.

conditions at a site. This section of the manual is designed to help Commissioners pick out the important elements in the submittal package necessary to understand existing hydrologic conditions, and to evaluate the potential hydrologic impacts of a proposed project.

Typically, the Notice of Intent package will contain the following information pertaining to hydrologic conditions:

- Plans showing existing and proposed conditions, including existing topography and proposed grading, drainage areas, drainage structures and systems, buildings, pavement (roads and parking areas) and other impervious areas;
- Plan denoting the proposed sediment and erosion control procedures to be implemented during construction;
- The Stormwater Management Form (WPA Form 3, Appendix C);
- A variety of hydrologic calculations pertaining to existing and proposed peak runoff rates, groundwater recharge, water quality volume, total suspended solids (TSS) removal rates, proposed conveyance system design (storm drain pipes, culverts, and channels), and the sizing of stormwater quality and quantity control facilities; and
- A narrative describing existing and proposed drainage conditions, and the measures proposed to mitigate adverse impacts (if any) associated with the management of runoff from the proposed development.

The following sections discuss these elements in greater detail, offer guidance on important points of a site visit; and suggest a checklist for reviewing the hydrologic elements of submittals to Conservation Commissions.

3.2 Required Site Plan Data

The site plan plays an important role in helping Conservation Commissioners understand what activities are being proposed on a site and what the potential impacts of these activities will be. Commissioners should evaluate whether the plan contains sufficient information to allow the evaluation of potential hydrologic impacts and the development of appropriate Orders of Conditions. The following discussion highlights the important format and content issues that should be addressed during the review process:

Format

The overall format of the site plans should generally comply with the guidelines set by the Massachusetts Department of Environmental Protection (DEP). Generally, a professional land surveyor and/or a registered professional engineer should stamp the plans. If the plans are unclear or difficult to read, the Commission has the right to have the applicant revise them.

Resource Areas

The boundaries of all resource areas, and any associated regulatory buffer zones, should be clearly delineated on the plan. For areas under the jurisdiction of the Riverfront Protection Act, the 200-foot Riverfront Area should be shown. When applicable, the 100-year floodplain boundary (determined from the appropriate source of information – see Chapter 9: Analysis of Floodplain Areas) should be clearly identified on all grading plans.

Commissioners should verify that the boundaries accurately represent the conditions on site, and that all resource areas have been identified, to ensure that all areas of jurisdiction have been addressed.

Topography and Grading

Site plans should show the existing and proposed grades within the proposed limit of work. Typically, plans should be prepared with contour intervals of two feet or less, to adequately evaluate the hydrologic impacts. One-foot contours may be required in very flat areas, to clearly indicate drainage patterns. Spot-grades, which typically mark elevations to the nearest tenth of a foot, are very helpful in sensitive resource areas or in areas where complex grading is proposed.

Where limited topographic information is available, data from United States Geological Survey (USGS) topographic maps may be substituted. These maps are often useful for obtaining information about drainage patterns for areas outside of the project site. However, these maps typically show only 10-foot or 3-meter contours, and may only provide limited detail. Topographic information from more detailed sources may sometimes be needed to fully evaluate hydrologic conditions. Designers and Conservation Commissioners should pay particular attention to the scale of USGS plans, as many are now published in metric units, instead of English units of measurement.

Topographic depressions should be identified on the plans. Additional information, such as field observations or hydrologic calculations, may be required to determine whether these areas may constitute Land Subject to Flooding (see Chapter 9).

Hydrologic Soils Groups

For most projects, hydrologic calculation procedures will require the data about the site’s soils. In particular, many procedures require information about soils classification according to Hydrologic Group (see Chapter 4 for a description of Hydrologic Soils Groups). The site plans should include information regarding the existing hydrologic soils groups located on the site. This information may generally be obtained from the United States Natural Resources Conservation Service (NRCS, formerly SCS) County soil surveys.

Conveyance Systems

The plans should show all existing and proposed drainage structures, closed stormwater conveyance systems (pipes and culverts), open conveyance systems (ditches and channels), impoundments, and natural drainage systems. When applicable, the plans should note the elevations of drainage structures' rims and inverts, and also identify pipe sizes. Existing and proposed water quality structures, such as detention and retention basins, should also be clearly identified. The inlets, outlets, overflow structures, and elevations of these facilities should be noted on the plans.

Drainage Patterns

To fully understand the potential hydrologic impacts of a proposed development, designers and reviewers must become familiar with the existing and proposed drainage patterns on a site. These drainage patterns include the paths of water entering, crossing, and leaving the site, as well as the areas where water may be stored on the site. Remember that movement of water includes both surface and subsurface components.

In the site plan submittal package, the applicant should provide a plan delineating the existing and proposed drainage areas. It is important to realize that it may or may not be possible to use a property line as a watershed/drainage area boundary. It may be necessary to refer to a town topographic map or a USGS map to identify the off-site contributing drainage area, if this information would effect the analysis. If possible, town drainage information should be consulted to identify any discharge pipes that may also contribute flow to a site. Similar sources of data may need to be used to follow the path of water downstream of the site, when downstream impacts may be of concern.

Applicants should also identify "design points", which serve as the locations where existing and proposed peak discharge rates will be calculated and impacts will be assessed. These points are typically the points of discharge leaving the site, the down-gradient property boundary, or the boundary of a resource area. Depending on the topography and size of the site, there may be more than one design point leaving the site. In some cases, a feature outside of the property boundaries (i.e., a culvert) may be deemed as a more suitable design point. Intermediate watershed areas (sometimes referred to as sub-areas or sub-catchments) may also be delineated to intermediate design points within the overall drainage area, such as catch basins or culverts.

The pre- and post-development watersheds and drainage patterns should be compared to determine if substantial hydrologic alterations are proposed as a result of the project. Applicants should provide adequate information to allow Commissioners to evaluate the impacts to the drainage patterns on site, the water regime of a resource area, and groundwater recharge.

Sediment and Erosion Control Measures

The submittal package should generally provide a plan denoting the proposed erosion and sediment control practices to be implemented during the construction phase of the project to protect resource areas. These practices may include the use of hay bales, silt fences, temporary drainage swales and detention basins, temporary sediment traps, stabilized construction entrances, and slope stabilization practices.

3.3 The Stormwater Management Form

The Stormwater Management Form should be submitted to Conservation Commissions as Appendix C of the Notice of Intent Form (WPA Form 3). This form and the required back-up data are intended to demonstrate compliance with the wetland regulations (310 CMR 10.05(6)(b)) and the DEP's Stormwater Management Policy ("the Policy").

A checklist has been provided at the end of this Chapter (Figure 3-2) to aid Commissioners in determining if the appropriate calculations and information have been provided with the Stormwater Management Form. Appendix G contains a copy of the form.[4]

The Stormwater Management Form identifies the basic information for evaluating compliance with each of the nine Performance Standards set forth by the Stormwater Management Policy. The standards listed in Table 3-1 are discussed in detail in *Stormwater Management Volume One: Stormwater Policy Handbook.*

"Property Information" Section of Form

This section of the form should be completed with information that is consistent with the information provided in later sections of the form pertaining to "New Development versus Redevelopment Projects" (see Standard 7), Water Quality Volumes (see Standard 4), and Critical Areas (see Standard 6).

"Stormwater Management Standards" Section of the Form

This section of the Form is designed to show a project's status of compliance with each of the nine performance standards listed in the Stormwater Management Policy. Where appropriate, applicants should provide additional information (i.e., calculations and/or additional narratives). In addition, the applicant should include a narrative describing which stormwater management standards have or have not been met. If a certain standard cannot be met, the narrative should explain why and additional information should be included to demonstrate how equivalent water quality and quantity protection will be provided.

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[4] The Stormwater Management Form is subject to change. A copy of the current form is posted at www.state.ma.us/dep/brp/ww/wwpubs.htm.

Table 3-1 DEP Stormwater Management Policy and Standards[1] as Published November 1996

The Department will presume that projects meeting the Stormwater Management Standards satisfy regulatory requirements. When one or more of the Standards cannot be met, an applicant may demonstrate that an equivalent level of environmental protection will be provided.

1. No new stormwater conveyances (e.g., outfalls) may discharge untreated stormwater directly to or cause erosion in wetlands or waters of the Commonwealth.
2. Stormwater management systems must be designed so that post-development peak discharge rates do not exceed pre-development peak discharge rates.[2]
3. Loss of annual recharge to groundwater should be minimized through the use of infiltration measures to the maximum extent practicable. The annual recharge from the post-development site should approximate the annual recharge from the pre-development or existing site conditions, based on soil types.
4. For new development, stormwater management systems must be designed to remove 80% of the average annual load (post-development conditions) of Total Suspended Solids (TSS). It is presumed that this standard is met when:
    a. Suitable nonstructural practices for source control and pollution prevention are implemented;
    b. Stormwater management best management practices (BMPs) are sized to capture the prescribed runoff volume; and
    c. Stormwater management BMPs are maintained as designed.
5. Stormwater discharges from areas with higher potential pollutant loads require the use of specific stormwater management BMPs (see chart in Volume One: Stormwater Policy Handbook, March 1997). The use of infiltration practices without pretreatment is prohibited.
6. Stormwater discharges to critical areas must utilize certain stormwater management BMPs approved for critical areas (see list in Volume One: Stormwater Policy Handbook). Critical areas are Outstanding Resource Waters (ORWs), shellfish beds, swimming beaches, cold water fisheries and recharge areas for public water supplies.
7. Redevelopment of previously developed sites must meet the Stormwater Management Standards to the maximum extent practicable. However, if it is not practicable to meet all the Standards, new (retrofitted or expanded) stormwater management systems must be designed to improve existing conditions.
8. Erosion and sediment controls must be implemented to prevent impacts during construction or land disturbance activities.
9. All stormwater management systems must have an operation and maintenance plan to ensure that systems function as designed.

[1]For detailed information regarding the Standards, refer to Stormwater Management Volume 1: Stormwater Policy Handbook (DEP, 1997a).

[2]As explained in the Policy, discharges to waters subject to tidal action do not need to maintain pre-development peak discharge rates.

Commissioners should refer to *Stormwater Management Volume One: Stormwater Policy Handbook* for a full explanation of each Performance Standard. The following discussion offers Commissioners guidance regarding the typical submittal information needed to document compliance with the Policy:

Commissioners should verify that the applicant has furnished calculations of the "water quality volume", as well as calculations documenting compliance with Standards 2, 3, and 4. Commissioners should also verify the accuracy of such calculations.

Standard 1: Untreated Stormwater

No new discharges of untreated stormwater may be discharged directly to, or cause erosion to, wetlands or water of the Commonwealth. Compliance with this standard should be documented by meeting Standards 2 through 9, plus providing measures to prevent erosion. Rooftop runoff, other than from areas of higher potential pollutant loading, that may be infiltrated directly is exempt from this standard.

Standard 2: Post-development Peak Discharge Rates

Typical documentation includes peak rate calculations for pre- and post-development conditions, and calculations supporting design of structures that will control peak discharge rates. This documentation is discussed in Chapters 4 and 6.

Note that this standard does not apply to sites where discharges occur to waters subject to tidal action.

Also note that many towns may require applicants to evaluate storm events in addition to the 2, 10, and 100-year events. Applicants and Commissioners should check local by-laws for relevant standards.

Under the Stormwater Management Policy, Conservation Commissioners will typically review project calculations of **runoff rate** *and* **runoff volume**. *For example, Standard 2 requires controlling* **peak discharge rates** *for certain storm events (see Chapter 6), while Standard 4 requires estimating a water quality treatment* **volume** *(see Chapter 7).*

Standard 3: Groundwater Recharge

Typical documentation includes soils data and calculation worksheets, estimating pre- and post-development annual recharge volumes, and providing the sizing parameters for recharge Best Management Practices. This documentation is discussed in Chapter 8.

Standard 4: 80% TSS Removal

Applicants must indicate the "sizing rule" used for determining the required runoff volume to be treated for water quality (i.e., the water quality volume) under the Stormwater Management Policy. The Policy defines the water quality volume as follows:

- *For discharges to "critical areas", the water quality volume is defined as one-inch of runoff times the total impervious area of the post-development site.*
- *For all other discharges, the volume to be treated is defined as 0.5-inches times the total impervious area of the post-development site.*

The amount of impervious area located on site under proposed conditions should be documented. Calculations of the runoff volume to be treated for water quality, based on either 1-inch or 0.5-inch rule, should be provided. In situations where clean rooftop runoff (except that from certain metal roofs as defined in the Policy) is being recharged, the recharge volume may be subtracted from the total water quality treatment volume.

Typical documentation includes the water quality treatment volume calculations, and calculations of annual TSS removal rates. Chapter 7 explains how to perform these calculations. Submittals should also include information showing that BMPs are sized according to practices outlined in *Stormwater Management Volume Two: Stormwater Technical Handbook.*

For new development projects, stormwater management systems must be designed to remove 80% of the average annual TSS load from post-development conditions. For redevelopment projects, this standard must be met to the maximum extent practicable. Suitable practices for source control and pollution prevention are also required to be implemented.

Total Suspended Solids (TSS) removal calculations, performed in accordance with the guidance given in Volumes I and II of the Policy, should be supplied as part of the NOI submittal package. The structural and non-structural methods should be clearly listed along with any associated TSS removal rates. Commissioners should compare the specified TSS removal rates with those listed in Volume I of the Policy. If a lower or higher removal rate has been used in the calculation or if the use of a BMP not addressed in the Policy is proposed, the applicant must supply back-up data to support the proposed TSS removal rate.

Certain innovative treatment technologies and traditional practices not listed in the Stormwater Management Policy do not have presumed TSS removal rates. Studies estimating the performance efficiency of both innovative and traditional BMPs are constantly being performed.. Appendix D of the Stormwater Management Policy Handbook Volume II explains the process for reviewing innovative treatment technologies that do not have the benefit of a presumed TSS removal rate.

The Commission has the right to request any missing information regarding water quality treatment performance calculations.

For redevelopment projects that do not meet the 80% TSS removal rate, the applicant must provide additional documentation as to why compliance with the standard cannot be achieved.

Standard 5: Higher Potential Pollutant Loads

Documentation should include a listing of land uses, and a listing of proposed BMPs. Note that restrictions apply to certain BMPs in areas of higher potential pollutant loading, and that source reduction and pretreatment are required. If recharge systems are proposed, applicants should provide calculations showing the sizing of the pretreatment system, as well as the recharge system. For proposed projects that contain land uses that may potentially produce higher pollutant loads, the use of infiltration practices without pretreatment is prohibited. For projects where an area of higher potential pollutant loading is located within or up-gradient of a critical area, infiltration is not allowed.

Commissioners should check the list of land uses with higher potential pollution loads, provided in *Stormwater Management Volume One: Stormwater Policy Handbook*. Commissions should also verify that a project qualifying for this list does not use a recharge system within the watershed of a "critical area", as defined in the Policy.

Standard 6: Protection of Critical Areas

"Critical areas" are defined in the Policy and on the Form. Commissioners should verify whether discharges are proposed to or near such critical areas.

Stormwater discharges to critical areas may use only stormwater BMPs that are approved for implementation in such areas. A list of these BMPs is provided in Volume I of the Policy. Calculations should be provided to verify that these structures have been designed to treat one-inch of runoff times the impervious surface of the post-development site.

Standard 7: Redevelopment Projects

Designers and Conservation Commissioners should refer to the *Stormwater Policy Handbook* to determine if a project is a "redevelopment project" as defined in the Policy. Commissioners should verify that all redevelopment projects meet the criteria specified in the explanation of Standard 7 given in that document.

Redevelopment of previously developed sites must meet the Stormwater Management Standards to the maximum extent practicable. Such projects include: (1) maintenance and improvement of existing roadways; and (2) development, rehabilitation, expansion, and phased projects on previously developed sites, provided that there is no net increase in impervious area over existing conditions. For such projects, applicants should furnish documentation comparing the total existing and proposed impervious areas.

In addition, the applicant should include a narrative describing which stormwater management standards have or have not been met. If a certain standard cannot be met, the narrative should explain why.

Standard 8: Erosion and Sediment Control

Commissioners should receive, at a minimum, documentation (i.e., a narrative or checklist) indicating the type of best management practices to be implemented during construction phases, their location, maintenance requirements, the frequency with which inspections will be performed, information on construction sequencing to provide for erosion and sediment control., and information on removing or cleaning out the controls at the conclusion of the project. In some cases (e.g., design of sediment basins), calculations supporting the design of erosion control BMPs may be required.

Standard 9: Operation and Maintenance Plan

An Operation and Maintenance Plan must be prepared for all proposed stormwater management systems and submitted to the Commission. This plan should indicate the following:

- Ownership of the BMPs;
- Parties responsible for operation and maintenance of the systems both during and subsequent to construction;
- A schedule for inspection and maintenance;
- A list of routine and non-routine maintenance tasks to be undertaken; and
- Provision for appropriate access and maintenance easements extending from a public right-of-way to the stormwater controls.

3.4 Additional Calculations and Related Documentation

In addition to the documentation provided for the Stormwater Management Form, a Notice of Intent package may contain other information that is important for evaluating the potential hydrologic impacts of a project. The extent of this information depends greatly on the characteristics of the site. This following list identifies other types of documentation and calculations that may be encountered during an NOI review. Subsequent chapters of this manual offer further discussion of the methodologies and assumptions associated with this information.

- Closed drainage system sizing calculations;
- Culvert design and analysis;
- Open channel system sizing calculations;
- Sizing of stormwater control structures (detention/retention/infiltration basins, water quality swales, and other BMPs);
- Compensatory flood storage calculations;
- Calculations associated with evaluating Isolated Lands Subject to Flooding;
- Hydrologic data associated with Riverfront Areas;

- Hydrologic information associated with Coastal Resource Areas, such as the Dune Volume/“540 Rule”.

3.5 The Site Visit

The site visit is an essential part of the review process, to evaluate potential hydrologic impacts to wetland resource areas. Conservation Commissions should plan the site visit once they have become sufficiently familiar with the site plan and proposed design. It is generally best to conduct the field inspection prior to the public hearing, so that any field conditions not evident on the plan, but possibly requiring special attention, can be addressed at that point. It may be useful to conduct a second site visit following the hearing, but before the issuing of the Order of Conditions.

By visiting the site, Commissioners will have a better understanding of the existing conditions in general, as well as the hydrologic regime of the affected wetland resource areas. The site visit may also help Commissioners understand the scale and character of the proposed project, particularly if inadequate topographic data is supplied. In some cases, it may be helpful to conduct the visit during or shortly following a storm event.

While on-site, Commissioners should verify the boundaries of resource areas, check topographic features (for example, possible topographic depressions), and observe existing drainage patterns. They should note any discrepancies between existing conditions encountered in the field and those shown on the plan. They should also note the location of proposed structures in relation to resource areas. This process may be made easier by having applicants stake the corners of proposed buildings and the centerlines of proposed roadways. It may also be helpful to have either the applicant or an appointed representative present at the site visit.

3.6 Checklists for Stormwater Management Reviews

To help Conservation Commissioners in evaluating projects for hydrologic impacts, this Handbook offers three checklists for use in the review of project proposals. These lists are not intended to be exhaustive, but rather an organized guideline for the evaluation thought process. The checklists are presented in the following figures:

- Figure 3-1 lists a number of questions that Commissioners can consider in reviewing a project’s potential hydrologic effects on regulated resource areas.
- Figure 3-2 lists items that Commissioners should observe when they conduct a site visit of a property under review.
- Figure 3-3 comprises a checklist of hydrologic data and supporting information that should be included in a submittal to the Commission.

Note: It should be emphasized that implementation of the Stormwater Management standards contained in the DEP Stormwater Management Policy does not reduce or supercede any other requirements in the regulations for the Wetlands Protection Act.

Figure 3-1 Evaluating Projects for Hydrologic Impacts

This is a basic list of questions Conservation Commissioners will need to address in the course of their hydrologic review. The list can be used together with the Site Visit Checklist (Figure 3-2) and the Submittal Checklist (Figure 3-3), to assist Commissioners in evaluating stormwater management aspects of a project.

- ☐ Has the Applicant submitted the Stormwater Management Form and all necessary supporting information, signed and stamped as applicable?
- ☐ Have all applicable resource areas on the site been correctly identified and delineated? [1]
- ☐ Have Critical Areas (as defined in the Stormwater Management Standards) downstream of the project site been correctly identified?
- ☐ Have the existing drainage patterns on the site been accurately represented? [1]
- ☐ Has the Applicant used acceptable methods/models for hydrologic calculations (refer to Chapters 4, 5, 6, and 7 for discussion of accepted calculation methods)? Are the values used for soils, land cover, and other factors required for the calculations consistent with actual field conditions? [1]
- ☐ Is the project subject to compliance with the Stormwater Management Standards? If so, have you verified its status with respect to development/redevelopment and the required water quality volume?
- ☐ Are the design points used in hydrologic calculations adequate to assess impacts on individual resource areas? The design points should be the same under existing and proposed conditions. The total drainage area analyzed should also be the same under existing and proposed conditions (although individual sub-areas may differ in size between the two conditions).
- ☐ How will the drainage patterns on the site be altered by the project (e.g., with respect to the volume, location, or rate of discharge)? Is this likely to impact individual resource areas or their functions?
- ☐ Will the existing peak flow rates from the site be replicated under proposed conditions for at least the 2-year and 10-year storm events? How will they be controlled? If peak rates are not controlled, has the applicant submitted documentation to show that such controls are not necessary (e.g., the project discharges to a watercourse subject to tidal action)?
- ☐ Have the impacts of the proposed project on downstream flooding in the 100-year frequency event been adequately assessed and mitigated?
- ☐ What impact will the proposed project have on groundwater recharge? Does the design provide adequate groundwater recharge per Standard #3 of the Stormwater Management Standards?
- ☐ Does the proposed project use appropriate BMPs to treat site runoff? Has the applicant documented that all stormwater runoff from impervious surfaces (except roof drainage that will be infiltrated) will be treated to achieve 80 percent removal of the TSS? Has the applicant sized facilities according to the appropriate sizing rule specified in the Stormwater Management Standards (1.0-inch times the contributing impervious area for discharges to Critical Areas, 0.5-inch times the impervious area for other discharges)?
- ☐ Does the proposed project constitute a land use with higher potential pollutant loads per Standard #5? If so, are source reduction and pretreatment provided?
- ☐ If the project discharges to a Critical Area, has the 1.0-inch sizing rule been used, and does the applicant propose one or more of the types of BMPs recommended in the DEP's Stormwater Management Handbook?
- ☐ Does the proposed project provide compensatory flood storage for any filling within the BLSF?

[1] Submitted information should be confirmed through on-site inspection.

Figure 3-2 Site Visit Checklist for Hydrologic Evaluation

Conservation Commissioners should try to visit each site to assess actual conditions, verify submittal data, and develop an understanding of the hydrologic regime of the property. To help with this hydrologic evaluation, here is a list of conditions to observe during a visit to the site:

- ☐ Verify that all resource areas on the site have been appropriately identified and delineated.
- ☐ Observe the drainage patterns on the site. Look at the overall conditions including drainage onto and leaving the site, as well as drainage to individual resource areas.
- ☐ Observe the locations of the analysis points used for developing the project stormwater management calculations. Confirm that these points are consistent with the drainage patterns of the site.
- ☐ Note whether soils conditions appear consistent with information submitted for review.
- ☐ Note whether land cover types are consistent with information submitted for review.
- ☐ Note evidence of flooding or flow backups on the site and in adjacent watercourses. Look for evidence such as high water marks on trees, rocks, culvert headwalls, and bridge abutments; channel scouring; flattened vegetation; and sediment deposits.
- ☐ Observe potential ILSF's and their contributing watersheds, and confirm that this information appears consistent with submittal documentation.
- ☐ Observe the locations of proposed buildings and paved areas (they should be staked or clearly marked) relative to resource areas.
- ☐ Observe the locations of key structural components of the stormwater management system (e.g., proposed outlets, stormwater detention basins, water quality treatment BMPs, recharge systems) relative to resource areas.

Figure 3-3 Submittal Checklist for Hydrologic Evaluation

Conservation Commissioners should verify that submittals are complete. The following list will assist in completing this process:

- ☐ Site Plans showing all Wetlands Protection Act resource areas and applicable buffer zones, existing and proposed topography, all proposed structures, and existing and proposed land cover (e.g., woods, lawn, impervious surface, etc.).
- ☐ Completed and signed Stormwater Management Form.
  - ☐ The type of project (new or redevelopment) is valid.
  - ☐ Critical Areas (if any) are identified.
  - ☐ Areas of Higher Potential Pollutant Loads (if any) are identified
- ☐ Hydrologic calculations for existing and proposed conditions.
  - ☐ Maps showing analysis points (same for existing and proposed conditions), existing and proposed drainage areas, and time-of-concentration paths, consistent with the drainage calculations.
  - ☐ Hydrologic soil groups from applicable U.S. Natural Resources Conservation Service (NRCS) County Soil Survey.
  - ☐ Calculations of existing and proposed peak runoff rates for the 2, 10, and 100-year, 24-hour storms.
  - ☐ Documentation that proposed peak discharge rates do not exceed existing rates for the 2 and 10-year storm events.
  - ☐ Documentation that proposed stormwater design does not result in increased flooding off-site for the 100-year, 24-hour storm event.
  - ☐ Calculation of runoff "water quality treatment volume", based on the correct sizing rule (1.0-inch for Critical Areas, 0.5-inch for other areas).
  - ☐ Documentation that Total Suspended Solids (TSS) removal rate has been calculated using methodology described in Volumes I and II of the Stormwater Management Policy, or that the applicant has used an acceptable alternative TSS analysis method.
  - ☐ Calculations of volume of runoff to be recharged to groundwater, as specified in Standard 3 of the Stormwater Management Policy.
  - ☐ Sizing calculations for all stormwater BMPs (e.g., detention ponds, water quality swales, other BMPs).
  - ☐ Documentation that BMPs have been sized according to guidelines specified in the Stormwater Management Policy, or that the applicant has used an acceptable alternative sizing methodology.
  - ☐ Calculations for sizing of proposed conveyance systems (e.g., culverts, storm drain pipes, open channels).
  - ☐ Calculations of compensatory flood storage for BLSF, if applicable.
  - ☐ Calculations supporting ILSF determination, if applicable.
  - ☐ Calculations of sand reservoir for frontal dune (540-Rule), if applicable.
  - ☐ Other calculations as warranted by unique characteristics of project.
- ☐ Stormwater Management Facilities Operation and Management (O & M) Plan for proposed stormwater management system.
- ☐ Sediment Erosion & Control Plan.

3.7 Sources of Technical Information and Assistance

> *Because of the specialized nature of hydrologic computations, Commissioners are encouraged to seek professional assistance to review submittals. Many communities have town engineers and other staff who can provide such assistance. Review services are often provided at the applicant's expense.*
>
> *Technical assistance may also be obtained from wetlands staff at the appropriate DEP regional office:*

Western Regional Office:	*(413) 784-1100*
Central Regional Office:	*(508) 792-7650*
Northeast Regional Office:	*(978) 661-7677*
Southeast Regional Office:	*(508) 946-2700*

The hydrologic and hydraulic calculations required to document a submittal to the Conservation Commission can be very complex. Generally, applicants will need to retain professionals with specialized training and experience to perform the necessary calculations, and develop appropriate designs for constructing projects. Conservation Commissioners are not expected to have the expertise to reproduce or verify these complicated hydrologic computations. The purpose of this manual is to provide Commissioners with some basic concepts, and to familiarize them with some of the accepted methodologies, to enable them to conduct a reasonable review of activities within their jurisdiction.

Sources of technical assistance and information are cited in later Chapters of this manual. The following is a list of MA DEP references that Commissioners may find useful; additional references are included in Appendix H.

Massachusetts Stormwater Management Volume 1: Stormwater Policy Handbook. March 1997. Massachusetts Department of Environmental Protection and Massachusetts Office of Coastal Zone Management.

Massachusetts Stormwater Management Volume 2: Stormwater Technical Handbook. March 1997. Massachusetts Department of Environmental Protection and Massachusetts Office of Coastal Zone Management.

Massachusetts Stormwater Management Policy: Supplemental Guidance. Technical Bulletin: Guidance for Stormwater Standard #3 (Recharge to Groundwater). (Publication Pending)

Delineating Bordering Vegetated Wetlands Under the Massachusetts Wetlands Protection Act. March 1995. Massachusetts Department of Environmental Protection, Division of Wetlands and Waterways.

Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas. 1997. Massachusetts Department of Environmental Protection.

Massachusetts Department of Environmental Protection Web Site at
http:// www.state.ma.us/dep/dephome.htm or www.mass.gov/dep

Chapter 4:
Estimating Runoff Quantities

This chapter contains some basic information about estimating stormwater runoff quantities, including:

- How is runoff related to rainfall?
- What runoff quantities need to be determined?
- Why should conservation commissioners be concerned about runoff volumes and rates?
- What methods are commonly used for estimating runoff?
- What are the typical steps for performing a runoff calculation?

For those who are interested in more detail, the chapter includes:

- Some more details about the technical components of runoff estimation methods.

4.1 How is Runoff Related to Rainfall?

Chapter 2 described the hydrologic cycle, and the general relationship among precipitation, runoff, and other components of that cycle. This Chapter will address the basic relationships between rainfall and runoff that serve as a basis for estimating runoff volumes and peak runoff rates. Primarily, this Chapter focuses on stormwater runoff, and its potential impacts on wetland resource areas.

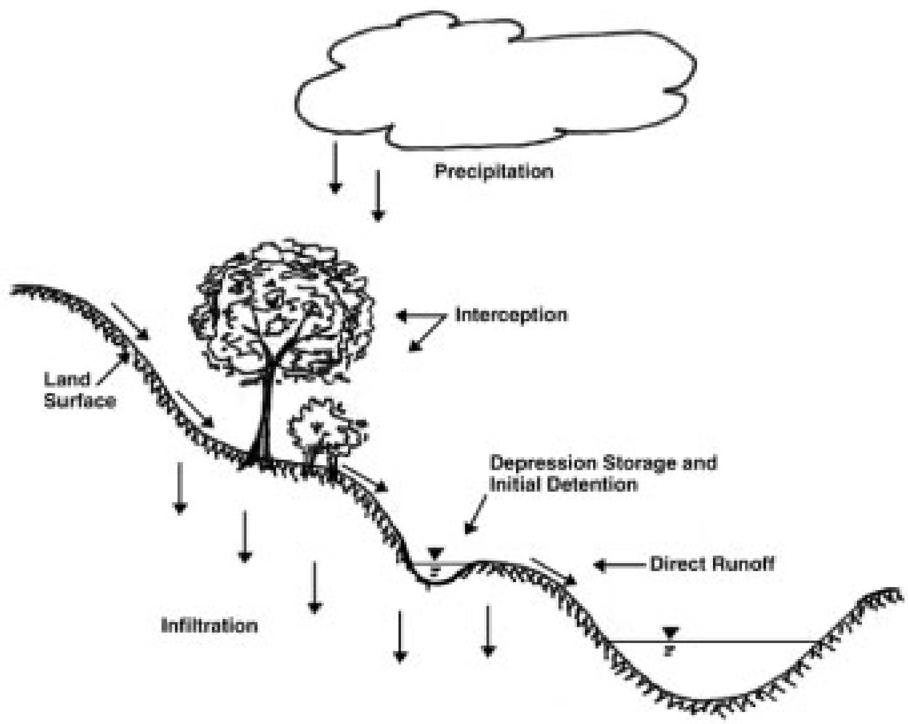
Figure 4-1 shows a schematic representation of the generation of stormwater runoff. When rain falls on the earth's surface, some of that rain is intercepted by the surfaces of vegetation located in its path (interception). Depending on soil characteristics and amount of rainfall, some or all of the remaining rainfall will enter the ground through pores in the surface soils (infiltration). As the remaining water, if any, flows overland, irregularities in the surface of the land trap some of this water as depression storage. The portion of this overland flow that reaches the watershed outlet is called direct runoff, or stormwater runoff.

This relationship can be expressed as a storm event water balance, by the following equation:

Runoff = Precipitation - Interception - Infiltration - Depression Storage

This very basic relationship is the basis for most methods used to estimate runoff. In hydrologic analysis, interception, infiltration, and depression storage are sometimes referred to as "abstractions". Thus, runoff is what remains of rainfall, after accounting for abstractions. The runoff estimating methods discussed in this manual each use a procedure for determining "hydrologic abstraction"; that is, determining the amount of runoff that results from a particular rainfall event. Note that a portion of the water from the various components expressed in this equation later becomes available for evapotranspiration (ET) as part of the hydrologic cycle.

Figure 4-1 Relationship of Direct Runoff to Precipitation



From the above equation, we can observe that anything that affects the "abstraction" processes will affect the amount of runoff. Reducing the extent of vegetation can reduce interception, increasing runoff. Installing pavement and other impervious surface can reduce infiltration, and increase runoff. Re-grading the land surface and changing the surface cover can alter the amount of depression storage, with associated changes in runoff. Thus, development of a site usually results in an increase in runoff. The potential effects of development are discussed further below.

4.2 What Runoff Quantities Need to be Determined?

When we estimate runoff, we are concerned with the quantities of **runoff volume** and **runoff rate**.

Runoff Volume

The **volume** of surface runoff that will occur on a site during a given rainfall event depends on a number of factors:

- Watershed area;
- Amount of precipitation;
- Rainfall event duration and intensity (volume per unit of time);
- Surface soils characteristics; and
- Land-use surface cover.

Under the Stormwater Management Policy, Standard 2 requires controlling peak discharge **rates** *(not* **volumes***) for the 2-year and 10-year frequency storm events.*

In analyzing the hydrology of wetland resource areas, several runoff volume quantities are of interest. For instance:

- The runoff volume associated with a storm event;
- The runoff volume over an extended time (e.g., annual runoff);
- A runoff volume for water quality treatment.

Runoff volumes are generally estimated in terms of “watershed inches”, cubic feet (ft^3), or acre-feet. A “watershed inch” is equivalent to a one-inch depth of water spread over the entire contributing watershed. An “acre-foot” is equivalent to one foot of water spread over an acre of area.

EXAMPLE: A watershed has an area of 2 acres. (a) If a 2-year 24-hour design storm of 3.1 inches results in 2 inches of runoff , what is the volume of runoff in acre-feet? (b) What is the volume in cubic feet?

(a) $\text{Volume} = 2 \text{ acres} \times 2 \text{ inches} \times \dfrac{1 \text{ foot}}{12 \text{ inches}} = 0.33 \text{ acre-feet}$

(b) $\text{Volume} = 0.33 \text{ acre-feet} \times \dfrac{43{,}560 \text{ ft}^2}{\text{acre}} = 14{,}375 \text{ ft}^3$

<u>Runoff Rate</u>

The term **runoff rate** refers to the volume of runoff discharging from a given watershed per unit of time. The rate at which runoff discharges from a given watershed depends on the following factors in additional to those affecting runoff volume:

- Surface roughness (determined by the type of surface cover);
- Location of impervious area in the watershed relative to the point of analysis;
- Slope of the ground surface;
- Distance the runoff must travel to the point of analysis.

Runoff rates (volume of runoff in a unit time) are usually estimated or measured in cubic feet per second (cfs).

Designers and Conservation Commissioners are often interested in the rate that runoff discharges to an outlet. Frequently, the effects that moving water has on a wetland resource area will be of concern. For instance, it may be necessary to learn whether a natural channel or a proposed culvert has the capacity to convey a particular stormwater flow. Therefore, procedures are often needed for determining **peak discharge rates** (also referred to as peak rate, peak runoff rate, and peak discharge) from a runoff event.

> ***What is a "Design Storm"?*** *A design storm is a hypothetical precipitation event used for analyzing or designing a hydraulic structure or stormwater management facility. A design storm is defined using several parameters, including total amount of precipitation during the event, duration of the event, intensity of precipitation at various times during the event, and the return period (or frequency of occurrence) of the event. These concepts are explained in Section 4.6 of this chapter.*

When analyzing the hydrology of wetland resource areas, a variety of runoff rates are of interest. Under MA DEP's Stormwater Management Policy, the post-development peak runoff rate should not exceed the pre-development peak runoff rate for the following **design storms**:

- The 2-year frequency, 24-hour storm event;
- The 10-year frequency, 24-hour storm event.

4.3 Why should Conservation Commissioners be concerned about Runoff Volumes and Rates?

As discussed in Chapter 2: Fundamentals of Hydrology, the functions of wetland resource areas are primarily driven by, and sensitive to, the presence or absence of water, and the movement of water through the wetland system. A change in any one component of a wetland resource area's water balance, can result in changes in the other components, which in turn can result in altering the wetland. Examples of these kinds of impacts include the following:

- Reducing the contributing watershed to a wetland can reduce the volume of runoff entering the wetland. Also, increasing the watershed area draining to a wetland can introduce additional volumes of water, changing the hydrologic character of the wetland;
- An increase in volume of runoff into a wetland can result in higher water levels for sustained periods, which may have adverse effects on the biological community in the wetland;
- Increases in peak rates of runoff can overtax the capacity of existing drainage systems, including natural watercourses;
- An increased frequency of **bankfull** flow events as the result of watershed changes can result in the erosion of natural stream banks.

The development of a site can result in significant changes to its shape (topography), cover characteristics, and drainage patterns. The addition of roads, parking lots, driveways, patios, roofs, walkways, and other impervious surfaces will reduce the amount of water infiltrating into the ground surface, and thus increase the volume of direct surface runoff. The provision of storm drainage channels and piping, in addition to alterations of the surface texture, will result in the runoff moving more quickly across the site, thus increasing peak rates of runoff.

Therefore, depending on the particular impact under study, Conservation Commissions may need to evaluate the total volume of runoff for an event or a period of time. More frequently, the primary focus of hydrologic analysis will be the estimation of peak rates of discharge of stormwater runoff during particular design events.

The remainder of this chapter discusses the estimation of runoff volumes and peak rates. Chapter 6 discusses strategies for controlling peak rates of stormwater discharge. Chapter 7 discusses estimating runoff volumes to provide water quality treatment.

4.4 What Methods are Commonly used for Estimating Runoff?

There are many methods available for the estimation of runoff volumes and rates. Under the Department's Stormwater Management Policy, runoff volume and rate should be estimated using Soil Conservation Service (SCS, now the Natural Resources Conservation Service) methods, assuming the necessary underlying assumptions of the SCS models are satisfied. The selection of methods depends on a number of factors, including:

- Whether the method will be used to estimate total runoff volumes, peak rates, or variations of flow rate with time over the duration of a storm event;
- Whether the values obtained by the method will be used for sizing storm drain pipes, detention facilities, water quality treatment facilities, or other purpose;
- Limitations inherent in each method;
- Data available for performing the calculations; and
- Whether the method requires calibration to actual field data.

Note, whichever method is used to evaluate hydrologic impacts, the user should be aware that the intent of the performance standards in the Wetlands Protection regulations and Stormwater Management Policy requires the post-project hydrologic budget to equal the pre-project hydrologic budget. This means that in addition to evaluation of a project using the methods described below, a hydrologic budget may need to be prepared in some cases, such as when drainage is directed away from its original sub-watershed, to demonstrate that the water budget to remaining wetland resource areas will be maintained at pre-project levels. The available methods to evaluate and design components of stormwater management systems are:

- **The Rational Method**
- **The SCS Curve Number/Unit Hydrograph Method**

  This method is described in detail in the *SCS National Engineering Handbook*, Section 4 – Hydrology and should be used to estimate runoff volumes and rates under the Department's Stormwater Management Policy, assuming the necessary underlying assumptions of the SCS models are satisfied. Please see Appendix C for further information. The Natural Resources Conservation Service (NRCS, formerly the SCS) developed this method, as well as the following models that use the method:

TR-20: Computer Program for Project Formulation, Hydrology (Soil Conservation Service Technical Release 20).

TR-55: Urban Hydrology for Small Watersheds (Soil Conservation Service Technical Release 55). This method is a simplified procedure that does not require the use of a computer; it is based on TR-20.

Please note, proprietary computer software for estimating runoff volume and rate often allow the user to select the specific runoff estimation method to be used, such as TR-20 and TR-55.

- **Other Methods that use Runoff Hydrographs and Hydrograph Routing To Characterize Runoff/Rainfall Relationships**
  - For example, the U.S. Army Corps of Engineers HEC-1 and HEC-HMS computer programs which allow the use of TR-20 input. (For further information on hydrographs and hydrograph routing, see the end of Section 4.6).
- **Statistical Methods that Use Existing Flood or Streamflow Data to Estimate Peak Steam Flows or Flood Elevations Based on Anticipated Frequency of Recurrence.**
  - An example is the PEAKFQ software application available from the US Geological Survey (http//water.usgs.gov/software/peakfq.html). This method uses a modification of the "log Pearson Type III" technique, described in "Bulletin 17B" (Interagency Advisory Committee on Water Data, 1982).

A number of commercially available computer software programs incorporate one or more of these methods, along with other estimating methods, and are widely used by the engineering community in Massachusetts. Some components of the SCS (now NRCS) Curve Number/Unit Hydrograph method are also used within other estimating procedures, such as HEC-1 and HEC-HMS.

Table 4-1 lists commonly used runoff estimating models, indicates when each model's use is generally applicable, and identifies some of each model's limitations. Generally speaking, the procedures should be used as follows:

Table 4-1 Runoff Estimation Methods, Applicability, and Limitations

Method or Model	Acceptable Application	Limitations
Rational Method	Sizing drainage pipes, culverts, and drainage channels.	Should not be used when detention storage structures are required. Other limitations are listed in Appendix B.
TR-55 Model Urban Hydrology for Small Watersheds	Estimating runoff curve number and runoff volume. Estimating time of concentration. Estimating peak rates (when detention storage is not required). Estimating peak rates and “rough sizing” of detention structures.	Should not be used for final design of detention storage structures. Other limitations are listed in Appendix C.
TR-20 Model Computer Model for Project Formulation, Hydrology	Estimating runoff curve numbers and runoff volumes. Estimating peak rates of discharge. Development of hydrographs. Performing runoff calculations that account for existing storage within the watershed. Performing routing calculations for proposed detention structures.	Reference material identifying limitations of model is cited in Appendix D.
Other Hydrograph Generation/ Hydrograph Routing Models	Similar applications as TR-20.	Users should furnish documentation of model assumptions and limitations, as part of hydrologic report.
Statistical Methods	Varies, refer to material documentation	Users should furnish documentation of model assumptions and limitations, as part of hydrologic report.

- **The Rational Method** is generally used for estimating peak flows, to develop designs for conveyance systems such as culverts, piped storm drains, and open channel systems. While there is an adaptation of the rational method that may be used for estimating detention storage volumes, the method is cumbersome to use in comparison to other available modeling tools. Also, it is not generally appropriate for development of peak rate control devices such as detention and retention basins. For those interested in how to use the Rational Method, Appendix B contains a summary of the procedure.

- **TR-55** is referenced in the Wetlands Protection regulations and Department’s Stormwater Management Policy Handbook and useful for estimating peak flows. The “runoff curve number” method of estimating volume of runoff, used in TR-55, is used in a number of other models. TR-55 is actually based on TR-20, and was developed at a time when computer software was not readily available to most designers and reviewers. The method has some limitations, especially for sizing detention facilities with low discharge rates or multiple outlets. Therefore, it should not be used for the final design of detention systems, including their final sizing.

The TR-55 manual, available from the NRCS, is a useful reference for those using TR-20 or other models based on the SCS Runoff Curve Number method. The manual contains a complete description of the procedure and pertinent charts for developing curve numbers (CN values), as well as the procedure for estimating time of concentration. For those interested in how to use TR-55, Appendix C contains a guidance summary that references the TR-55 manual. Appendix C also offers information to help verify whether the selection of a CN is reasonable.

- **TR-20, or a comparable model employing the development of runoff hydrographs and hydrograph routing** (see the explanation of these concepts, given in the end of Section 4.6), can be used to estimate runoff volumes, peak runoff rates, runoff rate as a function of time, and performance of storage structures. This type of method requires the use of a computer. This type of method should generally be used for the analysis of complex stormwater systems, especially those that use detention storage to control peak discharges. The performance of these methods will not be described in this manual; instead, you should refer to the software documentation for these models. However, Appendix D contains a sample of the computer output of a TR-20 analysis, annotated to show you where certain key information can be found.

Those interested in hydrology-related software available from public domain sources can check the following web-sites:
http://.water.usgs.gov/software,
http://www.wcc.nrcs.usda.gov/water/quality/text/hydrolog.html
http://www.hec.usace.army.mil/software/index.html
http://www.epa.gov/ceampubl/softwdos.htm

4.5 What are the Typical Steps for Performing a Runoff Calculation?

Table 4-2 presents a step by step overview of the process for estimating runoff volume and rate for a site. This general procedure is common to any runoff estimation method. As designers follow this process, they compile data, make assumptions, and perform calculations. Table 4-2 lists recommended information for designers to provide, to document the runoff estimation procedure, and to enable review by Conservation Commissions and their staff and consultants.

Table 4-2 Runoff Estimation Procedures General Approach

	Description of Step	Recommended Documentation	Items for Conservation Commissioners to Check During the Review Process
Step 1	Select Runoff Estimating Method Based on preliminary information about the watershed, and the purpose of the analysis, select appropriate method for estimating runoff volume and/or rate and/or hydrograph	Describe purpose of analysis, watershed description, and reason for selecting method in drainage analysis report narrative.	Use of Rational Method should generally be limited to pipe and channel sizing. Use of TR-55 should generally be limited to estimating runoff volumes. It may be used for estimating peak flows. When sizing detention facilities, it should only be used for preliminary estimations ("rough sizing"). Complex watersheds, and systems using detention storage for controlling discharges, should use a hydrograph generation/routing methodology (TR-20, or other comparable method).
Step 2	Identify Analysis Points	Show selected analysis points on pre- and post-development watershed plans.	The same analysis points should be examined for pre-development and post-development flows
Step 3	Delineate Watershed (Catchment) of Each Analysis Point	Show watersheds on pre- and post-development watershed plans.	While the contributing sub-watershed to each analysis point may change in area as a result of development, the total watershed analyzed (sum of all sub-watersheds) should be equal for pre-and post-development calculations
Step 4	Characterize Each Watershed (Catchment): Total area (A), expressed in units appropriate to the method Other parameters regarding land use, soils, and other features required as inputs to selected analysis method	Provide worksheets and calculations summarizing watershed information, and identifying the source of information.	
Step 5	Determine design event(s) to be analyzed, and obtain precipitation data in the format required for the selected method	Provide citations for regulatory and/or engineering standards used to select design events. Cite source of precipitation data.	Pre- and post-development analyses should use consistent data for precipitation. For instance, the 100-year rainfall used for analyzing existing conditions, should be the same rainfall used for post-development conditions.
Step 6	Determine runoff coefficient (Rational Method) or runoff curve number (SCS Curve Number method). *If using another methodology, determine the runoff/precipitation volume relationship using "hydrologic abstraction" procedure appropriate to the selected method.*	Provide worksheets, calculations, and reference citations for runoff coefficients, curve numbers, or other relevant parameters.	For example, for Rational Method, determine runoff coefficients (see Appendix B). For TR-55, TR-20, and comparable methods, determine Runoff Curve Numbers (see Appendix C).

Table 4-2 Runoff Estimation Procedures General Approach (continued)

	Description of Step	Recommended Documentation	Items for Conservation Commissioners to Check During the Review Process
Step 7	Determine Time of Concentration (tc) for each analysis point.	Provide worksheets, calculations, and references; show travel paths on pre- and post-development watershed plans.	Travel paths should represent the longest travel time, not necessarily the longest distance. Also, for methods such as TR-55 or TR-20 that identify a "sheet flow" component, that component should not exceed a distance of 50 feet except under special circumstances (see Appendix C).
Step 8	For each analysis point, determine runoff volume and/or rate using the equation(s) and/or hydrograph generation/routing procedures specified by the selected method.	Provide worksheets, calculations, references, and computer input and output documentation. This information should be organized in a fashion that facilitates independent review.	Post-development peak rates should be compared to pre-development conditions for each analysis point. Results at multiple analysis points should not be artificially summed, to give a fictitious "peak rate" for an entire site.

Specific comments on each step of this procedure follow:

Step 1: Select Analytical Method

With a general knowledge of the size and character of the watershed under study, and an understanding of the advantages and limitations of the available methodologies, the designer must select the appropriate method and model for estimating runoff volumes or peak discharge rates. Designers should generally provide a narrative as part of the NOI submittal (or a separate drainage report in support of the submittal). This narrative or report should identify the methods chosen for analyzing runoff from the development site, and indicate how the assumptions of those methods are consistent with the watershed under analysis.

Note that more than one method or model may be used for a particular project. For example, the overall site might be evaluated using TR-20, to develop detention facilities for controlling peak flows from a proposed development. The Rational Method might be used for sizing pipes within the development.

Step 2: Identify Analysis Points

Once a hydrologic method is selected, the first step in estimating runoff by any method is the selection of “analysis points”. Except for the rare instance in which a site is essentially a basin with no outlet, any runoff that occurs must leave a site at one or more locations. These locations must be identified to account for runoff from the entire area of the site that may be affected by proposed development.

Sometimes an analysis point will be obvious, as in the case where a stream or intermittent channel exits a site. In other cases, flow may actually leave an existing site as “overland flow” (consisting of sheet flow or shallow concentrated flow), distributed for some length along a boundary line. Each of these locations must be identified for the pre-development condition, and plotted on a plan showing the topography of the site, as well as off-site areas that drain to the site.

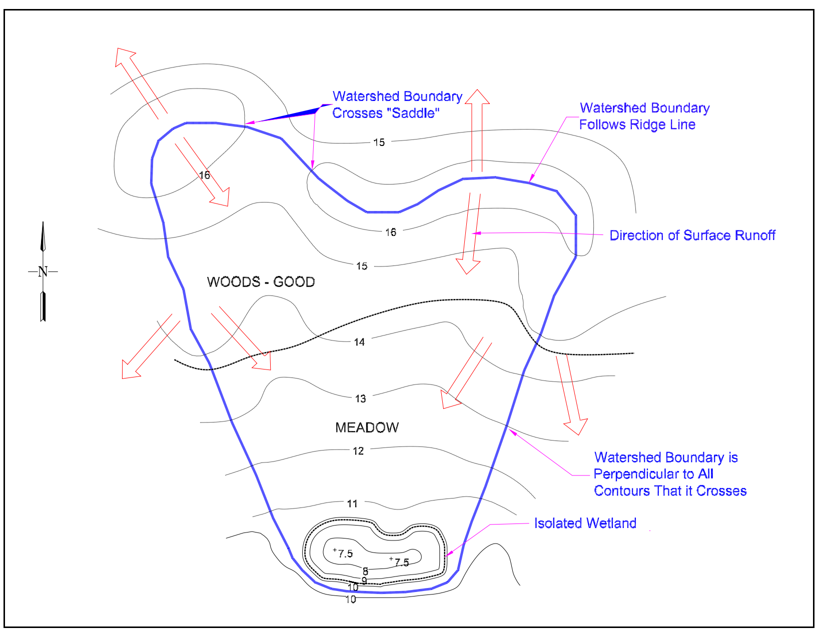
In many cases, analysis points will be selected at the property line of the proposed development, or at or near the limits of site disturbance within a property. In some cases, such as where there is a critical structure downstream of the property, an off-site analysis point may be necessary.

These same analysis points need to be evaluated for pre-development and post-development conditions. A common problem encountered in the review of drainage calculations is the failure of the designer to account for all original analysis points. Another common problem is that some designers will artificially lump calculations for multiple analysis points together. By doing this, they can sometimes show that overall peak rates for a parcel decrease as a result of development, when in fact the peak discharges at certain locations increase dramatically. The purpose of selecting consistent and discrete analysis points is to be able to assess impacts downstream of each location where changes in runoff are significant.

Step 3: Delineate Watershed of Each Analysis Point

Each analysis point has a contributing **watershed**. Each watershed (or **sub-watershed, catchment,** or **contributing watershed area)** should be delineated on a plan using available topographic mapping, as topographic relief defines the horizontal limits of a watershed. Some of the watersheds may extend beyond the limits of the actual site under study. The off-site areas must be included in the analysis. A pre-development watershed map and a post-development watershed map should be prepared. Figure 4-2 illustrates the delineation of a watershed's boundaries.

Figure 4-2 Determining Watershed Boundaries



This Plan Shows the Contributing Watershed of the Isolated Wetland

Proposed development plans for a site may include changes in grading of the land surface, that result in post-development sub-watersheds of different shape and size than the pre-development sub-watersheds. Some sub-watersheds may even be eliminated as a result of the new grading. Therefore, individual analysis points may end up having different contributing watersheds under pre- and post-development conditions. However, the sum of the areas of all sub-watersheds to all analysis points should be the same for pre- and post-development conditions. That is, the total area analyzed for pre- and post-development should be the same. Therefore, a sufficient number of sub-watersheds must be identified to allow evaluation of the impacts to individual resource areas affected by the project.

Step 4: Characterize Each Watershed

Each watershed needs to be characterized according to several factors, depending on the runoff estimation method. Submittals for Conservation Commission review should include information documenting how the designer has determined the pertinent factors. These factors may include:

- Watershed area (also referred to as "catchment area" or "drainage area"), usually measured in acres or square miles, depending on the method (1 square mile = 640 acres);
- Watershed slope (some methods); generally measured as the change in elevation divided by horizontal distance, and usually expressed as a percentage;
- Watershed shape (some methods), such as a width to length ratio;
- Drainage patterns (paths that runoff follows as it flows through the watershed);
- Soil characteristics of the watershed (some methods; see discussion under "Watershed Characteristics" in Section 4.6 below);
- Land-use cover types of the watershed.

The guidance materials for each particular computation method will provide more detail on the watershed parameters needed for that method.

Step 5: Select Precipitation Event for Analysis

Precipitation is usually measured in inches of depth (or watershed inches). For estimating runoff, depending on the method used, certain information is needed in order to select a depth for use in the analysis. When using precipitation data, the following information is generally required:

- Design frequency of the event (e.g., 2-year, 10-year, or 100-year frequency storm);
- The duration of the event. For example, with the Rational Method, the rainfall duration is considered equal in length to the time of concentration (explained under Step 7 below). For the TR-55 and TR-20 methods, a 24 hour event is usually used;
- The distribution of depth of rainfall over time, for the event selected (e.g., for the TR-55 or TR-20 methods, a Type III synthetic rainfall distribution is used for Massachusetts).

Additional discussion of rainfall distribution and intensity concepts is provided later in this chapter.

The design event and duration are frequently specified by regulatory standard. The designer must comply both with local by-laws and state guidelines (the Stormwater Management Policy requires the analysis of the 2, 10, and 100-year, 24-hour storms; current DEP policy also requires using rainfall data from the TP-40 Atlas).

Some additional information on storm-frequency concepts is included later in this Chapter.

Step 6: Determine Runoff/Precipitation Relationship

Most methods for estimating runoff involve a procedure to define the relationship between rainfall and runoff based on land cover (and in some cases, on soil and slope characteristics). The Rational Method uses a runoff coefficient (see Appendix B for more information). TR-55, TR-20, and a number of other models use the SCS Runoff Curve Number method (see Appendix C; Runoff Curve Number is also described in detail in the TR-55 manual). The designer should include documentation for review, showing how runoff coefficients or curve numbers are derived for the site under study.

Step 7: Determine Time of Concentration

Calculations submitted for Conservation Commission review will typically include an estimate of the **time of concentration** (Tc) of a watershed. This parameter is equal to the time of travel of runoff from the hydraulically most distant point in the watershed, to the analysis point at the outlet of that watershed. The “hydraulically most distant point” is defined by the path of longest time, not necessarily the longest distance. For instance, the time of concentration across a very flat slope with a relatively short length, may be greater than for a longer, steeper slope.

Time of concentration is dependent on the roughness of the land surface, the slope, and the distance. Some methods for determining time of concentration also consider whether the flow is sheet flow, shallow concentrated flow, or channelized flow.

Designers should show travel paths used to estimate times of concentration on the watershed maps showing the pre- and post-development watersheds. Calculations of time of concentration should also be included.

Step 8: Determine Runoff Volume and Rate Using Selected Method.

Once the data in Steps 1 through 7 are compiled, the runoff calculations can be performed. Documentation of the calculations should be provided. Most often, this documentation will be in the form of computer output.

The computations can be complex, and difficult to follow. Commercially available computer programs vary in the format in which they show the input parameters and the results of calculations. Each submittal should have a narrative that explains how the model was applied, what assumptions were made, what the input parameters were and how they were developed. The narrative should also summarize the results of the analysis. Conservation Commissioners should not hesitate to ask for such a narrative, if one is not included in the submittal.

4.6 Some More Details about the Technical Components of Runoff Estimation Methods

As discussed above, a number of methods (or models) are available for estimating the volume of runoff from a storm event (or from a series of events), and for estimating the peak discharge rate associated with a given event. A full explanation of these methods is beyond the scope of this manual. However, the following provides a conceptual description of the general components of the various methods used to estimate runoff.

All methods use some or all of the following components:

- A determination of watershed characteristics;
- Selection of a precipitation event and its properties;
- A method of hydrologic abstraction (determination of how much rainfall becomes runoff);
- The generation of one or more runoff hydrographs;
- The routing of the hydrograph(s) through hydraulic structures.

Watershed Characteristics

The following sub-subsections provide additional information regarding selected parameters used to characterize watersheds, for performing runoff calculations:

<u>Soils</u>

Soil characteristics affect the volume and rate of storm runoff. Some hydrologic estimating methods specifically account for soil types (e.g., the SCS Runoff Curve Number method used in TR-55 and TR-20); others may not (e.g., some references for the runoff coefficient used in the Rational Method do not relate the coefficient to soil type). The choice of a hydrologic model for a specific application may be governed by the extent to which the model accounts for soil conditions.

An extensive description of soil characteristics and relationship to hydrology is not offered here. However, TR-55 and TR-20, and many related runoff models, use the NRCS classification of soils by "Hydrologic Soil Group" in the estimation of runoff volume, so this classification is explained below. NRCS Soil Surveys, generally available for most of Massachusetts, classify soil by soil type. Each soil type has a corresponding Hydrologic Soil Group, except for unclassified urban or disturbed soils. If the NRCS has not classified the soils, an on-site soil investigation should be performed.

The **Hydrologic Soil Group** (HSG) reflects the infiltration rate of the soil, the permeability of any restrictive layer(s), and the moisture-holding capacity of the soil profile to a depth of 60 inches. The infiltration rate of the soil affects runoff. Generally, the higher the rate of infiltration, the lower the quantity of stormwater runoff. Fine textured soils such as clay produce a greater rate of runoff than coarse-grained soils such as sand. The hydrologic soils groups are defined as follows (Source: NEH-4):

> *HSG A (Low runoff potential)*: Soils having a low runoff potential and high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels and having a high rate of water transmission.
>
> *HSG B*: Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
>
> *HSG C*: Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. These soils have a slow rate of water transmission.
>
> *HSG D (High runoff potential)*: Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission. *Note that Hydric soils generally fall into this category.*

<u>Changes in Site Soils</u>:

When a site is extensively reworked (i.e., cuts or fills in excess of 60 inches), the existing soils structure may be disturbed by mixing and compaction. As a result, the hydrologic group associated with the original surficial soils may not apply to the newly graded surface. The designer may need to adjust curve numbers to account for new soils conditions, as well as new cover conditions, to obtain realistic estimates of runoff for this scenario.

<u>Surface Cover</u>

The type of surface or ground cover and its condition also affect runoff volume, as they influence the infiltration rate of the soil. For example,

- Covering areas with impervious surfaces, such as parking areas, reduces infiltration and surface storage, thereby increasing the size of runoff volumes and peak discharges.
- Leaf litter and decomposing organic matter maintain the soil's infiltration potential while a bare soil may become sealed by the impact of falling rain. Also, vegetation and foliage retain some of the falling rain and increase the amount evaporated into the atmosphere. Foliage also transpires moisture into the atmosphere and creates a moisture deficiency in the soil that must be replaced by rainfall prior to the occurrence of runoff.
- Vegetation and litter also form barriers along the path of flowing water, decreasing its velocity and reducing the peak rate of runoff. This duff layer also maintains the micro-topography of the forest floor.

Precipitation Properties

To fully describe a precipitation event, four parameters must be used. They are the amount, the duration, the distribution, and the return frequency. For example, a fully described storm would be: 4.5 inches of rain, of 24 hour duration, having a type III distribution and a return frequency of 10 years.

<u>Precipitation Amounts:</u>

Precipitation is usually measured in inches of depth. Precipitation is typically recorded in total precipitation received in a 24-hour period. Rainfall amounts for shorter time frames are typically recorded by intensity (depth per unit time) and this data is presented in Intensity-Duration-Frequency curves (explained further below).

<u>Storm Duration</u>:

The **storm duration** is the length of time from the beginning of rainfall to the point when there is no more additional accumulation of precipitation. Storm duration can be quantified in terms of minutes, hours, and days, but usually no greater then five days. The duration of a storm is necessary for estimating the rate of runoff discharge. Accurate distributions for actual storms must rely on automatic recording rain gages located at major airports or National Weather Service (NWS) stations. Statistical summaries are compiled from the historic record of observations at these stations.

<u>Rainfall Distribution</u>:

Rainfall intensity is a depth of rainfall per unit of time, usually expressed in inches per hour. Storms will contain many intensities, grouped either randomly (as in a real storm), or in a set sequence (as in synthetic storm).

Rainfall intensity varies with time during a given storm for different geographical regions and also for different locations specific to a region, resulting in different **rainfall distributions**. The

Natural Resource Conservation Service (NRCS) – formerly the Soil Conservation Service (SCS), with the assistance of the National Weather Service, developed four synthetic 24-hour rainfall time distribution curves for the United States. These include Types I, IA, II and III (SCS NEH – 4, SCS TR-55). The Type III storm distribution is applicable throughout Massachusetts.

Rainfall is also spatially distributed during a given event. However, for design of most stormwater management facilities, common practice assumes that rainfall is uniformly distributed over the entire contributing watershed. This assumption does not necessarily apply to large, complex watersheds, for which SCS TR-20 or an equivalent model allowing this flexibility should be used.

Return Period/Frequency:

The **return period** (sometimes referred to as **frequency**) of a hydrologic event is the expected (or average) value of the recurrence interval (time between occurrences) of an event equal to or greater than a given magnitude. For example, in central Worcester County, Massachusetts, the return period between storm events with rainfall equal to or greater than 4.5 inches (24-hour storm duration) is 10 years (according to TP-40). Alternatively stated, 4.5 inches is the 10-year frequency, 24-hour duration storm for Worcester. The *probability* of a hydrologic event occurring in a given year is the inverse of the return period (the numeral 1, divided by the return period). Thus, the 10 year frequency storm has a 0.10 probability of being equaled or exceeded in any given year, and the 100–year frequency storm has a 0.01 probability of being equaled or exceeded in any given year. The reader is referred to hydrologic texts for more extensive discussions of frequency analysis.

Note that different types of hydrologic events can have different return periods (or frequencies). For example, the 100-year frequency storm *is a* **rainfall** *event. The 100-year* flood *is a* **peak stage** *or* **runoff** *event. A common assumption of hydrologic estimating methods is that the flood event corresponds to the rainfall event of the same frequency. This is not always true; for instance, a relatively minor storm accompanied by a spring snowmelt can result in a relatively major flood event. A flood event may also result from a coastal surge caused by high winds, independent of rainfall.*

Severity of a hydrologic event varies inversely with its return period; that is, very severe storms occur less frequently then moderate storm events. The choice of a storm frequency for designing a hydraulic structure can be based on analyzing the risk of damages from storms of greater severity compared to the costs of initial construction. For urban hydrology, this is not always done, in practice. Instead, regulatory criteria usually specify the storm frequency or frequencies used for analysis. For instance, the Stormwater Policy requires the analysis of the 2-year, 10-year, and 100-year frequency, 24-hour storms.

Rainfall Intensity – Duration – Frequency Relationships

For some runoff estimation methods (e.g., the Rational Method), rainfall is analyzed using rainfall intensity for a given design storm event. These intensities are obtained from curves or equations that relate the rainfall intensity, duration, and frequency (return period). Intensity-duration-frequency (IDF) curves are developed to describe this relationship; based on frequency analyses of rainfall event data at specific locations (some sources publish the data in the form of depth duration frequency maps, e.g., NOAA 35 and TP 40). The designer is referred to the hydrology literature for a more detailed discussion of the derivation of these IDF relationships.

“Storm Event” versus “Annual Average” Analyses

In a particular study of runoff impacts, designers or Commissioners may be concerned with peak runoff volumes and rates. In this case, design storms would be analyzed, using a rainfall event with a return frequency, duration, and distribution (or intensity) suitable for the analysis. That is, rainfall and runoff would be analyzed on a “storm event” basis.

For other analyses, designers are concerned with long-term averages. For instance, the design of facilities to improve water quality of stormwater discharge is primarily based on the achievement of average annual treatment goals. Similarly, design of facilities to maintain the recharge of groundwater is generally intended to achieve long-term average results. Unless a recharge system will be used to control peak rates of runoff, then designing for recharge is based on annual average results, rather than storm event analysis.

Later chapters will identify where it is appropriate to use storm events for analysis, and where annual averages should be used.

Hydrologic Abstraction Methodologies

Hydrologic abstractions are the processes where precipitation is reduced to surface runoff. That is, runoff is equal to the difference between precipitation and abstraction. As explained at the beginning of this chapter, there are three main abstraction processes that result in direct runoff: interception, infiltration, and surface or depression storage. These processes have been previously described in this manual (see Sections 2.2, 4.1). Note that storms with precipitation depth less than the initial abstraction depths do not produce runoff.

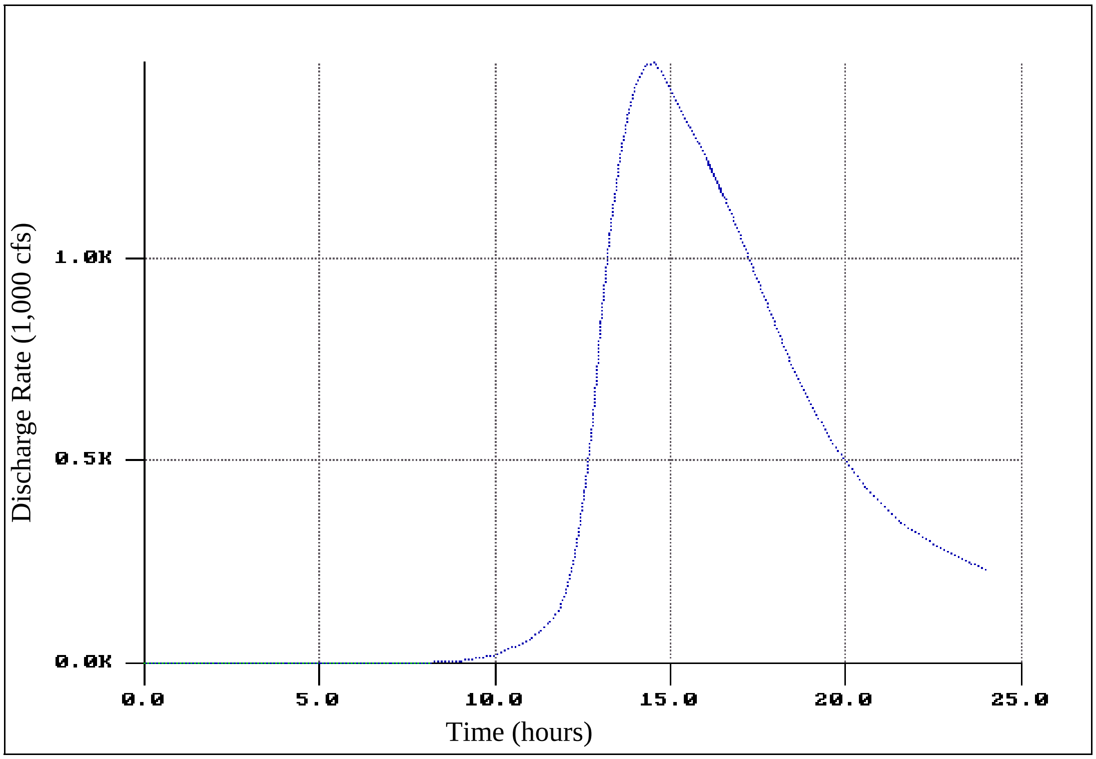
Numerous methodologies have been developed to account for hydrologic abstraction and all have specific limitations. One of the most commonly used abstraction methods is the SCS Runoff Curve Number Method. The Runoff Curve Number (CN) derived using this method accounts for soils characteristics as well as land-use cover. The curve number is used in an equation that relates initial abstractions (interception, depression storage) and soil storage (infiltration) to rainfall depth. This method is used in TR-55, TR-20, and other commonly employed models.

The Rational Method runoff coefficient indirectly accounts for abstractions, and also accounts for the **diffusion** of runoff. Diffusion is the process where runoff spreads over the surface as it flows toward an outlet. The Rational Method coefficient, C, therefore represents a “runoff rate coefficient”, and does not represent a percentage of rainfall. For this reason, the Rational Method is of limited use in estimating volumes of runoff, or in developing hydrographs.

Runoff Hydrograph Methodologies

If an observer chooses point of analysis, and measures the rate of runoff over the course of a storm event, he or she would see that runoff rate varies over time. Typically, the rate of runoff will start at a base level (zero, if the watershed is small) and rise to one or more peak rates, before eventually returning to the base level some time after the end of rainfall. The observer could draw a graph showing this variation of runoff rate over time. Such a plot of runoff rate versus time is called a **hydrograph**. Figure 4-3 shows an example of a hydrograph. As seen in Figure 4-3, the highest point on the hydrograph curve is the peak rate of runoff. The area under the hydrograph curve is the volume of runoff. A hydrograph can also be expressed in a numerical table, showing values of runoff correlated with time elapsed over the course of the event.

Figure 4-3 Typical Hydrograph



The purpose of runoff hydrographs is to characterize runoff events on the basis of time. This not only yields information for estimating peak rates, but also furnishes the designer with the basic data to perform routing calculations (discussed below).

Runoff hydrographs can be calculated for a synthetic design storm, as is typically done for routine drainage calculations. Runoff hydrographs can also be calculated for an actual rainfall event, where data is available relating rainfall to time (the plot of cumulative rainfall versus time or rainfall intensity versus time is referred to as a **hyetograph**).

The most commonly used hydrograph method is the "unit hydrograph", specifically the "SCS synthetic unit hydrograph". The TR-20 computer program and the TR-55 estimation procedure use this hydrograph method.

Other hydrograph methods include "linear reservoir" hydrographs, and "kinematic wave" hydrographs. An explanation of hydrograph theory is beyond the scope of this guidance manual, and will not be discussed further here. (For further information regarding hydrograph theory, consult a standard reference on hydrology, such as Bedient and Huber's *Hydrology and Floodplain Analysis*, 1988, Addison-Wesley Publishing Company).

The development of a hydrograph, and the computation of runoff rates by some "non-hydrograph" methods (e.g., Rational Method), often requires the estimation of the "time of concentration" or a "travel time".

Time of Concentration and Travel Time

The **Time of Concentration** (Tc), as described in Section 4.5, is the time required for water to travel from the hydraulically most remote part of the watershed to the point of analysis at the lower end of the watershed. The pathway with the longest time may or may not be the longest physical distance. **Travel Time** (Tt) is the time it takes water to travel from one location in a watershed to another. A Tc is determined by summing the Tt's along the flow path from the most remote point (time-wise) of a watershed. A Travel Time may be the time water flows form one point to another as sheet flow, shallow concentrated flow, or open channel or conduit flow. A Tc will generally contain a sheet flow component, probably have a shallow concentrated flow component, and may have an open channel or conduit flow component. These components are described as follows:

Sheet Flow: Sheet flow (less than 0.1 foot deep) is flow over a plane surface, which usually occurs in the headwaters of watersheds. Sheet flow is affected by the effective roughness of the land surface, and includes the effect of raindrop impacts; drag over the land surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment.

Reference is made to SCS (now known as NRCS) Technical Note N4 (SCS, 1986) for limitations as to length of sheet flow. In Massachusetts, the length of sheet flow is seldom greater than 50 feet. A distance of up to a maximum of 300 feet may be possible in a well-maintained, slightly sloped paved parking area or a slightly sloped grassed lawn. An on-site inspection (preferably during a runoff event) is the only way a validate the length of sheet flow.

Shallow Concentrated Flow: After approximately 50 feet (or under special circumstances, a maximum of 300 feet), sheet flow usually becomes shallow concentrated flow. If greater than 50 feet is used for sheet flow, the point at which shallow concentrated flow occurs should be justified on the basis of a site inspection (for existing conditions) or design grades (for proposed conditions).

Open Channel or Non-pressure Conduit Flow: The beginning point of channel flow under existing site conditions should be verified by an actual site inspection or by survey data. Open channel flow equations or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full elevation. Conduit (e.g., pipe) flow travel times are used only if the discharge is fully contained in the conduit under non-pressure flow. Pipes flowing under pressure cannot be modeled as non-pressure conduit flow.

Hydrograph Routing Methodologies

Routing is the process of determining how hydrographs respond to storage and hydraulic control in reservoirs (including ponds, lakes, detention basins) and streams. Routing is essentially the transformation of a runoff hydrograph flowing into a stream segment or reservoir (an inflow hydrograph), into a hydrograph flowing out of the stream segment or reservoir (an outflow hydrograph). Usually, the outflow hydrograph has a peak discharge that is reduced in magnitude, but expanded in time. This is because the runoff is temporarily stored in stream valleys and reservoirs.

Routing calculations are relatively complicated and time intensive, so they are normally done using computer models. (Appendix D presents a sample computer output for a TR-20 analysis.) Hydrograph routing is usually performed to account for the following:

- Natural ponds and reservoirs;
- Detention or retention structures;
- Rivers and channels, where storage is significant.

The most common method of performing routing calculations for stormwater management system design is the "storage-indication method" (or Modified-Puls method). Other common methods are listed in Table 4-3.

Table 4-3 Common Routing Methods

Type of Method	Method	Remarks
Reservoir Routing	Modified-Puls (Storage Indication)	Most common
	Linear Reservoir	
	Hydrodynamic Methods	
Channel Routing	Muskingum-Cunge	Most common
	Kinematic Wave	
	Dynamic Wave	
Catchment Routing	Time-Area Method	
	Clark Unit Hydrograph	
	Cascade of Linear Reservoirs	
	Kinematic Wave	
	Diffusion Wave	

Chapter 5: Conveying Runoff

This chapter presents some basic principles about the design of stormwater conveyance systems, with information on the following topics:

- Why do Conservation Commissioners need to know about conveyance system design?
- Some comments about overland flow;
- What are the basic types of conveyance systems?
- Some comments on "Open Systems";
- Some comments on "Closed Systems";
- Design considerations at the point of discharge;
- Conveyance system capacity relative to detention basin capacity.

5.1 Why Do Conservation Commissioners Need to Know About Conveyance System Design?

When a site is developed for an urban land use, provisions must be made to safely convey runoff away from the new pavements, roofs, and landscaped areas. Stormwater collection and conveyance systems are used to capture runoff as it crosses a site, and conduct this runoff to a suitable outlet. These conveyance systems may consist of "open systems" such as ditches, swales, and channels, or "closed systems" such as culverts and piped storm drains.

To meet the requirements of the Stormwater Policy, a portion or all of the runoff from a developed area must be directed to stormwater Best Management Practices (BMPs) to control peak rates (Chapter 6), provide water quality treatment (Chapter 7), and facilitate recharge (Chapter 8). Even runoff that requires no special treatment must be conveyed to an outlet in a manner which keeps stormwater away from buildings and other structures, and which prevents erosion of the land surface.

The Wetlands Protection Regulations and the Stormwater Policy do not contain specific criteria for the design and performance of conveyance systems. The Regulations and the Policy deal more specifically with the impacts of runoff, and with the quantity, quality, and location of the ultimate discharge of stormwater. However, to meet the objectives of the Regulations and the Policy, runoff must be conveyed by a properly designed system of open channels or enclosed culverts and drains. Thus, Conservation Commissioners should have a basic understanding of stormwater conveyance measures, and related design issues.

The design of stormwater conveyance systems can be complex, and should only be performed by qualified design professionals. Therefore, this chapter will not present a detailed description of how to design channels, pipes, and other drainage structures. Instead, the following sections discuss some basic concepts and principles that apply to the design of stormwater conveyance systems, and some design issues that Conservation Commissioners should watch for when they are reviewing projects.

5.2 Some Comments on Overland Flow

Before runoff enters a conveyance system, it runs over the land surface for some distance. This overland component of the stormwater flow path is an important feature to consider during the design process. The following issues should be addressed by the designer in developing site grading plans, to properly direct the flow of runoff over the land surface:

- A principal objective of drainage design is to conduct water away from dwellings and other important structures. Proposed site grading plans should be developed to accomplish this objective. Not only should the direction of flow be carefully considered, but sufficient slope should also be provided for water to run off efficiently. This objective must be accomplished without resulting in slopes that are too steep, which can result in erosion (see further discussion below).
- It is important to properly drain the surface and subsurface of pavements, to protect the physical integrity of the pavement and to provide for vehicular safety. Sufficient longitudinal gradients and pavement cross-slopes should be provided, to prevent standing water, hydroplaning conditions, and potential freezing of water on the pavement surface. Note that a poorly drained pavement may require additional ice control measures during the winter, including sand and salt applications; this can in turn result in a greater loading of particulates and deicing salts on the drainage system. Thus, proper pavement design can actually help control water quality in the long term.
- The use of relatively flat slopes, graded to create relatively long flow paths, is one means for helping to reduce peak flows. Where the slopes are vegetated or kept in natural condition, they also provide opportunity for natural infiltration to occur. Vegetated areas also help to filter runoff prior to its discharge to a conveyance system.
- Steep fill and cut slopes may be prone to erosion, which results in increased sediment loading to the drainage system. During design, this potential problem can be controlled, by proper design of slope gradients, as well as slope stabilization. The *Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas* (1997) provides guidance on the design of steep slopes with terraces, to minimize the potential for erosion on such slopes. In Massachusetts, it is typical practice to provide fill slopes in the range of 2:1 (two feet of horizontal distance for every one foot of vertical distance) to 4:1. The erosion control guidance recommends that such slopes be terraced so each segment of the slope is less than 20 feet in overall height, and water running down the slope travels no further than 50 feet before being intercepted by a terrace. Terraces are designed to conduct water laterally, along the contour, to a location where the water can be safely carried to the toe of slope by a properly designed conveyance measure.

- Sometimes, stormwater can be discharged from a pipe or other structure onto the ground, and converted to overland flow. For instance, a “level spreader” can be constructed under certain site conditions, as described in the *Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas* (1997). However, this practice is not always possible or desirable. If incorrectly done, the stormwater discharge will re-concentrate down-slope, potentially resulting in erosion of the slope and the deposition of sediment in a watercourse or other wetland resource area. Therefore, there are times – especially at the outlets of channeled and piped systems - when flow cannot be easily converted to overland flow. Under these conditions, suitable outlet protection measures are required, and this protected outlet may need to be close to the watercourse or other resource area, rather than set back away from it. Outlet protection is further discussed in Section 5.6.

5.3 What are the Basic Types of Conveyance Systems?

A number of conveyance measures may be used to collect and carry stormwater. Conveyance measures can be classified under two general categories: **open systems** and **closed systems**. Open systems consist of swales, ditches, terraces, diversions, and channels that are located on the land surface, and carry water in facilities that are open to the atmosphere. Closed systems consist of culverts, storm drain pipes, other enclosed conduits, and associated structures such as manholes and catch basins, that are usually located below the land surface. A typical site drainage design may incorporate some combination of both of these types of systems, together with overland flow, to direct runoff to a suitable point of discharge. Open and closed systems are discussed in Section 5.4 and Section 5.5, respectively.

5.4 Some Comments on “Open Systems”

Open systems can consist of natural features and man-made structures. Natural open conveyance systems include topographic swales, gullies, intermittent and perennial streams, and rivers. Man-made open conveyance systems include graded swales, ditches, canals, and other man-made channels.

The capacity of an open channel to convey flow depends on the channel gradient, the area of its cross section, its depth, the roughness of the channel, and under certain conditions, downstream water elevations. Channel designs should be documented with information on these various conditions.

Channels must be designed for two major criteria: *capacity* and *stability*. Channel design calculations should document that the channel has the capacity to convey design flows within the design cross section plus an allowance for freeboard[1] (capacity criterion). Channels must also be designed so that the channel can withstand the forces of moving water without damage to the channel lining (stability criterion). Some channels are lined with vegetation. Sometimes, vegetated channel linings can be reinforced with specially designed geo-synthetic materials

[1] Freeboard is an additional depth providing a safety factor against overtopping the embankment.

(referred to as Turf Reinforcement Materials – or TRMs). Some are lined with riprap (a form of stone lining). Other channels are lined with synthetic materials such as asphalt, concrete, interlocking concrete modules, or a combination of synthetic and natural materials. Each type of lining has limits as to the velocities it can withstand before eroding. Therefore, design calculations submitted for channels should include information to document channel stability.

If a channel will be designed for water quality treatment functions (e.g., a water quality swale), in addition to the conveyance function, then documentation of that aspect of the design also should be provided.

5.5 Some Comments on "Closed Systems"

Closed systems include culverts, storm drains, and appurtenant structures such as catch basins and drain manholes.

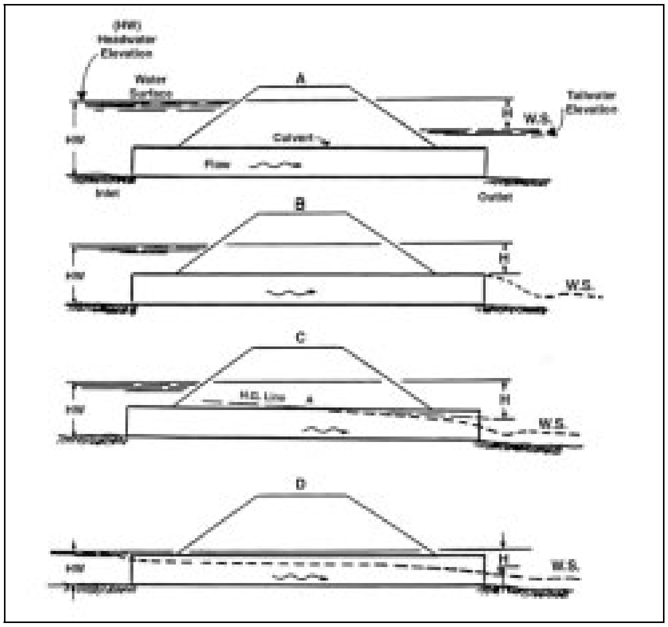
Figure 5-1 shows some examples of culverts crossing roadways (the views represent cross-sections of the roadway). Note that the culverts can carry flow under a variety of conditions. The rate at which water flows through a culvert can depend on the inlet shape and material of the culvert, the slope of the pipe, the roughness of the pipe, the depth of water at the inlet of the culvert (headwater depth) and the depth of water at the culvert outlet (referred to as the tailwater condition at the culvert). Design calculations for culverts should include an accounting of these factors. Sometimes, the inlet shape and material controls the rate of flow in a culvert, regardless of the conditions in the pipe barrel or downstream. In this case, the culvert is said to flow under **inlet control**. If the control of flow in the culvert is not governed solely by inlet conditions, the culvert is said to flow under **outlet control**. A correct culvert design calculation will either include an analysis of which condition prevails, or will consider both conditions, and select the culvert size and configuration that addresses the most conservative condition.

Figure 5-2 shows an example of a storm drain system. The system is shown in both plan view, and profile view. The system consists of catch basins, which collect runoff as it crosses the land surface. The catch basins discharge into pipes, which in turn discharge into drain manholes and other pipes. Eventually, the piped system outlets to a flow control structure (such as a detention basin) or a watercourse or other wetland resource area. The flow capacity of a drainage system depends on the sizes of pipes, their slope, and their interior roughness. The capacity also depends on the capacity of the inlet grates into the catch basins, as well as the energy losses that occur at catch basins, manholes, other drainage structures, and the pipe outlet. In addition, the capacity can be affected by **tailwater** conditions (the elevation of water at the system outlet). A correct storm drain system design will include an analysis that accounts for all of these factors, not just the friction loss within the pipes. This analysis will identify the hydraulic gradient (vertical profile of the water surface) in the drainage system, allowing for verification that the water surface elevation does not exceed the catch basin rim elevations.

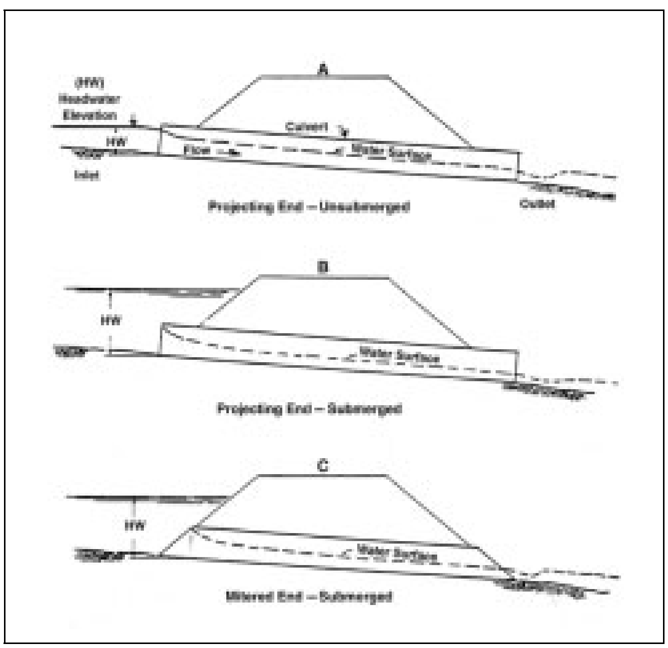
Storm drain systems are typically designed for the 2-year to 10-year frequency storm event. The appropriate storm event may be specified by local bylaw, or in some cases (such as state highway projects) by state or federal design standards.

Figure 5-1 Illustrations of Culvert Design Conditions

Outlet Control

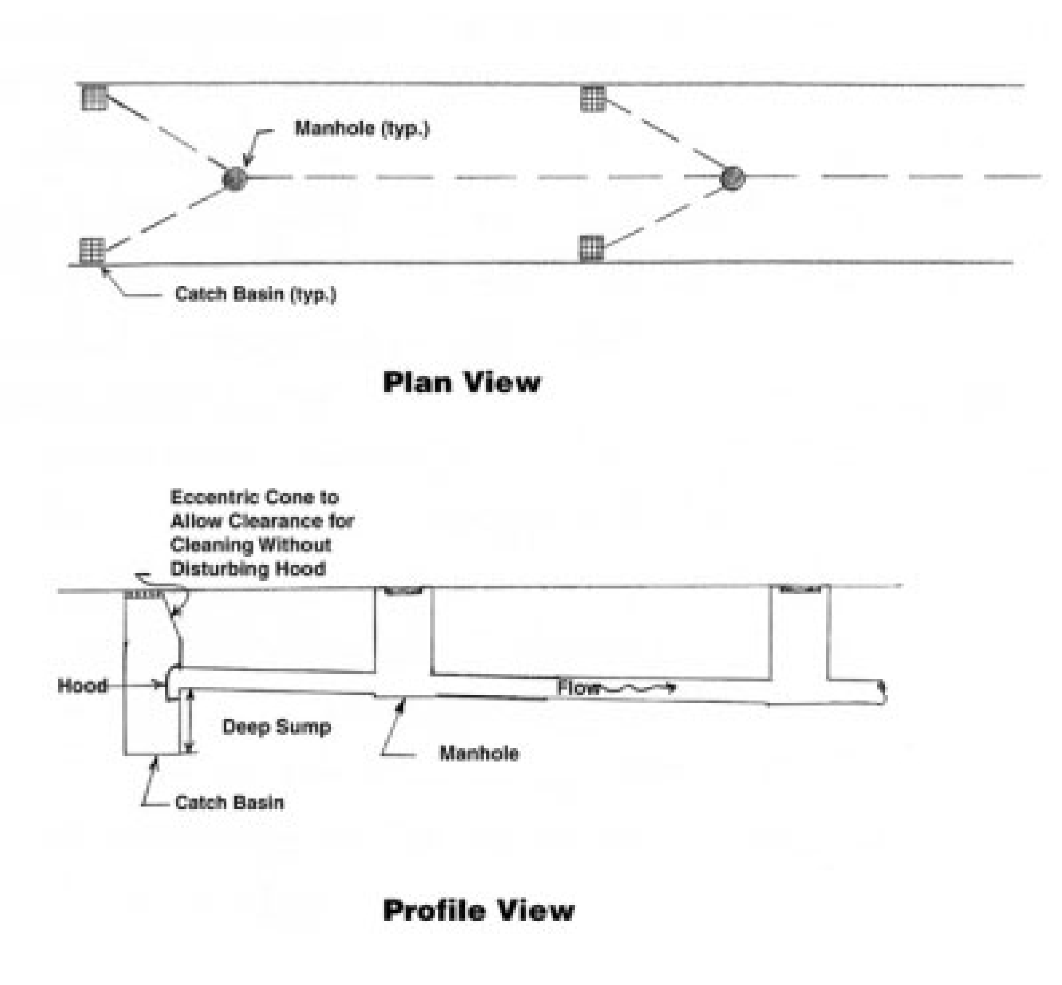


Inlet Control



(Federal Highway Administration, 1965)

Figure 5-2   Example of Storm Drain



5.6 Design Considerations at the Point of Discharge

The design of stormwater conveyance systems must consider two key factors at the point where the flows are discharged: tailwater conditions and outlet protection. These factors are discussed below.

Tailwater Conditions

Many storm drain systems are now designed to outlet into detention facilities, which control discharges from sites by the temporary storage of water (see Chapter 6). Often, the design storage elevation of the detention facility or other drainage structure will result in the outlet end of the pipe located below the water surface. Similarly, during certain storm events, natural watercourses will flow bank-full (or even over-bank onto their flood plains) at the location of a storm drain outlet. Such conditions create a "tailwater" on the outlet pipe and can affect the flow capacity of the pipe. Designers need to analyze the performance of the storm drains with a proper accounting of these tailwater conditions. Design calculations for pipes, culverts, and channels should include documentation of estimated tailwater conditions relative to the elevation of the outlet end of these conduits and channels.

Outlet Protection

Water discharging from the ends of piped and channelized systems, into a wetland resource area, can have enough velocity and associated energy to cause erosion in the vicinity of the outlet. Outlet pipes, and the outlet ends of some channels, may require measures to dissipate this energy, so that such erosion does not occur. Design of a conveyance system should include the design of energy dissipation measures at each outlet. The *Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas* (1997) and other engineering handbooks contain guidance on the proper design of riprap aprons, plunge pools, and other structures for the dissipation of flow energy at the outlets of pipes and conveyance channels. Designers should document how they have determined the dimensions and materials of outlet protection measures, in accordance with the practices recommended in such references.

5.7 Conveyance System Capacity Relative to Detention Basin Capacity

Stormwater conveyance systems are often designed to standards specified in local bylaws or according to typical engineering practice in a region. For instance, it has been a common practice to design piped storm drain systems for the 10-year frequency storm, or perhaps the 25-year storm, depending on local bylaws. On the other hand, detention basins for preventing offsite flooding may be designed for a different criterion. For example, a basin may be designed to store enough water to control flows to pre-development levels for the 100-year storm. This practice can result in a discrepancy between the detention basin's intended capacity, and what the storm drain system can deliver.

Designers need to show that the site drainage system is capable of safely conveying the design storm to a proposed detention facility. One option is to design the storm drain system to the same storm frequency as the detention basin. However, this is not always necessary. If the detention facility is provided for the 25 or 100-year event, the storm drains can still be designed to a lesser event, if the designer plans for an alternative flow path of adequate capacity for events exceeding the design flow of the storm drain. For instance, a designer may be able to show that the gutters along a pavement or an overflow swale or channel through the site, can safely convey the excess flows to the detention facility, without endangering structures or interfering with the access of emergency vehicles. In other words, design submittals should document how flows will be properly conveyed to detention facilities up to the maximum event for which the facilities are intended to function.

Chapter 6:
Controlling Peak Rates of Runoff

This chapter deals with stormwater "quantity control", through the control of peak runoff rates. The discussion addresses:

- Why do Conservation Commissioners need to know about controlling peak rates of runoff?
- How can project designs control peak discharge rates?
- What do the terms "detention" and "retention" mean?
- Can one BMP control storms of different design frequencies?
- What procedures are used to size detention and retention systems?
- Hydrologic settings where peak rate control may not be warranted.

6.1 Why Do Conservation Commissioners Need to Know About Controlling Peak Rates of Runoff?

Standard 2 of the Stormwater Management Policy states:

> *Stormwater management systems must be designed so that post-development peak discharge rates do not exceed pre-development peak discharge rates.*

When Conservation Commissioners are reviewing proposed activities within their jurisdiction, they will be reviewing the activities for compliance with this standard.

As explained in Chapter 2, the development of a previously undeveloped site for another use can alter the physical features affecting runoff. The development of an undeveloped site for an urban land use usually involves the creation of impervious surfaces (pavements and roofs) which have particularly significant effects on runoff and recharge. The primary effects of urban development include an increase in volume of runoff, and an increase in the peak rate of runoff.

The volume of water available for runoff increases because roofs, parking lots, streets, and other impervious surfaces reduce the amount of infiltration that can occur. Peak discharge rates increase because urban development alters surface cover and drainage features in a way that increases the velocity of runoff as it flows to the watershed outlet.

Higher peak rates of discharge can cause stormwater flows to exceed the capacity of the existing downstream drainage system. As a result, downstream areas may be subject to impacts such as flooding and increased stream bank erosion. The increased flooding can result in damage to downstream structures and other property. Increased flooding, especially if it occurs more frequently or for extended times, can also alter the hydrologic regime of wetland resource areas. Increased erosion can result in the transport of sediment to downstream areas, also affecting wetland resource areas.

By controlling peak rates of discharge from newly developed sites, these impacts can be prevented. By controlling a range of storm events, the discharge from a developed site can be made to more closely resemble pre-development conditions. Therefore, the Stormwater Management Policy recommends the control of post-development peak rates to meet the following criteria:

1. Post-development peak rates for the 2-year and 10-year frequency 24-hour storm events must be controlled to be less than or equal to pre-development conditions. These peak rates are evaluated either at the point of discharge from the development, or at the down-gradient property line. *Note: local by-laws, planning board regulations, and other regulations may require controlling other storm events, as well.*[2] *For instance, many communities require system designs for the 25-year storm. Also, state agencies (e.g., Massachusetts Highway Department) have standards for drainage design that specify storm-frequencies for the design of various types of structures.*

2. The 100-year storm event must be evaluated to demonstrate that there will not be increased flooding impacts off-site.

Based on these criteria, project designs must evaluate peak rates under pre- and post-development conditions (see Chapter 4) for a range of storm events. Based on this evaluation, the project designs may need to provide for stormwater management measures to either minimize the increase in peak discharge rates, or to control discharge rates to acceptable levels.

6.2 How Can Project Designs Control Peak Discharge Rates?

There are two general strategies for designing developments so that post-development peak discharges are not greater than pre-development conditions:

1. Design the site to minimize impervious areas, minimize steep slopes, maximize opportunities for infiltration, and maximize overland flow paths. This strategy employs land use and grading practices to minimize the increase in runoff volume, as well as the increase in peak discharge rates.

[2] Note that under the principles of state supremacy, state agencies are not subject to local bylaws and ordinances. However, pursuant to the Clean State Initiative, which identifies resource conservation as one of its goals, state agencies are to comply with all state environmental regulations. Because the first phase of review under the Wetlands Protection Act, M.G.L. c. 131 section 40, is through a local Conservation Commission, DEP encourages state agencies to take into account – whenever possible – local issues and/or concerns, as they often do, although they are not legally required to do so. In addition, state agencies are subject to federal requirements, such as compliance, where applicable, with Section 401 Water Quality Certification criteria and the National Pollution Discharge Elimination System.

2. Provide for the temporary storage of runoff from all or portions of the developed site, and regulate the release of water from the storage facility by outlet devices designed to control peak rates (detention storage), or by directing the flows into the ground (retention storage).

Usually, the first strategy will not prove sufficient to control peak discharge rates, because development inevitably requires the creation of some increase in impervious area, and the provision of drainage systems which accelerate the removal of stormwater from the site.

Therefore, site development will frequently require the provision of stormwater storage facilities (such as "detention" or "retention" structures) for controlling peak rates of runoff for selected design storms.

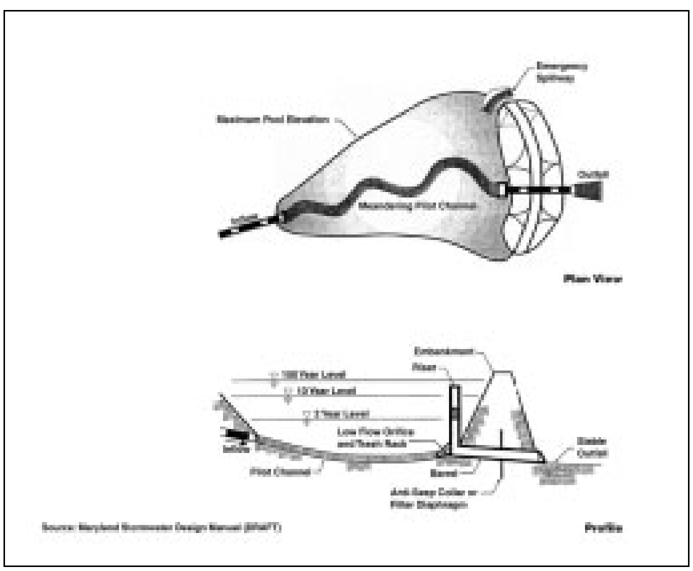
6.3 What Do the Terms "Detention" and "Retention" Mean?

There are two types of storage facilities for managing stormwater flows: **detention** devices or structures, and **retention** devices or structures.

Detention structures store water for a relatively short period of time. These facilities drain primarily by discharging either overland or directly to a man-made or natural watercourse. Examples of detention structures include detention basins, subsurface structures for temporary stormwater storage, and (on a larger scale) flood control reservoirs. Natural ponds, lakes, and stream channels also provide detention of water as it moves over the face of the earth.

Figure 6-1 shows an example of a conventional *detention basin* designed to control peak discharge rates.

Figure 6-1 Example of Conventional Stormwater Detention Pond

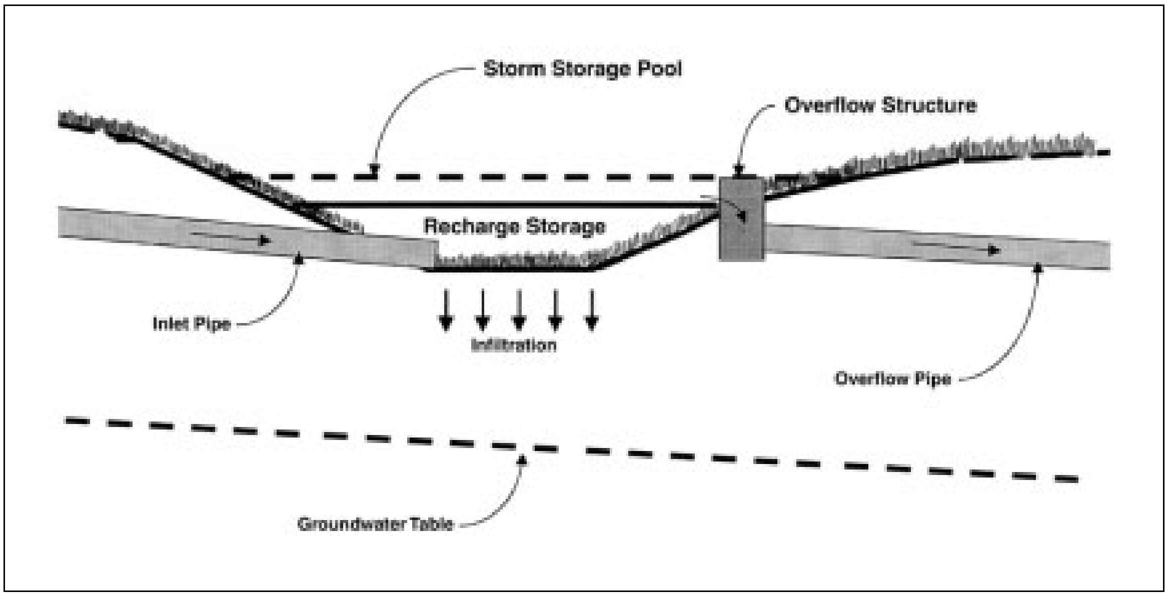


(Adapted from Maryland Department of the Environment, 2000)

Retention structures generally hold water for a relatively long period of time. Stored water in retention systems is depleted overtime primarily by infiltration or evaporation. In Massachusetts' climate, the net effect of evaporation is limited, because direct rainfall is generally sufficient to replace the water lost by evaporation. The distinguishing characteristic of retention facilities is that they do not have a surface discharge for most flows (although they may be designed with an overflow provision for extreme storm events). Examples of retention structures include recharge basins or ponds (sometimes referred to as infiltration basins), subsurface recharge systems such as dry wells and infiltration galleys, and water quality swales designed for infiltration.

Figure 6-2 shows an example of a typical recharge basin (a type of *retention basin*), designed to infiltrate stormwater into the ground.

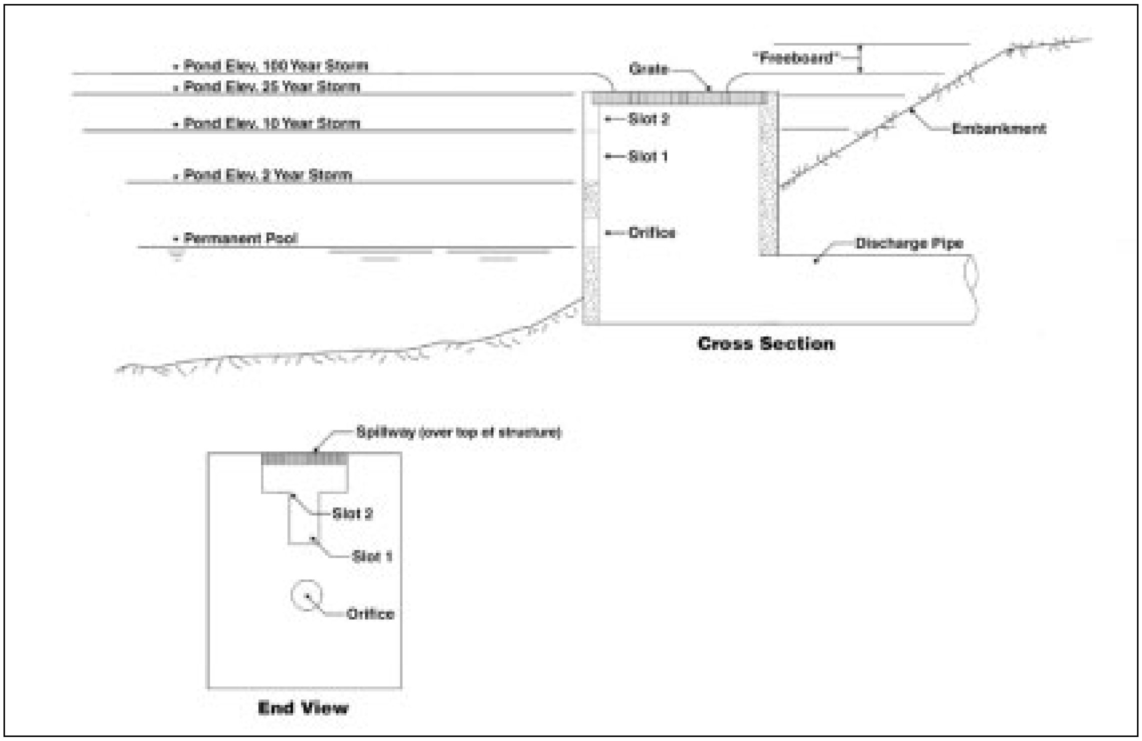
Figure 6-2 Recharge Basin: Typical Cross Section



6.4 Can One BMP Control Storms of Different Design Frequencies?

A stormwater storage facility can be designed to control peak discharges for a range of design storm events. This is accomplished by employing outlet control devices that have different release rates at different depths of storage. Figure 6-3 shows one example of the many ways in which an outlet structure can be designed to provide for multiple discharge rates, to account for the various design storms.

Figure 6-3   Outlet Structure Designed for Multiple Release Rates



6.5 What Procedures Are Used to Size Detention and Retention Systems?

Table 6-1 presents a step by step outline of the procedures used to design detention and retention systems. The outline also lists information that designers should provide in drainage calculations, to document the design of these facilities. The following additional comments further explain the steps listed in Table 6-1:

Step 1: Location of Detention/Retention Facility

For many projects, a detention facility will typically be located just upstream of an analysis point used for estimating peak runoff rates (see Chapter 4). However, for more complex projects, several detention basins may be located within a single watershed, or a single basin may be located some distance upstream of the analysis point. Available computer programs for analyzing runoff and detention storage, can account for such complex designs.

Step 2 and Step 3: Pre- and Post-Development Hydrographs

Chapter 4 describes the procedures for developing this information. From the pre-development hydrograph for each storm frequency chosen for analysis, the pre-development peak rate of discharge can be determined. The objective of the detention basin design procedure is to determine the basin size and outlet structure characteristics, that will control the release of post-development flows to less than or equal to this peak rate.

Step 4: Design of Detention Facility, and Development of Stage Storage Relationship

The development of a design for the size and configuration of a detention basin requires professional experience and judgment. Often, several potential designs will be analyzed to arrive at a configuration that will work on a particular site.

Table 6-1 Generalized Procedure for Estimating Detention (or Retention) Storage Volume

	Description of Step	Recommended Documentation
Step 1	Identify the location where the detention (or retention) facility will be constructed.	Show the detention or retention basin on the project site plan.
Step 2	Determine the pre-development hydrograph at the analysis point, for each frequency storm event that must be controlled. From this information, develop pre-development peak discharge rates for each design storm frequency.	Provide documentation listed in Chapter 4.
Step 3	Determine the post-development hydrograph at the analysis point, for each frequency storm event that must be controlled.	Provide documentation listed in Chapter 4.
Step 4	Develop a conceptual design for the detention storage facility, based on professional judgment, trial and analysis, and/or acceptable rough sizing method (e.g., approximate pond sizing method described in TR-55). Determine the stage/storage relationship for the facility.	Provide stage/storage volume calculations.
Step 5	Develop a conceptual design for an outlet control structure, for controlling peak discharges for the selected design storm events. Develop a stage/discharge relationship for the structure.	Provide information on hydraulic components of outlet structure, and stage/discharge calculations. Identify equations used and corresponding design assumptions.
Step 6	Using an accepted computation procedure, perform “routing calculations” using the information generated in Steps 1-5. These calculations yield an “outflow hydrograph” for each storm frequency. Each of these hydrographs will show the peak discharge of flow leaving the detention basin, accounting for storage within the basin.	Provide copies of calculations (usually consists of computer input and output files).
Step 7	Compare the peak discharge rate from the detention basin for each storm frequency, to the pre-development peak rate for the same storm frequency.	Provide summary table of final pre- and post-development (with detention) discharge rates. Provide rates for each analysis point (see Chapter 4).
Step 8	If the post-development peak rate is not controlled to a value less than or equal to the pre-development rate, revise the basin design or the outlet design, and repeat Steps 4-7.	Note: Documentation of trial calculations is not normally provided or required.

The TR-55 model (see Section 4.4 and Appendix C) describes an approximate pond sizing method that can be useful for “rough sizing” of detention basins, if the inflow and outflow peak discharge rates are known. However, the method produces results that are only approximate. Also, the method cannot be easily used for very low outlet discharge rates, which are typically required for water quality treatment basins. While a designer might use this method for conceptual sizing, it should not be used for final design. Generally, submittals to Conservation Commissions should not contain calculations for final design based on this method. Detention basins should be designed using full hydrographs, and an appropriate routing method. Most engineers engaged in storm water management design now have computer software that enables them to perform the necessary routing calculations.

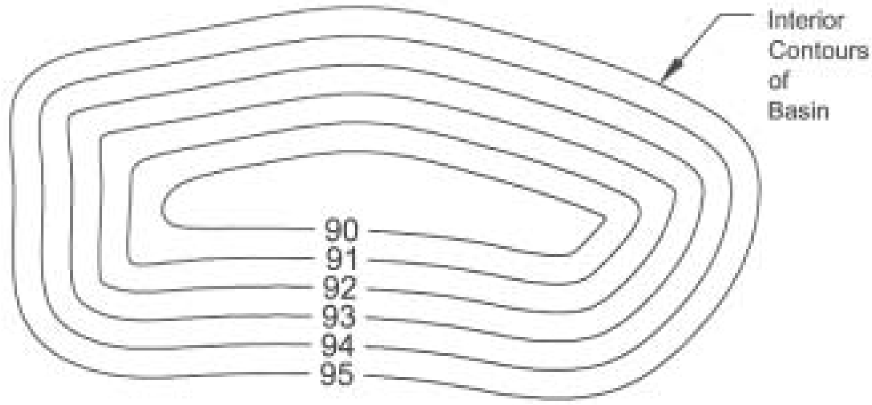
When the designer has estimated the horizontal layout and depth of a detention basin, this information is used to develop a **stage/storage relationship** for the basin. This relationship consists of a table or graph relating the elevation (or **stage**) of a potential water surface in the basin, to the amount of water that would be stored at that elevation. Figure 6-4 shows a typical plan, profile, and stage/storage computation for a detention basin. The stage/storage table is developed by measuring the interior area of the basin at each contour, determining the volume of water that would be stored between each successive contour (incremental volume), and determining the cumulative storage for each elevation (stage).

Step 5: Design of Outlet Structure, and Development of Stage/Discharge Relationship

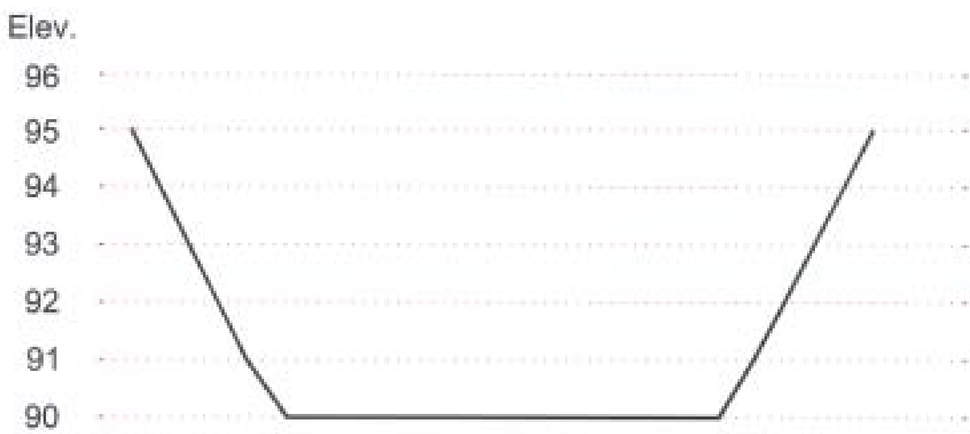
The release of water from a detention basin is generally controlled by an outlet structure. The release of water from a retention facility is generally controlled by infiltration. To design either type of facility (or a facility that combines aspects of both types), a designer needs to determine the relationship between the elevation of water in the basin, and the rate at which water discharges from the basin. This relationship is called the **stage/discharge relationship** for the basin. Designers should provide documentation of the stage/discharge relationship, and the equations and assumptions used to determine that relationship, when they submit calculations for review by Conservation Commissions.

The determination of discharge for each stage of elevation in a basin requires a knowledge of the mechanics of infiltration, flow over weirs, flow through orifices, pipe flow, and flow through other hydraulic structures. This hydraulic design methodology is beyond the scope of this manual. However, Conservation Commissioners should be aware that the development of this stage/discharge relationship is a key to performing the necessary calculations to verify the design of a detention basin and its outlet structure.

Figure 6-4   Plan/Profile and Stage/Storage Table for a Simple Basin



SCHEMATIC PLAN VIEW OF BASIN



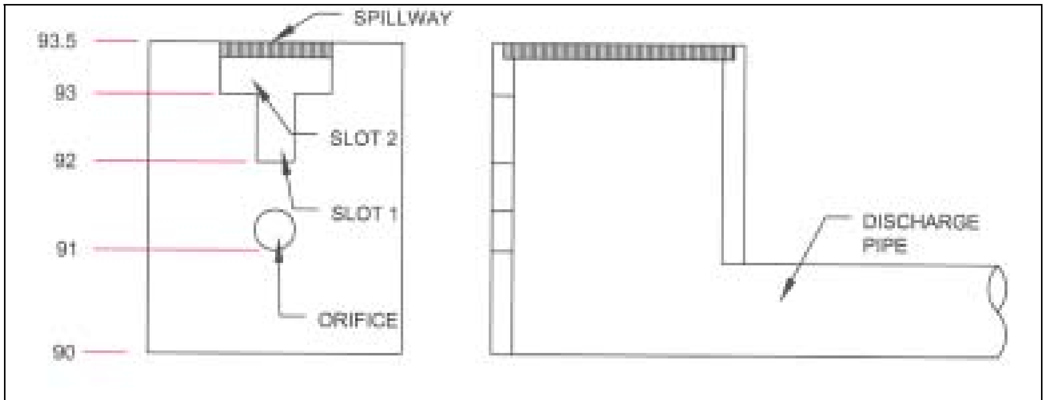
CROSS SECTION OF BASIN

Stage	Elevation Difference	Area	Average Area	Incremental Storage	Total Storage
(feet)	(feet)	(acres)	(acres)	(acre-feet)	(acre-feet)
90		0.48			0.00
	1		0.76	0.76	
91		1.04			0.76
	1		1.36	1.36	
92		1.68			2.12
	1		2.05	2.05	
93		2.42			4.17
	1		2.83	2.83	
94		3.25			7.01
	1		3.71	3.71	
95		4.16			10.71

STAGE vs. STORAGE TABULATION

Figure 6-5 shows one type of outlet structure, and a stage/discharge table computed for that structure.

Figure 6-5 Plan, Cross Section, and Stage Discharge Table for a Typical Outlet Structure



SCHEMATIC VIEW OF DROP INLET CONTROL STRUCTURE

Stage (feet)	Orifice Discharge (cfs)	Slot 1 Discharge (cfs)	Slot 2 Discharge (cfs)	Spillway Discharge (cfs)	Total Discharge (cfs)
90.0	0.0	0.0	0.0	0.0	0.0
91.0	0.0	0.0	0.0	0.0	0.0
91.5	0.7	0.0	0.0	0.0	0.7
92.0	0.9	0.0	0.0	0.0	0.9
92.5	1.2	0.6	0.0	0.0	1.8
93.0	1.3	1.6	0.0	0.0	2.9
93.5	1.5	2.9	1.1	0.0	5.5
94.0	1.6	4.4	3.1	4.4	13.5
94.5	1.8	6.2	5.8	12.5	26.3
95.0	1.9	8.1	8.9	23.0	41.9

STAGE vs. DISCHARGE TABULATION

<u>Step 6: Routing Calculations</u>

Chapter 4 discusses "hydrograph routing" and describes the available models for performing routing calculations. To perform the routing calculations, the designer needs to know the post-development inflow hydrograph (Step 3), the stage/storage relationship (Step 4), and the stage/discharge relationship (Step 5) for the proposed detention or retention basin.

Routing calculations should be performed using the full hydrograph, as provided by models such as TR-20, or other hydrograph generation/routing models. Only models that produce the full hydrographs should be used for the final sizing of detention basins and similar attenuation structures.

Some computation methodologies do not produce sufficient hydrographs for this purpose. The Rational Method produces only one point (the peak discharge) on a hydrograph, and should not generally be used for sizing detention facilities. TR-55 only produces a partial hydrograph. The model does not account for runoff for the first 11 hours of the input hydrograph for the Type III storm applicable to Massachusetts. It therefore ignores a significant volume of runoff from the earlier hours of the 24-hour design storm. This volume can occupy a significant portion of basin volume when the outlet structure is designed for a highly constricted release rate for lower stages, as is the case for most water quality control basins. Therefore, TR-55 should not be used for final sizing of detention basins and similar attenuation structures.

Appendix D includes an example of a computer printout for a project with a detention basin routing calculation. The example is annotated to identify input parameters and output results.

6.6 Hydrologic Settings Where Peak Rate Control May Not Be Warranted

There are some hydrologic settings where control of peak rates from a proposed development may not be warranted.

If a development discharges to a watercourse subject to tidal action, the Stormwater Management Policy does not require the control of post-development peak discharge rates to pre-development levels. An applicant should note that the proposed project is in the watershed of a watercourse subject to tidal action, when this case applies.

Developments near some non-tidal watercourses may also be able to be constructed without controlling peak rates of discharge under certain unique hydrologic conditions. As noted in previous discussion in this handbook, peak rates are typically analyzed at the point of discharge from a development, or at the down-gradient property line. However, there are situations where a development can be implemented without providing control of peak discharge rates at the property line, and yet result in no increase in peak flow rates in the receiving stream. This condition can occur, for example, where a development is adjacent to a stream whose watershed is very large relative to the development's drainage area, and where the stream's hydrograph peaks at a substantially different time than the peak discharge from the development. Conservation Commissioners should be aware that this design condition might occur, and should expect supporting documentation if an applicant's proposal does not include stormwater detention because of the unique hydrology of the receiving stream. In such a case, the burden is on the project proponent to show how the interests of the Wetlands Protection Act are protected, without the strict application of Stormwater Management Policy Standard #2.

In these instances where peak rate control is not needed, other Stormwater Management Policy Standards may still apply. As a result, stormwater treatment BMPs may still be necessary. Often, engineers will incorporate water quality treatment measures into the design of peak rate control measures. Where designers do not provide peak rate controls, they may still need to provide structures to address water quality control and recharge objectives.

Chapter 7:
Selecting and Sizing Facilities for Water Quality Treatment

In this chapter, you will read about estimating the "water quality volume" needed to size a Best Management Practice for stormwater quality treatment. You will also see how to analyze the treatment effectiveness of a series of BMPs. The chapter discusses the following topics:

- Why do Conservation Commissioners need to know about stormwater quality treatment?
- How is the "Water Quality Treatment Volume" determined?
- How is the TSS performance of a series of BMPs evaluated?
- Alternative techniques for demonstrating compliance with the treatment standard of 80% TSS removal.

7.1 Why Do Conservation Commissioners Need to Know About Stormwater Quality Treatment?

The quality of water discharged to wetland resource areas can affect the biological communities found in those resource areas. While wetlands have the ability to filter runoff and provide contaminant removal through biological uptake, this function can be altered by the pollutants commonly found in stormwater. Thus, Conservation Commissioners should be concerned with the quality of water discharged to wetlands, and with the treatment of stormwater to a degree that protects the interests of wetlands as defined under the Wetlands Protection Act.

Based on work done by the U.S. Environmental Protection Agency (EPA) and others involved in the development of technologies for treating stormwater, MA DEP has identified criteria which, if met by a stormwater management system, provide for an acceptable level of stormwater treatment. These criteria have been set forth in the Massachusetts Stormwater Management Policy. Therefore, when Conservation Commissions review projects within their jurisdiction, they will include a review of project design for achieving water quality objectives. If a project complies with the applicable standards of the Stormwater Policy, then the project is presumed to satisfy regulatory requirements.

Standard 4 of the Stormwater Management Policy states:

> *For new development, stormwater management systems must be designed to remove 80% of the average annual load (post-development conditions) of Total Suspended Solids (TSS). It is presumed that this standard is met when:*

(a) *Suitable nonstructural practices for source control and pollution prevention are implemented;*

(b) *Stormwater management best management practices (BMPs) are sized to capture the prescribed runoff volume; and*

(c) *Stormwater management practices are maintained as designed.*

The Stormwater Policy goes on to explain that the prescribed runoff volume indicated in paragraph (b) of Standard 4 will be based on the following:

(1) *For discharges to critical areas (as defined in the Policy), the volume to be treated is calculated as 1.0 inch of runoff times the total impervious area of the post-development project site.*

(2) *For all other discharges, volume to be treated is calculated as 0.5 inches of runoff times the total impervious area of the post-development project site.*

The majority of contaminants in stormwater runoff are attached to particulate matter suspended in the water column (i.e., suspended solids). Therefore, the percent removal of TSS is considered a reliable parameter for evaluating the water quality renovation effectiveness of a storm water management system.

The U.S. EPA recommends 80% TSS removal as a minimum target for surface water discharges of stormwater, for demonstrating that a proposed stormwater management system will effectively treat runoff and protect the quality of downstream resources. This criterion was established based on data collected under the EPA's Nationwide Urban Runoff Program or NURP (Athayde, et. al., 1983). The NURP study and other programs have found that many of the pollutants in urban runoff (e.g., nutrients, heavy metals, hydrocarbons) are associated with particulate matter, and would be removed with total suspended solids. Thus, if the TSS criterion is met, other pollutants will be reduced to levels that will minimize water quality impacts to the extent feasible with today’s best available technology.

Note that the 80% TSS removal goal is a long term average performance objective. In a particular stormwater management system, some large storms may receive a lesser degree of treatment, but this is offset by the greater degree of treatment achieved for the many small rainfall events handled by the system. Therefore, the sizing criteria for stormwater quality BMPs are based on average performance, rather than on any one individual storm event. Consequently, the sizing procedure for water quality treatment differs from the sizing procedure for controlling peak rates of discharge (discussed in previous chapters).

Section 7.2 below describes how to estimate the prescribed runoff treatment volume, **or water quality treatment volume**. Section 7.3 describes how to evaluate a series of Best Management

Practices (BMPs), to determine the TSS removal performance of a system, based on individual BMP TSS removal rates listed in the Stormwater Management Policy.

Section 7.4 discusses how projects may provide alternative demonstration of compliance with Standard 4 of the Policy, instead of using the presumptive criteria listed in the Policy. Project proponents have the option of showing that a project can achieve the specified level of treatment using alternative BMPs. Proponents can also demonstrate removal rates are achieved by alternative methods for estimating treatment performance.

7.2 How Is the "Water Quality Treatment Volume" Determined?

The "water quality treatment volume" is the quantity of stormwater that a BMP must capture and treat to provide 80% TSS removal on an average annual basis. Under the Stormwater Policy, for sites that are not within "critical areas", this volume is equal to a depth of 0.5 inch of runoff distributed over the impervious area (pavement and roofs) of a site.

In critical areas, the Stormwater Policy requires the volume to equal 1-inch depth over the impervious area. This sizing criterion provides an extra margin of safety for design, and in many cases will provide a greater degree of treatment than the 80% TSS removal goal.

Table 7-1 presents a step by step procedure for estimating the water quality treatment volume (V_{wq}). The following example is based on that procedure.

EXAMPLE: A proposed project will include the development of 1.3 acres of new pavement and rooftop. (a) If the project is located in a watershed of a public water supply, compute the water quality volume that must be treated to comply with the Stormwater Management Policy. (b) Compute the treatment volume for a similar project that is not located in a critical area.

(a) The watershed of a public water supply is defined by the Policy as a critical area, so the 1-inch sizing rule applies:

$$V_{wq} = 1 \text{ inch} \times \frac{1 \text{ ft}}{12 \text{ in.}} \times 1.3 \text{ acres} = 0.108 \text{ acre-feet}$$

$$= 0.108 \text{ acre-ft.} \times \frac{43{,}560 \text{ sq.ft.}}{\text{acre}} = 4704 \text{ cubic feet}$$

(b) If the project is not in a critical area, then the 0.5-inch rule applies:

$$V_{wq} = 0.5 \text{ inch} \times \frac{1 \text{ ft}}{12 \text{ in.}} \times 1.3 \text{ acres} = 0.054 \text{ acre-feet}$$

$$= 0.054 \text{ acre-ft.} \times \frac{43{,}560 \text{ sq.ft.}}{\text{acre}} = 2352 \text{ cubic feet}$$

Table 7-1 Estimating Water Quality Treatment Volume for a Proposed Development

	Description of Step	Recommended Documentation
Step 1	Identify Analysis Points. These points will be at the outlets of each watershed that will be provided with water quality treatment.	Show Best Management Practice (BMP) locations on post-development watershed plan.
Step 2	Delineate Watershed of Each Analysis Point	Show watersheds of each BMP on post-development watershed plan.
Step 3	Measure the total area of impervious surface for the proposed development contributing flow to each analysis point	Tabulate area calculations in the drainage calculations furnished for the project.
Step 4	For each BMP, determine whether device is in a "Critical Area" as defined in the stormwater policy.	Include this information in the tabulation of area calculations.
Step 5	Compute the water quality volume for the BMP based on the applicable sizing rule: Critical areas: $V_{wq} = 1.0/12 \times A \times 43{,}560$ Non-critical areas $V_{wq} = 0.5/12 \times A \times 43{,}560$ where: V_{wq} = required volume, in cubic feet; and A = contributing area, in acres.	Tabulate this information with the corresponding area calculations.
Step 6	Use V_{wq} for each BMP to size the device, according to guidelines in Volume 2 of the Stormwater Policy, or according to an alternative accepted engineering practice.	Document the sizing of each device in the calculations submitted for the project.

7.3 How Is the TSS Performance of a Series of BMPs Evaluated?

The MA DEP manual, *Stormwater Management Volume 1: Stormwater Policy Handbook*, includes a list of BMPs that may be used toward achieving the target rate of 80% TSS removal. The design rates identified by MA DEP are based on performance ranges for the listed management measures, as reported by various studies and design publications. The Stormwater Policy Handbook presumes that the tabulated design values for each BMP will be met by a project, if the BMP is designed based on the applicable sizing rule (as discussed in Section 7.2). The design should also follow the guidance provided in *Stormwater Management Volume 2: Stormwater Technical Handbook.*

The listed values for most BMPs are less than 80%. Therefore, to meet the specified TSS removal rate, a series of BMPs must be used. This Section of the chapter illustrates how to estimate overall TSS removal for a series of BMPs.

Figure 7-1 provides a worksheet for estimating the overall treatment performance of a series of Best Management Practices (sometimes referred to as a “treatment train”). Figure 7-2 provides an example of how the worksheet is used. Completing the worksheet involves the following steps:

1. Individual BMPs are listed in Column A, generally in the order in which they are applied on the site.

2. The TSS removal rate for each BMP is obtained from the table of design rates provided in *Stormwater Management Volume 1*. These rates are entered in Column B. If the device is not listed in Volume 1, then the designer will need to provide documentation of expected removal rates. If the designer wishes to use a different removal rate than given in *Volume 1* for a listed BMP, then the designer must document why a different rate is justified.

3. The initial TSS load (as a percent) for each BMP is entered in Column C. For the first BMP, the load is 100%. For subsequent BMPs, the initial load to each BMP equals the remaining load (Column E) from the preceding BMP.

4. The TSS amount removed is entered in Column D. This amount equals the removal rate in Column B, multiplied by the load in Column C.

5. The final load for each BMP is computed and entered in Column E. The final load equals the initial load for the BMP (Column C) minus the amount removed (Column D).

6. The overall removal rate equals the sum of the values in Column D. It also equals 100% minus the last final load listed in Column E.

Note that this procedure for determining the cumulative removal rates of a series of BMPs is an approximate one. It has been developed for application to the design rates listed in the *Stormwater Management Volume 1*, for determining presumptive compliance with Stormwater Policy Standard 4. Actual removal rates for a device may depend on the composition of the TSS load (in particular, the sizes of solid particles that make up this load), not just the total incoming load. Each BMP in a series can change the composition of particle sizes in the runoff it treats. Some spreadsheet and computer models can account for this effect. However, for evaluating compliance with the Stormwater Management Policy, the procedure reflected in the Worksheet in Figure 7-1 is considered sufficient.

Figure 7-2 presents an example of a TSS removal calculation, using the worksheet.

Figure 7-1   TSS Removal Worksheet

A BMP	B % Removal	C Initial Load	D Amount Removed	E Final Load
		100%		

Sum of Column D = Overall Removal % = _____________

Note: Last Value in Column E = TSS Remaining After Treatment

TSS Removal Rates Per DEP Stormwater Management Policy

BMP List	Design Rate	Range of Average TSS Removal Rates	Brief Design Requirements
Extended Detention Pond	70%	60-80%	Sediment forebay
Wet Pond (a)	70%	60-80%	Sediment forebay
Constructed Wetland (b)	80%	65-80%	Designed to infiltrate or retain
Water Quality Swale	70%	60-80%	Designed to infiltrate or retain
Infiltration Trench	80%	75-80%	Pretreatment critical
Infiltration Basin	80%	75-80% (predicted)	Pretreatment critical
Dry Well	80%	80% (predicted)	Rooftop runoff (uncontaminated only)
Sand Filter (c)	80%	80%	Pretreatment
Organic Filter (d)	80%	80%+	Pretreatment
Water Quality Inlet	25%	15-35% w/ cleanout	Off-line only; 0.1” minimum Water Quality Volume (WQV) storage
Sediment Trap (Forebay)	25%	25% w/cleanout	Storm flows for 2 year event must not cause erosion; 0.1” minimum WQV storage
Drainage Channel	25%	25%	Check dams; non-erosive for 2 yr.
Deep Sump and Hooded Catch Basin	25%	25% w/cleanout	Deep sump general rule = 4 x pipe diameter or 4.0’ for pipes 18” or less
Street Sweeping	10%	10%	Discretionary non-structural credit, must be part of approved plan

Notes:

(a) Includes wet extended detention ponds, wet ponds, multiple pond designs.
(b) Includes shallow marsh, extended detention wetlands, pocket wetland, and pond/wetland designs.
(c) Includes surface, underground, pocket, and perimeter designs.
(d) Includes compost, peat/sand, and bio/filtration designs.

Figure 7-2   Example of TSS Removal Calculation

PROBLEM: A project proponent proposes to treat stormwater for a newly developed site, using street sweeping and the following Best Management Practices (BMPs) in services (a "treatment train"):

- deep sump and hooded catch basins,
- extended detention basin with a forebay, and
- drainage channel (with check dams) designed to be non-erosive in the 2-year frequency, 24-hour storm.

Assuming the reviewing authority allows full credit for the street sweeping, what is the estimated TSS removal rate for the stormwater management system?

SOLUTION: The solution is presented in the following worksheet.

1. List the selected BMPs in Column A.

2. Refer to the table of design rates for TSS removal provided in *Stormwater Management Volume 1* (see table in Figure 7-1). List these in Column B.

3. Enter the initial TSS load (in percent) for each BMP in Column C. For the first BMP, the load is 100%. For subsequent BMPs, the initial load will equal the final load value in Column E for the preceding BMP.

4. For each BMP, compute the TSS amount removed and enter in Column D. To do this, multiply the design rate times the initial load. [Column D = Column B times Column C]

5. For each BMP, compute the final load for each BMP and enter in Column E. To do this, subtract the amount removed from the initial load. [Column E = Column C minus Column D]

6. The overall removal rate equals the sum of the values in Column D. It also equals 100% minus the last value listed in Column E.

Example

TSS Removal Worksheet

A	B	C	D	E
BMP	**% Removal**	**Initial Load**	**Amount Removed**	**Final Load**
Street Sweeping	10%	100%	10%	90%
Deep sump catch basins	25%	90%	23%	67%
Extended Detention (with forebay)	70%	67%	47%	20%
Drainage Channel	25%	20%	5%	15%

Sum of Column D = Overall Removal % = 85%

Note: Last Value in Column E = TSS Remaining After Treatment

7.4 Alternative Techniques For Demonstrating Compliance With The Treatment Standard of 80% TSS Removal

As stated in the *Stormwater Management Volume 1: Stormwater Policy Handbook*, designers may develop stormwater management system concepts that use other Best Management Practices than those listed in the handbook. Stormwater management technology is advancing, with the introduction of new concepts for treatment of runoff. The Policy provides for the opportunity to employ new technology to meet treatment objectives. If a designer proposes to use a differing technology, then that designer needs to provide documentation that the proposed BMP can achieve stated treatment levels. Documentation can include reference to field testing of the BMP, scientific literature and research regarding BMP performance, or other scientific and engineering data applicable to the proposed practice.

In the Commonwealth of Massachusetts, the Strategic Envirotechnology Partnership (STEP program) also evaluates the performance of new technologies offered by commercial vendors for the treatment of stormwater. This program, within the Executive Office of Environmental Affairs, provides technology assessment and performance verification of new technologies. Under this program, vendors submit information and performance data to STEP for evaluation. STEP *does not approve technologies*, but does produce Technology Assessment reports that summarize its review of the submitted information and data. Designers and Conservation Commissioners may find the STEP reports helpful in evaluating the proposed use of a new technology.

Designers may also wish to use an alternative method for determining the TSS removal performance of a particular BMP or series of BMPs. For instance, there are procedures for estimating the settling rates of the various sized particles found in urban runoff, when runoff is passed through a pond. Also, there are computer models available that can be used to evaluate treatment performance of BMPs. An example of such a model is the P8 Urban Catchment Model (Version 2.3) (Walker 1990; Palmstrom and Walker 1991; IEP 1990), which is publicly available.

A designer could elect to use one of these models to document TSS removal rates, instead of using the approximate values that are listed in *Stormwater Management Volume 1*. The review of such documentation is beyond the scope of this handbook.

Chapter 8:
Designing for Recharge

This chapter presents information on the design of recharge systems, including:

- How is recharge related to rainfall and runoff?
- What recharge quantities are of interest?
- Why should Conservation Commissioners be concerned about recharge?
- Constraints on the use of recharge systems.
- Estimating annual recharge volumes and sizing BMPs.
- Estimating device dewatering times.
- Comments on the continuing development of recharge technology.
- Review considerations.

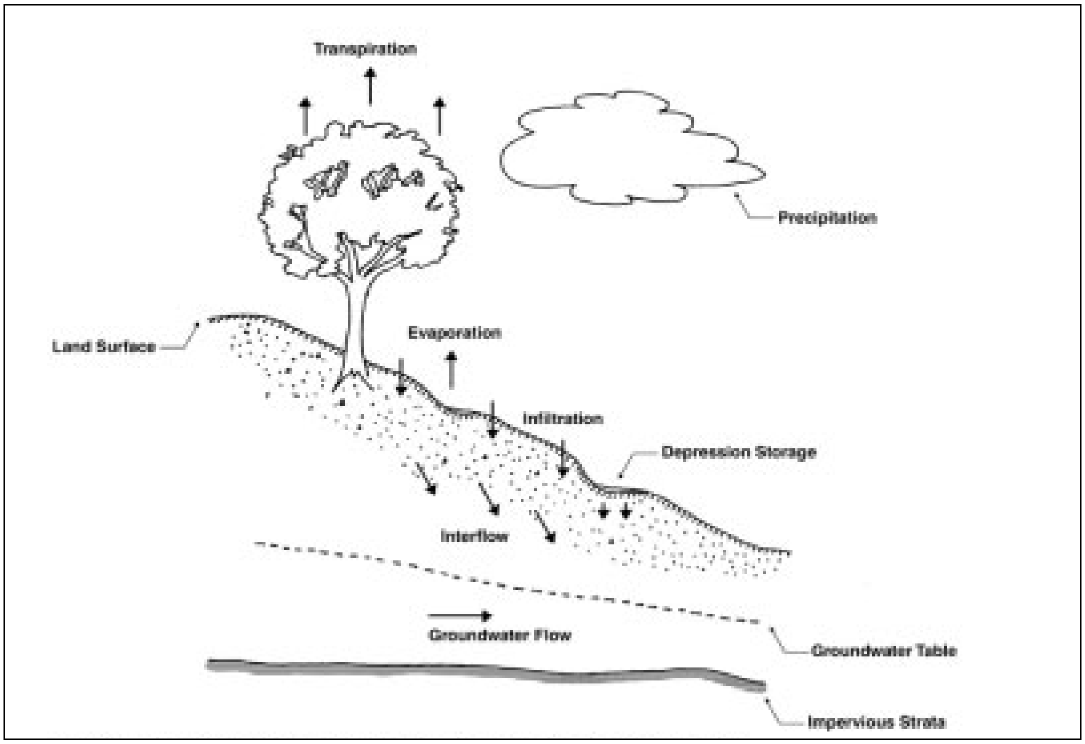
8.1 How Is Recharge Related to Rainfall and Runoff?

Chapter 2 described the hydrologic cycle, and the general relationship among precipitation, runoff, recharge and other components of that cycle. This Chapter will address some basic relationships between rainfall and recharge. The Chapter will focus on the effects of development on average annual recharge, and how stormwater management systems can be designed to maintain recharge to the extent practicable.

Figure 8-1 shows a schematic representation of the relationship of recharge to rainfall and runoff. Chapter 2 provides a description of the overall relationship among the various hydrologic components shown in Figure 8-1, and Chapter 4 discusses some key concepts about runoff. This Chapter further explores the relationship of recharge to precipitation, runoff, and other components of the hydrologic cycle.

As described in Chapter 2, part of the water falling as precipitation enters the ground surface as **infiltration**. The water that infiltrates the ground surface can follow a number of paths. It may become stored as soil moisture, available for uptake through plant roots. Some of the water taken up by vegetation returns to the atmosphere by evapotranspiration. Some of the water stored in the soil returns directly to the atmosphere as evaporation. The remainder of the water entering deeper into the ground is referred to as **recharge**. This water moves through the soil as interflow or groundwater flow.

Figure 8-1   Relationship of Recharge to Precipitation, Runoff, and Evaporation



The relationship of recharge over the long term to precipitation, runoff, and evapotranspiration can be expressed in simplified form by the following water balance:

Recharge = Precipitation - Runoff - Evapotranspiration

The method presented in this chapter for estimating recharge on an annual average basis derives from this very basic relationship.

8.2 What Recharge Quantities Are of Interest?

The Stormwater Management Policy establishes a standard for recharge measured on an average annual basis. Therefore, the quantities of importance include:

- Average annual recharge volume occurring under existing conditions;
- Average annual recharge volume occurring under proposed development conditions;
- The difference between the above volumes. In this manual, this difference is referred to as the **annual capture volume**, and represents the volume of water that must be infiltrated using a properly sized Best Management Practice, to compensate for the recharge that would otherwise be lost as a result of development.

Annual recharge volumes and annual capture volume are expressed as depths, in inches.

Once the annual capture volume is known, the size of Best Management Practice can be determined based on soils and system configuration. Section 8.5 of this chapter refers to a DEP Technical Bulletin that offers guidance for determining the size of a recharge BMP.

Finally, the design of many recharge BMPs results in devices that drain slowly over a period following a storm. In order to provide capacity for subsequent storm events, the devices normally should drain within two to three days. Therefore, the **dewatering time**, the time required to fully drain a device, must be estimated.

8.3 Why Are Conservation Commissioners Interested in Recharge?

The Stormwater Management Policy Standard 3 states:

> *Loss of annual recharge to groundwater should be minimized through the use of infiltration measures to the maximum extent practicable. The annual recharge from the post-development site should approximate the annual recharge from the pre-development site or existing site conditions, based on soil types.*

The development of sites generally involves the creation of impervious surfaces such as roofs and pavements. These surfaces reduce the amount of water that can infiltrate into the ground. The goal of this standard is to address the adverse impacts that result from the loss of natural infiltration. Reduced infiltration results in the loss of water available for recharge to groundwater. Reduced recharge can potentially result in lower local and regional groundwater levels, thus affecting wetland resource areas. Maintaining local and regional groundwater levels has become a critical issue in many areas of Massachusetts:

- In some areas, main-stem rivers may run dry during summer months, when base-flow depends on groundwater discharge;
- In some localities dependent on groundwater drinking water supplies, groundwater tables may become lowered, affecting the available supply; and
- In areas with critical wetland habitats, the alteration of wetland hydrology may significantly alter local ecosystems.

Because of the potential impact on wetland resource areas, Conservation Commissions must consider whether projects comply with Standard 3.

As is evident from the language in the standard itself, the intent is to capture the recharge lost on the site through development of impervious surfaces, by requiring the infiltration of stormwater runoff to approximate the natural recharge of the site. The volume to be recharged is determined on an average annual basis.

8.4 Constraints on the Use of Recharge Systems

The amount of recharge that may occur on an undeveloped site during any given event is a function of the rainfall characteristics, soils, land use/land cover, surficial geology, and topography. To comply with this performance standard, it is necessary to incorporate a system to collect and recharge some portion of the runoff from the developed site. As with any stormwater Best Management Practice (BMP), recharge system design varies depending on the project, site, and local and regional conditions.

The suitability of a site for installing a recharge system depends on a number of factors:

- on-site conditions, including depth to bedrock or impermeable soil layers, depth to groundwater, slope, soils characteristics, and post-development site land use;
- system design (including pre-treatment) and long-term maintenance;
- effectiveness of erosion and sediment controls during construction, selection of construction materials, and care used during construction

Recharge systems depend on the transfer of water into the ground through the surface of natural soils. Recharge systems are prone to failure due to clogging of this soil surface over time. Therefore, site selection, system design, installation practices, and maintenance of the system must consider the above factors.

Not all sites will be practicable for the installation of recharge BMPs. Designers and Conservation Commissions will need to consider the practicability of providing recharge systems on some projects. Note that DEP Underground Injection Control (UIC) requirements may apply.

8.5 Estimating Annual Recharge Volumes, and Sizing Recharge BMPs.

Appendix E of this handbook has been reserved for a Technical Bulletin prepared by the DEP, describing a methodology for estimating annual recharge and for sizing recharge BMPs. The Technical Bulletin procedure is recommended for the design of recharge systems in Massachusetts.

Designers may elect to use a different approach for estimating recharge volumes, and for determining the sizes of recharge systems. If a designer proposes an alternative approach, the project submittal should include an explanation and documentation of the procedures used.

8.6 Estimating Device Dewatering Times

The average time between storm events in Massachusetts is about two to three days. Recharge is maximized when the recharge system is emptied from one storm, prior to the onset of the next.

Maintaining saturated soil conditions for extended periods may adversely affect the performance of recharge systems. Therefore, it is desirable to dewater infiltration systems within 72 hours.

The time required to dewater a recharge system may be estimated by the following equation:

$$T_D = V_{RS} / (f / 12 * A_R)$$

Where:

T_D = Dewatering Time (hours)

V_{RS} = Volume of the recharge system storage (ft^3)

A_R = Recharge surface area (ft^2)

f = Design Infiltration Rate (inches/hr)

12 = Conversion from inches to feet

If T_D is less than or equal to 72 hours, the proposed recharge system is anticipated to dewater within acceptable time frames.

8.7 Comments on the Continuing Development of Recharge Technology

Stormwater management technology is advancing as designers and regulators obtain experience with treatment and recharge methodologies. While recharge practices have been used in some localities for some time, the extensive use of recharge for stormwater management is relatively new. Recharge estimation methods, and designs for accomplishing on-site recharge, may change with increased experience with these systems. Conservation Commissions should therefore be aware that designers may offer new methods and technologies for their review.

8.8 Review Considerations

The following provides a checklist of key review considerations related to recharge calculations:

- Suitable available data has been used to characterize soils on the site, and conditions have been confirmed by a site visit.
- Conditions assumed for the selection of recharge coefficients are consistent with those used for the selection of the pervious area Curve Numbers for the analysis of runoff volumes and rates.
- Physical site conditions that may limit the viability of recharge (e.g., depth to ground water, depth to bedrock) have been identified.
- Proposed depth of recharge storage can be accommodated while maintaining required separation from bedrock and groundwater, as well as adequate cover over the system (as appropriate to the type of design).
- Proposed system has been confirmed to dewater in less than 72 hours.

Chapter 9:
Analysis of Floodplain Areas

This chapter describes procedures used to analyze Bordering Land Subject to Flooding, and Isolated Land Subject to Flooding:

- Bordering Land Subject to Flooding (BLSF)
- Determining BLSF when FEMA data is available.
- Determining BLSF when FEMA data is unavailable
- Determining 10-year flood boundaries from FEMA data.
- Determining floodplain boundaries when FEMA data is unavailable.
- Evaluating Isolated Land Subject to Flooding (ILSF).
- Calculations for compensatory flood storage.

"Land Subject to Flooding", as defined in the Wetlands Protection regulations, has been divided into two categories for regulatory purposes, "Bordering Land Subject to Flooding" (BLSF) and "Isolated Land Subject to Flooding" ILSF. Land Subject to Flooding requirements should not be confused with Stormwater Management Policy requirements. Although there is a functional relationship between stormwater and flooding, the regulatory requirements are distinctly different. This chapter describes the basic concepts behind the hydrologic calculations pertaining to the determinations of Land Subject to Flooding.

9.1 Bordering Land Subject to Flooding (BLSF)

Under the Wetland Protection Act, Bordering Land Subject to Flooding (BLSF) is defined as land that is inundated by flood water rising from adjacent waterways and water bodies (310 CMR 10.57). The boundary of land under the Conservation Commission's jurisdiction as BLSF is the estimated maximum lateral extent of the flood waters that would theoretically result from the 100-year storm event. This is the event that has a one percent chance of being equaled or exceeded in any given year.

The 100-year floodplain boundary is always presented in terms of elevation, expressed in feet above mean sea level (in reference to an established datum, usually either the National Geodetic Vertical Datum – NGVD, or North American Vertical Datum – NAVD) or as a height above or below an arbitrarily established survey point on the site. Land above this elevation (such as an isolated mound or hill) is not subject to jurisdiction as BLSF under the Act, even if it is surrounded by floodplain.

BLSF's extend from the edge of the bank or from the wetland boundary, if a Bordering Vegetated Wetland is present. The regulations specify that the boundary of BLSF's should be determined as follows:

- By referencing the most recently available flood profile data prepared for the community under the National Flood Insurance Program (NFIP), currently administered by the Federal Emergency Management Agency (FEMA). The boundary delineated on the FEMA map is presumed to be accurate and may only be overcome by credible evidence from a registered professional engineer or other professional competent in such matters.
- Where FEMA flood profile data is unavailable, it shall be determined through observed or recorded maximum lateral extent of flooding. In the event of a conflict, it may be determined through calculations prepared by a professional engineer or other competent professional, utilizing the requirements specified in 310 CMR 10.57 and methodologies set forth in TR-55 and the *National Engineering Hydrology Handbook*.

Further information on each of the three methods listed above is provided in the following discussion:

9.2 Determining BLSF's When FEMA Data Is Available

The Federal Insurance Management Agency, formerly administered by the U.S. Department of Housing and Urban Development (HUD) and now overseen by FEMA, has investigated the existence and severity of flood hazards in Massachusetts on a town by town basis. These investigations were performed for the purpose of reducing flood risk to new and substantially improved structures built in the floodplains and providing flood insurance. Each Conservation Commission should have copies of the most recent Flood Insurance Study (FIS) resulting from the FEMA investigations, as well as a complete set of Flood Insurance Rate Maps (FIRM) prepared for the study. Some towns also have Floodway and Flood Boundary Maps, which depict floodways as defined by FEMA. If a Conservation Commission does not have copies, information of how to acquire the study report and maps may be obtained from:

FEMA Phone: 617-223-9561
J.W. McCormack Building
Room 442
Boston, MA 02109-4594

This information is typically available for most communities. FEMA Flood Insurance Studies (discussed below) should be considered the most reliable source of floodplain data unless evidence is provided to the contrary.

FEMA Flood Insurance Studies (FIS)

The federal Flood Insurance Studies provide information regarding the drainage area characteristics and flood elevations for substantial waterways and water bodies within a community. The information provided is based on theoretical models and field data collected for stream flow and channel characteristics. The degree of detail to which each analysis was completed is dependent upon the size and potential flooding impacts of the stream, lake or pond, as well as the existence of historical stream flow data. It is important to note that the studies rarely provide information on smaller streams or the upper portions of many named waterways.

For rivers and streams, the Flood Insurance Study report provides flood profiles for waterways of significant flood risk. Each report contains a variety of tables summarizing the drainage area and channel characteristics, the peak discharges of each studied waterway or water body at points of interest, and floodway data, which provides information on the *theoretical* flood elevations under several different scenarios. The latter of these tables, "Floodway Data", is of particular importance to Conservation Commissioners, as it provides the 100-year flood elevations for the particular area of study. This information is provided in the "Regulatory" column, under the "Base Floodwater Surface Elevation" heading. Note that no "floodways" are designated for tidally influenced portions of rivers and streams.

Also included in each report are a series of "Flood Profiles", which graphically show profiles of each waterway studied. The streambed and 10-, 50-, 100-, and 500-year flood elevations are provided on each profile, as well as major crossings, such as roads or other features.

If a proposed development or redevelopment project is located near a stream or waterbody that is likely to flood, the site may potentially contain BLSF. In this case, designers and Conservation Commissioners should consult the town's Flood Insurance Study, to ascertain whether the study contains profile data applicable to the site. If the data is available, the FIS profile information must be used to determine flood elevations at the site. The data presented in the "Floodway Data" tables and the "Flood Profiles" is then used to determine the 100-year flood elevation. To determine this elevation, Commissioners should first consult the FIRM maps to determine which cross-section the site is closest to. Depending on its location and the required detail of the analysis, the elevation may then be read directly from the tables or profile, or it may be interpolated between information provided at two subsequent cross-sections.

Figure 9-1 is a copy of a typical Floodway Data table. Figure 9-2 is a typical profile of a stream included in a Flood Insurance Study.

<u>FIRM and FBFM Maps</u>

The FEMA study for each town may include several Flood Insurance Rate Map (FIRM) panels, depending on the size of the community and the area studied. The maps typically provide 100-year flood elevations and delineation of the 100- and 500-year floodplain boundaries. Some communities also have Flood Boundary and Floodway Maps (FBFM), which show similar floodplain boundaries, as well as 100-year floodway. No topographic information is provided on these maps. Figure 9-3 shows part of a typical FIRM panel. Figure 9-4 shows part of a typical FBFM panel. These maps are helpful in determining if a site contains BLSF. However, the FIS profile must be used to determine the elevation(s) of the 100-year flood applicable to the site.

The elevations are then plotted on the topographic plan of the site, to determine the extent of BLSF. If a FIS profile is not available, then the alternative methods for BLSF determination specified by the Wetland Protection Regulations must be used (listed in Section 9.1).

Figure 9-1 Floodway Table

FLOODING SOURCE		FLOODWAY			BASE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY	WITHOUT FLOODWAY (FEET NGVD)	WITH FLOODWAY	INCREASE
Neponset River								
A	10,620[2]	70[4]	741	3.7	47.1	47.1	47.1	0.0
B	14,650[2]	63[4]	799	2.5	47.3	47.3	47.8	0.5
C	15,610[2]	80[4]	761	2.4	47.4	47.4	48.0	0.6
D	15,680[2]	80[4]	772	2.3	47.5	47.5	48.1	0.6
E	16,200[2]	109[4]	760	2.4	47.6	47.6	48.2	0.6
F	16,340[2]	109[4]	815	2.2	47.7	47.7	48.3	0.6
G	20,000[2]	85[4]	908	2.0	47.9	47.9	48.6	0.7
H	25,780[2]	143[4]	1,912	1.1	48.0	48.0	48.9	0.9
I[1]	26,795[2]	163	1,377	1.5	48.0	48.0	48.9	0.9
J	28,420[2]	73	1,241	1.7	48.1	48.1	49.0	0.9
K	29,320[2]	116	1,197	1.9	48.1	48.1	49.1	1.0
L	29,700[2]	105	1,300	1.7	48.2	48.2	49.1	0.9
M	31,280[2]	63	814	1.9	48.3	48.3	49.2	0.9
N	32,450[2]	92	643	2.4	48.3	48.3	49.3	1.0
Ponkapoag Brook								
A	2,000[3]	100	624	0.5	49.7	49.7	50.7	1.0
B	3,869[3]	50	287	1.1	51.0	51.0	51.6	0.6
C	4,459[3]	75	324	1.0	51.1	51.1	51.9	0.8
D	5,178[3]	47	142	2.2	51.4	51.4	52.1	0.7
E	5,283[3]	50	205	1.6	52.7	52.7	53.4	0.7
F	6,070[3]	50	193	1.7	52.9	52.9	53.6	0.7

[1]Cross section outside corporate limits

[2]Feet above corporate limits

[3]Feet above confluence with Neponset River

[4]This width extends beyond corporate limits

FEDERAL EMERGENCY MANAGEMENT AGENCY

TOWN OF CANTON, MA

(NORFOLK CO.)

FLOODWAY DATA

NEPONSET RIVER - PONKAPOAG BROOK

TABLE 3

Figure 9-2   Flood Profile

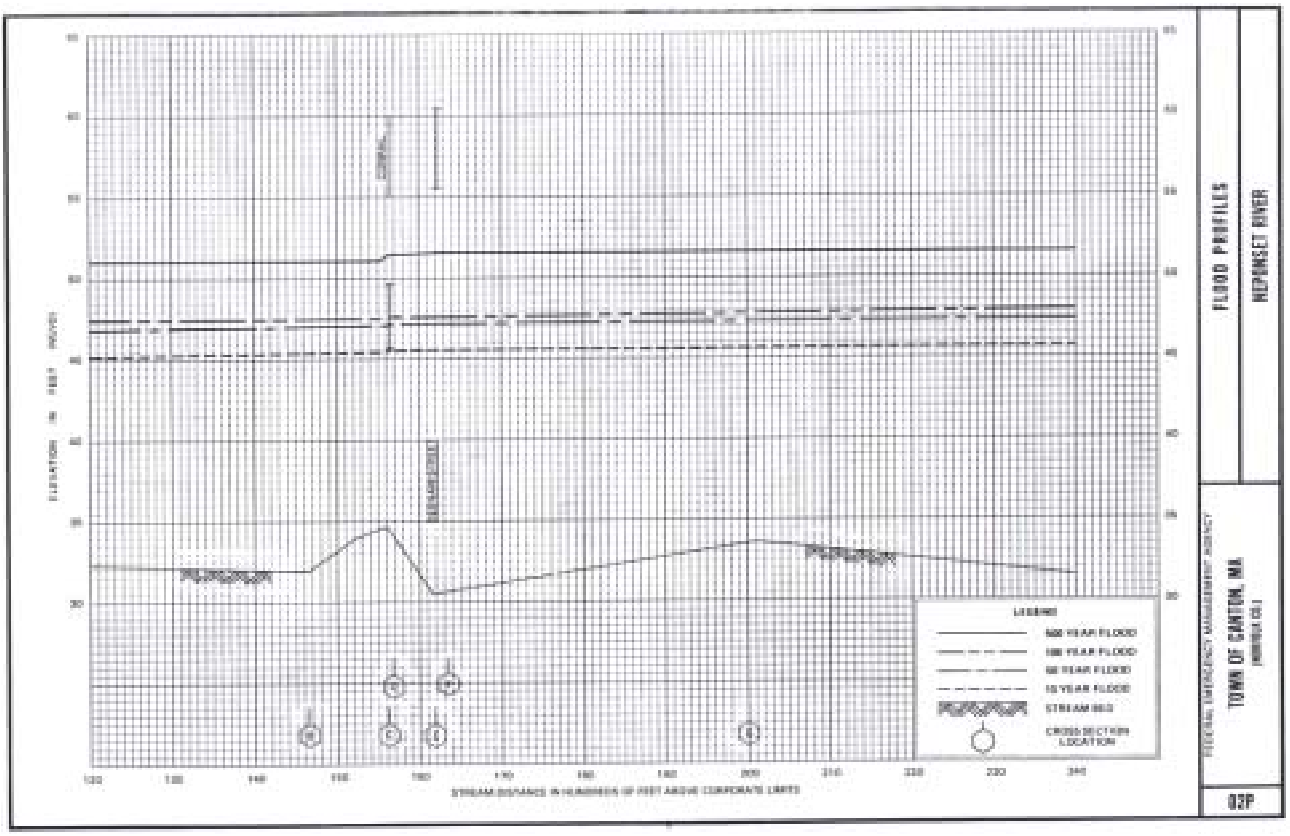


Figure 9-3 FIRM Panel

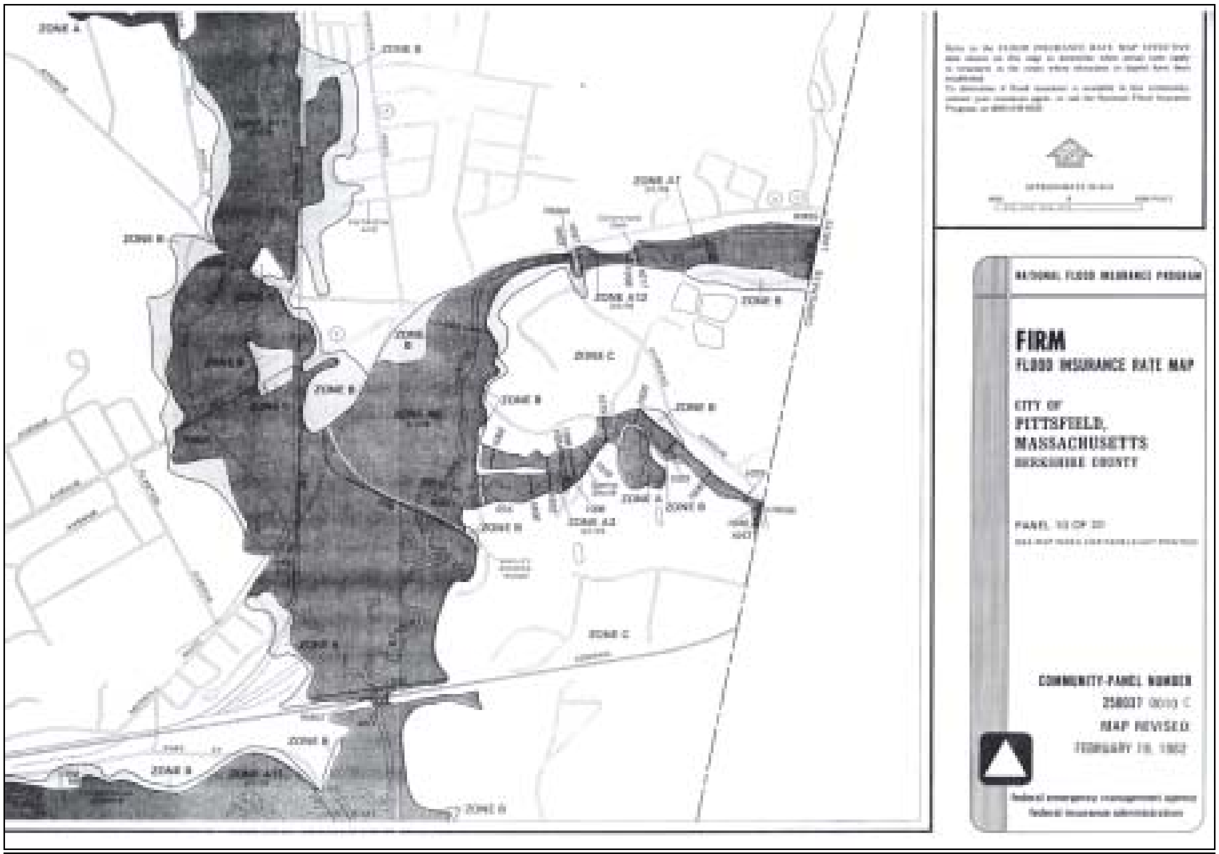
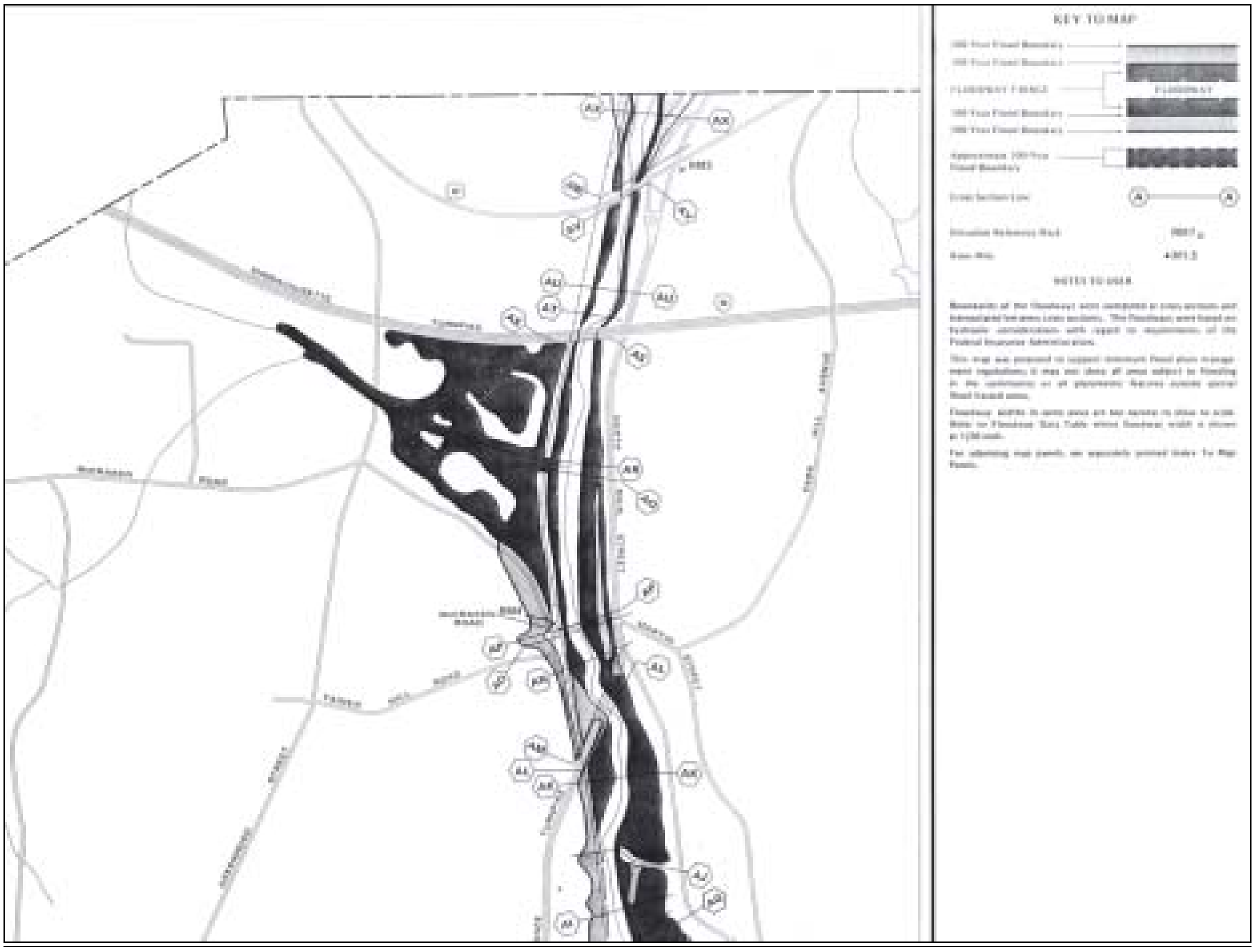


Figure 9-4 FBFM Panel



Floodplain Boundaries

The 100- and 500-year floodplain boundaries are typically shown on each FIRM map. On these maps, the 100-year floodplain boundary corresponds to areas of special flood hazards (identified as Zones A through VE). The 500-year floodplain boundary corresponds to areas of moderate flood hazards. For areas studied by approximate methods, only the 100-year floodplain boundaries are delineated. Commissioners should note that small areas shown within the 100-year flood boundary, but lying above the 100-year flood elevation, may not be shown on the maps, due to the limitations of scale or the lack of topographic data.

Each map includes "Base Flood Elevation Lines", which give the approximate elevation of the 100-year flood at certain locations. In addition, some maps may include a "Base Flood Elevation", which indicates a uniform 100-year flood elevation within a special flood hazard zone. The Wetlands Protection Regulations (310 CMR 10.57) require the use of the flood profiles in the Flood Insurance Study to determine the 100-year and 10-year flood elevations. Absent such a profile in an FIS, applicants must use a specified procedure to determine these elevations (see Section 9.3). The FIRM and FBFM maps should not be used in place of the FIS or specified procedure. However, the information shown on these maps can be useful for comparison purposes and to help corroborate results obtained by the specified analyses.

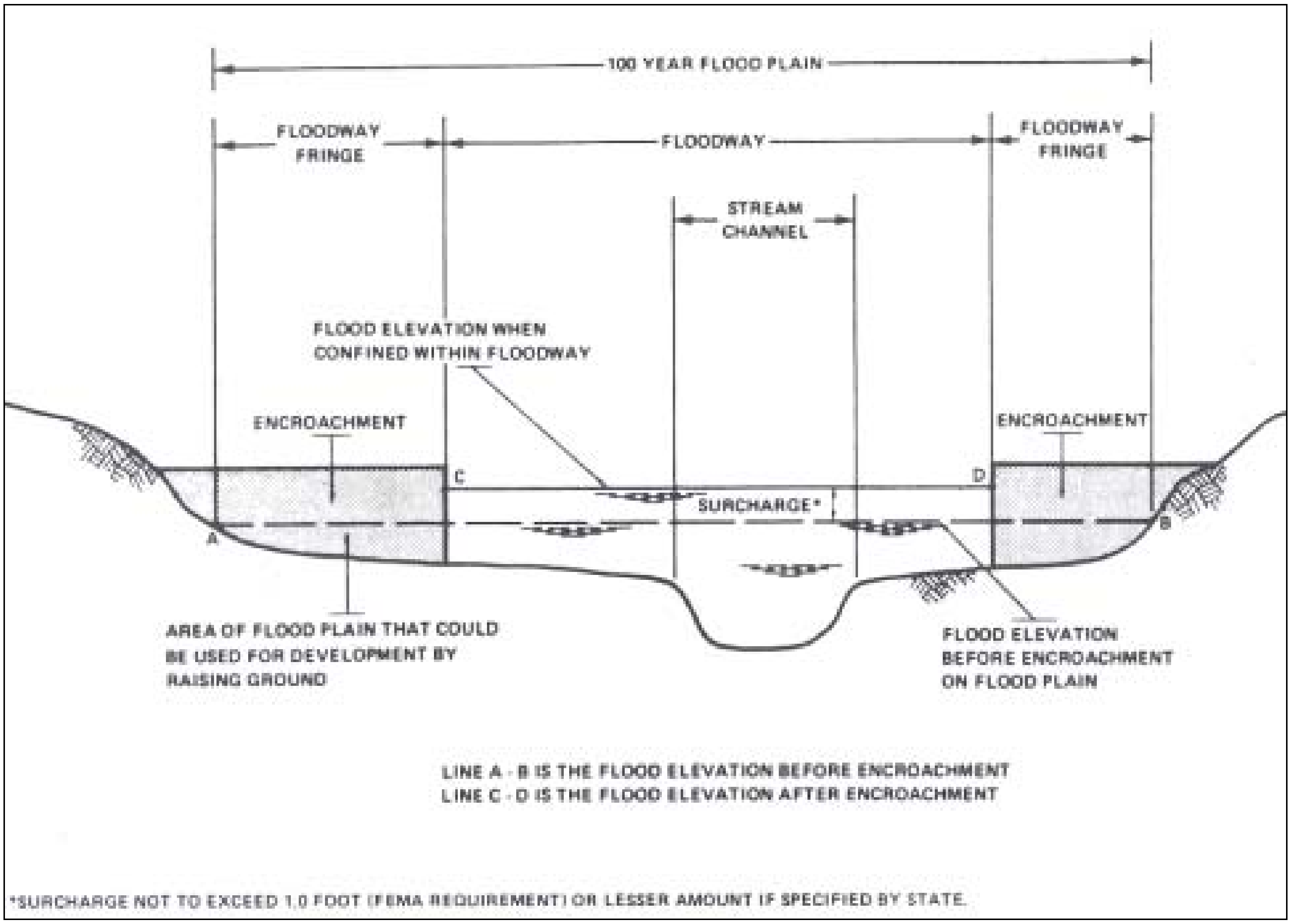
In cases where adequate topographic information is submitted on a site plan, Commissioners should use the spot elevations or contour at the 100-year flood elevation (determined from the flood study) as the floodplain boundary, rather than the 100-year flood boundaries delineated on the FIRM maps.

If significant development has occurred within a given watershed since the completion of the FEMA study, the flood elevations and boundaries may no longer be accurate. However, the Regulations specifically state that the National Flood Insurance Program (NFIP) profile data is presumed accurate, unless credible evidence from a registered professional engineer, or other professional competent in such matters, is presented. If Commissioners believe that the FEMA information is out of date, they should work with their municipality to arrange for the study to be updated by FEMA.

Floodways

FEMA defines floodways as the channel of a stream, plus any additional floodplain areas, that must be kept free of encroachment so that the 100-year flood can be carried without an increase in flood elevation greater than one-foot. If a town participates in the NFIP, then FEMA requires the town to adopt a local bylaw that does not allow any encroachment within a designated floodway, as construction in a floodway would lead to increase in flooding of one foot or more. It should be noted that these "floodways" have not been determined for all areas included in the FEMA studies. Some towns do not have Flood Boundary and Floodway Map panels. Figure 9-5 shows a schematic cross-section of a floodplain, with the floodway indicated.

Figure 9-5 Floodway Schematic



The floodway widths presented on the maps are based on the data provided for each cross-section in the "Floodway Data" table of the Flood Study. Boundaries are interpolated between cross-sections.

Projects that involve disturbance of more than one-half acre of floodway must be reviewed under the Massachusetts Environmental Policy Act (MEPA).

9.3 Determining BLSF When FEMA Data Is Unavailable

The Wetland Protection Act identifies the following two methods for determining BLSF's when FEMA data is unavailable:

- Maximum lateral extent of flood water which has been observed or recorded;
- In the event of a conflict, engineering calculations prepared by a professional engineer or other professional competent in such matters, based on the methodologies set forth in TR-55 and the *National Engineering Hydrology Handbook*.

Further description of each method is presented in the following sections.

Observed or Recorded Flood Elevations

Where observed flood elevations are submitted for use as the floodplain boundary, the Commission should attempt to obtain reproducible evidence of the flood elevations. Verbal confirmation by observers is not sufficient. Instead, written descriptions of the conditions observed and date of observation should be required. If possible, stage elevations, nearby gage records, and/or rainfall data for the date of the observations should also be provided. In addition, all available physical evidence, such as photographs of flood damage or the water surface within a flooded area in relation to known features, or written records of depth measurements correlated with observation times at specific locations, should be submitted as back-up data.

Commissioners should investigate the possibility that a blocked culvert, broken tide gate, or other temporary obstruction may have caused an observed flooding event.

Engineering Calculations

All engineering calculations, submitted in those situations where NFIP FEMA flood profile data is unavailable and there is a conflict between the maximum lateral extent of flooding observed or recorded (or where there are no such observations or records), shall comply with the following provisions set forth in the Wetland Protections regulations:

- The calculations must be based on a Type III, seven-inch, 24-hour design storm. *[Note: this 7- inch storm is only used for determining the regulatory 100-year flood boundary; it is not necessarily the appropriate value to use for estimating peak rates for the 100-year design storm (see Chapter 4). For peak rate estimates, the value for the peak rate event given in the precipitation data for Massachusetts (Appendix F) should be used.]*
- The calculations should be based on methodology described in the U.S. Soil Conservation Service (SCS, now known as NRCS) Technical Release 55 (TR-55), *Urban Hydrology for Small Watersheds*, and Section 4 of the SCS, *National Engineering Hydrology Handbook.* Note that TR-55 does not provide a water surface profile. The hydrologic parameters developed using TR-55 will need to be used to develop a hydrograph and route it through the waterbody (see Section 4.6) to generate water-surface profiles or elevations.
- Calculations must be performed by a registered professional engineer or other professional competent in such matters.

9.4 Determining 10-year Flood Boundaries from FEMA Data

The 10-year flood boundary is the estimated maximum lateral extent of the floodwater that will theoretically result from the statistical 10-year frequency storm. There is a 10-percent chance of this storm being equaled or exceeded within any given year.

The Wetland Protection Act specifies that this boundary may be determined in the same three ways that are used to calculate the 100-year flood boundary (please refer to Sections 9.2 and 9.3).

When preparing engineering calculations, however, a Type III, 24-hour design storm with the rainfall volume of 4.8 inches shall be used. *[As noted above, this rainfall volume is only used for determining the regulatory 10-year flood boundary; it is not necessarily the appropriate value to use for estimating runoff rates.]*

Typically, FEMA studies do not include flood elevations for the 10-year event in the “Floodway Data” tables. However, most studies provide information on how to compute the 10-year flood elevations from 100-year flood values. Additionally, some studies include the 10-year flood elevations on the “Flood Profile”.

9.5 Evaluating Isolated Land Subject to Flooding (ILSF)

Under the Wetland Protection Act, Isolated Land Subject to Flooding (ILSF) is defined as isolated depressions or closed basins without an inlet or outlet (310 CMR 10.57). In this instance, the phrase “without an inlet or outlet” should not be interpreted literally. All basins must have some type of outlet at some elevation where water will overtop and be allowed to leave the basin. Similarly, there must be some flow of water into the basin, be it surface or groundwater fed. Instead, the condition that there be “no inlet” means that there should be no hydrologic connection with the 100-year floodplain. This stipulation is used to distinguish ILSF’s from Bordering Land Subject to Flooding, which is defined by 100-year flood elevations (DWW Policy 85-2, cited in DEP, 1995).

In order to be classified as an ILSF, the depression must confine standing water, at least once a year, to a volume of at least 0.25-acre-feet (10,890 cubic feet) and to an average depth of at least six-inches. The phrase “at least once a year” refers to the statistical one-year storm event, and is not dependent upon field observations and measurements (DWW Policy 85-2, cited in DEP, 1995).

The ILSF definitions presented here represent a combination of the definition presented in the Wetland Protection Act and the article, “ILSF Definition: Interpretation of 310 CMR 10.57(2)(b): Definition of Isolated Land Subject to Flooding (DWW Policy 85-2)”, prepared by the Massachusetts DEP in the publication *Wetlands Protection Program Policies*, dated March 1995.

Table 9-1 presents a step by step procedure for evaluating a potential ILSF. The steps are further explained following the figure.

Table 9-1 Outline of ILSF Procedure

Step 1. Is the area **<u>isolated</u>?**

- a. No inlet;
- b. No outlet;
- c. No connection to other water body by 100 year flood plain;
- d. If a, b, and c are true, then this could be an ILSF; go to step 2.

Table 9-1 Outline of ILSF Procedure(Continued)

Step 2. **<u>Can the area confine</u>** a volume of water:

- greater than or equal to ¼ acre-feet (10,890 cubic feet), and
- to an <u>average</u> depth of 6 inches?

a. Compute volume to elevation of lowest point on crest of depression;

b. If volume ≥ ¼ acre-ft., determine the area of the depression at the elevation of the lowest point on the crest;

c. Divide the volume of the depression by the area to obtain the average depth in feet;

d. Multiply average depth in feet by 12", to obtain average depth in inches;

e. If average depth ≥ 6", then this could be ILSF; go to Step 3.

Step 3. **<u>Does the area confine</u>** a volume of water, at least once per year:

- greater than or equal to ¼ acre-feet, and
- to an <u>average</u> depth of 6 inches?

a. Theoretically, could be based on observations or recorded data. However, if in any particular year or years, the minimum volume of water is not observed, one cannot conclude that the depression does not contain the statistical "one-year event". Therefore, compute volume of runoff to the depression by following steps:

b. Graph the depth vs. volume and depth vs. area relationships for the depression;

c. From observations of surficial conditions and soils data for the site of the depression, determine the seasonal high groundwater elevation in the depression. If this groundwater elevation results in standing water in the depression, determine the depth. From the depth vs. volume graph, determine the volume occupied by seasonal high groundwater;

d. Determine area contributing to depression, determine curve number, and estimate runoff volume for 1-year frequency rainfall event (TR-55). If there is standing groundwater in the depression (Step 3.c.), use a curve number of 100 for the area occupied by groundwater;

e. Add the volume of standing groundwater (3.c.) to the volume of runoff from the 1-year storm (3.d.);

f. If the combined volume (3.e.) < ¼ acre-ft, then the area is not an ILSF;

g. If the volume > ¼ acre-ft., then proceed to the following steps to determine depth;

h. Determine the depth corresponding to the volume computed in 3.e., using the depth to volume graph developed in 3.b.;

i. Determine the area corresponding to the depth determined in 3.h., using the depth to area graph developed in 3.b.;

j. Divide the volume by the area, to obtain the average depth in feet;

k. Multiply average depth in feet by 12", to obtain average depth in inches;

l. If average depth < 6", then the area is not an ILSF.

m. If average depth > 6", then proceed to step 4 to determine extent of ILSF.

Step 4. **<u>Determine the extent</u>** of the ILSF

a. Determine highest elevation of water recorded or observed; if such data are not available, or if there is a conflict of opinion regarding this elevation, then:

b. Obtain an opinion certified by a professional engineer, supported by calculations, as to the probable extent of flooding. Recommended procedure:

   i. Determine volume of runoff from contributing watershed for 7-inch, 24 hour precipitation event (TR-55). Use curve number of 100 for area of standing groundwater; and assume there is no infiltration into the soil within the ILSF;

Table 9-1 Outline of ILSF Procedure(Continued)

ii. Add this runoff volume to the volume of standing groundwater;

iii. Determine depth occupied by this volume from the volume/depth curve, and the elevation corresponding to this depth; or

iv. If this volume exceeds available volume at the depression's crest, then route the 100-year storm through the basin, with the crest acting as the outlet control (assume no infiltration within the ILSF); determine the maximum depth of storage and corresponding elevation;

v. If there is physical evidence of the level of flooding at the site, record the elevation by survey. Compare this elevation to that computed in Step 4.b.iii or 4.b.iv (whichever step applies). The contour corresponding to the higher of these elevations is the extent of the ILSF.

Step 1: Is the area isolated?

Commissioners should begin by identifying all isolated depressions from existing topography submitted as part of the site plan package. This may be difficult to do if topographic maps do not provide contours at close enough intervals, such as maps based on USGS quads where only 10-foot (or 3 meter) contours are typically shown. If site conditions warrant, Conservation Commissions may want to consider requesting that plans be submitted with one or two-foot contours.

Once potential ILSF's have been identified, Commissioners should determine whether the depression has an inlet and/or an outlet, as defined above. The basin does not have an "inlet" if no hydrologic connection with the 100-year flood event or any surrounding waterbodies or waterways can be identified. Similarly, the basin does not have an "outlet" if the required volume of water (1/4 acre-foot) is confined within the depression below the elevation at which water will overtop. The procedure outlined in the following step should be used to determine whether such a volume can be confined.

Step 2: Can the area confine the specified volume of water?

In order to be characterized as an ILSF, a depression must confine a volume of water greater than or equal to 0.25 acre-feet (10,890 cubic feet) and to an average depth of six-inches. When a Commission suspects that an isolated depression may meet these requirements, the applicant should provide calculations documenting the amount of water the depression can hold, as well as the amount of runoff entering the basin under existing conditions. Oftentimes, these calculations will be completed by computer analysis. The following procedure may be used by Commissioners to verify the accuracy of such calculations.

<u>Volume Calculation</u>

Commissioners should first compute the potential flood-storage volume of the basin. The lowest point in the depression and the crest elevation (i.e., elevation at which water would begin to overtop the basin) should both be identified, if possible, from spot grades. If spot grades are not available, the approximate elevation should be calculated to the nearest tenth based on slopes.

Once this is complete, the volume between different contour depths should be calculated from topographic data. The area of each contour should be either approximated from the plan or determined using a planimeter, a device that calculates areas directly. The areas will typically be expressed in units of square feet or acres. Using these areas, the volume between any two contours may be calculated from the following formula:

$$V = \frac{(A_l + A_u) \times \Delta h}{2}$$

where, A_l represents the lower contour's area, A_u represents the upper contour's area, Δh represents the change in elevation (i.e., $A_u - A_l$) and V is the volume stored between the two contours.

When calculating areas where the elevation given is a spot grade (i.e., at the bottom or crest of the depression) rather than a contour, Commissioner's should approximate the location of the contour represented by the spot elevation.

Finally, the volume between each contour interval should be summed to compute the total volume of the basin. If this volume has been computed in cubic feet, the conversion factor of one-acre equal to 43,560 square feet should be used to convert to acre-feet (one acre-foot represents the volume of water that would cover one-acre of land to a depth of one-foot*). If this volume is greater than 0.25 acre-feet, then the average depth of the basin should be calculated.*

Average Depth Calculation

For this calculation, the area of basin at its crest (i.e., elevation at which water begins to overtop the basin) should first be calculated (in square feet). The total volume of the basin (in cubic feet) calculated in the previous step should then be divided by this area to obtain the average depth (in feet), and multiplied by 12 inches/foot to convert the depth to inches.

$$\text{Average depth} = \frac{V_t \text{ (cu. ft)}}{A_c \text{ (sq. ft.)}} \times (12 \text{ in/ft})$$

Where V_t represents the total volume of the basin and A_c represents the area at its crest

If this depth is greater than six inches, and the volume condition was met, then the basin has the potential to hold the specified volume of water. The next step is then to determine whether or not this actually occurs at least once a year, based on the hydrologic conditions in the area.

Step 3: Does the area confine the specified volume of water at least once per year?

Theoretically, this determination could be based on field observations or recorded data. However, if in any particular year or years, the minimum volume of water is not observed, your

Commission cannot conclude that the depression does not contain the statistical “one-year” event. As a result, you may want to require NOI packages involving ILSF determinations to include back-up calculations. Commissioners may verify these calculations using the guidance provided in the following sections.

Groundwater Contributions

Commissioners should verify that all calculations submitted for ILSF determinations include an accurate depiction of groundwater contributions to the potential volume of water confined in a depression. However if the seasonal high groundwater table is clearly below the elevation of the bottom of the depression, this is irrelevant.

In order to determine the groundwater contribution, Commissioners should first create a plot of the volume versus depth and area versus depth for a given basin from the flood-storage relationships determined above (see Step 2). The seasonal high groundwater elevation should then be determined from observations of surface conditions and soils data for the site of the depression. If this groundwater elevation will result in standing water in the depression (i.e., if the seasonal high groundwater elevation is greater than the bottom elevation of the basin) its depth should be determined. The volume occupied at this depth may then be determined from the volume versus depth graphs.

Runoff Contributions

Commissioners should follow the guidelines discussed in Chapter 4 of this manual when determining the total volume of runoff contribution to a basin. This involves delineating the contributing drainage area to a basin and determining the corresponding watershed characteristics, in order to determine runoff curve number. The regulations specify that no infiltration should be accounted for within the potential ILSF. As such, a curve number of 98 or 100 should be used for the bottom of the basin. Using the volume of rainfall from a one-year, 24-hour storm event, the runoff volume is then computed using the method outlined in TR-55. The volume of runoff should then be added to the volume of standing groundwater in the basin, if applicable. If this volume is less than 0.25 acre-feet, the basin is not an ILSF. However, if it is greater, the average depth to which water rises in the basin should be computed (as in Step 2).

Average Depth Calculations

The graph of volume versus depth previously created should be used to determine the depth corresponding to the total runoff volume calculated above. Using the depth versus area graph previously developed, determine the area corresponding to this depth. Divide the total contributing volume (runoff and groundwater contributions) by the area just determined to calculate the average depth, in feet. Multiply the depth by 12-inches/foot to determine the depth in inches. If this depth is less than six-inches, the basin is not an ILSF. If it is greater than six-inches, the basin may be categorized as an ILSF under the criteria specified in the Wetland Protection Act, and its extent must be determined.

Step 4: Determine the extent of the ILSF

The extent of an ILSF is defined in the Act as the largest observed or recorded volume of water confined within the area. In the event of a conflict of opinion regarding the extent of water confined in an ILSF, the applicant may submit an opinion certified by a registered professional engineer, supported by calculations, as to the extent of said water. The Wetland Protection Regulations, 310 CMR 57 (2)(b)3 identifies the requirements for the calculation.

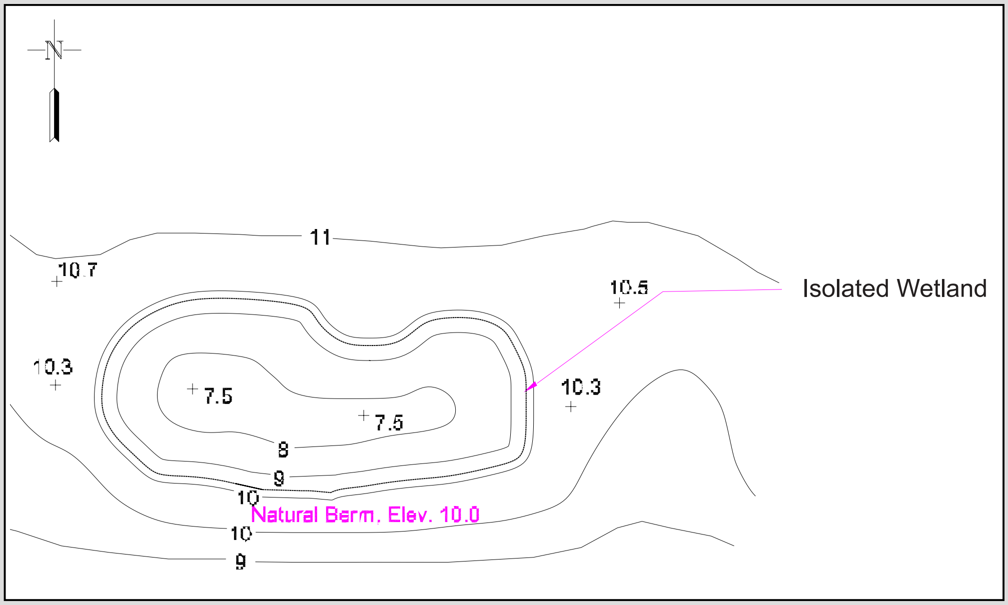
For this calculation, the runoff volume should be determined for Type III, 7-inch, 24-hour storm event, using the same contributing area and watershed characteristics employed when determining the ILSF (see Step 3). Commissioners should verify that the areas and curve numbers are consistent in both analyses. The computed runoff volume should then be added to the volume of standing groundwater, if applicable. The depth occupied by this volume, and the corresponding peak elevation, should be determined from the depth versus volume graphs previously discussed.

If the volume exceeds the available capacity of the basin, then the 100-year storm should be routed through the basin (see Chapters 4 and 6 for procedures), with the crest acting as the outlet control (i.e., the elevation at which water begins to leave the basin). No infiltration should be accounted for in the basin. The maximum depth of storage and the corresponding elevation should be determined.

If there is physical evidence of the level of flooding at the site, the elevation should be recorded by survey. This elevation should then be compared to that computed in hydrologic analysis. The contour corresponding to the higher of these elevations is the extent of the ILSF.

Figure 9-6 presents an example of an ILSF calculation.

Figure 9-6   Examples of ILSF Calculations



PLAN OF ISOLATED WETLAND

<u>Problem 1:</u>

Determine if the isolated wetland depicted in the plan is an Isolated Land Subject to Flooding (ILSF). The following information has been provided by the applicant, and confirmed by the commission:

- The wetland has no discernible inlet or outlet, based on topographic mapping and field observation. It is not included within the 100-year flood plain, based on an examination of the FEMA Flood Insurance Study and FIRM panels for the town.
- There is no reliable record of the volume or depth of runoff stored in this depression. However, field observations and test pits show that seasonal high groundwater elevations are below the bottom of the depression.
- The watershed has a Runoff Curve Number of 72. Based on a 1-year frequency rainfall depth of 2.6 inches, the estimated runoff depth from this watershed has been calculated to be 0.58 inches.
- The storage volume versus depth (stage) relationship for the depression is presented in the following table:

Figure 9-6 Examples of ILSF Calculations (continued)

Stage vs. Storage Tabulation

Stage (feet)	Depth (feet)	Elevation Difference (feet)	Area (acres)	Average Area (acres)	Incremental Storage (acre-feet)	Total Storage (acre-feet)
7.5	0		0.00			0.00
		0.5		0.03	0.02	
8	0.5		0.06			0.02
		1.0		0.12	0.12	
9	1.5		0.17			0.13
		1.0		0.25	0.25	
10	2.5		0.32			0.38

Solution 1:

Step 1: Is the area isolated?

Yes. Based on the information furnished for the site, the depression has no inlet or outlet, and is not connected to another water body by the 100-year flood plain.

Step 2: Can the area confine a volume of water greater than 0.25 acre-feet to an average depth of at least 6 inches?

The total volume of the depression in the table is 0.38 acre-feet, which exceeds the 0.25 acre-feet volume criteria.

The average depth corresponding to this volume is calculated as follows:

$$d = \frac{\text{(total volume)}}{\text{area at total volume}} = \frac{0.38\text{ acre-feet}}{0.32\text{ acres}} \times \frac{12\text{ inches}}{\text{foot}} = 14.25\text{ inches}$$

Yes, the area can confine at least 0.25 acre-feet at a depth of at least 6 inches.

Step 3: Does the area confine a volume of water equal to or greater than 0.25 acre-feet to an average depth of at least 6 inches, at least once per year?

Absent a reliable record of the storage of water in this depression, the applicant has furnished an estimate of runoff into the depression for the 1-year frequency storm event. This depth must be converted to a volume, by multiplying times the area of the watershed:

$$V = 0.58\text{ inches} \times 1.5\text{ acres} \times \frac{1\text{ foot}}{12\text{ inches}} = 0.073\text{ acre-feet}$$

Figure 9-6 Examples of ILSF Calculations (continued)

This volume is less than 0.25 acre-feet. Therefore, the depression is <u>not</u> an ILSF under the Wetlands Protection Regulations.

Step 4: In this example, Step 4 (determining the extent of the ILSF) is not required.

<u>Problem 2:</u>

If the wetland has a drainage area of 5.3 acres (instead of 1.5 acres), determine if it is an ILSF. Assume that the applicant has furnished the following additional information:

- During a 7-inch, 24-hour storm, the runoff depth from the watershed has been calculated using TR-55 to be 3.83 inches.
- Using the TR-20 computer program to route the runoff during this storm event through the storage volume provided by the depression, the applicant's engineer has determined that the depth of flow will be 0.3 feet over the top of the natural berm at the south side of the depression. This would result in ponding of water to an elevation of 10.3 feet in the depression.

<u>Solution 2:</u>

Step 1: Same as for Problem 1.

Step 2: Same as for Problem 1.

Step 3: Does the area confine a volume of water equal to or greater than 0.25 acre-feet to an average depth of at least 6 inches, at least once per year?

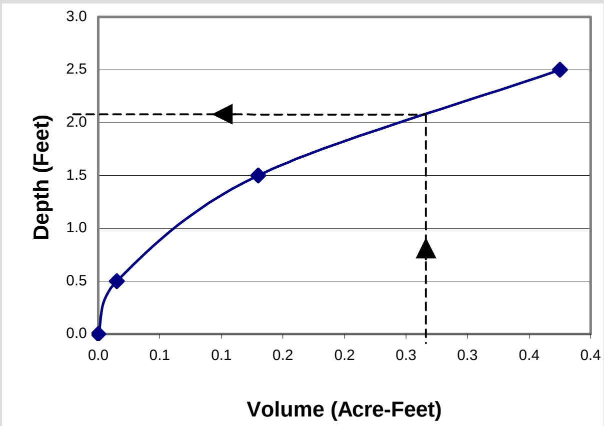
Absent a reliable record of the storage of water in this depression, the applicant has furnished an estimate of runoff into the depression for the 1-year frequency storm event. This depth must be converted to a volume, by multiplying times the area of the watershed:

$$V = 0.58 \text{ inches} \times 5.3 \text{ acres} \times \frac{1 \text{ foot}}{12 \text{ inches}} = 0.26 \text{ acre-feet}$$

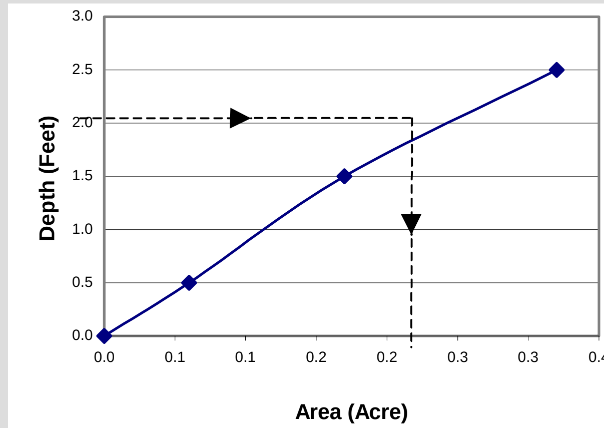
This volume exceeds 0.25 acre-feet. Therefore, the depression may be an ILSF, if the average depth of this volume equals or exceeds 6 inches. To determine the average depth, plot depth vs. volume and depth vs. area from the table presented by the applicant:

Figure 9-6 Examples of ILSF Calculations (continued)

Depth vs. Volume



Depth vs. Area



From the depth vs. volume graph, determine that the maximum depth of storage for 0.26 acre-feet is 2.1 feet. From the depth vs. area graph, determine that the area of the stored volume of water corresponding to the depth of 2.1 feet is 0.26 acres. The average depth corresponding to this volume is calculated as follows:

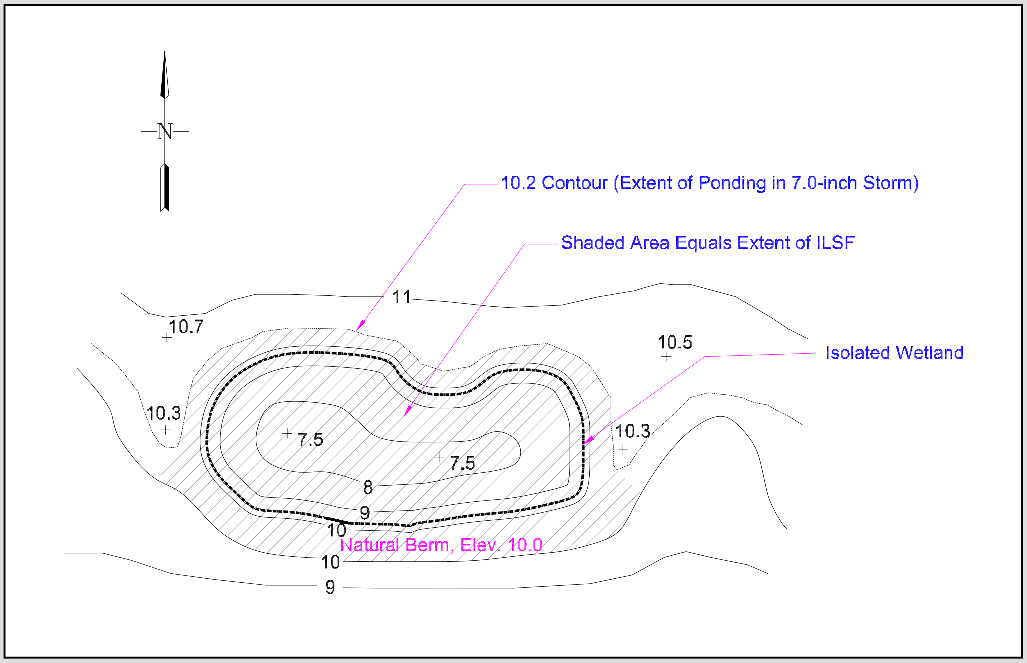
$$d = \frac{\text{(stored volume)}}{\text{area at stored volume}} = \frac{0.26 \text{ acre-feet}}{0.26 \text{ acres}} \times \frac{12 \text{ inches}}{\text{foot}} = 12 \text{ inches}$$

This depth exceeds 6 inches. The depression is therefore an ILSF under the Wetlands Protection Regulations.

Step 4: Determine the extent of the ILSF.

Absent physical evidence of flooding or a reliable record of stored water levels in this depression, the applicant has provided a hydrologic calculation that shows that during a 7-inch, 24-hour frequency storm, the elevation of the water surface in the depression will be 10.2 feet. Using the available topographic mapping, the Commission and/or applicant should plot the 10.2-foot contour on the plan (as shown in the following figure). The extent of the ILSF is established by this contour, and by the outside edge of the natural berm, as shown by the shaded area in the figure.

Figure 9-6 Examples of ILSF Calculations (continued)



PLAN OF ISOLATED WETLAND SHOWING EXTENT OF ILSF IN PROBLEM 2

9.6 Calculations for Compensatory Flood Storage

Under the provisions of the Wetlands Protection Act (310 CMR 10.57(4)(a)):

> "Compensatory flood storage shall be provided for all flood storage volume that will be lost as the result of a proposed project within Bordering Land Subject to Flooding, when in the judgment of the issuing authority the loss will cause an increase or contribute incrementally to an increase in the horizontal extent and level of flood waters during peak flows.
>
> "Compensatory storage shall mean a volume not previously used for flood storage and shall be incrementally equal to the theoretical volume of flood water at each elevation, up to and including the 100-year flood elevation, which would be displaced by the project."

Commissioners should verify that there is an unrestricted hydraulic connection between the affected waterway or water body and the proposed storage.

The key issue is that compensatory storage has to be provided equally AT THE SAME ELEVATION THAT STORAGE IS BEING REMOVED. Also, it is a separate volume from that required for peak rate attenuation under Standard No. 2 of the Stormwater Management Policy.

When compensatory storage is proposed on a site, Conservation Commissions should require applicants to provide documentation of the incremental volumes being filled below the 100-year flood elevation versus the incremental storage volumes being provided. Commissioners should verify that these volumes are satisfactorily equivalent. Engineers may use computer-modeling techniques to perform these calculations.

If Commissioners wish to verify the compensatory flood storage calculations provided in a NOI package, they should first identify all areas of fill within the 100-year floodplain and all areas of proposed storage. Commissioners should request applicants to submit a plan clearly delineating these areas. Once these areas have been noted, the volume of fill and the volume of excavation for compensatory storage can be estimated from the plans by one of several methods. The following are three common examples:

1. Many engineering firms have computer programs with Digital Terrain Modeling (DTM) capability. These programs can use the topographic data for a site to estimate volumes of fill or volumes of excavation below the 100-year flood plain surface.

2. Another common method of estimating fill and excavation ("cut") volumes involves plotting cross sections of the fill and cut areas, measuring the area of each cross section, and estimating the volume of fill or cut between subsequent cross-sections by the "average end area method". The volume between two cross sections is computed by the formula:

$$V = \frac{(A_1 + A_2) \times L}{2}$$

   where, A_1 represents the fill (or cut) area of the first cross section, A_2 represents the fill (or cut) area of the second cross section, L represents the distance between the two cross sections, and V is the fill (or cut) volume between the two sections.

   In this method, fills and cuts are typically accounted separately for each pair of cross sections. The volumes between cross-sections are then tabulated and summed, to obtain total estimated fill and cut volumes.

3. A third method of estimating flood storage loss and compensation is the "contour/area" method. This method uses measurements of contours shown on topographic plans of the affected areas. This method should be used only where the water surface of the 100-year flood is level, or can be reasonably represented by an approximately level surface. (The other methods discussed above can be used for level or sloping water surfaces). In the contour/area method, the hypothetical flood storage volume for pre-development conditions is estimated by measuring contours within the "footprint" of proposed fill and proposed excavation areas. Then, the volume of flood storage is measured within the same "footprint" under proposed conditions. Both measurements assume a hypothetical "prism" or column of water with vertical sides defined by the "footprint" and extending from the ground up to the elevation of the 100-year flood. Note that unless fill areas and cut areas are

analyzed separately, this method estimates *net* flood storage volume; the actual volume of fill or cut is not necessarily estimated by this method. The method can be particularly useful where a grading scheme involves both cutting and filling activities in close proximity to each other.

In each case, the volume between any two contours is calculated from the following formula:

$$V = \frac{(A_l + A_u) \times \Delta h}{2}$$

where, A_l represents the lower contour's area, A_u represents the upper contour's area, Δh represents the change in elevation (i.e., $A_u - A_l$) and V is the cut or fill volume between the two contours.

When calculating areas where the elevation is given as a spot grade (i.e., at the bottom of a depression or crest of a ridge) rather than a contour, the analyst should approximate the location of the contour represented by the spot elevation. The volume between subsequent contours is computed, and the volumes are tabulated and summed to obtain total flood storage for pre-development and post-development conditions.

Other fill and excavation volume methods can be employed. Commissioners should request an explanation of how calculations have been done by an applicant, if they are not familiar with the method used.

Once the pre- and post-development storage volumes are computed, they can be compared to determine if incremental flood storage compensation is provided in accordance with the Wetlands Regulations. Figure 9-7 presents an example of a tabulation of volumes for compensatory flood storage analysis.

Figure 9-7 Example of Compensatory Flood Storage Analysis

Problem:

A project proposal includes grading within Bordering Land Subject to flooding. The design engineer has estimated fill and excavation volumes. The computation used cross-sections of the graded area, to separately estimate volumes of cuts and fills below the 100-year flood surface (elevation 296.0, as determined from the Flood Insurance Study). The following information summarizes the engineer's analysis. Does the project comply with the "incremental compensatory storage" requirement of the Wetlands Regulations?

Figure 9-7 Example of Compensatory Flood Storage Analysis (continued)

Elevation (feet above mean sea level)	Incremental Volume of Fill (cubic feet)	Incremental Volume of Excavation (cubic feet)
292		
	1100	1150
293		
	900	925
294		
	650	670
295		
	145	135
296		
Total Volume	**2745**	**2880**

Analysis:

Even though the overall volume of compensating storage exceeds the overall volume of fill within the floodplain, the project design does not comply with the Wetland Regulations requirement. This is because the incremental volume of excavation (flood storage compensation) between elevation 295 and 296 feet is less than the flood volume displaced by fill for that same elevation increment. The project design could be modified to reduce the fill or increase compensatory storage between elevations 295 and 296, and would then comply with the regulation.

Chapter 10:
Analysis of Riverfront Areas

This chapter briefly addresses Riverfront Areas. The following topics are discussed:

- General Comments Regarding Hydrology and Rivers
- Distinguishing Perennial from Intermittent Streams
- Determining the Mean Annual High-Water Line of a River Under the Wetlands Protection Act
- Sources of Hydrologic Information About Streams

10.1 General Comments Regarding Hydrology and Rivers

The hydrologic and hydraulic behavior of streams can be very complex. Analysis of the hydrology and hydraulics of streams requires an understanding of the many factors that influence the flow of water into and within these water courses. Hydrologic and hydraulic calculations often involve the use of sophisticated analytical techniques and modeling tools. For those interested in a greater understanding of rivers, the following reference is recommended as a starting point:

Leopold, L. B. 1994. *A View of the River.* Harvard University Press, Cambridge, MA.

Also, Conservation Commissioners should be aware that there are many valuable sources of information about streams and rivers, as well as analytic and modeling tools, to aid the analysis of impacts to these aquatic systems. Some of these tools have been discussed in other Chapters of this handbook. For example:

- Peak flows in streams can be analyzed using a number of the modeling tools discussed in Chapter 4. However, as watersheds increase in size, some models can no longer be used. For instance, TR-55 should not be used for watersheds greater than 2,000 acres. TR-20 should not generally be used for watersheds greater than 20 square miles. Major rivers generally have much larger watersheds, and must be analyzed by other techniques.
- Flood elevations along rivers are described in the FEMA Flood Insurance Studies. The interpretation of this information is discussed in Chapter 9 of this manual.
- Sometimes, major new structures are proposed along or crossing rivers (for example, new bridge crossings). Computer modeling techniques (for example, HEC-RAS, developed by the US Army Corps of Engineers) are available for evaluating the profile of a river surface

under given flow conditions. These modeling tools can be used for evaluating the impacts of proposed structures on depths of flow and flooding elevations.

- The USGS has compiled a wealth of information on streams and rivers throughout the United States, including the Commonwealth of Massachusetts. The USGS work includes gaging data on selected streams, hydrologic and hydraulic studies, and methodologies for estimating various types of flow conditions in streams. Section 10.4 of this Chapter lists some sources of information provided by USGS, as well as by other entities.

10.2 Distinguishing Perennial from Intermittent Streams

At the time of writing of this manual, the DEP is in the process of developing a new method to distinguish perennial from intermittent streams. The methodology will rely upon U.S.G.S. maps, watershed size, surficial geology, hydrologic data, and logistic regression equations. Ultimately, new DEP maps will be developed based on this methodology. In the meantime, project proponents and Conservation Commissioners should refer directly to the Wetlands Protection Regulations, and any current policy interpretations published by DEP, for guidance on the determination of perennial/intermittent streams.

10.3 Determining the Mean Annual High-Water Line of a River Under the Wetlands Protection Act

The Mean Annual High-Water Line (MAHW) of a river must be determined in accordance with the Wetlands Protection regulations. Field indicators of bankfull conditions shall be used to determine the MAHW line. There are established scientific methodologies for locating bankfull indicators in the field. Bankfull indicators, include, but are not limited to: changes in slope, changes in vegetation, stain lines, tops of point bars (note that tops of point bars indicate the minimum elevation of bankfull conditions), changes in bank material, or bank undercuts. In most rivers, the first observable break in slope is coincident with bankfull conditions and the MAHW. In some river reaches, bankfull field indicators occur above the first break in slope. These rivers are typically characterized by at least two of the following features: low gradient, meanders, oxbows, histosols, a low-flow channel, or poorly defined or nonexistent banks. In tidal rivers, the MAHW line is coincident with the mean high water line determined under 310 CMR 10.23.

Project proponents and Conservation Commissioners should refer directly to the Wetlands Protection Regulations, and any current policy interpretations published by MA DEP, for guidance on the determination of the Mean Annual High-Water Line of a River.

10.4 When Rivers Flow Through Ponds or Lakes

When rivers flow through ponds or lakes, issuing authorities will need to determine if the pond or lake is a river for purposes of the riverfront provisions contained in the Wetlands Protection regulations. The starting point in making a determination is the current USGS map or more recent map provided by the DEP. A water body identified as a lake, pond, or reservoir is a pond or lake, unless the issuing authority determines the water body has primarily riverine characteristics. Riverine characteristics include, but are not limited to, an inlet and outlet through the water body in question, unidirectional flow that can be visually observed or measured, and horizontal zonation (as opposed to vertical stratification typically associated with lakes and ponds). In coastal areas, unidirectional flow may be tidally influenced. Great Ponds (i.e. any pond which contained more than 10-acres in its natural extent) are never rivers.

Project proponents and Conservation Commissioners should refer directly to the Wetlands Protection Regulations, and any current policy interpretations published by MA DEP, for guidance.

10.5 Sources of Hydrologic Information About Streams

The following lists some sources of information about streams in Massachusetts, and may prove useful in the evaluation of projects that affect Rivers:

Interagency Advisory Committee on Water Data. 1982. *Guidelines for Determining Flood Flow Frequency.* Bulletin 17B of the Hydrology Committee, Office of Water Data Coordination, U.S. Geological Survey. Reston, VA.

Ries, Kernell G. III. 1999. *Streamflow Measurements, Basin Characteristics, and Streamflow Statistics for Low-Flow Partial-Record Stations Operated in Massachusetts from 1989 Through 1996.* U.S. Geological Survey Water Resources Investigations Report 99-4006.

Ries, Kernell G. III. 1994. *Development and Application of Generalized-Least-Squares Regression Models to Estimate Low-flow Duration Discharges in Massachusetts.* U.S. Geological Survey Water Resources Investigations Report 94-4155.

Ries, Kernell G. III. 1993. *Estimation of Low-flow Duration Discharges in Massachusetts.* U.S. Geological Survey Open File 93-38.

Rocky Mountain Forest and Range Experiment Station. "A Video Guide to Field Identification of Bankfull Stage in the Western United States." Available from the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Research Station, Suite 368, 2150 Centre Avenue, Bldg. A, Fort Collins, CO 80526 (Telephone: 970-295-5983).

U.S. Geological Survey web site at www.water.usgs.gov/

Chapter 11:
Analysis of Coastal Resource Areas

This chapter briefly addresses coastal resource areas. The following topics are discussed:

- Wave action
- Sediment transport
- Determining Land Subject to Coastal Storm Flowage Using FEMA Data and Maps
- Evaluating dune performance in the Velocity Zone (the “540 Rule”)
- Hydraulic conditions in spawning areas
- Tidal exchange in tidal inlets

The behavior of waves in the coastal environment and the response of the shoreline to wave action are complex processes. This Chapter offers a description of some of the basic concepts, to assist Conservation Commissioners in understanding the issues involved with proposed activities in the coastal zone.

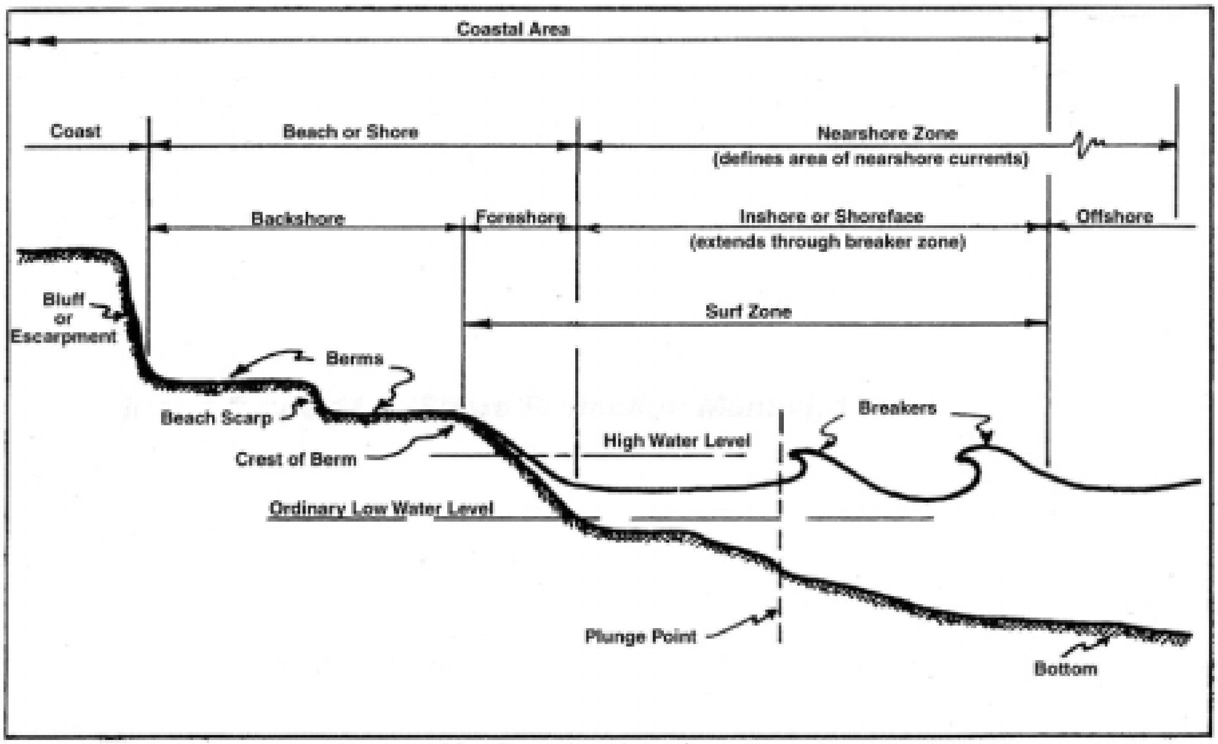
For a deeper understanding of the physical processes that occur in the coastal area, particularly the process of wave action, sediment transport, and tidal exchange, the reader should refer to accepted texts on coastal engineering and shore protection. A primary source of information is the following reference:

> U.S. Army Corps of Engineers. 1984. *Shore Protection Manual*. Volumes I and II. Coastal Engineering Research Center, Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi.

Figure 11-1 presents a schematic cross-section of a typical beach profile. This figure provides a visual definition of terms as used in this Chapter.

Coastal areas are comprised of a wide variability of coastal landforms. A coastal area may comprise exposed shoreline, or it may be sheltered shoreline such as bays, estuaries, marshes, and lagoons. The shoreline may have beaches as depicted in Figure 11-1, or may have other characteristic landforms, such as rocky promontories. The geologic history of the shoreline, and its interaction with waves, currents, and storms, determine the form of the shoreline and its ability to withstand the erosive forces of the action of wind and water.

Figure 11-1 Visual Definition of Terms Describing a Typical Beach Profile



(Source: US Army Corps of Engineers, 1984.)

11.1 Wave Action

As noted in the above introduction, the mechanics of wave action can be complex. Computation methods for describing waves are beyond the scope of this manual. This Section will be limited to a brief description of waves and related terminology.

Figure 11-2 shows a schematic cross-section showing typical characteristics of a simple wave. The **wave height** is the vertical distance from wave crest to the wave trough. The **amplitude** of the wave is the vertical distance from the crest to the stillwater level, or from the stillwater level to the trough. The amplitude equals one-half of the wave height.

If someone observes a series of waves passing a stationary object, and measures the time that it takes two successive wave crests to pass that object, that time equals the **period** of the waves. The **wavelength** is the distance between the successive crests. The **wave celerity** is the speed of the wave (also referred to as the **phase velocity**, when describing a single wave). For the simplest case of waves, which can be described by linear wave theory, the wave celerity (C), wavelength (L), and period are related by the simple equation:

$L = CT$ where

L = wavelength in feet,

C =wave celerity in feet per second, and

T = wave period in seconds.

For waves moving through deep water (depths greater than one-half the wavelength), the relationships of celerity and wavelength to the period can be approximated by the following equations:

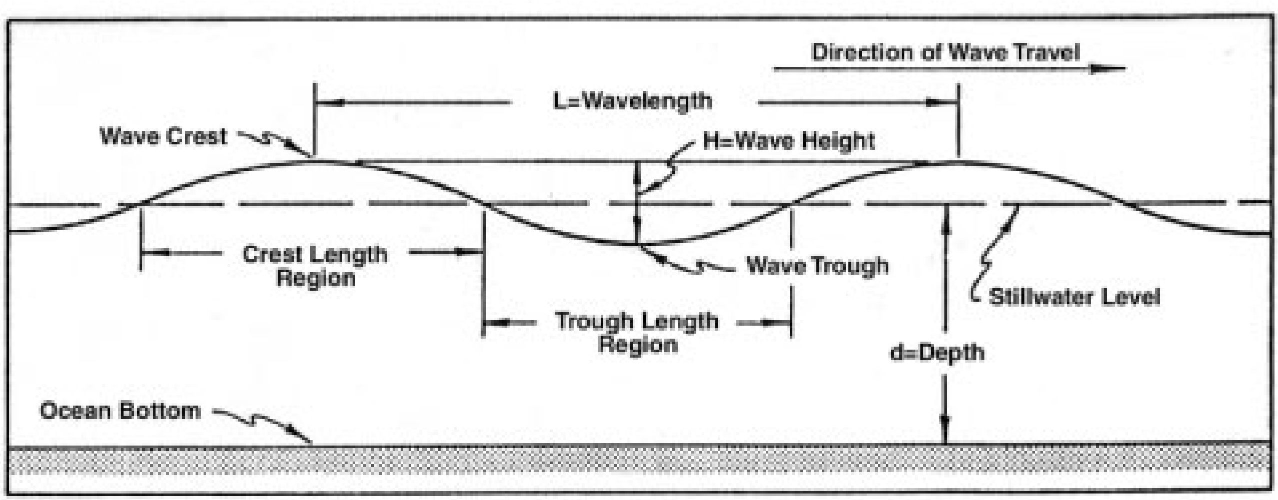
$$C = \frac{gT}{2\pi}$$

$$L = \frac{gT^2}{2\pi}$$

For shallower water, where the depth is less than half the wavelength ($d < 0.5L$), the relationship of celerity and wavelength to the period is more complex, and requires the iterative solution of equations using hyperbolic functions. The interested reader is referred to the *Shore Protection Manual* for further information on these equations.

The height, length, and period of wind generated waves are determined by several factors, including:

Figure 11-2 Wave Characteristics



(Source: U.S. Army Corps of Engineers, 1984)

- The **fetch**, which is the distance the wind blows over the sea in generating the waves. In sheltered coastal areas, the fetch is often limited by the landform or obstruction that forms the shelter;
- The wind speed;
- The duration (length of time the wind blows);
- The water depth;
- The **decay distance**, which is the distance the wave travels from the generating area.

The wind simultaneously generates waves of varying heights, lengths, and periods. A more complete description of the above terms and their interrelationships can be found in the *Shore Protection Manual*.

As a wave moves shoreward in shallow water (shoaling water), its profile becomes steeper. The gently rolling shape of a series of waves then transforms to a series of sharp crests and flat troughs. At a certain point, the wave breaks at the shore. The break point depends on the wave height, period, bottom slope, and water depth. When waves break either on a beach or on a structure, the up-rush of water after breaking is referred to as **runup**. This runup expends the wave's remaining energy. The runup height depends on the slope and roughness of the beach or structure against which the wave breaks. Generally, the rougher the surface, the less the runup.

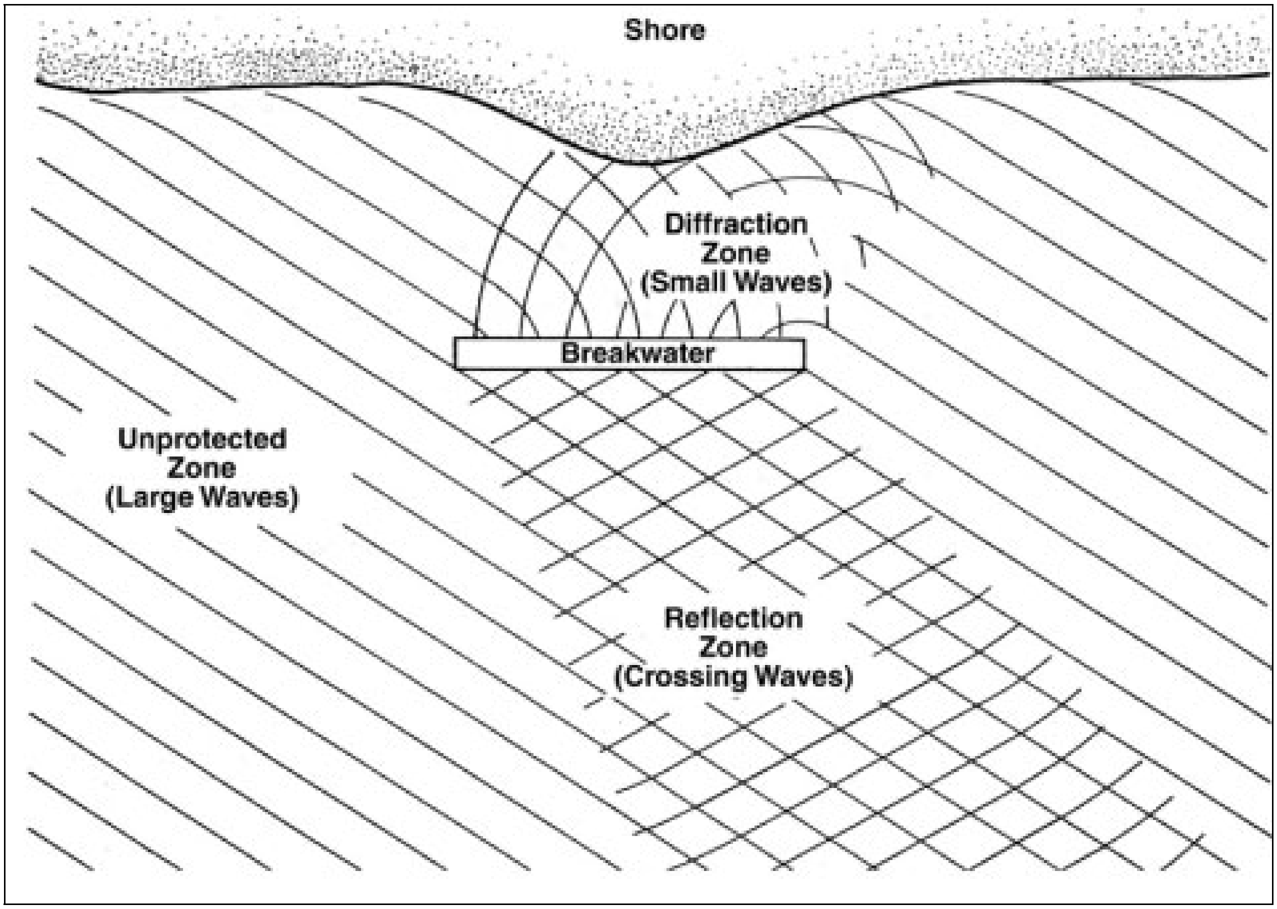
When waves encounter a solid barrier such as an offshore breakwater (see Figure 11-3), **wave diffraction and wave reflection** occur. Wave diffraction occurs in the shadow of the structure, when waves pass the structure and wave energy is transferred along their crests to the quiet area on the protected side of the structure. The resulting waves in the protected area are smaller than the ones in the adjacent unprotected area.

Wave reflection occurs on the offshore side of the structure. The portions of the waves striking the structure are reflected back toward the open water. If the incoming waves are parallel with the structure, the reflected waves can reinforce the incoming waves (or incident waves), resulting in standing waves twice as high as the incident waves. This process can result in considerable bottom scour at the toe and offshore of the structure. If the incident waves strike at an angle, the reflected waves can result in a water surface with crossing wave crests that will be rough and choppy. These short-crested waves can also cause considerable bottom scour. For these reasons, the configuration and location of offshore structures must account for anticipated wave conditions and the resulting erosive forces.

11.2 Sediment Transport

Shoreline areas can be made up of a large variety of materials, including rock, boulders, cobbles, gravels, sand, silt and clay. In the coastal environment, these materials are referred to **as littoral materials**. These materials derive from the deterioration and erosion of coastal landforms; the weathering and erosion of landforms and rock materials in inland areas which are transported to

Figure 11-3 Wave Diffraction and Reflection



(Source: US Army Corps of Engineers, 1981)

the shore by rivers and streams; the disintegration of shells, coral, or algae; and the production of organic material by coastal marshes and wetlands.

The shoreline is where the tides, waves, and winds attack the land, and where the land responds by a variety of measures that effectively dissipate the energy of these attacks. The beach and the near-shore zone are the areas most directly affected by the forces of the sea, and consequently they are the most dynamic areas in the coastal zone.

On most beaches, the littoral materials comprise a range of material from fine sands to cobbles. The character and size of the beach sediments, as well as the slope of the beach, depend on the forces to which the beach is exposed, and the character of materials available along the coast. Much of this material originates inland. Waves and currents move the beach materials along the shore in a constant process, transporting great volumes of material over time. Clays and silts are generally not found on beaches, as the near-shore turbulence keeps these fine materials in suspension. These fine materials are deposited either further from shore, or in quiet lagoons, marshes, and estuaries.

The littoral materials on a beach are moved along the shoreline by a process called **littoral transport**. In this process, waves and currents displace material and transport it along the shore. As waves approach the shoreline, the breaking of the waves and the resulting turbulent conditions suspend the beach materials. As a wave generally breaks at an angle to the beach, the sediment particles tend to move up the beach at an angle with the turbulent water in the general direction of the wave advance. The motion of the water stops a short distance up the beach, then reverses direction, moving more directly down the slope of the beach (the foreshore) by the force of gravity. The next wave repeats the process. The sediment suspended by this wave action also moves with the long-shore current. These processes result in the movement of the sandy material in a zig-zag pattern up and down the beach. This process occurs continuously, and is the beach's normal response to wave and current action.

During storms, the beach is subject to more severe forces, and its response to these forces is more pronounced. Storm surges allow larger waves to pass over offshore bars without breaking. When the waves finally do break, the remaining surf zone is not wide enough to allow dissipation of the energy of the storm waves. That energy is expended on the erosion of the beach, the berm, and sometimes the dunes. Under storm conditions, these higher features of the shore zone are exposed to wave attack, because of the storm surge. Eroded material is carried offshore, where it deposits as an offshore bar. This offshore bar can eventually cause future waves to break at a distance from the shore. In this way, a beach's dynamic response to a storm may result in sacrificing some beach and, possibly, dune material for the development of a natural feature that provides future protection.

Shoreline erosion occurs over time as a result of these responses of beaches to the forces in the coastal environment, as affected by natural and man-induced causes. These include the following:

<u>Natural Causes of Shoreline Erosion</u>

- *Sea level rise*. A long term rise in the level of the ocean exists in many areas of the world, and results in a long-term recession of the shoreline, due to direct flooding and also to a natural adjustment of the beach profile to the higher water level.
- *Variability in the littoral sediment supply*. Natural changes in flooding patterns can affect the delivery of material from inland sources.
- *Storm waves*.
- *Wave surge and overwash*. When the storm surge and storm waves overtop the protective dunes, the dune and beach areas are subject to severe erosion, with deposition of the material on the landward side of the dune.
- *Deflation*. The removal of loose material from a beach by wind action.
- *Longshore sediment transport*.

- *Sorting of beach sediment*. This process involves the sorting of various size particles in the sediment material by wave action, redistributing sediment particles by size or hydraulic properties. This process is an important consideration in the design of beach nourishment projects, to avoid the loss of desirable materials by natural wave action.

Man-Induced Causes of Shoreline Erosion

- *Land subsidence from removal of subsurface materials.* Removal of natural resources (e.g., gas, oil, coal, groundwater) under a coastal area may cause subsidence of a beach.
- *Interruption of littoral transport processes.* This activity is probably the most important cause of erosion due to human activity. Modifications of inlets by dredging and channel control, construction of harbor structures, and construction of protective works can interrupt the transport of sediment along the shore, and in some cases interrupt the supply of material for this natural process.
- *Reduction in supply of sediment to the littoral zone.* Inland activities can affect the natural processes of erosion and sedimentation that result in delivery of material to the coastal zone.
- *Concentration of wave energy on beaches.* Coastal structures, both in the active beach zone and on the backshore, can increase the amount of wave energy dissipated on the material near the structure, affecting the rate of erosion.
- *Increase in water level variation.* Deepening and widening of navigation inlets may affect the tidal range within a harbor or bay, affecting the range of beach exposure to erosive action.
- *Change in natural coastal protection.* Dredging of near-shore bars, leveling of dunes, destruction of beach vegetation, paving of backshore areas, and construction of channels for navigation on the backside of narrow barrier islands, can affect the behavior of waves under storm conditions and result in accelerated erosion.
- *Removal of material from the beach.* This activity results in a direct loss of the supply of material for sediment transport.

11.3 Determining Land Subject to Coastal Storm Flowage Using FEMA Data and Maps

Chapter 9 discusses the analysis of flood plains and the use of FEMA data in detail. The following discussion highlights some of the features of FEMA documents that pertains to coastal areas.

- In the community's Flood Insurance Study (FIS), the flood profiles for coastal rivers and streams show the extent of tidal flooding for the lower reaches of those water courses.

- In the Flood Insurance Study, a tables are included showing the corresponding stillwater flood elevations for tidal flooding. Figure 11-4 shows an example of such a table.
- In the Flood Insurance Study, the floodway data table presents some information for base flood and floodway elevations, that does not include an accounting for the backwater effects due to the tidal flooding. Users of the table should be aware of this condition, when using this table. Figure 11-5 shows an example of such a table.
- In the Flood Insurance Study, a table is provided to show the elevation of the base flood accounting for wave heights in the "coastal flood with velocity" zones. An example of such a table is included as Figure 11-6.
- On the Flood Insurance Rate Map (FIRM) panels, the mapped flood boundary information includes, as applicable, areas that are subject to "coastal flood with velocity (wave action). These include Zone V (base flood elevations and flood hazard factors not determined), and Zones V1-V30 (base flood elevations and flood hazard factors determined). For these latter zones, the approximate flood elevations are listed on the maps in parentheses, along with the zone number; e.g., Zone V2 (EL20). Figures 11-7 provides an example of a FIRM panel in a coastal community.

Generally, the information included in the FIS reports should be used to determine the 100-year flood plain in coastal areas. The FIRM panels can be used to assist in identifying these areas, and to help identify the corresponding information in the FIS.

Figure 11-4 Sample Stillwater Elevations Table

	ELEVATION (feet)			
FLOODING SOURCE AND LOCATION	10-YEAR	50-YEAR	100-YEAR	500-YEAR
MASSACHUSETTS BAY				
From the Cohasset-Hull corporate limits to Government Island, including Little Harbor and Cohasset Cove	9.4	10.3	10.6	11.5
THE GULF				
From Border Street to 300 feet north of Supper Island	9.6	10.5	10.8	11.7
Near Supper Island	9.3	10.1	10.4	11.3
200 feet south of Supper Island to Stanton Road	7.8	8.5	8.8	9.5
Stanton Road to Scituate-Cohasset corporate limits	7.4	8.2	8.4	9.2
STRAITS POND				
Entire shoreline within the corporate limits	7.8	8.6	9.0	9.8
JAMES BROOK				
From Border Street tide gate to Elm Street	4.9	6.5	9.6	11.5

Figure 11-5 Sample Floodway Table

FLOODING SOURCE	PANEL[1]	ELEVATION DIFFERENCE[2] BETWEEN 1.0% (100-YEAR) FLOOD AND			FHF	ZONE	BASE FLOOD ELEVATION[3] (NGVD)
		10% (10 YR.)	2% (50 YR.)	0.2% (500 YR.)			
Walnut Hill Stream							
Reach 1	04	-1.0	-0.3	+1.0	010	A2	Varies
Reach 2	04	-0.4	-0.1	+0.2	005	A1	Varies
Rattlesnake Run							
Reach 1	02	-0.7	-0.2	+0.4	005	A1	Varies
Turkey Hill Run							
Reach 1	02	-2.0	-0.4	+0.6	020	A4	Varies
Reach 2	02	-1.4	-0.5	+1.3	015	A3	Varies
Reach 3	02	-3.4	-1.3	+1.0	035	A7	Varies
James Brook							
Reach 1	02,04	-0.8	-0.2	+0.5	010	A2	Varies

[1]Flood Insurance Rate Map Panel
[2]Weighted Average
[3]Rounded to the nearest foot - see map

TABLE 6A

FEDERAL EMERGENCY MANAGEMENT AGENCY

TOWN OF COHASSET, MA
(NORFOLK CO.)

FLOOD INSURANCE ZONE DATA

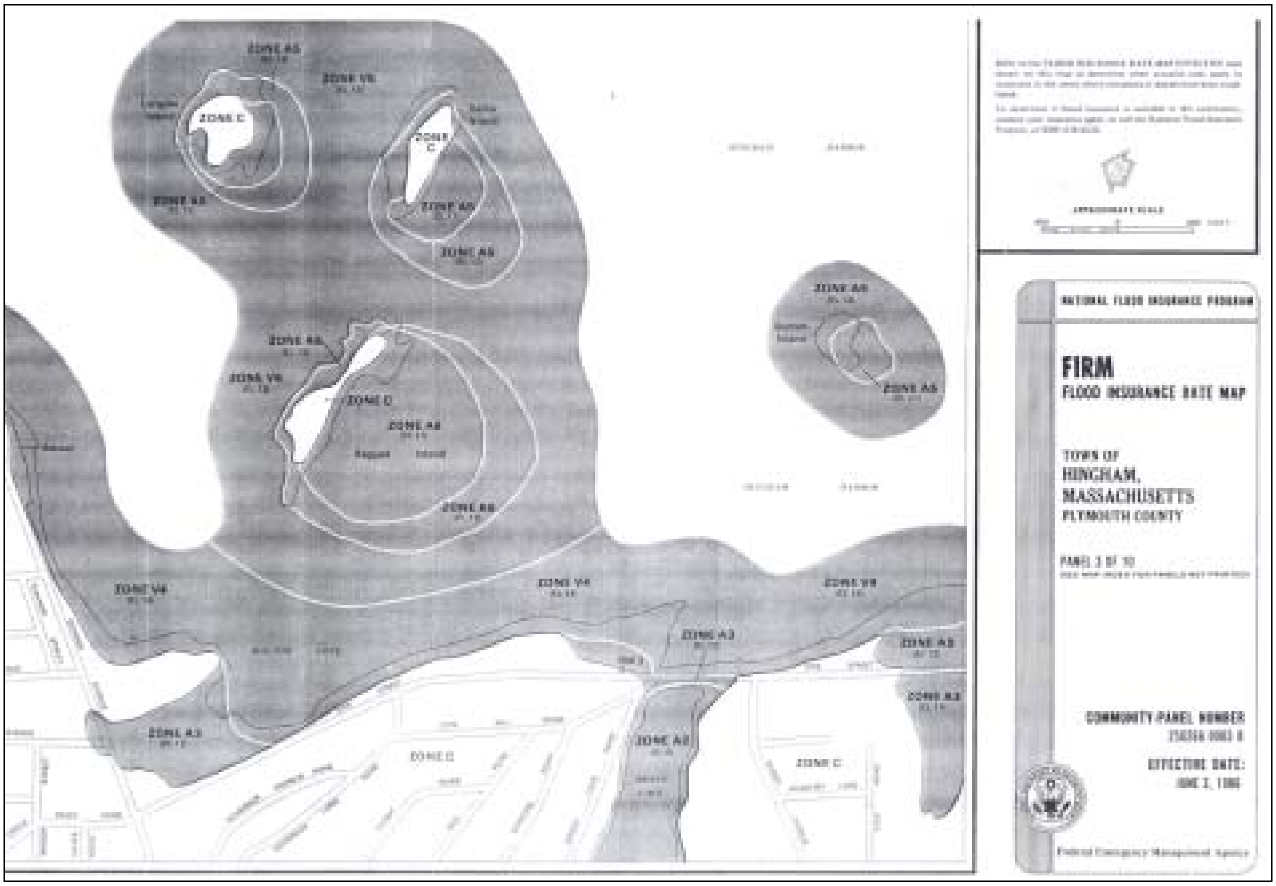
WALNUT HILL STREAM, RATTLESNAKE RUN, TURKEY HILL RUN AND JAMES BROOK

Figure 11-6 Sample Table of Velocity Zone Elevation Info.

Flooding Source	Stillwater Elevation 10-Year	Stillwater Elevation 100-Year	FHF	Zone	Base Flood Elevation (Feet NGVD)*
Massachusetts Bay	9.4	10.6	020	V4	13-16
			010	V2	13-26
			020	A4	11-13
			015	A3	11-12
			010	A2	11-21
	Shallow Flooding - Average Depth 1.0 Foot and 2.0 Feet			AO	--
The Gulf	9.6	10.8	010	A2	11
	9.3	10.4	010	A2	10
	7.8	8.8	010	A2	9
	7.4	8.2	010	A2	8
	4.9	9.6	045	A9	10
Straits Pond	7.8	9.0	010	A2	9
Richardsons Brook	9.2	10.6	015	A3	11

*Due to map scale limitations, base flood elevations shown on the FIRM represent average elevations for the zones depicted.

Figure 11-7   Sample FIRM Panel



11.4 Evaluating Dune Performance in the Velocity Zone (the "540 Rule")

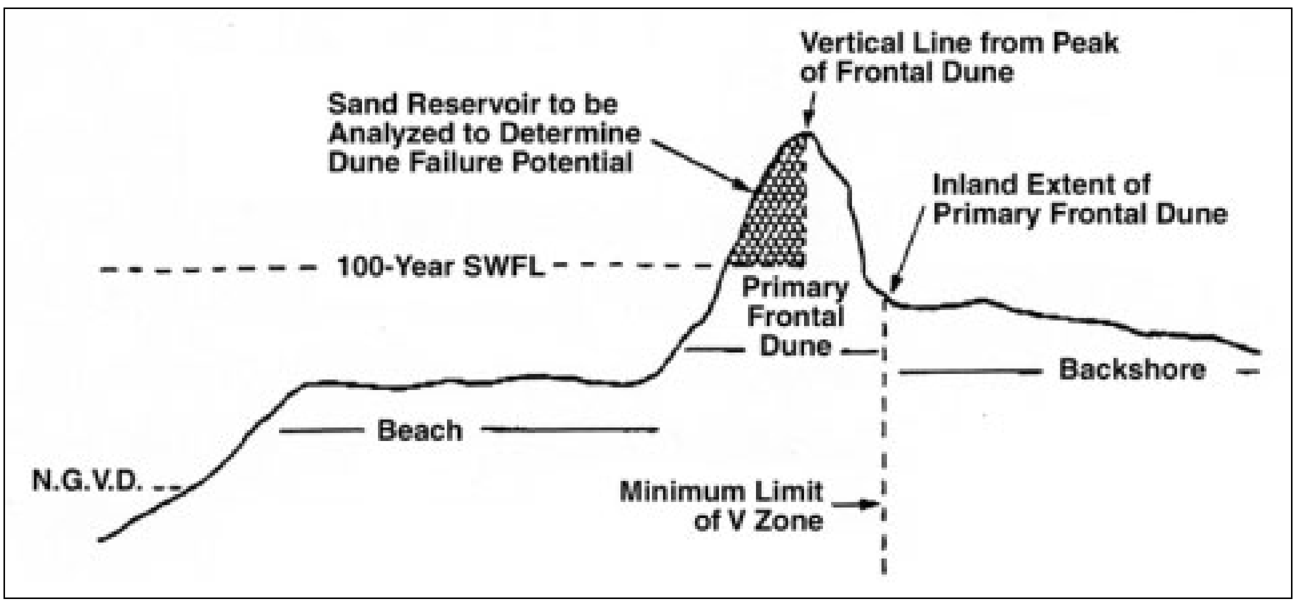
The Federal Emergency Management Agency (FEMA) has developed a criterion for evaluating a dune, to determine if it is considered an effective barrier to base flood storm surges and associated wave action during the base flood event (100-year storm). This criterion is also applied by the MA DEP in determining the landward extent of the base flood event, and has come to be known as the "540 Rule".

Figure 11-8 presents a schematic cross-section of a dune, showing the factors considered in determining dune failure potential, in connection with mapping the "flood zone with coastal velocity (wave action)" (V zones).

To determine if a dune is an effective barrier to base flood surges and associated wave action, the following procedure is applied:

Step 1: Obtain topographic survey of the dune under evaluation, consisting of cross-sections at sufficient intervals to characterize the dune. Generally, cross-sections at 50 foot intervals along the axis of the dune should be obtained, with additional cross-sections at apparent changes in side slopes (perpendicular to axis) or gradient (along the axis).

Figure 11-8 Factors to be Considered in Determining Dune Failure Potential and V Zone Mapping (the "540 Rule")



Step 2: Plot the cross-sections to scale on drawings. The area of the sand reservoir (see figure 11-8) will be measured from these cross-sections. This may be done directly from a printed scale drawing using a planimeter. Frequently, this measurement is now done on computer, using computer aided drafting software.

Step 3: Determine the 100-year stillwater flood level (SWFL) from the FEMA Flood Insurance Study (FIS) applicable to the area. Plot this elevation on the cross-sections developed in Step 2.

Step 4. Determine the peak of the dune at each cross-section, and plot a vertical line from the peak to the SWFL, as shown in Figure 11-8.

Step 5. Measure the area of the "sand reservoir", comprising the seaward volume of the dune lying above the SWFL and on the seaward side of the vertical line from the peak of the dune.

Step 6. If the cross-section of the dune contains a sand reservoir equal to or exceeding 540 square feet in area, then the dune is considered an effective in attenuating wave action in a coastal flood. (Defuses the term "540 Rule" because of this criterion.) In this case, the landward limit of the V-zone is equal to the inland limit of the frontal dune. The inland limit of the frontal dune occurs at the point where there is a distinct change from a relatively steep slope to a relatively mild slope. This point is indicated schematically on Figure 11-8.

11.5 Hydraulic Conditions in Spawning Areas

Conservation Commissions will sometimes be concerned with the impacts of a proposal on the hydraulic conditions in a fish spawning area for an anadromous or catadromous fish species, or whether a particular area is suitable for spawning. The requirements for spawning areas vary by fish species, and the hydraulic aspects of those requirements can be complex quantities to predict. Generally, the key hydraulic parameter of concern is the velocity of flow in the vicinity of the potential spawning bed.

If flow velocities in a particular area need to be evaluated, the best method of characterizing these velocities is to perform field measurements during the spawning season, or at another time when flows are similar to those prevailing during the spawning season. It is possible to estimate velocities, if flow data is available at a stream cross section, the cross-section of the stream is known, and the corresponding depth of flow is known. However, this data will only yield an average velocity for the cross-section. Velocities in a stream or river cross-section under a given flow condition can vary widely over the cross-section. The velocity at the location of the substrate material that is suitable for spawning cannot be determined directly by such a calculation.

The alteration of a channel in the vicinity of a spawning area may alter the average velocity and the velocity distribution near that alteration. Estimating the effects of such an alteration before it is implemented can be problematic. In major projects that could affect a significant spawning area, the use of laboratory constructed hydraulic models can be used to predict the impacts of proposed activities. However, such modeling can be costly, and generally limited to large-scale projects.

If Conservation Commissions need to evaluate spawning habitat, including hydraulic factors influencing the suitability of the habitat, they should consult with fisheries biologists and hydraulic engineers competent in the analysis of fisheries habitat. Some possible resources include:

Division of Fisheries & Wildlife
251 Causeway St, Suite 400
Boston, MA 02114-2152
(617) 626-1590

Division of Marine Fisheries
251 Causeway Street
Suite 400
Boston, MA 02114
(617) 626-1520

Caleb Slater, Ph.D.
Anadromous Fish Project Leader
Mass Wildlife Field Headquarters
1 Rabbit Hill Road
Westborough, MA 01581
(508) 792-7270 x133

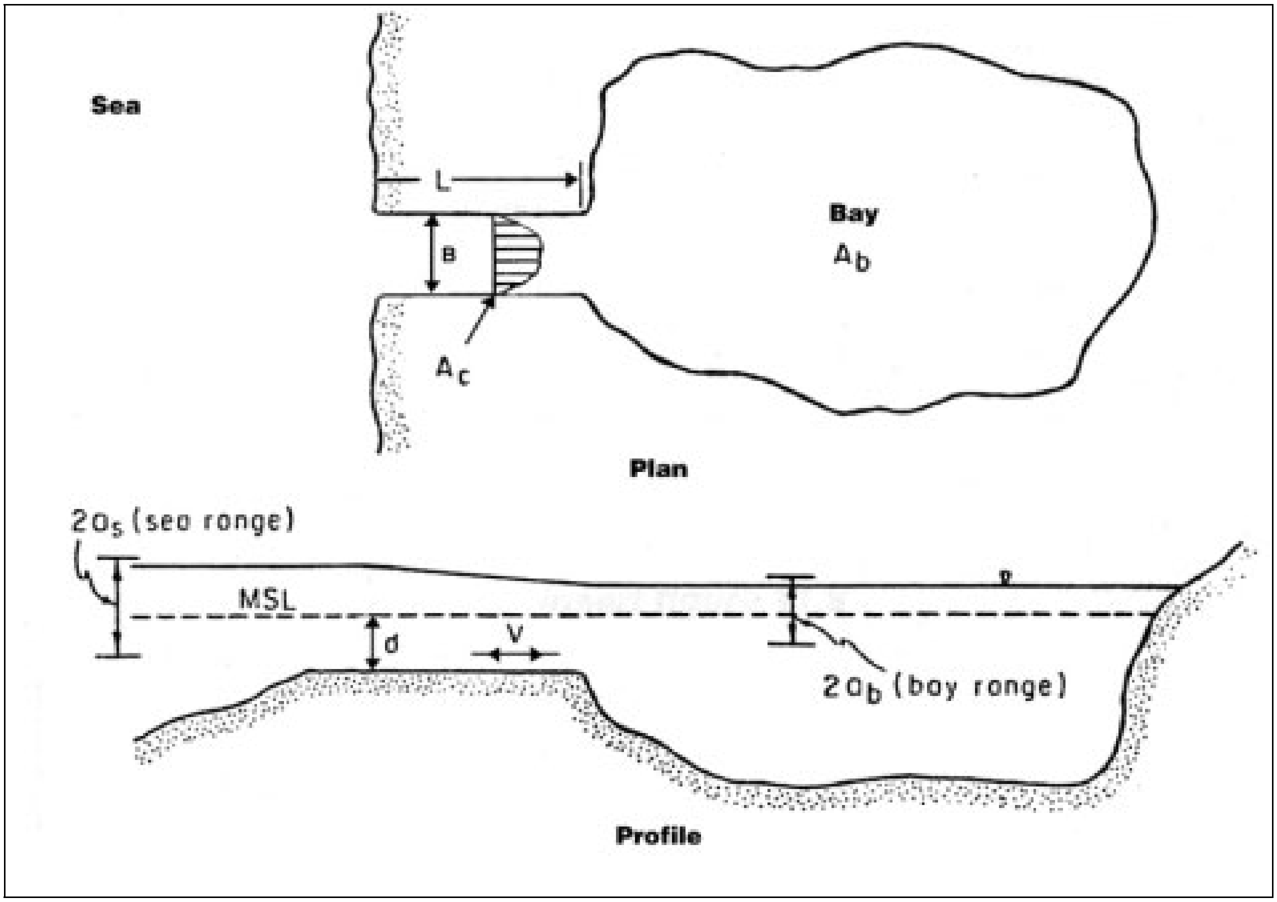
The Silvio Conte Anadromous Fish Research Center
Turners Falls, MA
(413) 863-9475

11.6 Tidal Exchange in Tidal Inlets

Conservation Commissions may wish to know information about the volume of tidal exchange in a tidal inlet, such as a small bay or coastal marsh. As an example, Figure 11-9 shows a hypothetical case of a small bay connected to the ocean by a channel.

The procedure for determining the volume of tidal exchange and the velocity of flow in the inlet channel is somewhat complex, and will not be presented in detail here. However, Conservation Commissioners should be aware that procedures are available for evaluating the flow in such inlets.

Figure 11-9 Sea-Inlet-Bay System



Chapter 4 of the *Shore Protection Manual* presents a procedure for calculating the time-dependent average velocity of flow in the inlet channel, and the bay tidal level range. The procedure assumes the inlet is sufficiently small that inlet currents are driven by the differences in elevation between the inlet and bay water elevations.

To perform the procedure, information is needed about the following:

- area of the bay (A_b) at Mean Sea Level (MSL),
- the cross-sectional area (A_c) of the inlet channel below MSL,
- the inlet channel length and hydraulic resistance,
- hydraulic entrance and exit loss coefficients for the inlet channel, and
- the ocean tidal period and amplitude (a_s).

With this information, the *Shore Protection Manual* procedure will provide information about the average and maximum velocity in the inlet channel, and the bay tidal amplitude (a_b). The volume of water that flows into and then out of the bay, known as the tidal prism (P), is given by the following equation:

$$P = 2A_b a_b$$

This procedure is based on the following assumptions:

- The sea tidal cycle is sinusoidal (that is, a plot of tide elevation versus time would be shaped like a sine curve),
- The bay water level rises and falls uniformly (the bay water surface remains horizontal),
- The inlet channel depth is large relative to the sea tidal range,
- The bay walls are vertical over the bay tidal range (no extensive flooding of tidal flats),
- There are negligible density currents at the inlet, and negligible inflow to the bay from other sources.

If these assumptions are not applicable, then a more complex analysis would be required using computer modeling techniques. Such modeling may require additional information regarding the bathymetry (underwater topography) of the bay and the inlet channel, hydrologic and hydraulic information about the sources of inflow, tidal data from historic records, and other information. The modeling software would need to account for how the flow in the channel is governed by water levels on the sea-ward and bay-ward ends of the channel.

Appendix A: Glossary

Abstractions – In hydrologic analysis, the processes that reduce precipitation (interception, infiltration, and depression storage), with the remaining water becoming surface runoff.

Acre-foot – A volume equal to an area of one acre times a depth of one foot.

Amplitude – The vertical distance from the crest of a wave to the still-water elevation, or from the still-water elevation to the wave trough. Amplitude is equal to one-half of the "wave height".

Antecedent Moisture Condition (AMC) – A qualitative indication of the moisture content of surficial soils at the beginning of a storm event.

Antecedent Precipitation Index (API) – An indication of the amount of water, in inches, present in soil at a given time.

Anti-Seep Collar – A device installed around a culvert, pipe or conduit through an embankment, which lengthens the path of seepage along the exterior of the conduit.

Aquifer – An underground water-producing geologic formation.

Background Load – Naturally occurring levels of pollutants in a stream prior to watershed development.

Bankfull – The elevation (or stage) of a river at which the flow (discharge) actively creates, modifies, and maintains the river's channel. During *bankfull discharge*, the water is moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in morphologic change to the river system.

Barrel – The concrete or corrugated metal pipe that passes runoff for the riser portion of an outlet structure, through the embankment, and finally discharges to outfall point.

Base Flow – The portion of stream flow that is not due to storm runoff, and is supported by interflow and groundwater outflow into a channel.

Bedload – The sediment in a stream channel that mainly moves by sliding or rolling on or very near the bottom during normal flows and bankfull events.

Bedrock – Solid rock located on or below the ground surface of he earth.

Best Management Practice (BMP) - In stormwater management, a structure or practice designed to prevent the discharge of one or more pollutants to the land surface and thus minimize their availability for wash-off by stormwater, or a structure or practice to temporarily store or treat urban stormwater runoff to reduce flooding, remove pollutants, and provide other amenities.

BLSF – Bordering Land Subject to Flooding, as defined under the Massachusetts Wetlands Protection Act.

Catchment – See **Watershed**.

Channel Erosion – The widening, deepening, and headward cutting of small channels and waterways, due to erosion caused by moderate to larger floods.

Check Dam - (a) A log or gabion structure placed perpendicular to a stream to enhance aquatic habitat. (b) An earthen or log structure used in grass swales to reduce water velocities, promote sediment deposition, and enhance infiltration.

Conservation – The protection, improvement, and use of natural resources according to principles resulting in the greatest economic and social benefits.

Contributing Watershed Area – Geographic extent of land area contributing its runoff of the point of interest. (Also referred to as "catchment")

Curve Number – See "Runoff Curve Number"

Decay Distance – The distance a wave travels from the point at which it is generated.

Depression Storage – As precipitation falls on the ground, the storage of a portion of the water in the irregularities and small depressions on the land surface.

Design Storm – A selection rainfall event of specified amount, intensity, duration, and frequency used as the basis of design.

Detention – The temporary storage of runoff in a structure or waterbody.

Detention Time – The average amount of time a volume of water is detained in a BMP. This time may differ from the amount of time it takes to completely drain a particular BMP (see Dewatering Time).

Dewatering - Refers to a process used in detention/retention facilities, whereby water is completely discharged or drawn down to a pre-established pool elevation. Dewatering allows the facility to recover its design storage capacity in a relatively short time after a storm event.

Dewatering Time – The length of time to completely drain the temporary storage volume of water from a Best Management Practice. If the practice is intended to be dry between storms, dewatering time is the time to drain the entire volume. If the practice is designed with a permanent pool of water, the dewatering time is the time required to drain the device from flood level (for the design event) to the permanent pool level.

Diffusion – The process where runoff spreads over the surface as it flows toward an outlet.

Direct Runoff – (Also referred to as excess precipitation, stormwater runoff, or runoff) When precipitation falls on the earth, the water remaining after the combined effects of interception, depression storage, and infiltration. This water flows over the surface of the ground.

Discharge Rate – See **Runoff Rate**.

Discharge Structure – The outlet structure of a structural BMP, such as a pond, designed to release water at a design flow rate (or multiple flow rates, depending on depth of storage)

Drainage Area – The numerical measure of the area of a watershed.

Drawdown – The act of lowering a water-surface elevation.

Duration – See **Storm Duration**.

Emergency Spillway – The channel of a pond-type BMP, designed to pass a storm event exceeding the design capacity of the primary discharge structure.

Excess Rainfall – See **Direct Runoff**.

Erosion – The wearing of the land surface by water or wind and the subsequent detachment and transportation of soil particles.

Estuary – A body of water consisting of fresh and salt water where the tide meets the river's current.

Evaporation – The process whereby water returns to the atmosphere as water vapor, from the surfaces of the land and water bodies.

Evapotranspiration – The combined loss of water from a given area during a specified time by evaporation and by transpiration from plants (the biological process whereby plants take up water and release it as water vapor).

Exfiltration – The downward movement of runoff through the bottom of an infiltration BMP into the soil layer.

Extended Detention – A stormwater management BMP that provides for the gradual release of a volume of water over a time interval designed to increase settling of urban pollutants, and protect downstream channels from frequent flooding.

FEMA – United States Flood Emergency Management Agency.

FIRM – Flood Insurance Rate Map.

Fetch – The distance the wind blows over a body of water in generating waves.

Floodplain – The low land adjacent to a waterbody subject to flooding.

Forebay – An extra storage area provided near an inlet of a pond BMP to trap incoming sediment before it accumulates in a pond BMP.

Freeboard – The space from the top of an embankment to the highest water elevation expected for the largest design storm stored. The space is required as a safety margin in a pond or basin.

Grade – The slope of a land surface, road, or stream bottom.

Gradient – The change of elevation, velocity, pressure, or other characteristic per unit length.

Groundwater Flow – The saturated flow of water through the ground (this process occurs within the groundwater table).

Groundwater Recharge – See **Recharge**.

Groundwater Table – The zone within the soil where the void spaces between soil particles are filled with water. This zone is also referred to the “saturated zone.”

Head – In hydraulics, the height of water above a reference plane.

Head Loss – Energy loss in hydraulic flow due to friction, turbulence, velocity change or flow direction.

Head Water, Head Water Depth – In hydraulics, the difference in elevation between the water elevation at the inlet of a pipe, and the invert of the pipe.

Headwaters – The source of a river or stream or the water upstream of a structure or point in a stream.

Hydrograph – A graph or table displaying discharge, depth (stage), velocity, or another property of flowing water versus time.

Hydraulics – The physical science and technology of the static and dynamic behavior of fluids. Hydraulics deals with practical applications of fluids in motion (such as the transmission of energy associated with water flowing through pipes and culverts).

Hydrology – The study of the movement of water between the earth's atmosphere, surface, and subsurface.

Hydrologic Abstraction – See "Abstractions".

Hydrologic Cycle – The circulation of water between the earth's atmosphere, surface, and subsurface.

Hydrologic Regime of a Wetland- The relationship of water in its various forms (overland surface water flows, channelized flows, groundwater storage and flows, pond storage, flood storage) within the wetland setting.

Hydrologic Soil Group – For the SCS Runoff Curve Number method, the classification of a soil relative to its runoff potential, based on infiltration rate of the soil, permeability of restrictive layers, and moisture-holding capacity of the soil profile.

Hydrograph – A plot of runoff rate versus time for a particular storm event.

Hyetograph – A plot of cumulative rainfall or rainfall intensity versus time for a particular precipitation event.

Hydrograph Routing – See **Routing**.

IDF Curves – Intensity-Duration-Frequency Curves. Graphical plots showing the relationship between rainfall intensity, storm duration, and frequency (return period) for a geographic location or region.

ILSF – Isolated Land Subject to Flooding, as defined under the Massachusetts Wetlands Protection Act.

Impervious Surface – A hard surface area which either prevents or retards the entry of water into the soil mantle as under natural conditions prior to development, and/or a hard surface area which causes water to run off the surface in greater quantities or at an increased rate of flow from the flow present under natural conditions prior to development. Common impervious areas include, but are of limited to, rooftops, walkways, patios, driveways, parking lots or storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and oiled, macadam, or other surfaces which similarly impede the natural infiltration of stormwater.

Impoundment – The body of water retained by a berm, dam, or dike.

Infiltration – The downward movement of water through the land surface at ground level into the underlying subsoil.

Infiltration Rate – A soil characteristic which describes the maximum rate at which water enters the soil.

Inlet Control – In culvert design, the condition where inlet shape and material controls the rate of flow in the culvert.

Intensity – See **Rainfall Intensity**.

Interception – As precipitation falls on the earth's surface, the trapping of a portion of the water on the surfaces of plants.

Interflow – The unsaturated flow of water through the soil. This process occurs in the ground above the water table.

Invert – The lowest point on the inside of a culvert or pipe.

Level Spreader – A device used to spread out stormwater runoff uniformly over the ground surface as sheet flow (i.e., not through channels). The purpose of level spreaders is to prevent concentrated, erosive flows from occurring, and to enhance infiltration.

Littoral Materials – The materials that make up shoreline areas, including rock, boulders, cobbles, gravels, sand, silt, and clay.

Littoral Transport – The movement of littoral materials along the shoreline, as a result of wave action and currents.

Low-flow Channel – An incised or paved channel from inlet to outlet in a dry basin which is designed to carry low runoff flows and/or baseflow, directly to the outlet without detention.

Mean depth – The average depth described as the cross-sectional area of an inundated channel divided by its surface width. For a water body or storage basin, mean depth is the volume of the basin divided by its surface area.

NRCS – United States Department of Agriculture, Natural Resource Conservation Service. Formerly known as Soil Conservation Service (SCS).

Nonpoint Source Pollution – Pollution caused by sediment, nutrients, and organic and toxic substances originating from land-use activities and/or from the atmosphere, which are carried to surface waterbodies by runoff. Nonpoint Source (NPS) Pollution occurs when the rate at which these materials entering water bodies exceeds natural levels.

Outfall – The point or structure of a conduit discharging to a waterbody.

Outlet Control – In culvert design, the condition where flow in the culvert is not governed solely by inlet conditions, but may also be affected by friction losses in the culvert barrel and/or downstream water elevations.

Overflow Rate – Detention basin release rate divided by the surface area of the basin. It can be thought of as an average flow rate through the basin.

Phase Velocity – See **Wave Celerity**.

Peak Discharge – Also referred to as peak discharge rate, peak flow rate, peak runoff rate. The maximum flow for a given hydrologic event at specified location.

Pervious – Allowing the passage of water.

Point Source – A distinct, identifiable source of pollutants.

Precipitation – Water from the earth's atmosphere (where it is stored as water vapor) that falls on the earth's surface (rain, snow, hail, fog).

Rainfall Distribution – The variation in rainfall intensity over the duration of a particular storm event.

Rainfall Intensity – The rate at which precipitation occurs at a given instant.

Rational Method – A method for estimating peak rates of runoff from small watersheds (drainage areas less than 20 acres). The method is typically used for the sizing of storm drainage pipes, culverts, and channels. The method relates peak discharge to rainfall intensity/duration/frequency, time of concentration, and land-use cover.

Reach – The smallest portion of a drainage system consisting of uniform cross-section, shape, and slope.

Recharge – Of water that infiltrates into the ground, the portion that moves deeper into the ground and moves through the ground as interflow (unsaturated flow) and groundwater flow (saturated flow). Recharge results in the replenishment of groundwater.

Recurrence Interval – The time between occurrences of an event equal to or greater than a given magnitude. See **Return Period**.

Release Rate – The rate of discharge in volume per unit time from a detention facility.

Retention – The holding of runoff in a basin without release except by means of evaporation, infiltration, or emergency bypass

Return Period – (Also referred to as "storm frequency".) The expected or average value of the recurrence interval (time between occurrences) of an event equal to or greater than a given magnitude.

Riser – The vertical portion of an inlet to a conduit, extending from the barrel to the water surface.

Routing – The mathematical process of determining how hydrographs respond to storage and hydraulic control in reservoirs (including ponds, lakes, and detention basins) and watercourses (rivers and streams).

Runoff – See **Direct Runoff**.

Runoff Curve Number Method – A method developed by the SCS (now known as the NRCS) for estimating runoff, accounting for soils characteristics and land-use cover. In this method the Curve Number relates volume of runoff to interception, depression storage, soil storage, and rainfall depth.

Runoff Hydrograph – See **Hydrograph**.

Runoff Rate – Also referred to as discharge rate. The measure of the volume of runoff per unit of time, reaching a particular point of interest on the earth's surface.

Runoff Volume – The total volume of water that occurs as "Direct Runoff" during a particular storm event. This volume is usually measured in inches of depth over the extent of the contributing watershed.

Runup – The up-rush of water on a beach or coastal structure when waves break on the beach or structure.

SCS – United States Department of Agriculture – Soil Conservation Service. Now known as the Natural Resource Conservation Service (NRCS).

Sediment – Mineral and organic soil material that is transported in suspension by wind or flowing water, from is origin to another location.

Sheet Flow – Runoff which flows over the ground surface as a thin, even layer, not concentrated in a channel.

Short-Circuiting – The passage of runoff through a BMP in less than the theoretical or design treatment time.

Slope – A ratio of run (horizontal) to rise (vertical), usually expressed as a ratio (e.g. 3:1).

Soil moisture – Water that is stored in the soil on the surfaces of soil particles.

Stage – The elevation of the water surface in a storage structure (e.g., reservoir, detention basin) or water body.

Stage/Discharge Relationship – A table, graph, or mathematical equation that relates the discharge rate from a reservoir or other water body to the elevation (stage) of the water surface in the water body.

Stage/Storage Relationship – A table, graph, or mathematical equation that relates the volume of storage in a reservoir or water body to the elevation (stage) of the surface of the stored water.

Storm Duration – The length of time from the beginning of rainfall to the point when there is no more additional accumulation of precipitation.

Storm Frequency – See **Return Period**.

Stormwater, or Stormwater Runoff – See **Direct Runoff**.

Stormwater Management – The process of controlling the quality and quantity of stormwater to protect the downstream environment.

Surface Storage – The storage of water on the surface of the earth, including natural waterbodies, damned impoundments, stormwater detention and retention structures, and surface depressions.

TP-40 Atlas – *Technical Paper No. 40, Rainfall Frequency Atlas of the United States*. This atlas relates rainfall depth to storm duration and frequency, by geographic location, based on statistical analysis of rainfall records. This information is used in a number of methods for estimating runoff volumes and runoff rates for given design storm events.

TR-55 – *Technical Release No. 55, Urban Hydrology for Small Watersheds*. This publication describes a methodology developed by the SCS (now NRCS) for estimating runoff volumes and peak discharge rates. The method uses the Runoff Curve Number Method for relating runoff depth to rainfall depth, and graphical or tabular methods for relating peak discharge to the runoff depth.

TR-20 – *Technical Release No. 20, Project Formulation – Hydrology*. This publication comprises the watershed computer model developed by the SCS (now NRCS) for hydrologic analysis. The method uses runoff hydrographs and hydrograph routing to estimate runoff volumes, runoff rates, and storage structure performance for any specified precipitation event.

Tailwater – In hydraulics, the difference between the theoretical or actual elevation of the water surface at the outlet end of a pipe, and the invert of the pipe.

Tidal Prism – The volume of water that flows into and then out of a bay, as a result of tidal action.

Time of Concentration – The time required for water to travel form the hydraulically most distance point to the outlet of a watershed, or the total of all travel times in a watershed.

Transpiration – The process by which water vapor escapes from living plants and enters the atmosphere.

Travel Time – The time interval required for water to travel from one point to another through a part (reach) of a watershed.

Type III Storm – A synthetic distribution of rainfall intensity over time, used to develop peak rates of discharge in the SCS TR-55 runoff estimation method, and used in developing runoff hydrographs using SCS TR-20 and certain other computerized hydrologic computation methods.

USGS – United States Geological Survey.

Uniform Flow – A state of steady flow where the mean velocity and cross-sectional area remain constant.

Volume of Runoff – See **Runoff Volume**.

WPA – Massachusetts Wetlands Protection Act, Massachusetts General Law Chapter 131 Section 40

Water Balance – Also referred to as "Water Budget." The quantitative description of the movement of water through a wetland or water body, accounting for all pathways of water moving into (inputs) and out of (outputs) the water body.

Water Budget – See **Water Balance**.

Water Quality – Pertaining to the presence and amount of pollutants in water.

Water Quality Treatment Volume – For this handbook, the volume of runoff that must be used to determine the design of a Best Management Practice (or series of practices), to achieve a specified level of treatment (in this case, 80% removal of total suspended solids – TSS) under the Massachusetts DEP Stormwater Management Policy.

Water Quantity – Pertaining to the volume, rate of discharge, and velocity of water.

Water Table – The upper surface of groundwater in a saturated zone of soil or bedrock.

Watershed – The region contributing runoff to designated point of interest on the earth's surface. Sometimes referred to as "catchment."

Wave Celerity – The speed of a wave. Also referred to as "phase velocity".

Wave Diffraction – The modification of wave height and direction that occurs when waves encounter a solid barrier.

Wave Height – The vertical distance from the crest of a wave to the trough of a wave.

Wave Reflection – The propagation of waves back toward open water, when incoming waves encounter a solid barrier.

Wavelength – The horizontal distance between successive wave crests.

Appendix B: Rational Method

Applicability

Required output: peak discharge only

Drainage area: less than or equal to 20 acres

Description of Method

The Rational Method is used for determining peak discharges from small drainage areas. This method is traditionally used to size storm sewers, channels, and other stormwater structures, which handle runoff from drainage areas less than 20 acres.

The method is typically used for sizing drainage conveyance systems (storm drains, culverts, and drainage channels), with limited contributing areas.

The Rational Formula is expressed as q=C*i*A

where:

q = Peak rate of runoff in cubic feet per second

C = Runoff coefficient, an empirical coefficient representing a relationship between rainfall and runoff

i = Average intensity of rainfall in inches per hour for the time of concentration (Tc) for a selected frequency of occurrence or return period.

Tc = The rainfall intensity averaging time usually referred to as the time of concentration, equal to the time required for water to flow form the hydraulically most distant point in the watershed to the point of design.

A = The watershed area in acres

Note that in this equation, with “i" expressed in inches/hour and A expressed in acres, these units dimensionally yield a resulting “q” in cubic feet per second (cfs).

Table B-1 presents a chart showing the steps to follow to use the Rational Method to estimate peak runoff rates.

Table B-1 Runoff Estimation Rational Method

	Description of Step	Reference
Step 1	Identify Analysis Points	
Step 2	Delineate Watershed of Each Analysis Point	
Step 3	Characterize Each Watershed: Total area (A), expressed in acres Land cover type, soils, and slope condition – corresponding to table of runoff coefficients Area of each cover/soils/slope complex	
Step 4	Determine Runoff Coefficient (C) Determine c for each unique sub-area, based on cover/soils/slope complex Determine weighted c for each watershed	See Table of Runoff Coefficients
Step 5	Determine Time of Concentration (t_c) Note that this time is sometimes expressed in hours, and sometimes in minutes, and may need to be converted to appropriate units for computing intensity	For consistency of practice, this manual recommends determining t_c using procedure in MassHighway Drainage Manual.
Step 6	Determine Rainfall Intensity (i) Note that intensity must be expressed in units of inches/hour	See Appendix F: Rainfall Intensity/ Duration/Frequency Curves
Step 7	Determine Peak Discharge (q, expressed in cfs) Use Rational Formula: $q = C * i * A$	

Assumptions (Adapted Form Rossmiller, 1980)

1. The peak rate of runoff at any point is a direct function of the tributary drainage area and the average rainfall intensity during the time of concentration to that point.

2. The return period of the peak discharge rate is the same as the return period of the average rainfall intensity or rainfall event.

3. The rainfall is uniformly distributed over the watershed.

4. The rainfall intensity remains constant during the time period equal to Tc.

5. The relationship between rainfall and runoff is linear.

6. The runoff coefficient, C, is constant for storms of any duration or frequency on the watershed.

Note that these assumptions represent a simplification of what actually occurs during a rainfall event, and that they limit the use of the method to relatively small, homogeneous land areas.

Limitations

1. The Rational Formula only produces one point on the runoff hydrograph, the peak discharge rate. Where a hydrograph is required, other methods must be used.

2. When basins become complex, and where sub-basins combine, the Rational Formula will tend to overestimate the actual flow. The overestimation will result in the oversizing of stormwater management systems.

   For this reason, the formula should not be used for larger developments, as a basis for establishing predevelopment flow rates, which are used to define the restrictions needed for peak rate control. The artificially high estimates could result in release rates higher than existing conditions, resulting in adverse effects downstream.

3. The method assumes that the rainfall intensity is uniform over the entire watershed. This assumption is true only for small watersheds and time periods, thus limiting the use of the formula to small watersheds.

4. The results of using the formula are frequently not replicable from user to user. There are considerable variation in interpretation and methodology in the use of the formula. The simplistic approach of the formula permits, and in fact requires, a wide latitude of subjective judgment in its application.

Primary Reference:

ASCE, 1992 and Rossmiller, 1980

Runoff Coefficients for Rational Formula

Type of Drainage Area	Runoff Coefficient, C*
Business:	
Downtown areas	0.70 – 0.95
Neighborhood areas	0.50 – 0.70
Residential:	
Single-family areas	0.30 – 0.50
Multi-units, detached	0.40 – 0.60
Multi-units, attached	0.60 – 0.75
Suburban	0.25 – 0.40
Apartment dwelling areas	0.50 – 0.70
Industrial:	
Light areas	0.50 – 0.80
Heavy areas	0.60 – 0.90
Parks, cemeteries	0.10 – 0.25
Playgrounds	0.20 – 0.40
Railroad yard areas	0.20 – 0.40
Unimproved areas	0.10 – 0.30
Lawns:	
Sandy soil, flat, 2%	0.05 – 0.10
Sandy soil, average, 2 - 7%	0.10 – 0.15
Sandy soil, steep, 7%	0.15 – 0.20
Heavy soil, flat, 2%	0.13 – 0.17
Heavy soil, average 2 - 7%	0.18 – 0.22
Heavy soil, steep, 7%	0.25 – 0.35
Streets:	
Asphaltic	0.70 – 0.95
Concrete	0.80 – 0.95
Brick	0.70 – 0.85
Drives and walks	0.75 – 0.85
Roofs	0.75 – 0.95

* Higher values are usually appropriate for steeply sloped areas and longer return periods because infiltration and other losses have a proportionally smaller effect on runoff in these cases.

Appendix C: SCS TR-55 Method

The following discussion provides an overview of TR-55. TR-55 is a runoff estimation procedure developed by the Soil Conservation Service (now the Natural Resource Conservation Service – NRCS) and which can be applied using to a site without requiring the use of a computer program. It is also available in a software version for computer use. It is a useful method for estimating peak flow rates, and can sometimes be used for ***roughly approximating sizes*** of storm water detention facilities. It should not be used for final design or sizing of detention basins and similar structures.

This Appendix does not offer detailed directions on how to use the TR-55 method. If you are going to use this method, you **must** obtain a copy of the source document for this method:

Urban Hydrology for Small Watersheds (Technical Release Number 55)
U.S.D.A. Soil Conservation Service (June 1986)

This document is available free on the Internet at the following address. Be sure to download both the computer program **and the supporting documentation**:

http://www.wcc.nrcs.usda.gov/water/quality/common/tr55/tr55.html

To use this method, you will have to read that manual and understand the procedure. The manual provides a concise, step-by-step description of each component of the method, and identifies the assumptions and limitations for applying the method. Periodically, local offices of the NRCS and other agencies offer workshops designed to instruct people in the use the method. **You are strongly advised not to use this method without a copy of the TR-55 manual for reference.**

The flow chart in Table C-1 presents the step by step procedure for the use of TR-55 to estimate runoff volume and peak rates of runoff. It cross-references the TR-55 manual by Chapter.

The following discussion highlights some common problems encountered in the use of TR-55 for performing drainage calculations:

- This method should only be used when the underlying assumptions of the model apply.
- TR-55 manual method or various computer adaptations of the model should not be used to design detention structures that are required to store runoff as soon as it occurs (in the early hours of the runoff hydrograph). The model truncates the rising limb of the input hydrograph, ignoring a significant volume of runoff from the earlier hours of the design

24-hour storm. This volume can occupy a significant portion of basin volume when the outlet structure is designed for a highly constricted release rate for lower stages, as is the

Table C-1 Runoff Estimation TR-55 Method

	Description of Step	Reference
Step 1	Identify Analysis Points	
Step 2	Delineate Watershed of Each Analysis Point	
Step 3	Characterize Each Watershed: Total area Land cover type NRCS Soils Hydrologic Groups (HSG) Area of each cover/HSG complex	TR-55 Chapter 2 TR-55 Appendix A
Step 4	Determine if TR-55 is applicable for analysis	TR-55 Chapter 1
Step 5	Determine whether **Graphical Peak Discharge Method** or **Tabular Hydrograph Method**	TR-55 Figure 1-1
Step 6	Determine Runoff Curve Number (CN) Select appropriate TR-55 Figure or Table for determining CN Determine CN for each unique sub-area, based on cover/HSG complex Determine weighted CN for each watershed	TR-55 Chapter 2 TR-55 Figure 2-2 TR-55 Table 2-2, Figure 2-3, Figure 2-4, as appropriate. TR-55 Worksheet 2
Step 7	Determine Volume of Runoff (Q) *Note that this volume is expressed in inches of depth over the area of the watershed*	TR-55 Chapter 2 and Worksheet 2
Step 8	Determine Time of Concentration and Travel Time Note that this time is expressed in hours	TR-55 Chapter 3 and Worksheet 3
Step 9	Determine Peak Discharge (q, expressed in cfs) Graphical Peak Discharge Method Tabular Hydrograph Method	 TR-55 Chapter 4 and Worksheet 4 TR-55 Chapter 5 and Worksheets 5a and 5b

case for most water quality control basins. The modeling should also use a hydrodynamic method of pond routing; the graphic method of pond sizing provided in TR-55 is useful for rough sizing estimates during the conceptual design process, but a routing model such as TR-20 should generally be used for final design.

- Design storms used for filings under the Wetlands Protection regulations and Stormwater Management Policy must be based on Technical Paper 40 (TP-40) published by the U.S. Weather Bureau (now the U.S. National Weather Service) in 1961 in accordance with DEP written guidance published in the DEP Waterlines newsletter – Fall 2000. More stringent design storms may be used under a local bylaw or ordinance. However, DEP will continue to require the use of TP-40 in any case it reviews under the Wetlands Protection Act and Stormwater Management Policy.

- Care should be taken in selecting the points of analysis for which calculations will be performed. A point should be selected for each significant swale or stream exiting the development site. Sometimes, a significant length of a property line can be considered an analysis "point", if flow exits the property as "sheet flow" or "shallow concentrated flow". ***These same analysis points should be used for post-development calculations.*** While the contributing watersheds may change in size and shape, the impacts at each of the original analysis points need to be determined. A frequent error encountered in engineering calculations is that designers recombine watersheds to lump analysis points together, which effectively masks the effects on some of the initial analysis points.

- Care should be taken to include contributing areas, including area outside the limits of the project, within the watershed of each analysis point.

- Care should be taken to assign correct curve numbers to sites. Written information should be provided to the issuing authority documenting the choice of hydrologic conditions when developing curve numbers, including, whenever curve numbers are composited, whether the hydrologic conditions in the sub-watersheds are homogenous or heterogeneous, and the calculations compositing the curve numbers.

    - A common error is to use a curve number corresponding to "Woods in poor hydrologic condition". Most woods in Massachusetts have forest litter and brush covering the soil, and should be considered in "good hydrologic condition". A few trails on the forest floor should not change this.

    - A common error when there are multiple sub-watersheds and when the hydrologic conditions within the sub-watersheds are not homogenous, is the development of a composited curve number. In accordance with the procedures outlined in TR-55, curve numbers should only be composited between sub-watersheds if hydrologic conditions are homogenous.

    - Curve numbers should be verified for both the pre-project and post-project conditions.

- Average antecedent moisture conditions (AMC II) should generally be used for design. The adjustment of curve numbers to account for dry or wet conditions is normally only applicable when analyzing a particular event "after the fact", or for some other specialized study.

- Curve numbers should be developed with a correct accounting for "connected" and "unconnected" impervious areas. Drainage calculations should include worksheets that document how the curve numbers have been developed.
- If the weighted curve number is less than 40, TR-55 should not be used for estimating runoff.
- In developing time of concentration flow paths, overland flow should not normally exceed 50 feet. Where it can be demonstrated that the ground surface has a uniform grade (as on a uniformly sloped parking lot), the overland flow path may be greater than 50 feet. In no case should it exceed 300 feet. Also, once overland flow transitions to "shallow concentrated" or "channelized" flow, calculations should not show a transition back to "overland flow".
- Times of concentration should be determined to the most remote point in the watershed based on the time it takes water to travel, not necessarily on distance of travel. For example, a short, flat slope may have a longer travel time than a long, steep slope. In that case, the path with the longest time should be used for determining the time of concentration.
- Times of concentration or travel times in channels and conduits should be computed according to accepted engineering practices for estimating velocities in these conveyances. Usually, bank full velocities should be used for channels; pipe-full velocities should be used for enclosed conduits.
- The designer should not interpolate figures outside the limits of the charts and tables provided in TR-55.
- Chapter 6 of TR-55 presents a method of estimating storage volumes for detention basins. While a designer might use this method for conceptual sizing, it should not be used for final design. Generally, the NOI submittals should not contain calculations for final design based on this method. Detention basins should be designed using full hydrographs, and an appropriate routing method. Most engineers engaged in storm water management design now have computer software that enables them to perform the necessary routing calculations.

SCS TR-55 GRAPHICAL METHOD

Applicability

This wetland determines peak runoff, the runoff volume, and the time to peak for a single homogeneous sub-area or watershed only. Applicable for drainage areas up to 2000 acres.

Description Of Method

The Graphical Method was developed from hydrograph analyses using TR-20. It provides a simplified approach to estimating peak runoff and total runoff volumes while accounting for slope, soils, and watershed shape. Refer to TR-55 for a detailed description of the use of the method.

Assumptions

See TR-55 and TR-20 reference material.

Limitations

1. Refer to applicable chapters of TR-55 for specific limitations, including those pertaining to the derivation of Curve Number (CN) and Time of Concentration (Tc).

2. TR-55 is based on open and unconfined flow over land or in channels. For large events during which flow is divided between sewer and overland flow, more information about hydraulics is needed to determine Tc. After flow enters a closed system, the discharge can be assumed constant until another flow is encountered at a junction or another inlet.

3. The Graphical Peak Discharge method is derived form TR-20 (SCS 1983) output. The use of Tc permits it to be used for any size watershed within the scope of he curves or tables. The Graphical method is used only for hydrologically homogeneous watersheds because the procedure is limited to a single watershed subarea.

4. The Graphical method provides a determination of peak discharge only. If a hydrograph is needed or watershed subdivision is required, use the Tabular Hydrograph method. Use TR-20 if the watershed is very complex, a higher degree of accuracy is required, or if detention facilities are designed to store flows form the early hours of a design storm.

5. The watershed must be hydrologically homogeneous, that is, describable by one CN. Land use, soils, and over are distributed uniformly throughout the watershed.

6. The watershed may have only one main stream or, if more than one, the branches must have nearly equal Tc's.

7. The method cannot perform valley or reservoir routing.

8. The ponding factor can be applied only for ponds or swamps that are not in the Tc flow path.

9. Accuracy of peak discharge estimated by this method will be reduced if la/P values are used that are outside the range given in the TR-55 reference. Th limiting la/P values are recommended for use.

10. This method should be used only if the weighted CN is greater than 40.

11. When this method is used to develop estimates of peak discharge for both present and developed conditions of a watershed, use the same procedure for estimated Tc.

12. Tc values with this method may range for 0.1 to 10 hours.

Primary Reference

Soil Conservation Service, 1986

SCS TR-55 TABULAR METHOD.

Applicability

This method is applicable for drainage areas up to 2,000 acres and where the requirements of TR-20 listed in applicability section are not needed.

Description of Method

The Tabular Method approximates TR-20, which is a more detailed hydrograph procedure; TR-55 is in fact derived from a simplification of the TR-20 model. Th Tabular Method can develop composite flood hydrographs at any point in a watershed by dividing the watershed into **homogeneous** subareas. In this manner, the method can estimate runoff form non-homogeneous watershed. The method is especially applicable for estimating the effects of land use change in a portion of a watershed. It can also be used to estimate the effects of proposed structures. Refer to TR-55 for a detailed description of the use of the method.

Assumptions:

See TR-55, TR-20 and NEH-4 reference material.

Limitations

1. Refer to applicable chapters of TR-55 for specific limitations, including those pertaining to the derivation of Curve Number (CN) and Time of Concentration (T_c).

2. TR-55 is based on open and unconfined flow over land or in channels. For large events during which flow is divided between piped or channelized and overland flow, more information about hydraulics is needed to determine Tc. After flow enters a closed system, the discharge can be assumed constant until another flow is encountered at a junction or another inlet.

3. The Tabular Hydrograph method is derived from TR-20 output. The use of Tc permits it to be used for any size watershed within the scope of the curves or tables. The Tabular Method can be used for a heterogeneous watershed that is divided into a number of homogeneous sub-watersheds. Hydrographs for the sub-watershed can be routed and added.

4. The Tabular Method is used to determine peak flows and hydrographs within a watershed. However, its accuracy decreases as the complexity of the watershed increases. To compare present and developed conditions of a watershed, use the same procedure for estimating Tc for both conditions.

5. Use the TR-20 computer program instead of the Tabular Method if any of the following conditions applies:

- T_t is greater than 3 hours
- T_c is greater than 2 hours
- Drainage areas of individual subareas differ by a factor of 5 or more.
- The entire composite flood hydrograph or entire runoff volume is required for detailed flood routings. The TR-55 hydrograph is based on extrapolation and is only an approximation of the entire hydrograph. The TR-55 hydrograph is also "terminated" – that is, several hours at the beginning at the hydrograph are not provided in the TR-55 tabulation. This makes the wetland inappropriate for sizing structures designed to store runoff early in the storm event.
- The time of peak discharge must be more accurate than that obtained through the Tabular Method.
- CN is less than 30.

Primary Reference

Sol Conservation Service, 1986

Appendix D:
SCS TR-20

Applicability

This method is applicable for drainage areas up to 20 square miles. The TR-20 hydrologic model or an equivalent must be used for watershed analysis where any of the following conditions are applicable.

1. Sub-areas are significantly different in size (greater than 5:1 ratio of one subarea to another), land use (cover), or hydrologic soil groups.

2. An outflow hydrograph from a detention pond is needed.

3. A detention basin has multiple sub-areas in its drainage area, requiring accurate peak discharge values and composite runoff volumes.

4. Multiple detention structures are used either in parallel or in series.

5. Conveyance channel storage is large.

6. Calibration of the model using actual rainfall amounts and distribution is needed.

7. Flow (splitting) diversions are required.

8. Detention basins designed for extended detention are required.

Description Of Method

SCS TR-20 Hydrologic Model is a watershed computer model, which uses the SCS Synthetic Unit Hydrograph to calculate runoff from any specified precipitation event. SCS TR-20 performs reservoir routing using the storage-indication method and channel routing using the Modified Att-Kin method. Time of concentration, travel time and antecedent moisture conditions are taken into account. The program provides hydrographs at any desired location allowing the evaluation of the effects of urbanization of other varied conditions within a watershed. The program allows for the analysis of nine different rainstorm distributions over a watershed and can utilize varied combination of land treatment, flood water retarding structures, divisions and channel configurations. Up to 200 reaches and 99 structures may be analyzed. The model can be used in design or watershed simulation. It maybe calibrated to actual events for large projects.

A sample of a computer output for a TR-20 analysis is attached. This sample has been annotated, to illustrate where key information may be found when reviewing and interpreting the results of the method.

Assumptions

Refer to primary reference material.

Limitations

Refer to primary reference material.

Primary Reference

Soil Conservation Service, 1983

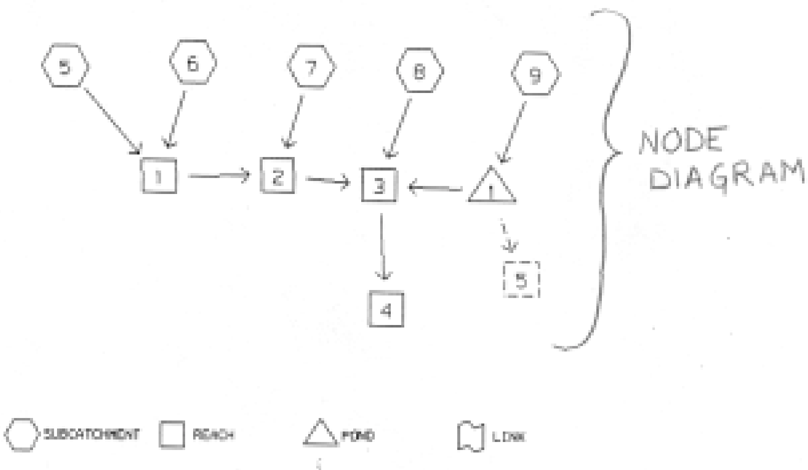
TR-20 EXAMPLE:

The following pages provide an example of a TR-20 based computer output. The example includes the generation of a runoff hydrograph. It also includes a detention structure routing calculation. The output has been annotated to show where key information appears.

Different commercial computer packages are available for performing hydrologic calculations. The output formats of these software packages may vary considerably from the example shown. Conservation Commissioners may wish to request an explanation of the format by the applicant. Also, Commissions may engage the assistance of a qualified professional, to help them review calculation submittals.

TYPE III 24-HOUR RAINFALL

WATERSHED ROUTING ==



SUBCATCHMENT 5	= subarea 5	->	REACH 1
SUBCATCHMENT 6	= post-development	->	REACH 1
SUBCATCHMENT 7	= post-development	->	REACH 2
SUBCATCHMENT 8	= post-development	->	REACH 3
SUBCATCHMENT 9	= post-development	->	POND 1
REACH 1	= reach 1	->	REACH 2
REACH 2	= reach 2	->	REACH 3
REACH 3	= reach 3 (combined 5,6,7,8)	->	REACH 4
REACH 4	= reach 4 (combined 5,6,7,8,9)	->	
POND 1	= detention pond	->	REACH 3
POND 1 secondary	= detention pond	->	REACH 5

TYPE III 24-HOUR RAINFALL= 3.40 IN (2yr?)

WATERSHED HYDROGRAPH SUMMARY

SUBCATCHMENT 5   subarea 5

RUNOFF VOLUME IN ACRE-FEET

PEAK= 1.99 CFS @ 12.21 HRS, VOLUME= .19 AF

PEAK DISCHARGE RATE

ACRES	CN	
.93	70	woods (good)
.15	77	woods (thin)
.34	98	roof
.30	78	wetland
1.72	78	

RUNOFF CN CALCULATION

COMPOSITE RUNOFF CN

WATERSHED AREA

SCS TR-20 METHOD ← HYDROGRAPH METHOD
TYPE III 24-HOUR ← RAINFALL DISTRIBUTION
RAINFALL= 3.40 IN ← RAINFALL DEPTH
SPAN= 10-20 HRS, dt=.1 HRS

Method	Comment	Tc (min)
TR-55 SHEET FLOW	Segment ID:1-2	10.2
Woods: Light underbrush n=.4 L=50' P2=3.4 in s=.03 '/'		
SHALLOW CONCENTRATED/UPLAND FLOW	Segment ID:2-3	4.8
Unpaved Kv=16.1345 L=740' s=.025 '/' V=2.55 fps		
CHANNEL FLOW	Segment ID:3-4	2.2
a=24 sq-ft Pw=14' r=1.714'		
s=.002 '/' n=.08 V=1.19 fps L=160' Capacity=28.6 cfs		
	Total Length= 950 ft Total Tc=	17.2

SHEET FLOW TRAVEL TIME

SHALLOW CONCENTRATED FLOW TRAVEL TIME

CHANNEL FLOW TRAVEL TIME

TIME OF CONCENTRATION CALCULATION

TIME OF CONCENTRATION

SUBCATCHMENT 6   post-development

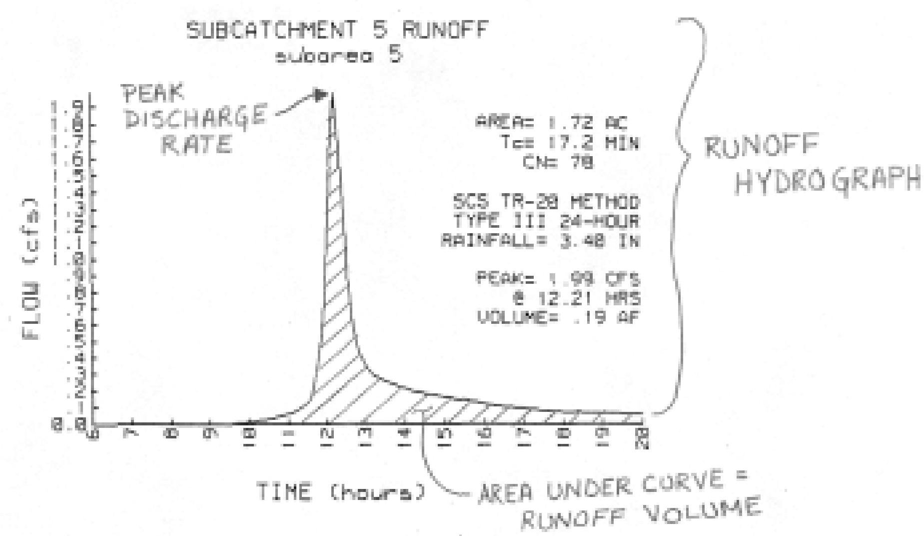
PEAK= 4.61 CFS @ 11.99 HRS, VOLUME= .29 AF

ACRES	CN	
.45	98	roof
.73	98	pavement
.29	74	lawn
.03	98	sidewalk/concrete
.02	78	wetland
1.52	93	

SCS TR-20 METHOD
TYPE III 24-HOUR
RAINFALL= 3.40 IN
SPAN= 10-20 HRS, dt=.1 HRS

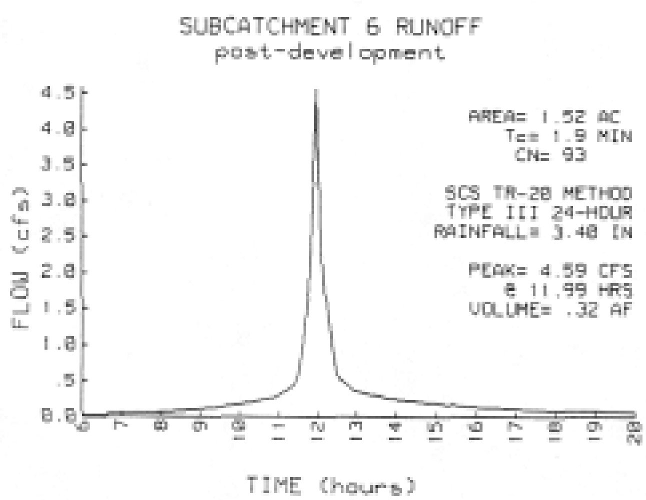
Method	Comment	Tc (min)
TR-55 SHEET FLOW	Segment ID:1-2	.7
Smooth surfaces n=.011 L=50' P2=3.4 in s=.02 '/'		
SHALLOW CONCENTRATED/UPLAND FLOW	Segment ID:2-3	1.0
Paved Kv=20.3282 L=240' s=.04 '/' V=4.07 fps		
CIRCULAR CHANNEL	Segment ID: 3-4	.4
12" Diameter a=.79 sq-ft Pw=3.1' r=.25'		
s=.015 '/' n=.013 V=5.56 fps L=120' Capacity=4.4 cfs		
	Total Length= 410 ft Total Tc=	2.1

TYPE III 24-HOUR RAINFALL= 3.40 IN



Page 13

TYPE III 24-HOUR RAINFALL= 3.40 IN



TYPE III 24-HOUR RAINFALL= 3.40 IN

PEAK FLOW INTO DETENTION POND

POND 1 detention pond

PEAK FLOW OUT OF DETENTION POND

```
Qin =  3.84 CFS @ 12.18 HRS,  VOLUME=  .35 AF
Qout=  1.81 CFS @ 12.52 HRS,  VOLUME=  .30 AF,  ATTEN= 53%,  LAG=  20.6 MIN
Qpri=  1.80 CFS @ 12.52 HRS,  VOLUME=  .29 AF
Qsec=   .02 CFS @ 12.52 HRS,  VOLUME=  .01 AF
```

POND ELEVATION, AREA & STORAGE TABLE

ELEVATION (FT)	AREA (AC)	INC.STOR (AF)	CUM.STOR (AF)
84.0	.03	0.00	0.00
85.0	.05	.04	.04
85.5	.09	.04	.08
86.0	.10	.05	.12
87.0	.13	.12	.24
88.0	.18	.16	.39

ROUTING METHOD

```
STOR-IND METHOD
PEAK STORAGE =        .13 AF
PEAK  ELEVATION=     86.0 FT
FLOOD ELEVATION=     88.0 FT
START ELEVATION=     84.0 FT
SPAN= 6-20 HRS, dt=.1 HRS
Tdet= 90.6 MIN (.3 AF)
```

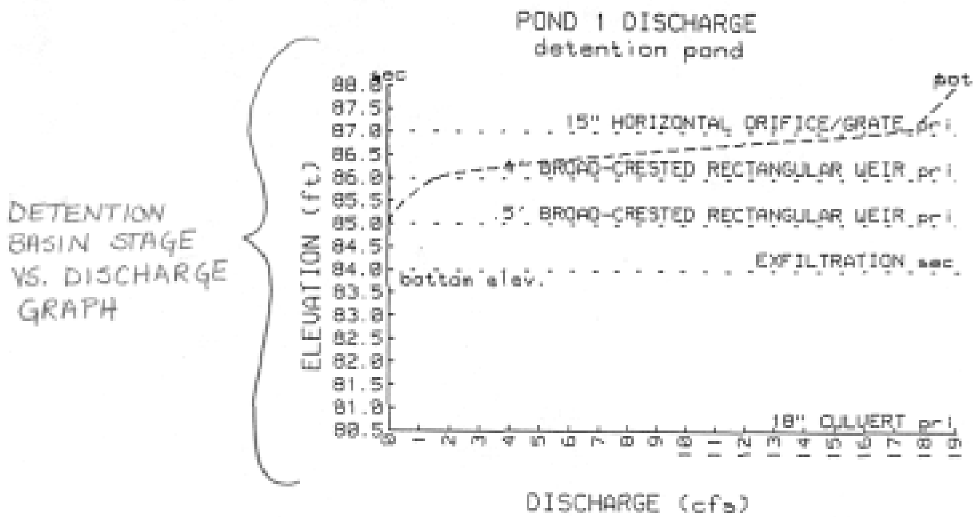
MULTIPLE STAGE OUTLET CONTROL SPECIFICATIONS

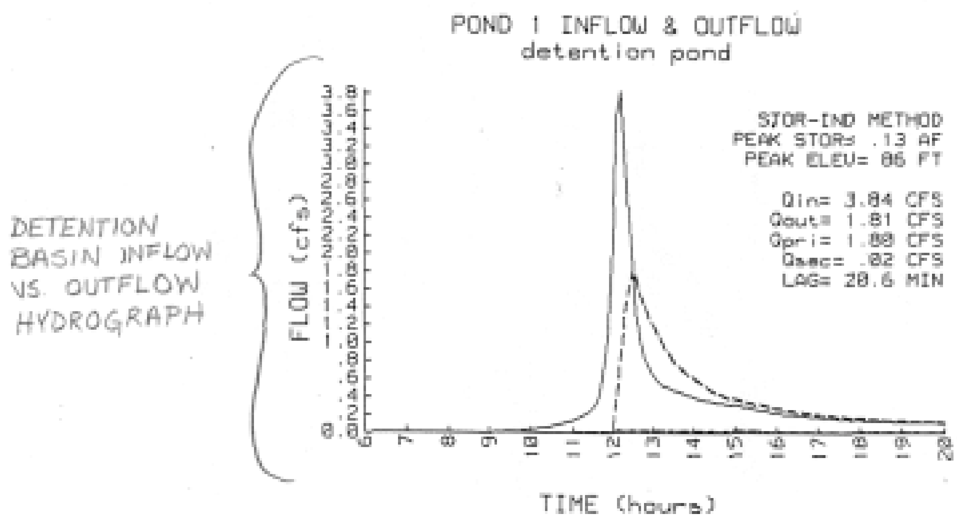
```
# ROUTE  INVERT     OUTLET DEVICES
1   4     86.0'   4' BROAD-CRESTED RECTANGULAR WEIR
                  Q=C L H^1.5  C=3.1, 3.1, 3.1, 3.1, 3.1, 3.1, 3.1, 3.1
2   4     87.0'   15" HORIZONTAL ORIFICE/GRATE
                  Q=.6 Area SQR(2gH)  (Limited to weir flow @ low head)
3   S     84.0'   EXFILTRATION
                  V= .000375 FPM over (SURFACE AREA - .03 AC)
4   P     80.5'   18" CULVERT
                  n=.013  L=120'  S=.005'/'  Ke=.5  Cc=.9  Cd=.6
5   4     85.0'   .5' BROAD-CRESTED RECTANGULAR WEIR
                  Q=C L H^1.5  C=3.1, 3.1, 3.1, 3.1, 3.1, 3.1, 3.1, 3.1

Primary Discharge
└─4=Culvert
   ├─1=Broad-Crested Rectangular Weir
   ├─2=Orifice/Grate
   └─5=Broad-Crested Rectangular Weir

Secondary Discharge
└─3=Exfiltration
```

TYPE III 24-HOUR RAINFALL= 3.40 IN





Appendix E:
Massachusetts DEP Stormwater Management Policy Standard 3: Recharge

Technical Bulletin

This Appendix is reserved for the Technical Bulletin currently undergoing preparation by the Massachusetts DEP.

Appendix F:
Precipitation Data for Massachusetts

F-1. Design Storms for Massachusetts from *Rainfall Frequency Atlas of the United States* (TP-40)

F-2. Design Storms from *Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada (*the "Cornell Study")

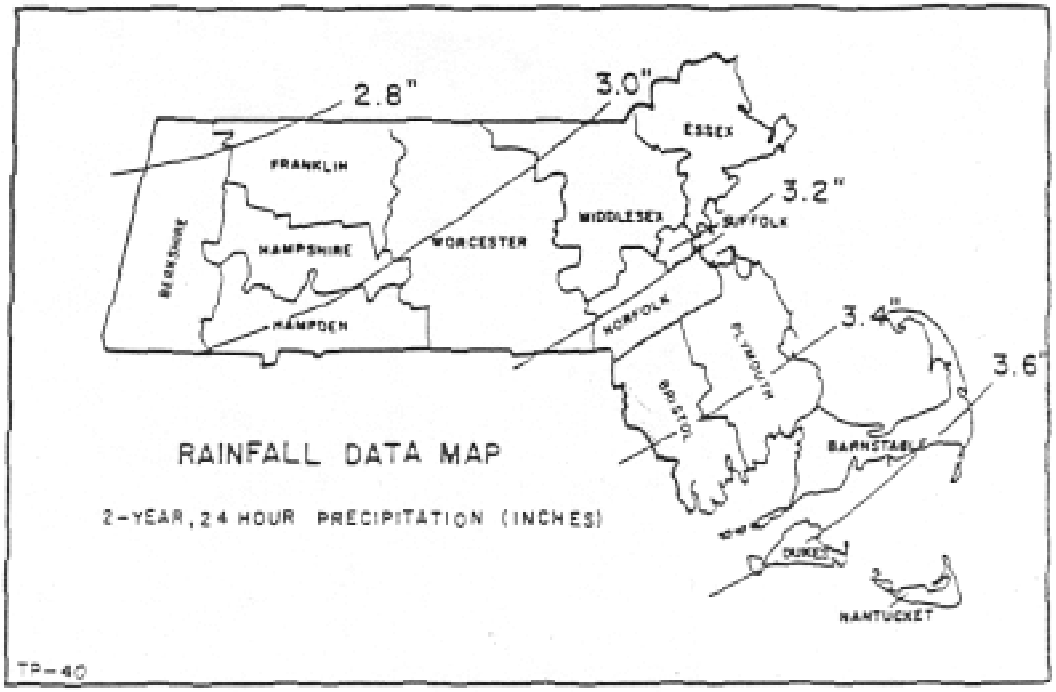
F-3. Rainfall Intensity/Duration/Frequency Curves For Selected Locations in Massachusetts

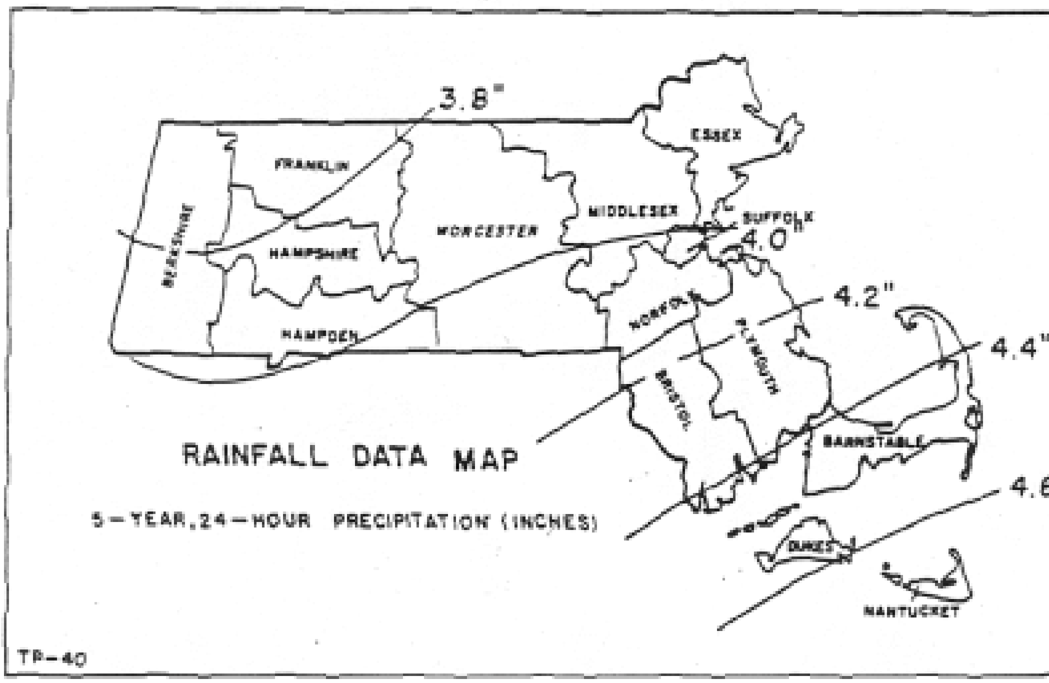
F-1. Rainfall Data for Massachusetts from *Rainfall Frequency Atlas of the United States* (TP-40)

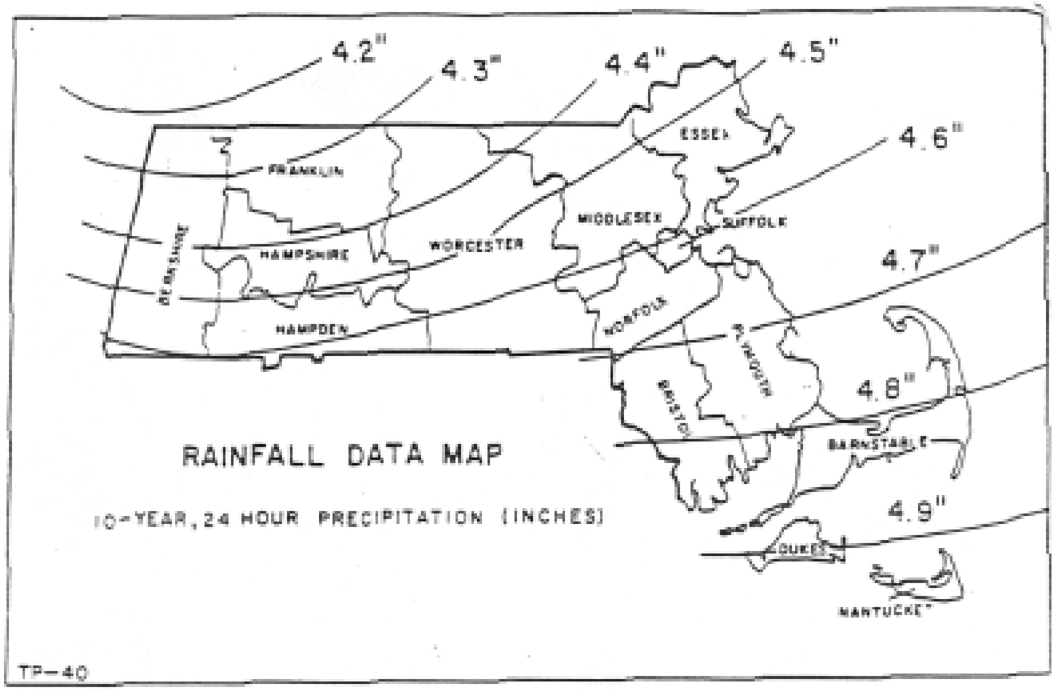
- Users of this Handbook should note that current MA DEP written guidance (see DEP Waterlines newsletter -- Fall 2000) requires the use of TP-40 Rainfall Data for calculations under the Wetlands Protection Regulations and the Stormwater Management Policy. More stringent design storms may be used under a local bylaw or ordinance. However, DEP will continue to require the use of TP-40 in any case it reviews under the Wetlands Protection Act and Stormwater Management Policy.

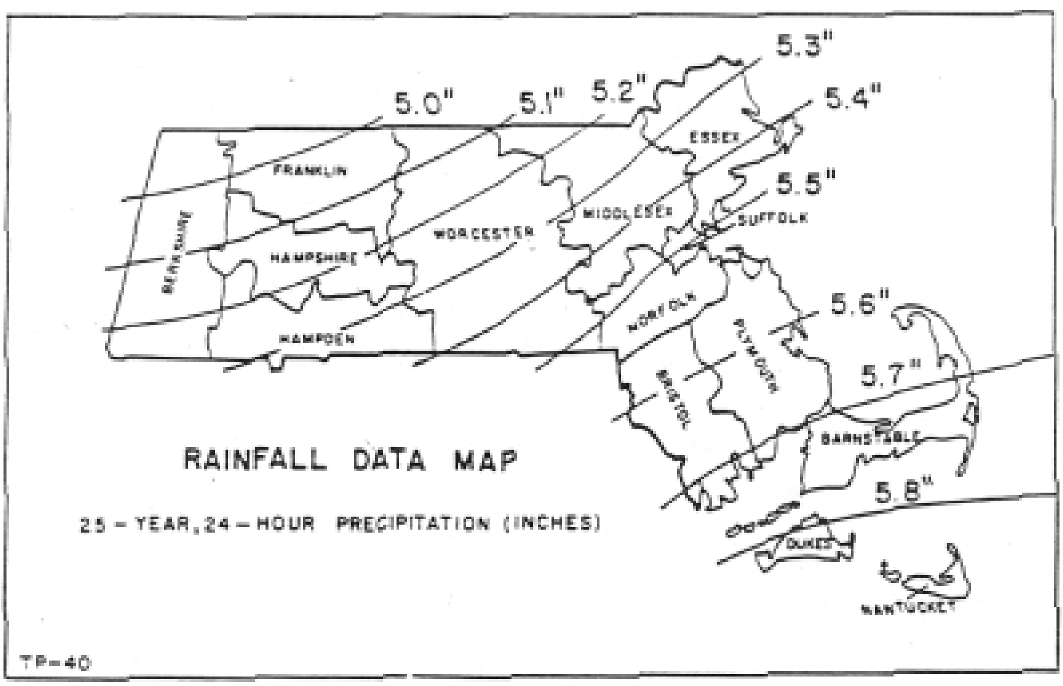
Adjusted Technical Paper 40 Design Storms for 24-hour Event by County

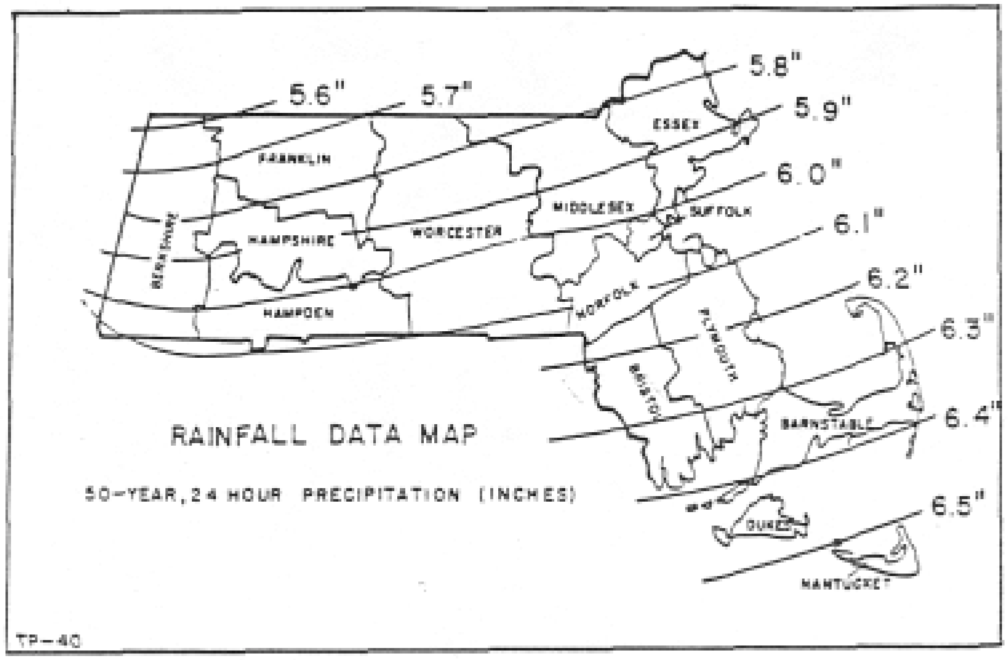
County Name	1-yr 24-hr	2-yr 24-hr	5-yr 24-hr	10-yr 24-hr	25-yr 24-hr	50-yr 24-hr	100-yr 24-hr
Barnstable	2.5	3.6	4.5	4.8	5.7	6.4	7.1
Berkshire	2.5	2.9	3.8	4.4	5.1	5.9	6.4
Bristol	2.5	3.4	4.3	4.8	5.6	6.3	7.0
Dukes	2.5	3.6	4.6	4.9	5.8	6.5	7.2
Essex	2.5	3.1	3.9	4.5	5.4	5.9	6.5
Franklin	2.5	2.9	3.8	4.3	5.1	5.8	6.2
Hampden	2.5	3.0	4.0	4.6	5.3	6.0	6.5
Hampshire	2.5	3.0	3.9	4.5	5.2	5.9	6.4
Middlesex	2.5	3.1	4.0	4.5	5.3	5.9	6.5
Nantucket	2.5	3.6	4.6	4.9	5.8	6.5	7.2
Norfolk	2.5	3.2	4.1	4.7	5.5	6.1	6.7
Plymouth	2.5	3.4	4.3	4.7	5.6	6.2	7.0
Suffolk	2.5	3.2	4.0	4.6	5.5	6.0	6.6
Worcester	2.5	3.0	4.0	4.5	5.3	5.9	6.5

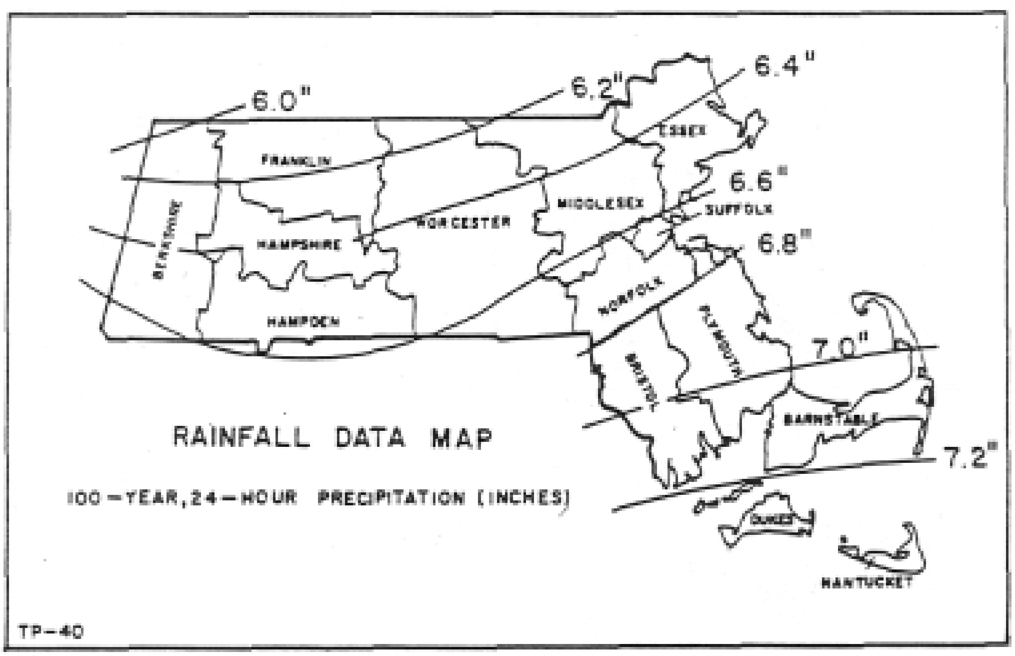

2.8"
3.0"
3.2"
3.4"
3.6"
ESSEX
FRANKLIN
MIDDLESEX
SUFFOLK
BERKSHIRE
HAMPSHIRE
WORCESTER
NORFOLK
HAMPDEN
PLYMOUTH
BRISTOL
BARNSTABLE
DUKES
NANTUCKET
RAINFALL DATA MAP
2-YEAR, 24 HOUR PRECIPITATION (INCHES)
TP-40


3.8"
ESSEX
FRANKLIN
MIDDLESEX
SUFFOLK
4.0"
BERKSHIRE
HAMPSHIRE
WORCESTER
NORFOLK
4.2"
HAMPDEN
PLYMOUTH
4.4"
BRISTOL
BARNSTABLE
4.6
DUKES
NANTUCKET
RAINFALL DATA MAP
5-YEAR, 24-HOUR PRECIPITATION (INCHES)
TP-40


4.2"
4.3"
4.4"
4.5"
4.6"
4.7"
4.8"
4.9"
ESSEX
FRANKLIN
MIDDLESEX
SUFFOLK
BERKSHIRE
HAMPSHIRE
WORCESTER
NORFOLK
HAMPDEN
PLYMOUTH
BRISTOL
BARNSTABLE
DUKES
NANTUCKET
RAINFALL DATA MAP
10-YEAR, 24 HOUR PRECIPITATION (INCHES)
TP-40


5.3"
5.0"
5.1"
5.2"
5.4"
5.5"
5.6"
5.7"
5.8"
ESSEX
FRANKLIN
MIDDLESEX
SUFFOLK
BERKSHIRE
HAMPSHIRE
WORCESTER
NORFOLK
PLYMOUTH
HAMPDEN
BRISTOL
BARNSTABLE
DUKES
NANTUCKET
RAINFALL DATA MAP
25-YEAR, 24-HOUR PRECIPITATION (INCHES)
TP-40

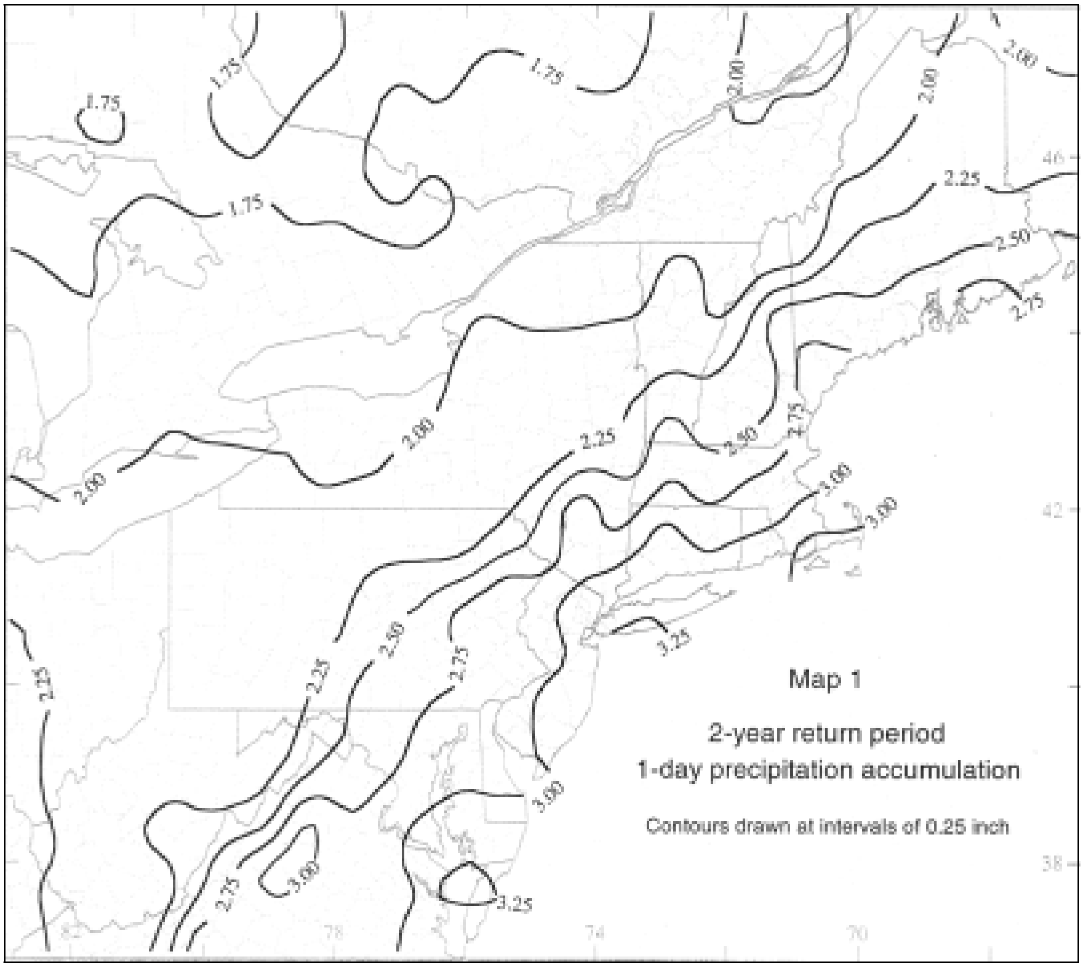

5.6"
5.7"
5.8"
5.9"
6.0"
6.1"
6.2"
6.3"
6.4"
6.5"
ESSEX
FRANKLIN
MIDDLESEX
SUFFOLK
HAMPSHIRE
WORCESTER
NORFOLK
HAMPDEN
PLYMOUTH
BRISTOL
BARNSTABLE
DUKES
NANTUCKET
RAINFALL DATA MAP
50-YEAR, 24 HOUR PRECIPITATION (INCHES)
TP-40


6.0"
6.2"
6.4"
6.6"
6.8"
7.0"
7.2"
ESSEX
FRANKLIN
MIDDLESEX
SUFFOLK
BERKSHIRE
HAMPSHIRE
WORCESTER
NORFOLK
HAMPDEN
PLYMOUTH
BRISTOL
BARNSTABLE
DUKES
NANTUCKET
RAINFALL DATA MAP
100-YEAR, 24-HOUR PRECIPITATION (INCHES)
TP-40

F-2. Rainfall Data from *Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada (*the "Cornell Study")

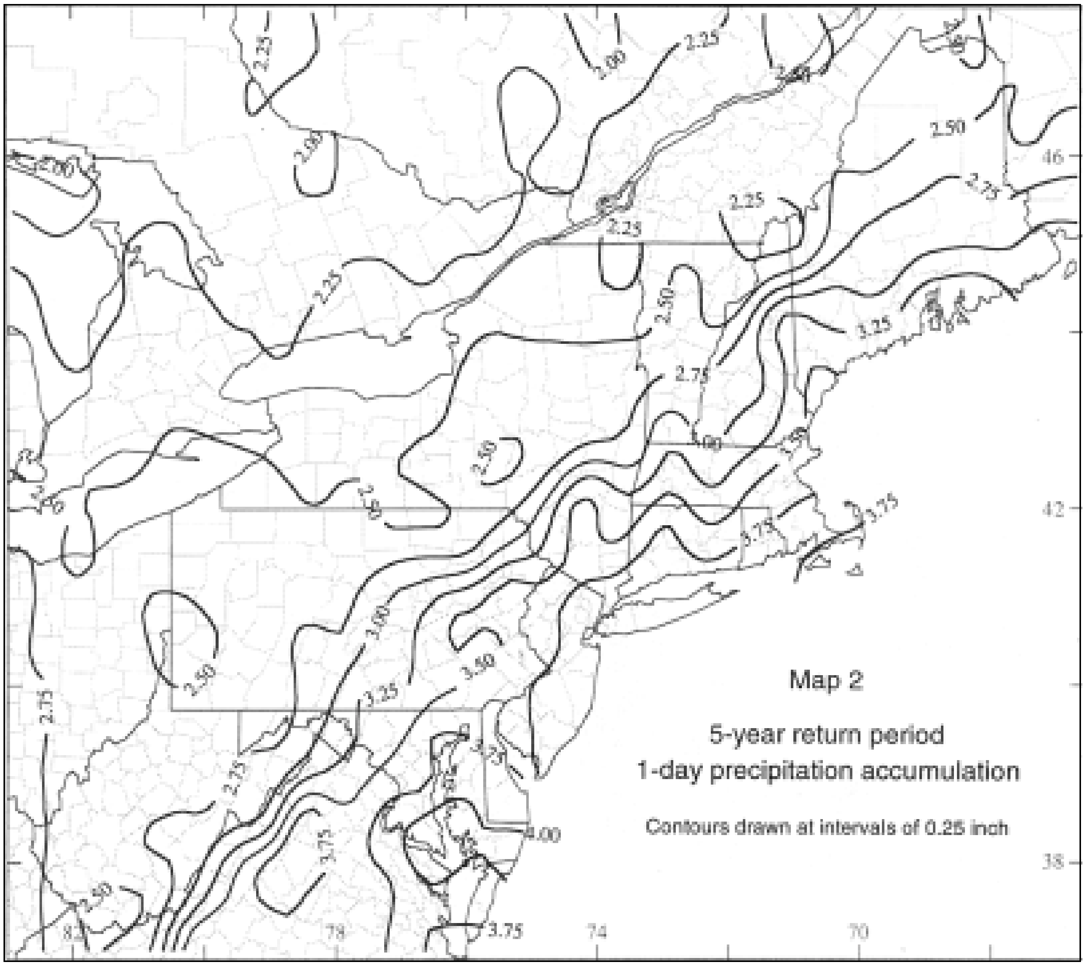
The following maps are printed with permission of the Northeast Regional Climate Center. For this Handbook, a note has been added regarding a conversion factor that must be applied to obtain values for a 24-hour duration storm.

Handbook users should also note that MA DEP currently requires use of TP-40 Rainfall Data (see Appendix F-1).



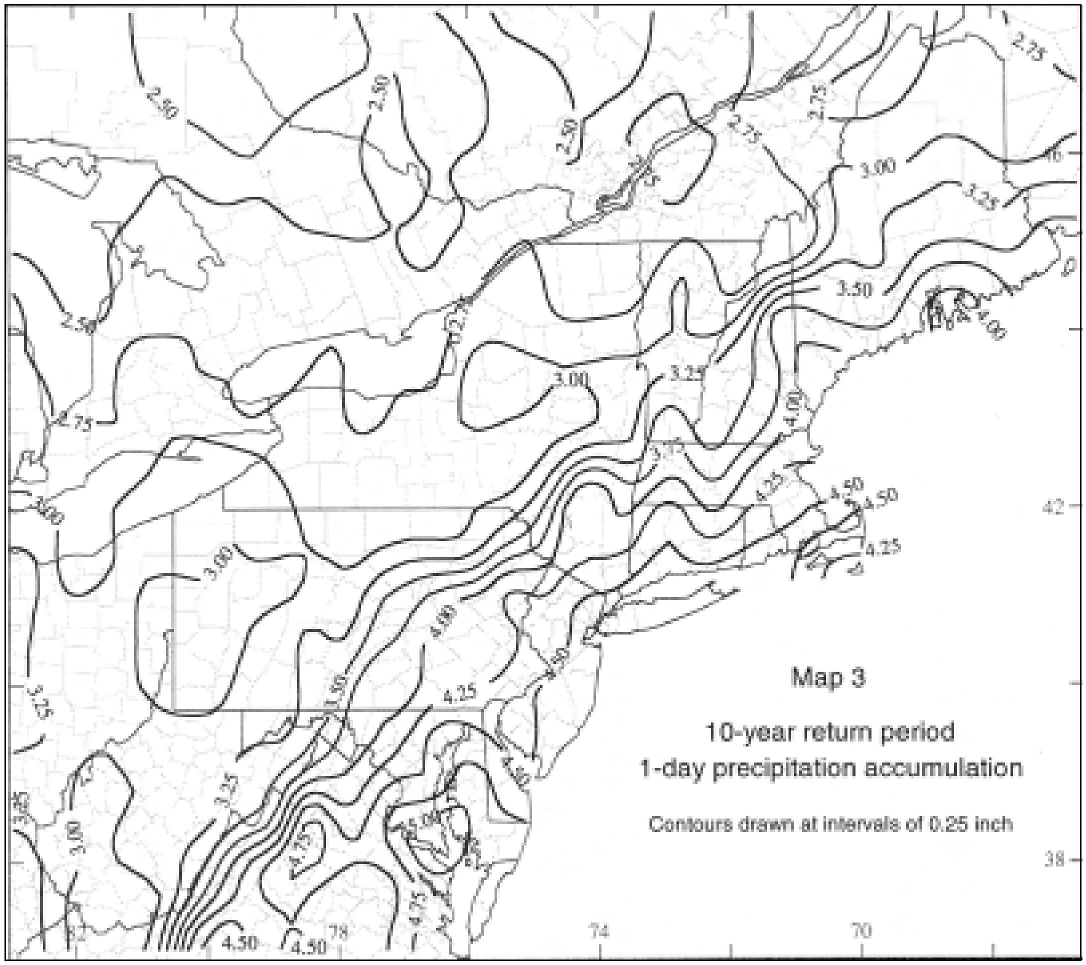
Note: To obtain precipitation value for 24-hour duration storm event, multiply value from map by a factor of 1.13.

Adapted from: Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada



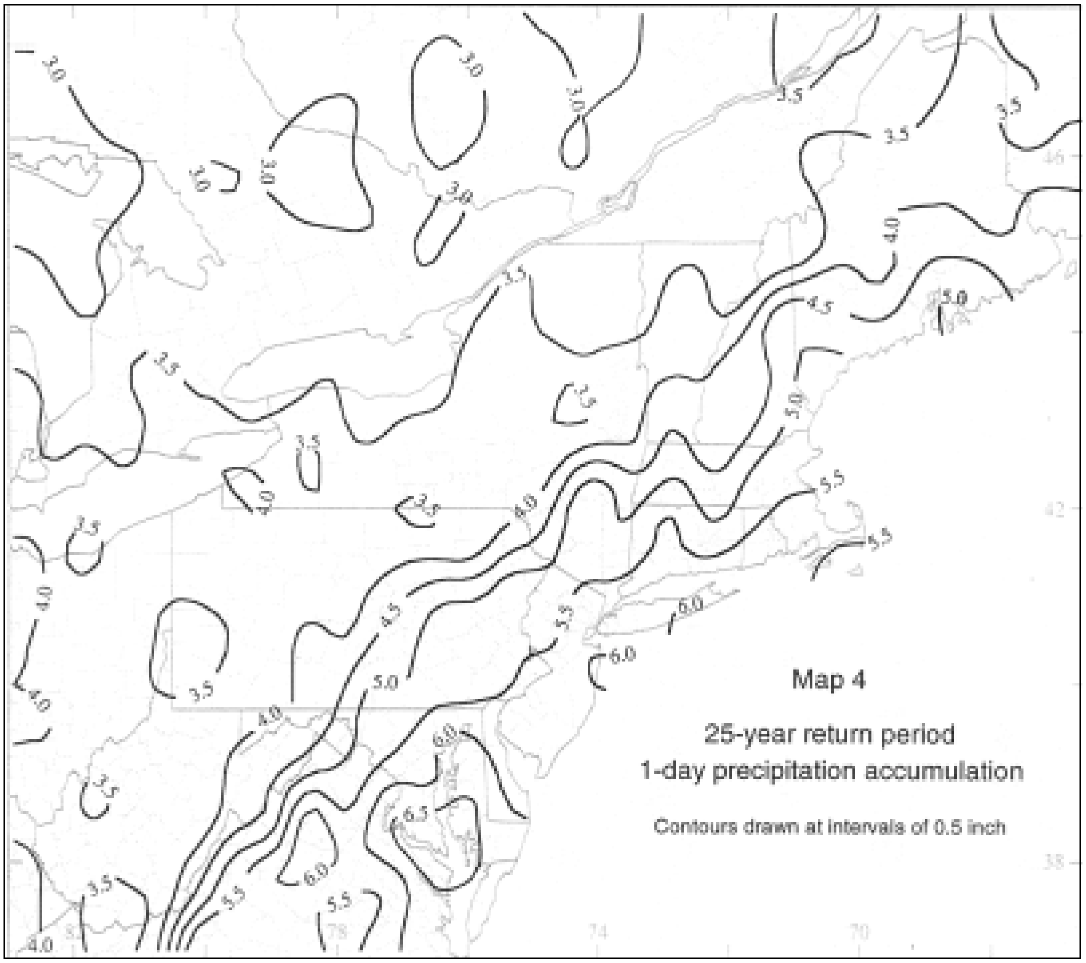
Note: To obtain precipitation value for 24-hour duration storm event, multiply value from map by a factor of 1.13.

Adapted from: Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada



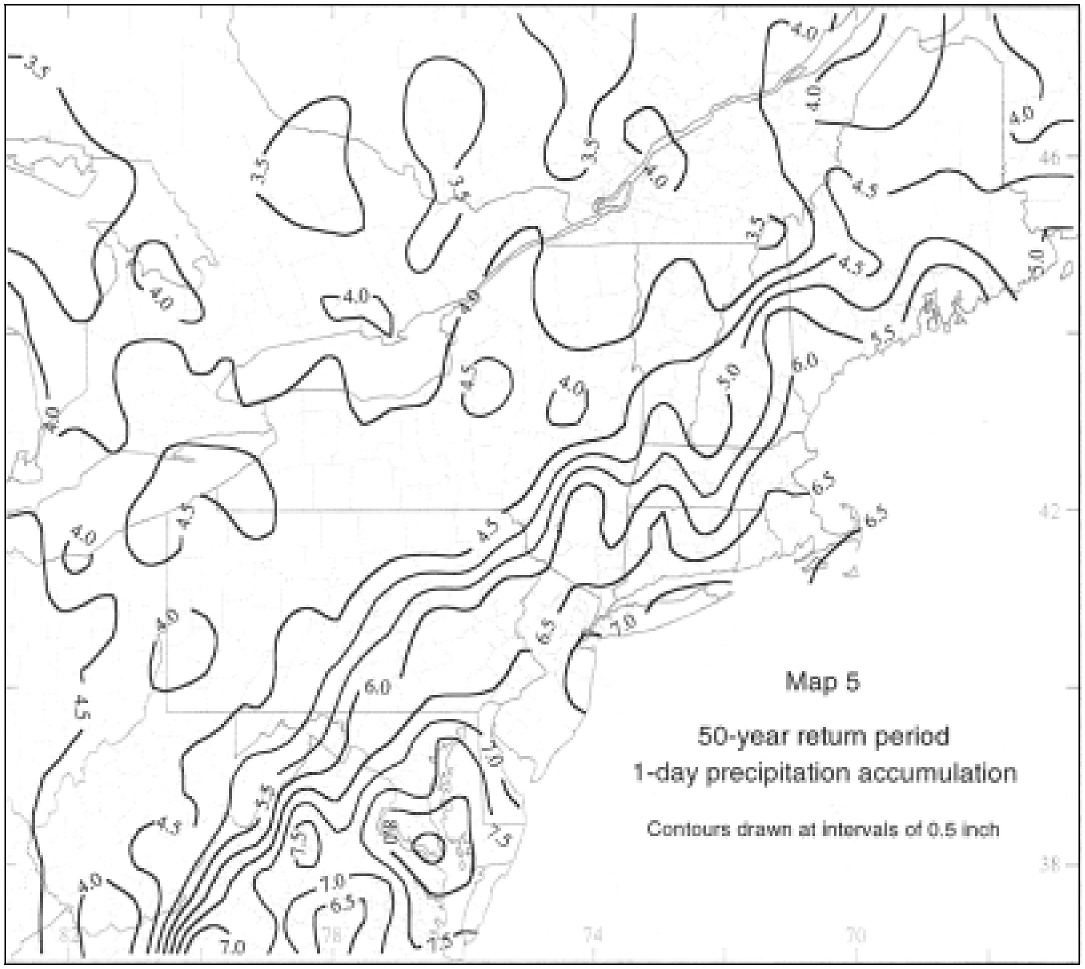
Note: To obtain precipitation value for 24-hour duration storm event, multiply value from map by a factor of 1.13.

Adapted from: Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada



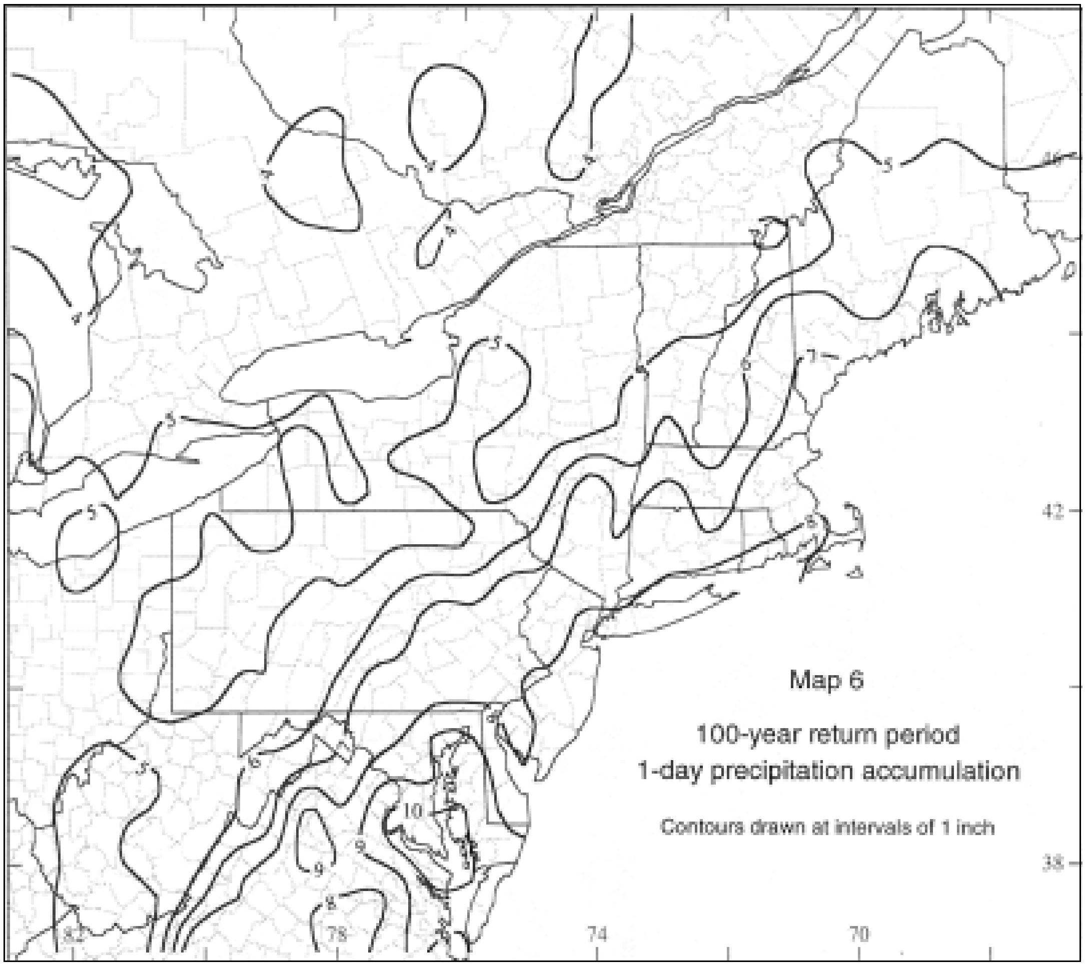
Note: To obtain precipitation value for 24-hour duration storm event, multiply value from map by a factor of 1.13.

Adapted from: Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada



Note: To obtain precipitation value for 24-hour duration storm event, multiply value from map by a factor of 1.13.

Adapted from: Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada

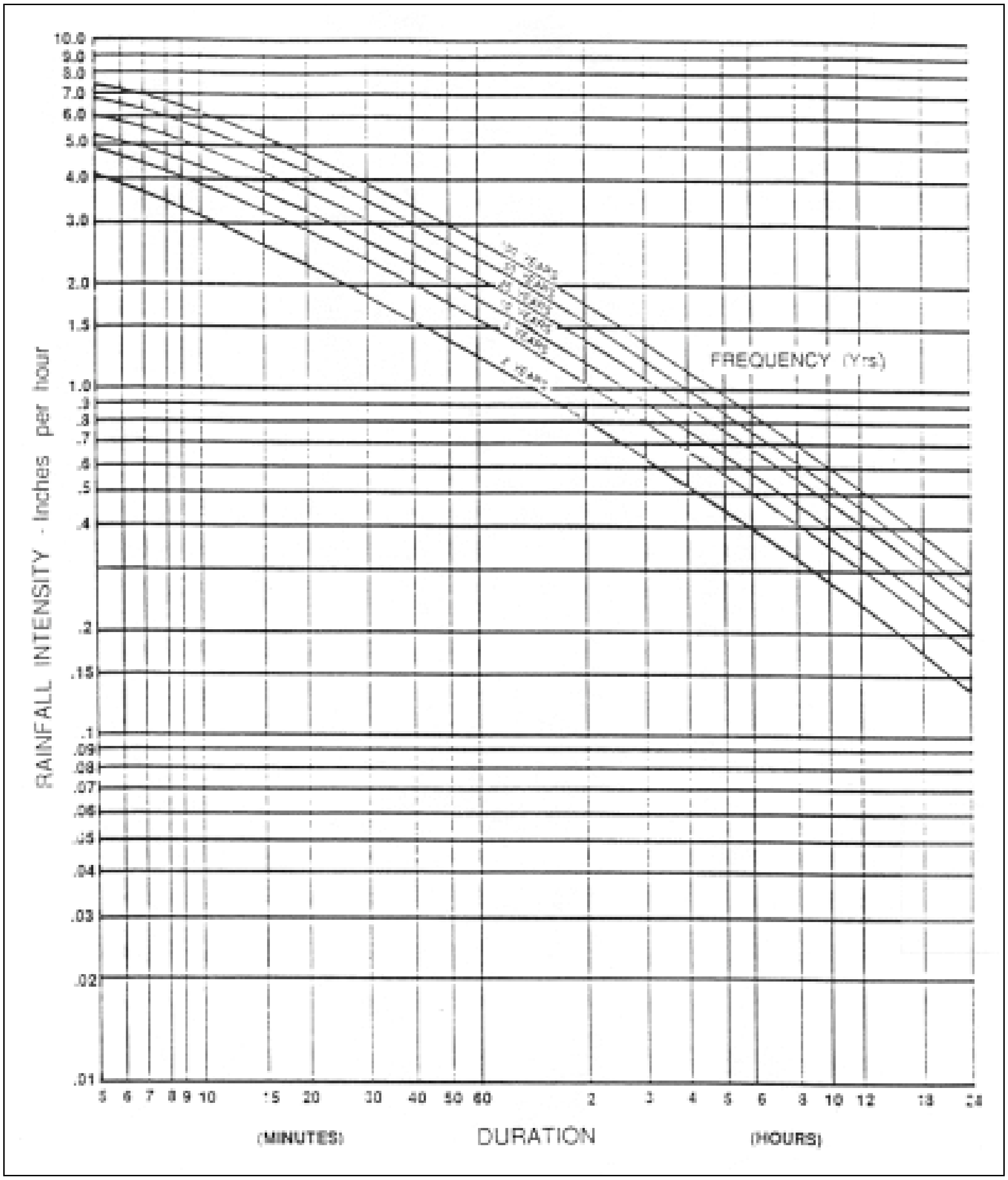


Note: To obtain precipitation value for 24-hour duration storm event, multiply value from map by a factor of 1.13.

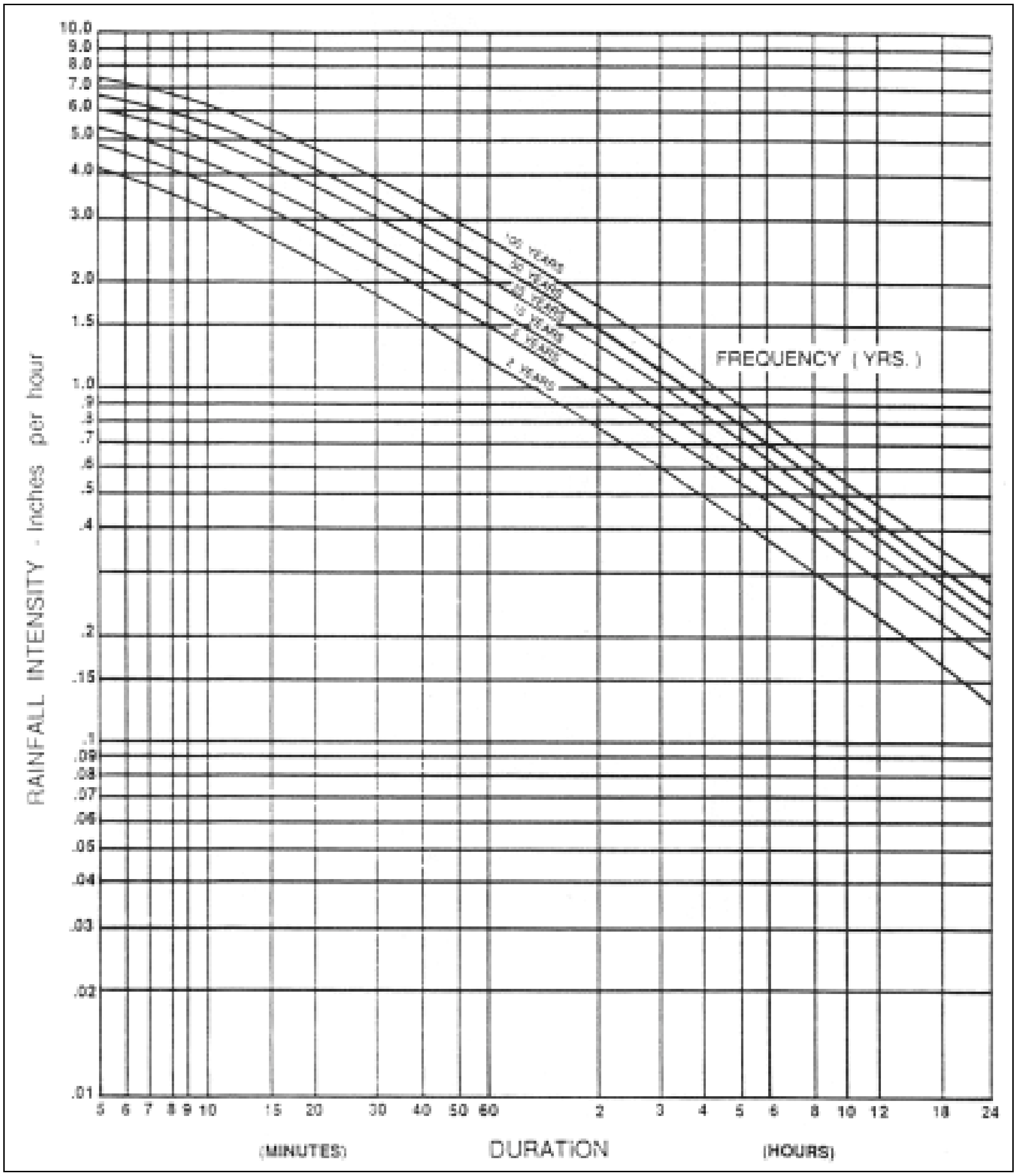
Adapted from: Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada

F-3. Rainfall Intensity/Duration/Frequency Curves For Selected Locations in Massachusetts

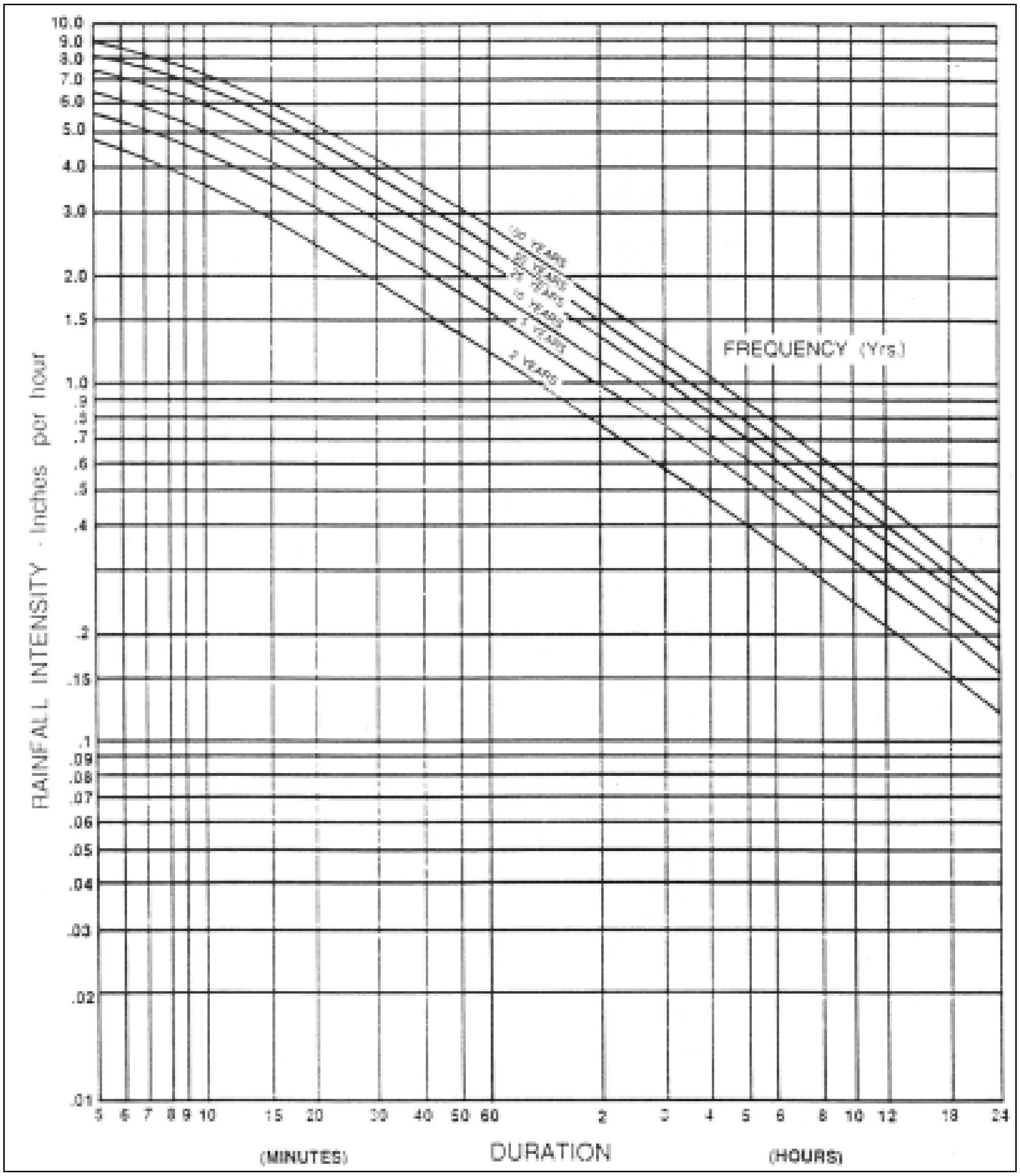
The following IDF Curves are adapted from the MassHighway Drainage Manual.



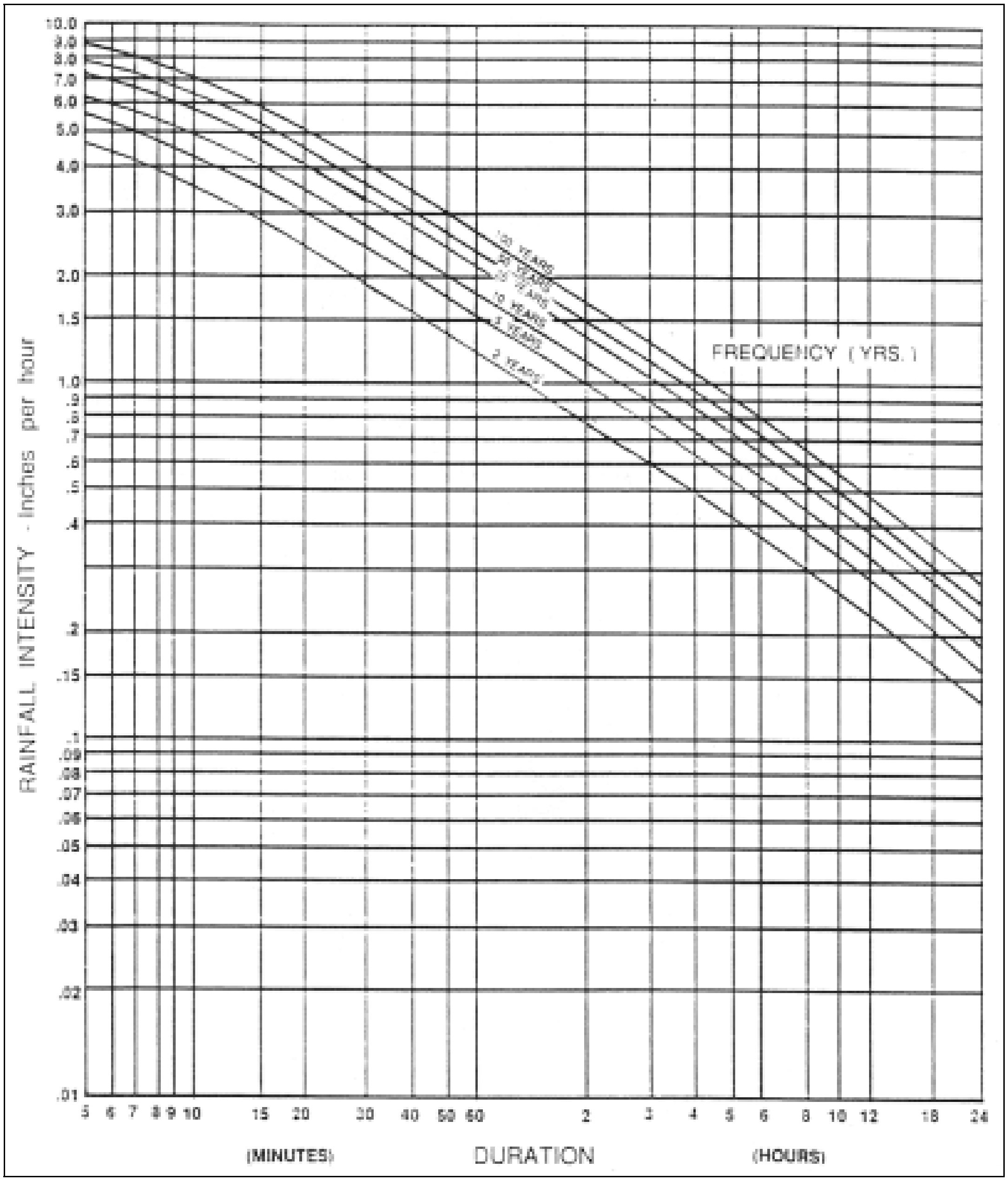
Intensity – Duration – Frequency
Curve for Barnstable, MA



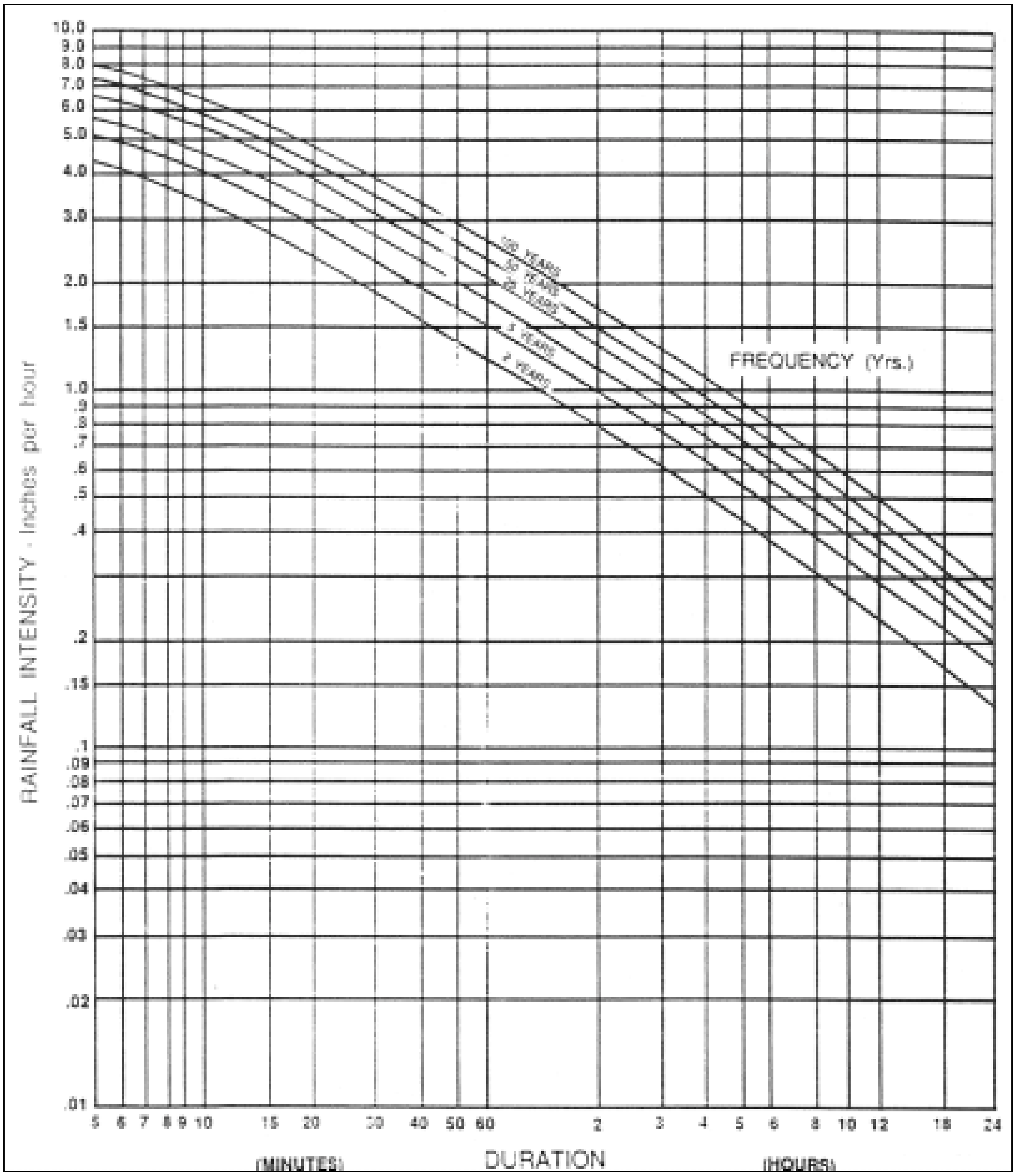
Intensity – Duration – Frequency
Curve for Boston, MA



Intensity – Duration – Frequency
Curve for Pittsfield, MA



Intensity – Duration – Frequency
Curve for Springfield, MA



Intensity – Duration – Frequency
Curve for Worcester, MA

Appendix G:
DEP Stormwater Management Form

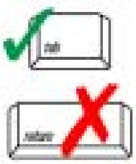
Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands

WPA Appendix C – Stormwater Management Form

Massachusetts Wetlands Protection Act M.G.L. c. 131, §40

A. Property Information

Important:
When filling out forms on the computer, use only the tab key to move your cursor - do not use the return key.



Note:
This November 2000 version of the Stormwater Management Form supersedes earlier versions including those contained in DEP's Stormwater Handbooks.

1. The proposed project is:

New development ☐ Yes ☐ No

Redevelopment ☐ Yes ☐ No

Combination ☐ Yes (If yes, distinguish redevelopment components from new development components on plans). ☐ No

2. Stormwater runoff to be treated for water quality are based on which of the following calculations:

☐ 1 inch of runoff x total impervious area of post-development site for discharge to **critical areas** (Outstanding Resource Waters, recharge areas of public water supplies, shellfish growing areas, swimming beaches, cold water fisheries).

☐ 0.5 inches of runoff x total impervious area of post-development site for other resource areas.

3. List all plans and documents (e.g. calculations and additional narratives) submitted with this form:

B. Stormwater Management Standards

DEP's Stormwater Management Policy (March 1997) includes nine standards that are listed on the following pages. Check the appropriate boxes for each standard and provide documentation and additional information when applicable.

Standard #1: Untreated stormwater

☐ The project is designed so that new stormwater point discharges do not discharge untreated stormwater into, or cause erosion to, wetlands and waters.

B. Stormwater Management Standards (cont.)

Standard #2: Post-development peak discharges rates

☐ Not applicable – project site contains waters subject to tidal action.

Post-development peak discharge does not exceed pre-development rates on the site at the point of discharge or downgradient property boundary for the 2-yr, 10-yr, and 100-yr, 24-hr storm.

☐ without stormwater controls

☐ with stormwater controls designed for the 2-yr, and 10-yr storm, 24-hr storm.

☐ the project as designed will not increase off-site flooding impacts from the 100-yr, 24-hr storm.

Standard #3: Recharge to groundwater

Amount of impervious area (sq. ft.) to be infiltrated: ______________________

Volume to be recharged is based on:

☐ The following Natural Resources Conservation Service hydrologic soils groups (e.g. A, B, C, D, or UA) or any combination of groups:

______________________ ______________________
(% of impervious area) (Hydrologic soil group) (% of impervious area) (Hydrologic soil group)

______________________ ______________________
(% of impervious area) (Hydrologic soil group) (% of impervious area) (Hydrologic soil group)

☐ Site specific pre-development conditions: ______________ ______________
Recharge rate Volume

Describe how there calculations were determined:

____

____

____

List each BMP or nonstructural measure used to meet Standard #3. (e.g. dry well, infiltration trench).

____

____

____

Does the annual groundwater recharge for the post-development site approximates the annual recharge from existing site conditions?

☐ Yes

☐ No

B. Stormwater Management Standards (cont.)

Standard #4: 80% TSS Removal

☐ The proposed stormwater management system will remove 80% of the post-development site's average annual Total Suspended Solids (TSS) load.

Identify the BMP's proposed for the project and describe how the 80% TSS removal will be achieved.

____

____

____

If the project is redevelopment, explain how much TSS will be removed and briefly explain why 80% removal cannot be achieved.

____

____

____

Standard #5: Higher potential pollutant loads

See Stormwater Policy Handbook Vol. I, page I-23, for land uses of high pollutant loading

Does the project site contain land uses with higher potential pollutant loads

☐ Yes If yes, describe land uses:

____

☐ No

Identify the BMPs selected to treat stormwater runoff. If infiltration measures are proposed, describe the pretreatment. (Note: If the area of higher potential pollutant loading is upgradient of a critical area, infiltration is not allowed.

____

____

____

Standard #6: Protection of critical areas

See Stormwater Policy Handbook Vol. I, page I -25, for critical areas.

Will the project discharge to or affect a critical area?

☐ Yes If yes, describe areas:

____

☐ No

B. Stormwater Management Standards (cont.)

Identify the BMPs selected for stormwater discharges in these areas and describe how BMPs meet restrictions listed on pages I-27 and I-28 of the Stormwater Policy Handbook – Vol. I:

____

____

____

Note: components of redevelopment projects which plan to develop previously undeveloped areas do not fall under the scope of Standard 7.

Standard #7: Redevelopment projects

Is the proposed activity a redevelopment project?

☐ Yes If yes, the following stormwater management standards have been met:

____

____

☐ No ______________________________

The following stormwater standards have not been met for the following reasons:

____

____

____

☐ The proposed project will reduce the annual pollutant load on the site with new or improved stormwater control.

Standard #8: Erosion/sediment control

☐ Erosion and sediment controls are incorporated into the project design to prevent erosion, control sediments, and stabilize exposed soils during construction or land disturbance.

Standard #9: Operation/maintenance plan

☐ An operation and maintenance plan for the post-development stormwater controls have been developed. The plan includes ownership of the stormwater BMPs, parties responsible for operation and maintenance, schedule for inspection and maintenance, routine and long-term maintenance responsibilities, and provision for appropriate access and maintenance easements extending from a public right-of-way to the stormwater controls.

____
Plan/Title Date

____
Plan/Title Date

WPA Appendix C – Stormwater Management Form

Massachusetts Wetlands Protection Act M.G.L. c. 131, §40

C. Submittal Requirements

DEP recommends that applicants submit this form, as well as, supporting documentation and plans, with the Notice of Intent to provide stormwater management information for Commission review consistent with the wetland regulations (310 CMR 10.05 (6)(b)) and DEP's Stormwater Management Policy (March 1997). If a particular stormwater management standard cannot be met, information should be provided to demonstrate how equivalent water quality and water quantity protection will be provided. DEP encourages engineers to use this form to certify that the project meets the stormwater management standards as well as acceptable engineering standards. For more information, consult the Stormwater Management Policy.

D. Signatures

Applicant ______________________ Date ________

Signature ______________________

Representative (if any) ______________________ Date ________

Signature ______________________

Appendix H: References

Literature References

American Society of Civil Engineers, 1992 Design and Construction of Urban Stormwater Management Systems, ASCE – Manuals and Reports on Engineering Practice No. 77. American Society of Civil Engineers and the Water Environment Federation. New York, NY.

Bedient, P.B. and W.C. Huber. 1992. *Hydrology and Floodplain Analysis (2nd Edition).* Addison-Wesley Publishing Company. Reading, MA.

Chow, V.T., D.R. Maidment, and L.W. Mays. 1988. *Applied Hydrology*. McGraw-Hill Book Company. New York, NY.

DEP. 1997a. *Stormwater Management Volume One: Stormwater Policy Handbook.* (March 1997), MA Department of Environmental Protection and MA Office of Coastal Zone Management, Boston, MA.

DEP. 1997b. *Stormwater Management Volume Two: Stormwater Technical Handbook.* (March 1997), MA Department of Environmental Protection and MA Office of Coastal Zone Management, Boston, MA.

Dunne, T. and L. Leopold. 1978. *Water in Environmental Planning.* W.H. Freeman Company. New York, NY.

Federal Highway Administration. 1965 (Reprint 1980). *Hydraulic Charts for the Selection of Highway Culverts.* Hydraulic Engineering Circular No. 5. U.S. Department of Transportation. Washington, DC.

Ferguson, B.K. 1994. *Stormwater Infiltration*. Lewis Publishers. Boca Raton, FL.

Franklin, Hampden, Hampshire Conservation Districts. 1997. *Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas*. (Prepared for Massachusetts DEP, Office of Watershed Management, Nonpoint Source Program.) Northampton, MA.

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. *Stream Channel Reference Sites: An Illustrated Guide to Field Technique.* USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO.

Hershfield, D.M. 1961. *Rainfall Frequency Atlas of the United States.* Technical Paper 40. U.S. Department of Commerce. Washington, D.C.

Interagency Advisory Committee on Water Data. 1982. *Guidelines for Determining Flood Flow Frequency.* Bulletin 17B of the Hydrology Committee, Office of Water Data Coordination, U.S. Geological Survey. Reston, VA.

Jermu, M.C. and R. Andrle. 1997. Morphology of a Wetland Stream. In *Environmental Management*, Vol. 21, No. 6, pp. 921-941. Springler-Verlag New York Inc., for USGS Library.

Leopold, L.B. 1994. *A View of the River.* Harvard University Press, Cambridge, MA.

Leopold, L.B. 1997. *Water, Rivers and Creeks.* University Science Books, Sausalito, CA.

Maryland Department of the Environment. 2000. *2000 Maryland Stormwater Design Manual, Volumes I & II.* Prepared by the Center for Watershed Protection and the Maryland Department of the Environment, Water Management Administration. Baltimore, MD.

Ponce, V.M. 1989. *Engineering Hydrology, Principles and Practices.* Prentice Hall. Englewood Cliffs, NJ.

Rawls, W.J., D.L. Brackensiek, and K.E. Saxton. 1982. Estimation of Soil Water Properties, in *Transactions of the American Society of Agricultural Engineers*, Vol. 25, No. 5.

Ries, Kernell G. III. 1993. Estimation of Low-flow Duration Discharges in Massachusetts. U.S. Geological Survey Open File 93-38.

Ries, Kernell G. III. 1994. Development and Application of Generalized-Least-Squares Regression Models to Estimate Low-flow Duration Discharges in Massachusetts. U.S. Geological Survey Water Resources Investigations Report 94-4155.

Ries, Kernell G. III. 1999. Streamflow Measurements, Basin Characteristics, and Streamflow Statistics for Low-Flow Partial-Record Stations Operated in Massachusetts from 1989 Through 1996. U.S. Geological Survey Water Resources Investigations Report 99-4006.

Rocky Mountain Forest and Range Experiment Station. "A Video Guide to Field Identification of Bankfull Stage in the Western United States." Available from the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Research Station, Suite 368, 2150 Centre Avenue, Bldg. A, Fort Collins, CO 80526 (Telephone: 970-295-5983).

Rossmiller, July 1980 "The Rational Formula Revisited". In: International Symposium on Urban Storm Runoff. University of Kentucky, Lexington, KY.

Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology, Printed Media Companies. Minneapolis, MN.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Department of Environmental Programs, Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T., P. Kumble, and M. Heraty. 1992. *A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-Point Source Pollution in the Coastal Zone*. Department of Environmental Programs, Metropolitan Washington Council of Governments, Washington, DC.

Soil Conservation Service. 1985. *National Engineering Handbook, Section 4 - Hydrology.* Engineering Division, Soil Conservation Service, USDA. Washington, DC.

Soil Conservation Service. 1986. *Technical Release 55: Urban Hydrology for Small Watersheds, 2nd Edition.* Engineering Division, Soil Conservation Service, USDA. Washington, DC.

US Army Corps of Engineers. 1981. *Low Cost Shore Protection: A Guide for Engineers and Contractors.* Washington, DC.

US Army Corps of Engineers. 1984. *Shore Protection Manual (Volumes 1 and 2).* Coastal Engineering Research Center, Department of the Army, Waterways Experiment Station. Vicksburg, MS.

USEPA. 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. 840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Walker, W.W., Jr. 1990. *P8 Urban Catchment Model Program Documentation*. Prepared for IEP, Inc. and the Narragansett Bay Project. Concord, MA.

Wilks, D.S. and R.P. Cember. 1993. *Atlas of Precipitation Extremes for the Northeastern Unitied States and Southeastern Canada.* Northeast Regional Climate Center Research Series, Publication No. RR 93-5. Cornell University, Ithaca, NY.

Web Site Links

Note: These web links are current as of March 2002 and are subject to change at any time.

General Hydrology and Wetlands Topics

- ☐ http://www.mass.gov/dep (MA DEP - regulations, plant lists, stormwater policy, BVW Manual, Wetlands Program Policies, etc)
- ☐ http://www.mass.gov/envir/mwi/watersheds.htm (EOEA Watershed Initiative)
- ☐ http://www.mass.gov/dfwele/dfw/nhesp/nhpubs.htm (MA DFW, Natural Heritage Program - Vernal Pools, Wildlife Habitat Maps)
- ☐ http://www.epa.gov/OWOW/ (US EPA – Wetlands, Oceans and Watersheds)
- ☐ http://www.nwi.fws.gov/ or http://wetlands.fws.gov/ (US FWS: National Wetlands Inventory Center). This web site is temporarily not in operation. See http://www.fws.gov.
- ☐ http://www.nmfs.noaa.gov/ (US National Marine Fisheries)
- ☐ http://www.ma.nrcs.usda.gov/ (NRCS MA Office, includes links to information about soil surveys in Massachusetts)
- ☐ http://www.pwrc.usgs.gov/wli/ (USDA NRCS Wetlands Science Institute hosted by USGS)
- ☐ http://www.iwr.usace.army.mil/iwr/Regulatory/regulintro.htm (US Army Corps of Engineers – Wetlands and Regulatory Page)
- ☐ http://www.nae.usace.army.mil/ (US Army Corps Of Engineers, New England District)
- ☐ http://www.nwrc.usgs.gov/ (USGS National Wetlands Research Center)
- ☐ http://ma.water.usgs.gov/ (USGS Water Resources Information, including stream flow, floods, droughts, and StreamStats)
- ☐ http://www.usda.gov/stream_restoration/ (US Inter-agency Stream Restoration Guide)
- ☐ http://www.stream.fs.fed.us/ (US Forest Service stream systems technology center – information about stream/river processes and channels, including fluvial geomorphology, and references related to bankfull conditions used in assessing the Mean Annual High Water mark of rivers. Also link to software XSPRO and other public domain software)
- ☐ http://www.capecodcommission.org/bylaws/wetandwild.html (Cape Cod Commission - wetlands bylaw page)
- ☐ http://www.maccweb.org/macc.html (Massachusetts Association of Conservation Commissions)
- ☐ http://www.amws.org/ (Association of Massachusetts Wetland Scientists)
- ☐ http://www.sws.org/wetlandweblinks.html (Society of Wetland Scientists - links page)
- ☐ http://www.mindspring.com/~rbwinston/wetland.htm (Private site: Richard Winston's Wetlands Links)
- ☐ http://www.newea.org/wetlands.htm (New England Water Environment Association – Wetlands page)
- ☐ http://www.nws.noaa.gov/er/box/ (National Weather Service, Boston Office, New England River Forecast Center, Floods/Drought information)

- ☐ http://www.fema.gov/nfip (FEMA National Flood Insurance Program)
- ☐ http://www.wcc.nrcs.usda.gov/water/quality/common/neh630/4content.html (NRCS National Engineering Handbook, Part 630 Hydrology)

Wetlands Plants

- ☐ http://www.nwi.fws.gov/bha/ (US FWS: National Wetlands Plant List). This web site is temporarily unavailable. See http://www.fws.gov
- ☐ http://plants.usda.gov/ (USDA NRCS Plant List)
- ☐ http://www.mass.gov/dep/brp/ww/files/nwiplant.zip (US FWS: Massachusetts Wetlands Plant List, zip file)

Wetlands Soils

- ☐ http://www.ma.nrcs.usda.gov/soils/index.htm (USDA NRCS Massachusetts Soil Survey)
- ☐ http://www.pwrc.usgs.gov/WLI/ (USDA NRCS Wetlands Science Institute – link to hydric soils information)
- ☐ http://www.statlab.iastate.edu/soils-info/osd/ (USDA NRCS Soil Survey via Iowa State University)
- ☐ http://www.statlab.iastate.edu/soils/hydric/ (USDA NRCS Hydric Soils via Iowa State University)

Wetlands Mapping

- ☐ http://www.mass.gov/dep/brp/ww/files/wcpbroch.pdf (DEP Wetlands map information)
- ☐ http://www.mass.gov/dep/brp/ww/files/wcpdist.htm (DEP Wetlands Ortho photo map use and distribution information)
- ☐ http://www.mass.gov/mgis/ Massachusetts GIS Maps, including wetlands maps
- ☐ http://ortho.mit.edu/ (Ortho photos for the greater Boston area)
- ☐ http://coast.mit.edu/ (Ortho photos for the coast of Massachusetts)
- ☐ http://www.gisdatadepot.com/ (Commercial site with downloads of National Wetlands Inventory Data)
- ☐ http://www.mass.gov/dfwele/dfw/dfw_pond.htm (Massachusetts Fish and Wildlife Pond Maps)
- ☐ http://mapping.usgs.gov/ (USGS topographic and other maps)
- ☐ http://www.nwi.fws.gov/ (US FWS National Wetlands Inventory Center, including electronic data and hard copy wetlands maps). This web site is temporarily not in operation. See http://www.fws.gov
- ☐ http://www.fema.gov/maps/ (FEMA Map Center: Flood Insurance Studies and Maps – Bordering Land Subject to Flooding and Land Subject to Coastal Storm Flowage)

Wetlands Regulations and Legal Decisions

- ☐ http://www.mass.gov/dep/matrix.htm (Laws and regulations enforced by DEP, including Wetlands 310 CMR 10.00, and Section 401 Water Quality Certification 314 CMR 9.00)
- ☐ http://www.mass.gov/oaa/oaahome.htm (DEP legal decisions)
- ☐ http://www.lawlib.state.ma.us/cmrindex.html (Massachusetts Trial Court Law Library index to all state regulations, including DEP regulations)
- ☐ http://www.wetlands.com/ (Commercial site containing some federal 401 regulations and legal decisions)

Stormwater

- □ http://www.mass.gov/dep or http://www.state.ma.us/dep (DEP home Page)
- □ http://www.epa.gov/OST/stormwater (US EPA Stormwater)
- □ http://www.epa.gov/npdes (US EPA NPDES)
- □ http://cfpub1.epa.gov/npdes/stormwater/swphase2.cfm?program_id=6 (US EPA NPDES Phase II)
- □ http://www.epa.gov/npdes/menuofbmps/menu.htm (US EPA BMPs)
- □ http://www.epa.gov/owm/mtbfact.htm (US EPA Fact Sheets)
- □ http://www.cwp.org (Center for Watershed Protection)
- □ http://www.stormwatercenter.net (Center for Watershed Protection Stormwater Manager Resource Center)
- □ http://www.forester.net/sw.html (Commercial site for Stormwater Journal)
- □ http://waterquality.about.com/cs/runoffresources/ (Commercial site with links)
- □ http://www.stormwater-resources.com (Private site hosted by Gordon England, contains recent research related to stormwater)
- □ http://www.nws.noaa.gov/er/hq/Tp40s.htm (Technical Paper 40)
- □ http://met-www.cit.cornell.edu/nrcc_home.html (NRCC Atlas for Precipitation Extremes in Eastern U.S. and Quebec)
- □ http://www.state.me.us/dep/blwq/stormwtr/material.htm#bmp (Maine Stormwater Manual)
- □ http://www.mde.state.md.us/environment/wma/stormwatermanual/ (Maryland Stormwater Design Manual)

Stormwater BMP Verification

- □ http://www.mass.gov/envir/pollution/step.htm (MA Strategic Envirotechnology Partnership or STEP)
- □ http://www.ceere.org/ (UMASS Center for Energy Efficiency and Renewable Energy/STEP Partner/STEP Verification Reports and other related publications)
- □ http://www.dep.state.pa.us/dep/deputate/pollprev/techservices/tarp/index.html (Technology Assistance Reciprocity Partnership currently includes Massachusetts, New Jersey, New York, California, Illinois, Pennsylvania, Virginia, and Maryland).
- □ http://www.epa.gov/etv/ (US EPA Environmental Technology Verification)
- □ http://www.bmpdatabase.org/ (EPA/ASCE National Stormwater Database)
- □ http://www.cerf.org/evtec/index.htm (Environmental Technology Verification Center hosted by the Civil Engineering Research Foundation of the American Society of Civil Engineers)
- □ http://www.etvcanada.com/ (ETV Canada)

Erosion and Sedimentation Control

- □ http://www.ieca.org/ (Commercial site: International Erosion Control Association)

Software Web Links (public domain)

- □ TR-20 and TR-55: http://www.wcc.nrcs.usda.gov/water/quality/text/hydrolog.html or http://www.wcc.nrcs.usda.gov/water/quality/common/h2oqual.html

- ☐ ACOE HEC-RAS, WEC-HMS, HEC-1, HEC-2 and other software: http://www.hec.usace.army.mil/software/index.html
- ☐ IEP/EPA P8: http://wwwalker.net/#Software (Private site hosted by William Walker)
- ☐ EPA SWMM: http://www.epa.gov/ceampubl/softwdos.htm or http://www.epa.gov/ednnrmrl/tools/model/swmm.htm
- ☐ EPA HSPF: http://www.epa.gov/ceampubl/softwdos.htm
- ☐ FEMA Flood Software: http://www.fema.gov/MIT/tsd/FRM_soft.htm
- ☐ USGS HSPF, MODFLOW, WSPRO and other software: http://water.usgs.gov/software/
- ☐ USGS MA/RI District StreamStats: http://ma.water.usgs.gov/streamstats/expert.htm (contains low-flow statistical analysis tool used to analyze flow in gaged and ungaged streams depicted on the USGS topographic map and located in certain river basins)
- ☐ USGS PEAKFQ: http://water.usgs.gov/software/peakfq.html (Bulletin 17b to determine flood peak recurrence intervals)
- ☐ WinXSPRO: http://www.stream.fs.fed.us/About.html

Regulatory References:

Massachusetts Statutes

MGL 30, Sections 61-62H	Massachusetts Environmental Policy Act (MEPA)
MGL 91, Sections 1-63	Waterways (Massachusetts Public Waterfront Act) (Chapter 91)
MGL 131, Section 40	Massachusetts Wetlands Protection Act (WPA)

Massachusetts Regulations

301 CMR 11.00	MEPA Regulations
310 CMR 9.00	Waterways Regulations
310 CMR 10.00	Wetlands Protection Regulations
310 CMR 15.00	The State Environmental Code, Title 5: Standard Requirements for the Siting, Construction, Inspection, Upgrade and Expansion of On-site Sewage Treatment and Disposal Systems and for the Transport and Disposal of Septage
310 CMR 27.00	Underground Injection Controls, Class I to V Injection Wells
314 CMR 3.00	Surface Water Discharge Permit Program
314 CMR 4.00	Massachusetts Surface Water Quality Standards
314 CMR 5.00	Ground Water Discharge Permit Program
314 CMR 6.00	Ground Water Quality Standards

314 CMR 9.00	401 Water Quality Certification for Discharge of Dredged or Fill Material, Dredging, and Dredged Material Disposal in Waters of the United States within the Commonwealth