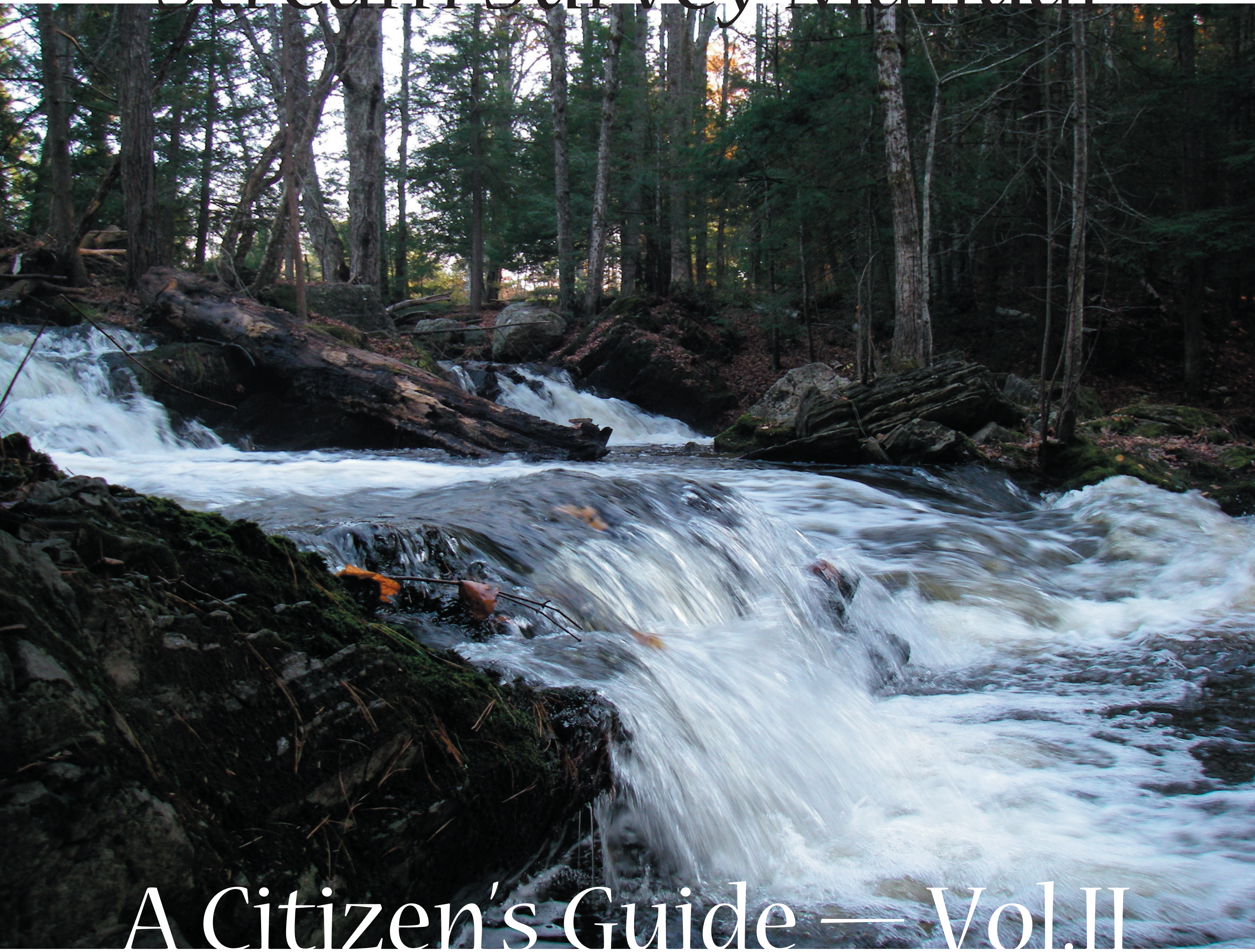
Stream Survey Manual



A Citizen's Guide — Vol.II

A CITIZEN'S PRIMER
on Stream Ecology, Water Quality, Hydrology, and Fluvial Geomorphology — Volume II

prepared by the Maine Stream Team Program of the
Maine Department of Environmental Protection

DEPLW-0965

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A CITIZEN'S PRIMER
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Table of Contents

Index of Tables and Figures: Volume II

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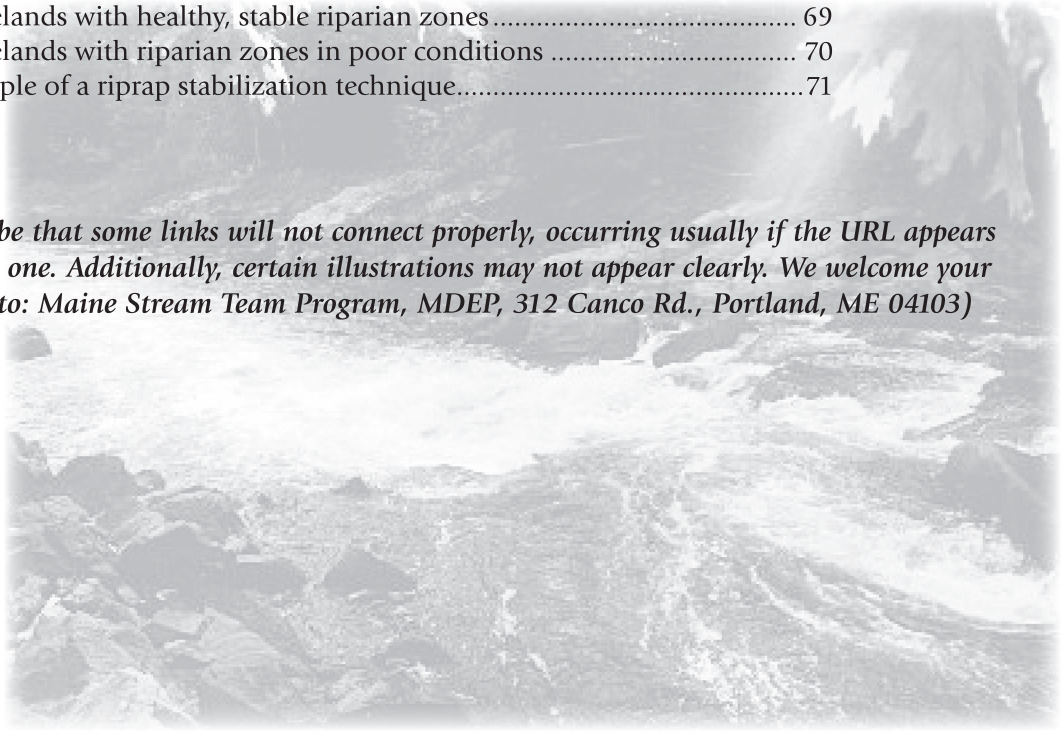

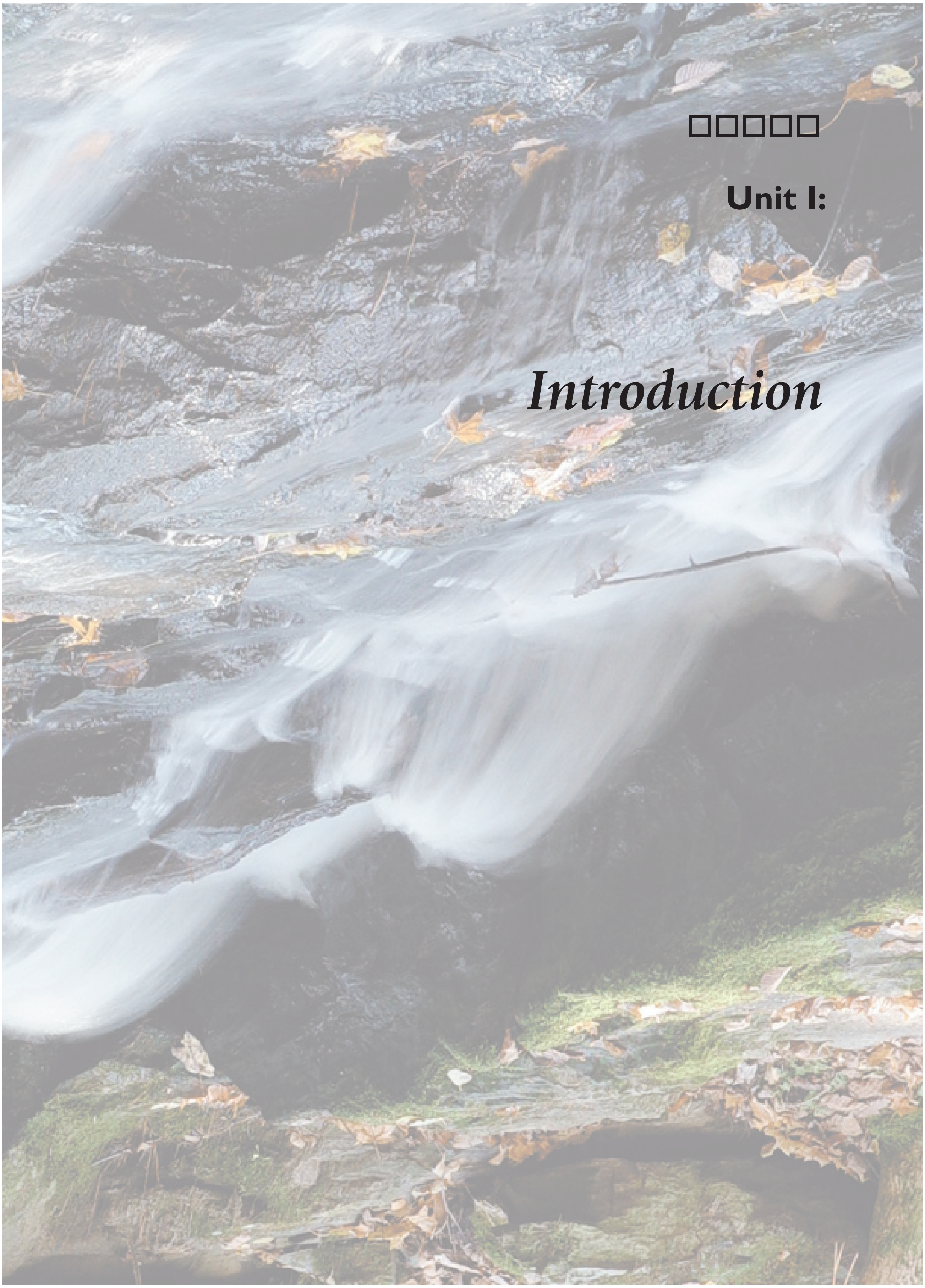

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Unit I:

Introduction

Unit 1: Foreword and Introduction

FOREWORD

The goal of Volume I of this manual series (**Stream Survey Manual:** MDEP, 2008) is to provide the basic, straightforward information required for a project manager or volunteer group leader to organize and carry out a stream watershed survey or a stream corridor survey *(Level I; stream habitat and stability visual assessment)*. Some background information about watershed and stream components and processes, as well as basic pollution information, is presented in Volume I, however, much of the volume is devoted to covering the logistics and organizational details revolving around these surveys. The goal of Volume II is to provide the reader with enough information to get them started on learning about streams, rivers, watersheds, ecology, water quality, pollution, and pollution prevention, at a level of detail that is greater than the overview version provided in Volume I.

While the intended primary audience of these volumes consists of leaders, project managers, and members of local county soil and water conservation districts, stream teams, watershed councils, as well as other groups who might perform stream/river habitat surveys or volunteer water quality monitoring, Volume II should also be a good resource for any Maine adult or youth interested in learning more about, surveying, or conserving Maine's streams and rivers.

Volume II should help point out very interesting creatures, habitats, and basic physical, chemical, and biological processes which folks can look for the next time they take a stroll alongside, fish, swim, or participate in surveying or monitoring efforts in their favorite stream or river. Numerous helpful book and website resources are listed throughout this volume for people wanting to obtain more details about the topics mentioned above. Additionally, many academic and professional stream/river courses are offered through local schools, institutions, and professional instructors, though this manual does not attempt to list them. *(Readers looking for a much shorter, simpler, but well-done, overview of Maine streams may wish to check out the Gulf of Maine Aquarium's online "STREAMS" document found at: http://www.gma.org/streams/streams.html.)*

Much of the information contained in this chapter was adapted from the various resources, including Cushing and Allan (2001), FISRWG (1998), Winter et al. (1998), USEPA (1997), MDEP (1996), Vermont Agency of Natural Resources (1999, 2004), Allan (1995), Allan and Castillo (2007), Murdoch et al. (1999), and Dates (1999/2000). *(References can be found in Appendix L.)*

INTRODUCTION

1. Background

Maine is very fortunate to have abundant water resources, including about 6,000 lakes and ponds, an enormous number of wetlands, and over 45,000 miles of streams and rivers. Many of these miles remain in good condition today. These miles of ***lotic*** (flowing) waters contain or support a diverse array of plants, insects, fish, amphibians, reptiles, and other wildlife which help define Maine's wild (and not-so-wild) places and bolster Maine's economy with recreational opportunities (e.g., fishing, rafting, boating, swimming, hiking, etc.) and Maine's quality of life.

Maine is very fortunate to have abundant water resources, including about 6,000 lakes and ponds, an enormous number of wetlands, and over 45,000 miles of streams and rivers. Many of these miles remain in good condition today.

Despite these facts, Maine citizens should not take these abundant resources for granted. Over the past few centuries, impacts from industries, municipalities, and polluted runoff from activities such as agriculture and forestry (particularly when done carelessly) have degraded a significant portion of our waterways. More recently, the increase and spread of urban and suburban development has also degraded water resources.

Additionally, pollution and threats originating from local and out-of-state sources (e.g., acid rain/deposition, mercury, invasive species, etc.) makes its way into and adds further stress to Maine waterways. Some of Maine's ecosystems, and certain species that inhabit them, are threatened or endangered.

The good news is that in recent decades, these problems have been significantly reduced due to the Federal Clean Water Act (described later in this unit as well as Unit 4), other environmental laws and policies, and the efforts of numerous local, county, state, and federal agencies; nonprofit organizations; educational institutions; and concerned individuals.

Issues and problems still remain, however, and Maine citizens (adults and youth) need to take an interest in learning about and protecting their streams and rivers in order to preserve these ecosystems for future generations. This manual attempts to get folks started.

For the sake of simplicity in this manual, the term "STREAM" will be used to represent brooks, creeks, and rivers, in addition to streams.

2. Definition of "stream" and "river"

Before we get started, it is important to discuss the definition of a stream and other similar bodies of water. A "**stream**" is a general term for a body of flowing water. It is a natural water course containing water at least part of the year. People sometimes use terms such as "**brook**" or "**creek**" to refer to smaller streams, and terms such as "**river**" to refer to larger streams, though this usage can vary by region, organization, or history.

Though it is not a focus for this document, we present one type of legal definition of "river, stream, or brook," according to **Maine's Natural Resources Protection Act** (Title 38 Section 480-B), for readers who are interested:

> "**RIVER, STREAM** or **BROOK**" means a channel between defined banks. A channel is created by the action of surface water and has two or more of the following characteristics.
>
> - It is depicted as a solid or broken blue line on the most recent edition of the U.S. Geological Survey 7.5-minute series topographic map or, if that is not available, a 15-minute series topographic map. [1995, c. 92, §2 (new).]
> - It contains or is known to contain flowing water continuously for a period of at least 3 months of the year in most years. [1995, c. 92, §2 (new).]
> - The channel bed is primarily composed of mineral material such as sand and gravel, parent material or bedrock that has been deposited or scoured by water. [1995, c. 92, §2 (new).]
> - The channel contains aquatic animals such as fish, aquatic insects or mollusks in the water or, if no surface water is present, within the stream bed. [1995, c. 92, §2 (new).]
> - The channel contains aquatic vegetation and is essentially devoid of upland vegetation. [1995, c. 92, §2 (new).]

"**River, stream** or **brook**" does not mean a ditch or other drainage way constructed, or constructed and maintained, solely for the purpose of draining storm water or a grassy swale. [2001, c. 618, §1 (amd).]

For the sake of simplicity in this manual, the term "**stream**" will be used to represent all flowing waters (e.g., brooks, creeks, streams, and rivers). The term "**river**" may occasionally be used to refer to relatively-larger flowing waterbodies.

3. Organization of this Volume

In the early 1970s, the United States Congress passed what is known as the federal Clean Water Act. The objective of the Clean Water Act was, and is today, to restore and maintain the chemical, physical, and biological integrity* of the Nation's (including Maine's) waters. *(More background information about the Federal Clean Water Act can be viewed at: http://www.epa.gov/watertrain/cwa.)*

Maine also has a water quality standards program in place to protect, restore, and maintain the chemical, physical, and biological integrity of Maine's waters. Information about that program can be found in **Unit** 4 and also at: http://www.maine.gov/dep/blwq/docmonitoring/classification/index.htm.

As listed below, the broad categories mentioned in the Clean Water Act (chemical, physical, and biological) have been reordered for the purpose of organizing the contents of this volume.

- Physical Properties
- Biological Properties, Ecological Processes, and Connectivity
- Chemical Properties, Water Quality, and Pollution Issues

(**NOTE**: Topics such as temperature, sediment pollution, and stormwater runoff can be considered to be physical properties or issues of streams and rivers. Discussion of these water-quality-related topics, however, is kept mostly within **Unit** 4 [**Chemical Properties, Water Quality, and Pollution Issues**] to help this document flow more smoothly.)

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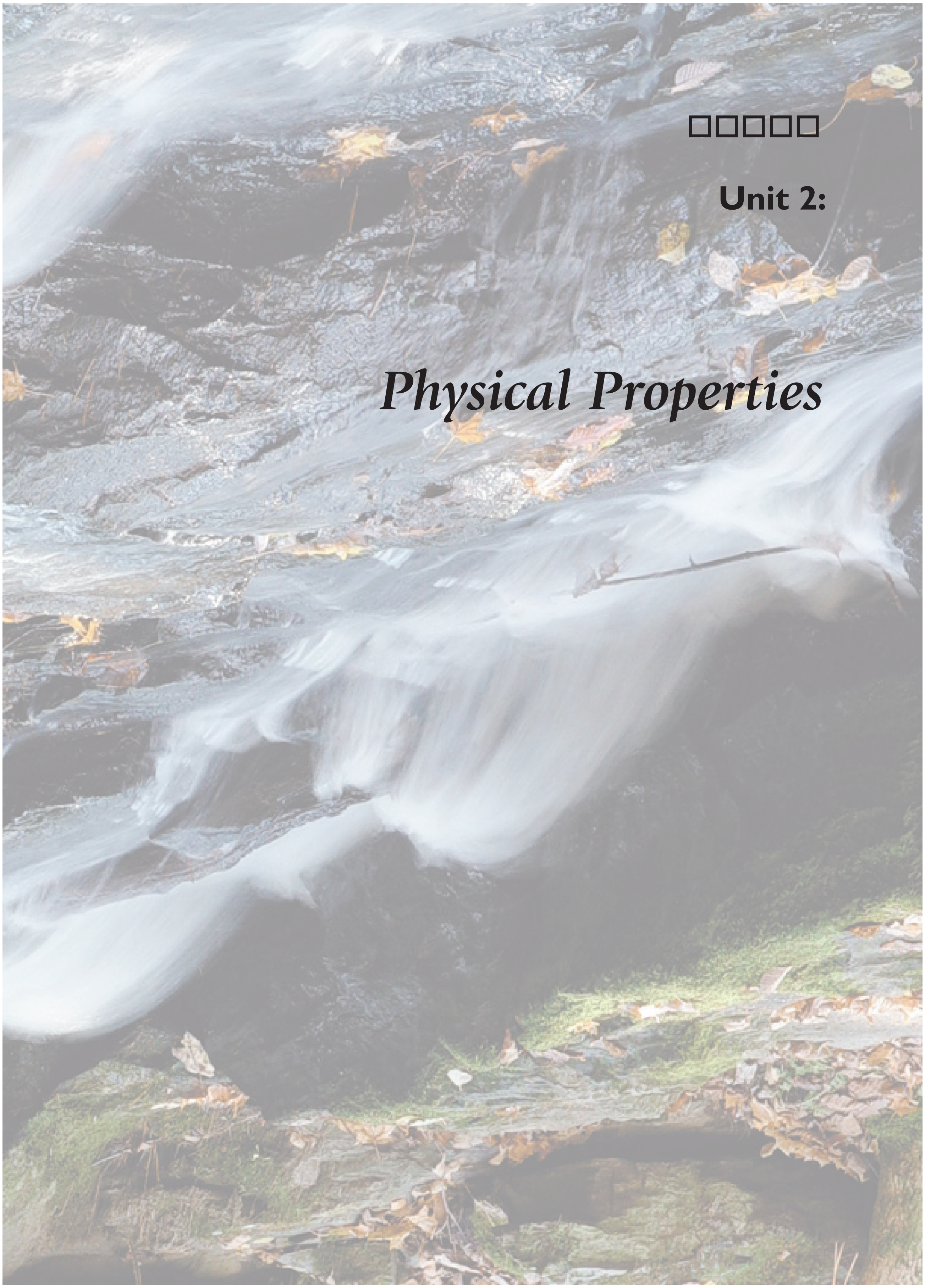
* The term "**integrity**" has been extensively explored as to its intent in the law and its application to water quality management. A dictionary definition (Webster) defines integrity as "a quality or state of being complete." What represents chemical, physical, and biological integrity is a range of conditions that maintain the structural and functional properties of the waterbody.



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Unit 2:

Physical Properties

Unit 2
Physical Properties

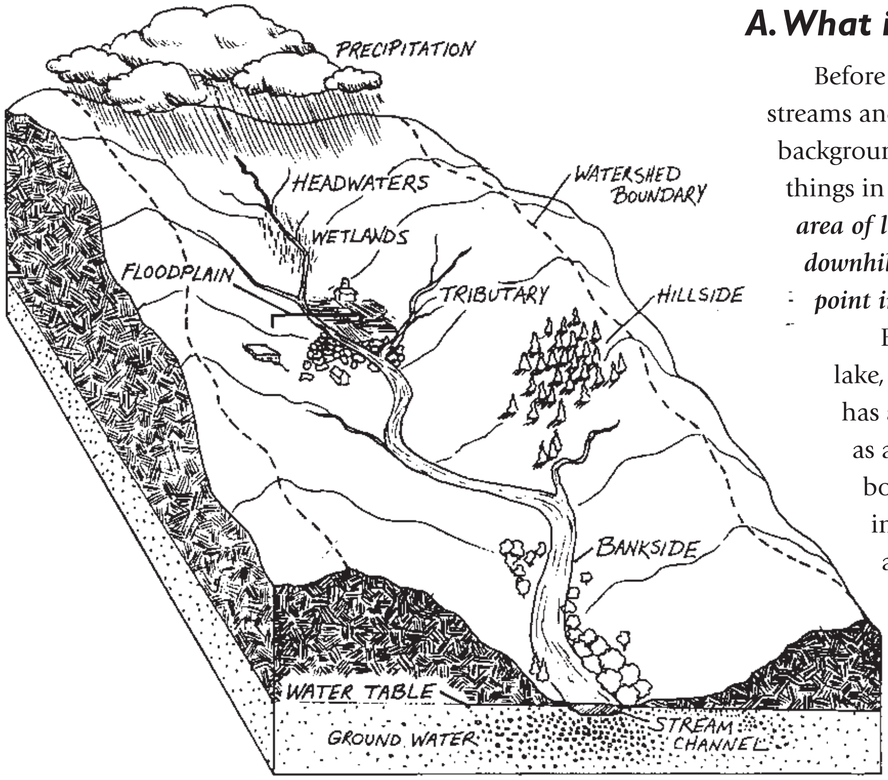


FIGURE 2-1

(Source: USEPA, 1997)

A. What is a Watershed?

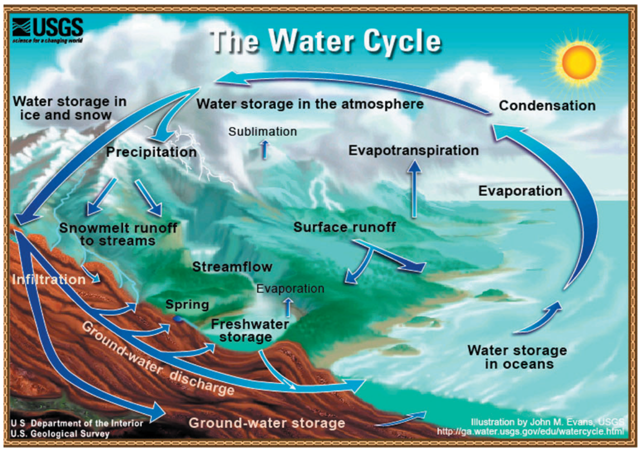
Before we can talk about the specifics of streams and rivers, we need to provide some background information in order to put things in perspective. ***A watershed is an area of land from which water drains downhill into a body of water at the low point in the landscape.***

Every river, stream, pond, wetland, lake, estuary, or coastal embayment has a watershed. Imagine a watershed as a bowl with a pool of water at the bottom. Water that falls onto the inside rim of the bowl flows down along the surface to the bottom of the bowl. Much like a bowl's rim, high points in the landscape, such as ridges and hilltops, are the boundaries that separate watersheds.

The shape and size of watersheds are determined by the topography of the land. A river (or large stream) watershed may be comprised of several smaller watersheds of tributary streams (or small rivers). **Figure 2-1** provides an illustration of an example stream watershed.

B. The Water Cycle (The Hydrologic Cycle)

FIGURE 2-2



(Illustration, John M. Evans, USGS; http://ga.water.usgs.gov/eduwatercycle.html)

Water continually cycles from earth to atmosphere, and then back to earth again. Water evaporates from oceans, lakes, and rivers into the atmosphere, where it later precipitates as rain or snow. Rain or melted snow either runs off directly into surface waters, or infiltrates the soil and rock, where it becomes groundwater.

Some water goes directly back into the atmosphere through a process called "**evapotranspiration**", a collective term that describes water movement back to the atmosphere as a result of plant transpiration and evaporation from soil surfaces and surface water bodies.

Groundwater eventually discharges to streams, lakes, wetlands, or oceans.

The sun’s heat drives the processes that cycle the water: evaporation (and evapotranspiration), condensation, and precipitation. Since the amount of water on earth is finite, it is critical that we keep it clean as it moves through the hydrologic cycle. **Figure 2-2** illustrates a generalized example of the water cycle.

Though only assigned a “zero,“these streams often are important contributors of clean, cool water and food materials for downstream ecosystems. They may have vibrant ecosystem processes and communities, some of which may take place underground during parts of the year.

C. Stream Order

A useful tool for describing streams is called the stream ordering system. It is a way to communicate the approximate location of a stream segment within a stream or river network (e.g., upper, middle, or lower part of a watershed). It also provides clues about a stream segment’s approximate channel size and depth. The Strahler (1957) stream ordering system is the most commonly used system.

Figure 2-3 shows an example stream ordering within the watershed of a medium-sized river. First (1st) order streams, designated in the figure by a “1,” are the uppermost streams that flow year-round (perennial streams) in watersheds. These streams have no perennial tributaries that drain into them. When two 1st-order streams join, they form a 2nd-order stream; when two 2nd-order streams combine, they form a 3rd-order stream; etc.

Note that the intersection of a stream with another stream of lower order does not raise the order of the stream below the intersection (i.e., a 4th order stream intersecting with a 2nd order stream is still a 4th order stream below the intersection).

On U. S. Geological Survey 7.5-minute topographic maps, 1st-order streams appear as single, solid blue lines without any solid blue lines upstream of them. Sometimes on these maps, dashed blue lines appear upstream of 1st-order streams. These streams do not flow during the entire year, but rather typically about six to nine months out of the year. These streams are called intermittent streams, and some scientists call them “0” (zero)-order streams. Though they only get assigned a zero, they often are important contributors of clean, cool water and food materials for downstream ecosystems, and they may have vibrant ecosystem processes and communities, some of which may take place underground during parts of the year.

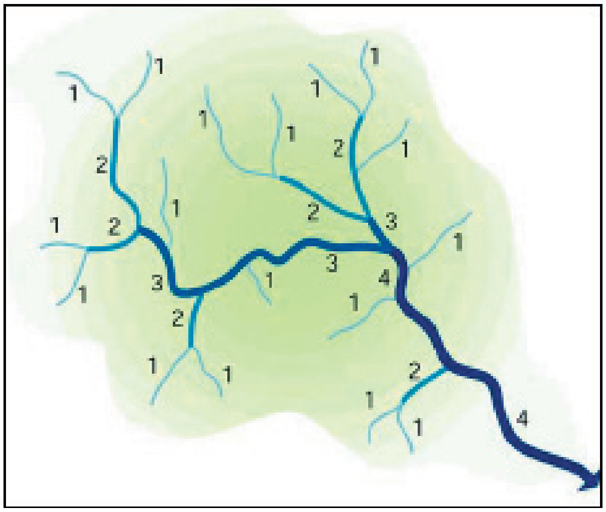


FIGURE 2-3
(Source: FISRWG, 1998)

Care must be taken in the use of the terms ***perennial*** and ***intermittent***. A perennial stream may flow year-round for most years, but during a drought may become intermittent or appear that way. Often, water flow may persist in the gravel bed of the stream. Likewise, intermittent streams are given that designation because in normal water years no surface water is left in the channel for portions of the year, though there may still be subsurface flow.

Typically, 1st- through 3rd-order streams are considered to be “low order” streams, while 4th- through 6th-order streams and rivers are “mid-order” streams, and those which are 7th-order or larger are “high order” streams.

D. Relative Number of Miles: Low Order Streams vs. High Order Streams

Many people, when they hear the words "**river**," think of large rivers like the Allagash, Aroostook, Penobscot, Kennebec, Androscoggin, Saco, Salmon Falls, etc. Still, it is important for us to realize that small and medium-sized streams and rivers are very important components of river systems.

In fact, Leopold and others (1964) estimated that of the approximately 3,231,130 total river/stream miles nationwide, roughly 50% of the stream miles are 1st-order streams. When 1st- through 3rd-order streams are combined, they make up about 85% of the United States' total river/stream miles. *(**FYI:** Maine has approximately 45,000 total river/stream miles. Also, as a point of reference, the Penobscot River is a 8th-order stream and the Mississippi River is a 10th-order stream.)*

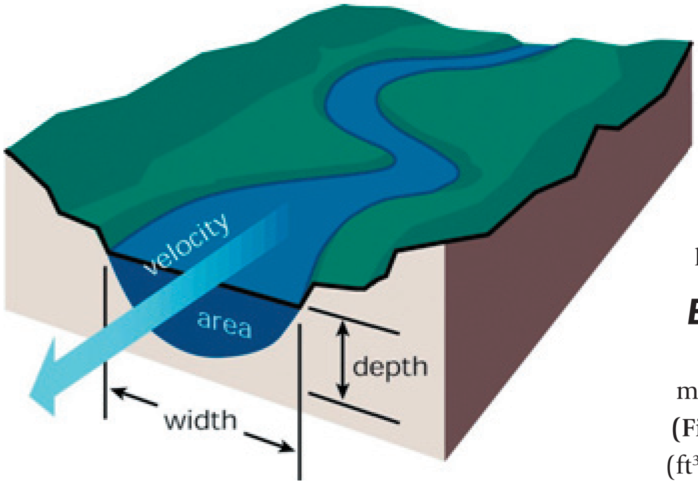


FIGURE 2-4 *(Source: FISRWG, 1998)*

These facts, plus the fact that small streams and rivers feed into our larger rivers, point to the vital importance of protecting small streams and rivers.

E. Stream Flow, Discharge, and Hydrology

Stream flow, or **discharge,** is the volume of water that moves over a designated location over a fixed period of time **(Figure 2-4)**. It is usually expressed as cubic feet per second (ft^3/sec) or cubic meters per second (m^3/sec).

The flow of a stream is directly related to the amount of water moving off the watershed into the stream channel. It is affected by weather, increasing during rainstorms and decreasing during dry periods. It also changes during different seasons of the year. For example, flows typically decrease during the summer months when temperatures and evaporation rates are high and shoreline vegetation is actively growing and removing water from the ground. August and September are usually the months of lowest flow for most streams in Maine.

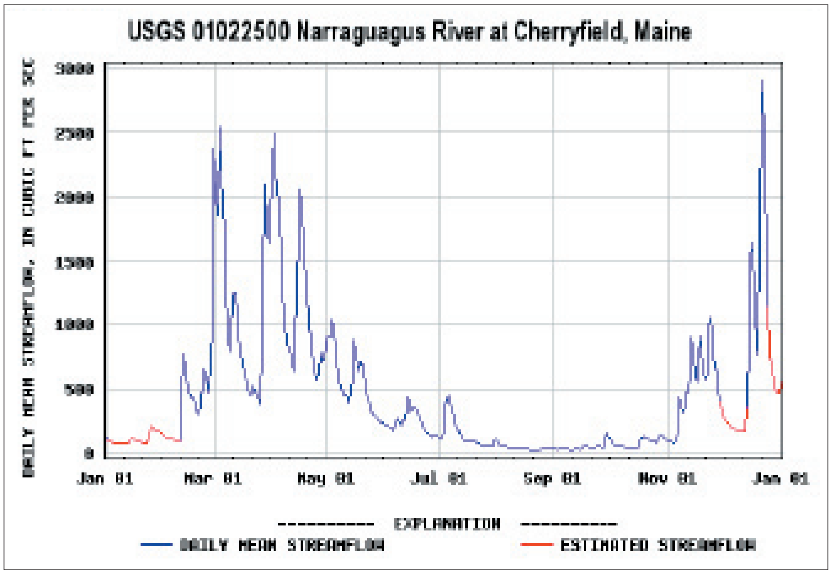


FIGURE 2-5 *(Source: USGS; http://me.water.usgs.gov)*

Figure 2-5 shows what is called a **hydrograph** of the Narraguagus River, an unregulated (non-dammed) river in Washington County. A hydrograph is a graph that depicts changes in stream or river flow over a given period of time. One can see how variable stream/river flow can be over a year. Aquatic organisms have evolved to be adapted to these seasonal changes during their life cycles. Human activities, however, can alter stream- and river-flow patterns from their historically natural patterns, and disrupt life cycles of some aquatic organisms. These activities can include things such as irrigation, industrial water withdrawals, hardening landscapes with asphalt and concrete (which prevents significant amounts of rainwater and melted snow from soaking into the ground and recharging groundwater), and dam regulation.

Stream velocity determines the kinds of organisms that can live in the stream (some species need fast-flowing areas; others need quiet pools). Stream velocity also affects the amount of silt and sediment carried by the stream. Sediment introduced to quiet, slow-flowing streams will settle quickly to the stream bottom. Fast moving streams will keep sediment suspended longer in the water column. Lastly, fast-moving streams generally have higher levels of dissolved oxygen than slow streams because they are better aerated. Some species need well-oxygenated waters while others can tolerate waters having moderately-low levels of oxygen in water.

Stream Velocity vs. Average Stream Velocity

Stream velocity, measured at a given point, is a measure of how fast the water current is moving, and is usually expressed in terms of meters per second or feet per second. The average stream velocity is the average time it takes for a molecule of water to move from the beginning to end of a stream segment of a given length.

In a typical* stream network, certain changes usually occur as one moves from upland headwaters to lowland river: discharge increases as more water enters the system from tributary streams and groundwater sources; the gradient (slope, steepness) of the stream decreases; and the width, depth, and average velocity of the stream increase. Contrary to what one might expect because of changes in gradient, average stream velocity actually often increases as one moves from steeper headwater sections to lowland river sections. Even though mountain stream waters usually have high velocities at any given location, these waters tend to be relatively shallow and they crash in a turbulent manner against large cobbles and boulders on the stream bottom. On the other hand, flowing waters moving through larger, deeper river sections tend to be more laminar (flowing smoothly; opposite of turbulent) and flowing over materials (e.g., small gravels, sands, etc.) that present less resistance to flow than the larger materials commonly found in mountain streams. Laminar flow, plus increased discharge, generally leads to higher average velocities downstream *(Gordon et al. 2004, Monroe and Wicander, 2005).*

*(**NOTE:** There are plenty of exceptions to the typical stream network's progression of steep headwaters to flatter lowland sections as described above.)

Calculating or Estimating Discharge

Discharge is the term used to describe the volume of water moving down the channel per unit time **(Figure 2-4)**. The basic unit of measurement used in the United States to describe discharge is cubic feet per second (cfs or ft^3/sec); another common (and preferred) unit is cubic meters per second (m^3/sec).

Discharge (stream flow) can be measured/calculated or estimated in a number of ways. In general, simplified terms, an equation to calculate discharge is:

$Q = A\,V$

where:

Q = Discharge in ft^3/sec (or m^3/sec)
A = Cross-sectional area of a stream through which the water is flowing in square feet (or square meters)
V = Average velocity in the downstream direction in feet per second (or meters per second)

More precise and accurate measurement/calculation methods can be found in publications such as the U.S. Geological Survey document by Rantz et al. (1982). For the purposes of this citizen-oriented document, however, we provide good method for estimating stream flow in wadable streams and rivers in Appendix I.

F. Zones and Regions within Stream/River Systems

There are some basic terms that are used by people who study or monitor streams and rivers which allow them to communicate clearly with other scientists and volunteers. **Figure 2-6** presents a general illustration of zones or regions within streams and stream corridors. Some of these features may be reduced in size or importance or even absent at certain locations within a stream or river network, depending upon the size and slope of the channel, local geological characteristics, and time of year, but this generalized illustration helps us point out some key features one might see.

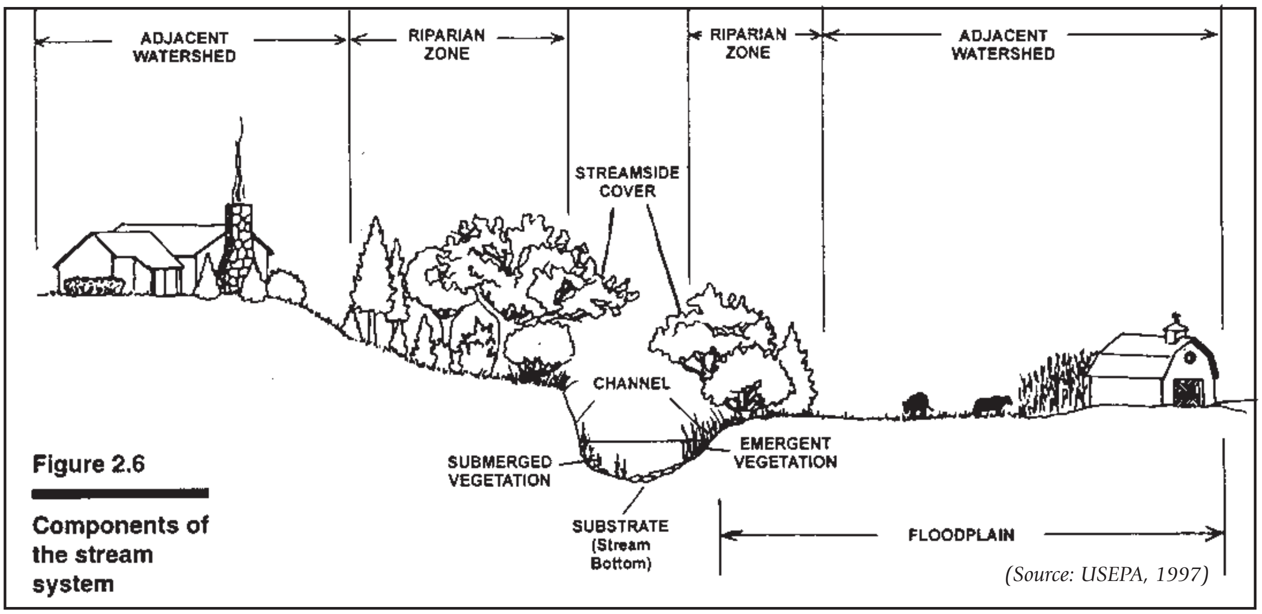


Figure 2.6

Components of the stream system

(Source: USEPA, 1997)

FIGURE 2-6

As represented in **Figure 2-6,** the **channel** is the feature most of us think of when we imagine a stream or river. Much of the year, it holds most of the water that makes up a stream. Its shape is carved by the variable amounts of water and sediment, driven by gravity, which flow through it. During warm, dry months, the water-level in the channel is lower, and this amount of water makes up the **low-flow channel.**

If water remains in the channel year-round, the lowest flow level of the year is called **baseflow.** When it rains, or when snow melts, water levels rise in channels. At a certain point, the water level rises to what is known as the bankfull height **of a stream or river channel** *(this is described more later)*. **Bankfull width** is the width of the water in the channel when water levels are at bankfull height (also known as **bankfull depth**).

There are a number of criteria used to determine where, at a particular site, bankfull height exists.

Most commonly, bankfull height is at the level where the streambanks begin to transition, moving in an upward direction, from being somewhat or very steep into flat areas like floodplains. *(For more details on determining bankfull height, see Section I below.)* (Floodplains may be absent in steep streams with very narrow valleys such as in the upper regions of mountains.)

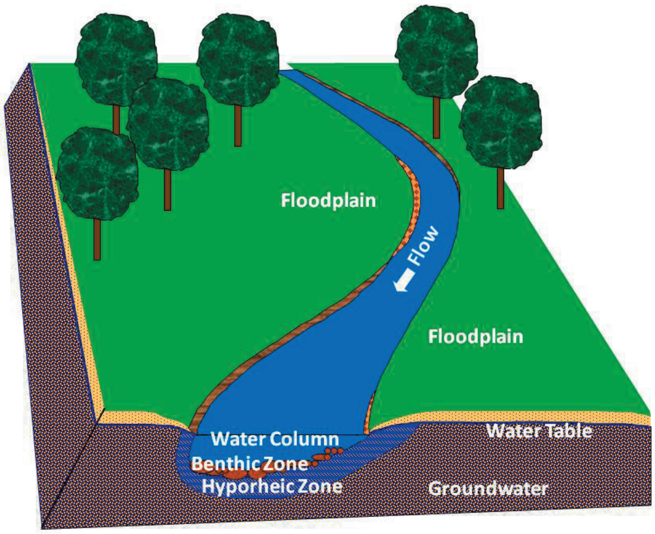
In many stream and river reaches, there often is a second flat surface that exists at an elevation higher than both the channel and floodplain. This surface, known as a **terrace,** is usually an abandoned floodplain that was adjacent the stream when it was flowing at a higher elevation many years ago *(for example, where the house sits in Figure 2-6)*.

In many streams in the northeastern United States, stream and river waters spill over their banks onto the floodplain on average of about every two years, sometimes rising to significant heights above the floodplain surface. In general, small (flooding) storms happen about every 1.5 to 5 years and only flood the floodplain with a small or moderate depth of water. You may sometimes hear scientists talk about 10, 25, 50, 100, and 500 year storms. These are storm events that are statistically predicted to occur once every 10, 25, 50, etc. years. The 500-year storm is a very big storm and it can inundate floodplains (and possibly beyond) with lots of water.

Riparian zones are areas adjacent streams, rivers, and other waterbodies, and include streambanks and floodplains. They typically are covered with trees, shrubs, ferns, and grasses, unless the vegetation has been removed by human activities. Vegetation in riparian zones has root systems that typically are adapted to wetter soil conditions. Riparian zone extent varies in width away from stream channels based upon factors such as how far away from the channel wet soils extend and where steep valley walls exist. In many cases, riparian zones have widths that range from about 75 - 300 feet. Riparian zones and floodplains are very critical components of stream and river ecosystems, and their contributions and functions will be discussed more later in this chapter.

The **channel bottom** is the layer of materials, such as boulders, cobbles, gravels, sands, and silts (and sometimes bedrock or ledge), that exist on the bottom of a channel due to earth-scouring actions of the stream waters acting locally and from materials that have been eroded at upstream locations and deposited locally. From a biologist's perspective, this area is known as the **benthic zone,** and these rocky/sandy (or woody) materials are sometimes referred to as the channel bottom **substrate** because some animals, such as aquatic insects, cling on to them so they don't get washed downstream by the water current. (**Figure 2-7** illustrates regions commonly found within stream and river systems.) In healthy waterbodies, benthic zones often have very diverse and abundant biological communities, and commonly are the most productive part of stream ecosystems. *(Biological communities will be discussed later.)* The region of water above the benthic zone is the **water column.** In some streams, there also can be a region where surface and groundwaters mix called the **hyporheic zone,** which lies a short distance beneath and beside stream/river channel benthic zones and floodplains. These hyporheic zones have biological communities and ecosystem processes that are a unique blend of those found in stream/river and groundwater ecosystems. *(All of these zones and regions will be discussed further later in this chapter.)*

FIGURE 2-7



Stream Bottom Substrate Size Categories

Stream bottom substrate can be broken down into size categories. Those categories, based upon a scheme devised by Wentworth (1922), are presented in the table below.

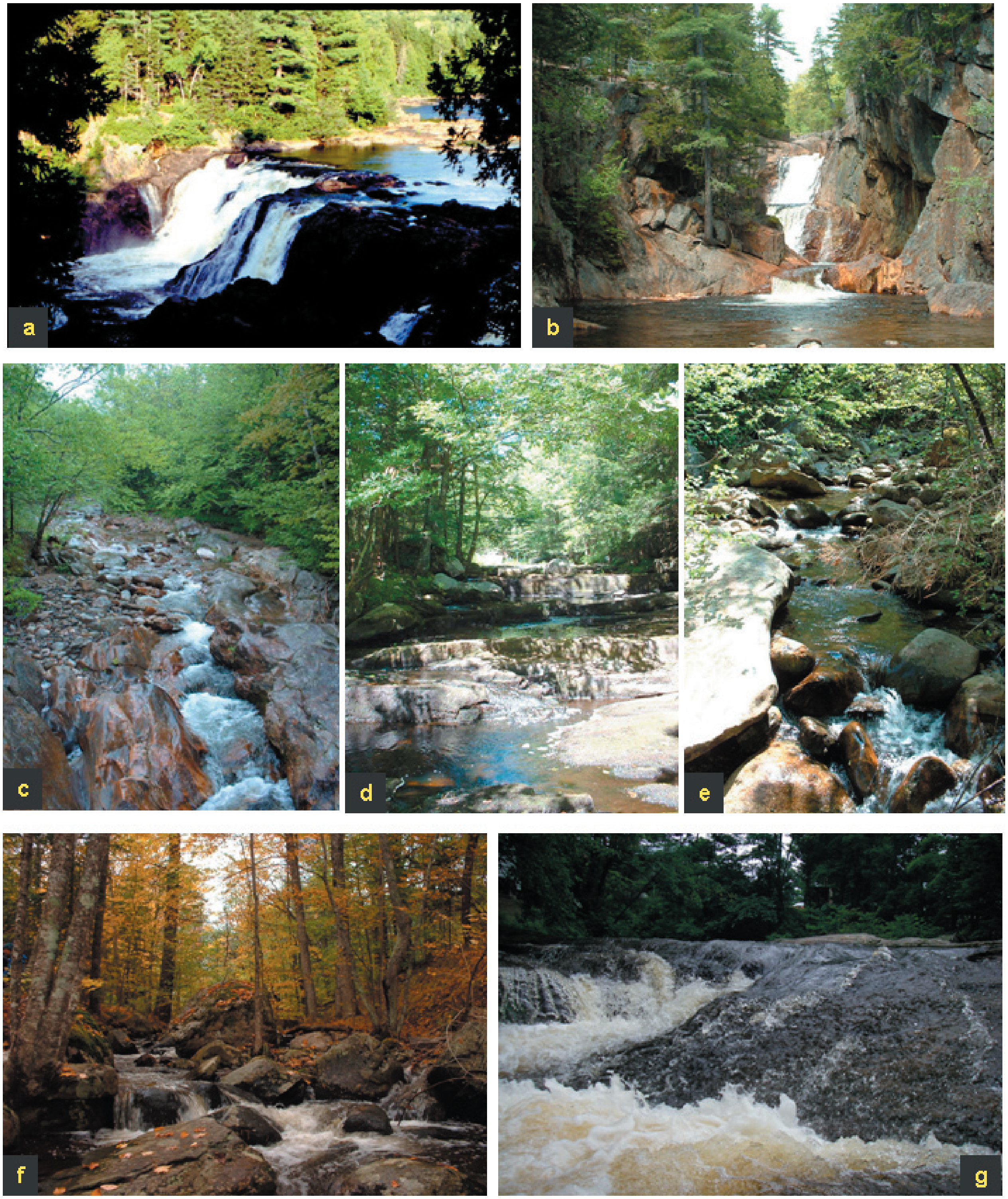
Size Class	Millimeters	Inches	Approximate Relative Size
Bedrock	> 2048	> 80	Bigger than a car; (a.k.a. ledge)
Boulder*	> 256	> 10.1	Bigger than a basketball
Cobble	64 – 256	2.5 - 10.1	Tennis ball to basketball
Gravel	2 – 64	0.08 – 2.5	Peppercorn to tennis ball
Sand	0.06 – 2.00	0.002 – 0.08	Salt to peppercorn
Silt/Clay	< 0.06	< 0.002	Finer than salt

* Some scientists break out another group within the boulder category as "Rubble", which range from approximately from 10 to 20 inches in diameter (i.e., small boulders; larger than a basketball but smaller than a beach ball).

G. Basic Stream/River Types and Habitats

In most cases, stream and river channels have different habitat types at different points along their lengths. *(In this section, the term "habitats" refers to those found in the water column and benthic regions of streams/rivers)*. In many parts of the country, including Maine, streams often start up in the mountains or hills as rivulets and springs and, after traveling many miles, turn into flatter rivers that eventually drain into the ocean. While this is a common situation, there are also many instances in Maine where streams don't originate out of the mountains, but rather originate from low-elevation springs, wetlands, ponds, and lakes.

FIGURE 2-8



(Some examples of different stream and river habitat types in Maine: #a, b waterfalls; #c-f step-pool; #g cascade.
Photos by: (Maine DEP) #a John Sowles, #b-g Jeff Varricchione)

Figures 2-8, 2-9, and **2-10** show examples of different types of stream and river habitats one might encounter in Maine. These types include, but are not limited to, **waterfalls, cascades, step-pool, pool-riffle-run, glide(run)-pool**, and **deep river** habitats. Each of these types of habitats favor different assemblages of aquatic organism.

Pools provide fine sediments through which certain types of invertebrate animals (organisms such as aquatic insects) can dig and crawl to gather food. Pools also provide areas of slower water,

FIGURE 2-9

(Some examples of different stream and river habitat types in Maine: #a-c pool-riffle sequences; #d low-gradient, glide-pool, sandy stream; #e low gradient, sandy river with associated salt marsh. Photos by: (Maine DEP) Jeff Varricchione, #e: www.fws.gov/northeast/rachelcarson/habitat.html)

where important food materials such as leaves can drop out of the flowing water column and remain a food resource for organisms such as invertebrates. Pools provide holding areas for certain fish species and protection, especially from avian (bird) predators.

Riffle areas, on the other hand, are areas where water splashes over rocks, dissolving oxygen in the process. Water is shallower and faster in riffles, thereby favoring different life forms and species that feed by filtering food particles from the passing water, and organisms that are adapted to holding their position in the current. **Figure 2-11** provides illustrations of typical riffle-pool sequences (some of the most common habitats found in stream and river systems) from a bird's-eye-view perspective. Note that the term *thalweg* (a German word) is used to describe the deepest, fast-flowing part of a channel.

(We will cover topics such as aquatic organisms and water quality in more detail later in this document.)

FIGURE 2-10

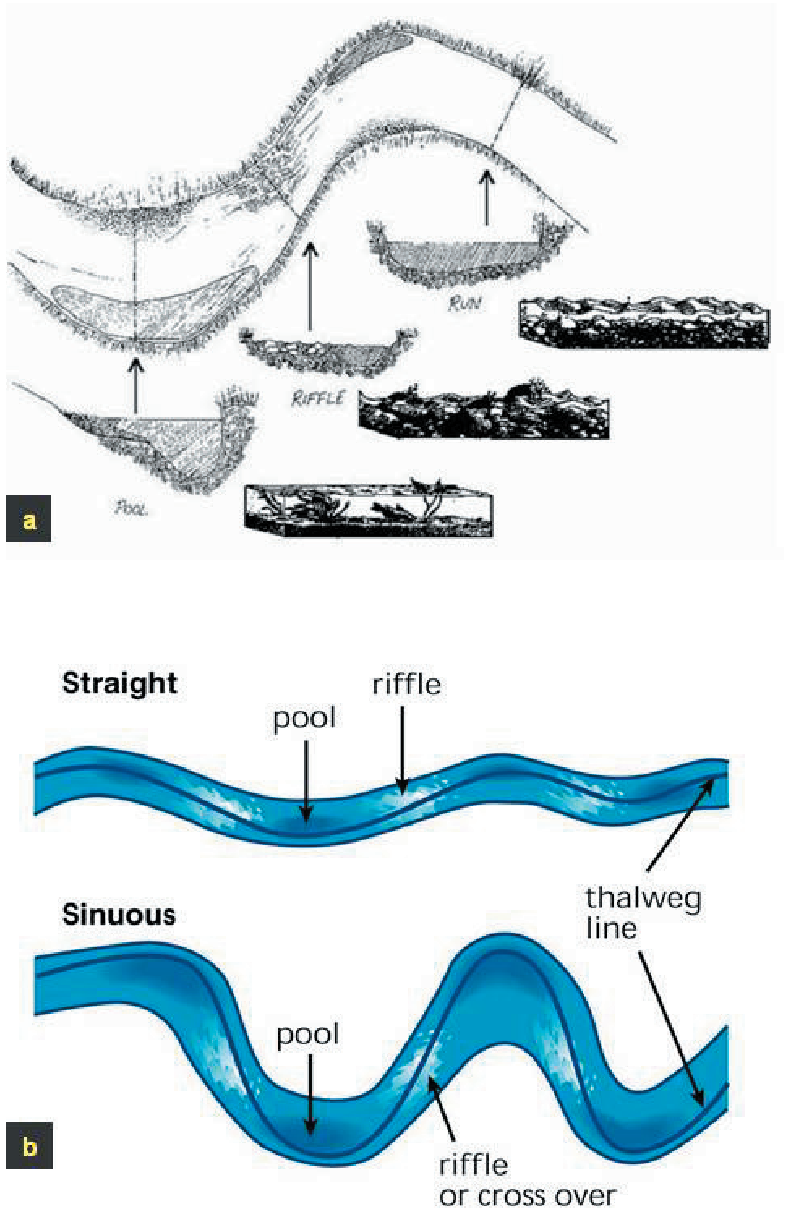
(Some examples of deep river habitat types in Maine. Photos by: (Maine DEP) Jeff Varricchione)

H. Interactions between Surface Water, Groundwater, and the Hyporheic Zone

Some of the most valuable resources the state of Maine has to offer are its miles of rivers and streams. As we study rivers, though, we tend to forget how little of the water on this planet is actually found in them. Water in rivers makes up only 2% of all fresh surface water on this planet. (Lakes and wetlands make up the rest.) Surface water itself makes up less than one half of one percent of all fresh water. Where is the rest of that fresh water? More than two-thirds of it is frozen in glaciers and ice caps. Almost all of the rest is groundwater. That means that for every cup of water in a river or stream, there are around 300 gallons of water in the ground! In Maine, about 60% of people use groundwater for drinking and household activities, but that climbs to 90% of people in rural areas. Clearly we have a vested interest in protecting groundwater for our own consumption. But groundwater is also very important for rivers and streams as well.

Groundwater is, as the name implies, water in the ground. It is found in the tiny pore spaces between grains of sand and in the fractures of bedrock. Water gets into the ground primarily from infiltration of precipitation and "leaking" surface waters. Near ground surface, the pore spaces are mostly filled with air. As one goes deeper underground, more of the pore spaces are filled with water. Eventually one reaches a point where all the pore spaces are all filled; this is called the **water table** *(see* ***Figure 2-12****)*. The zone below the water table is called the saturated zone, because all the pore spaces are saturated with water. In many parts of the country, within the saturated zone are **aquifers,** layers of sand and rock through which groundwater flows easily. These tend to be layers with larger, well-connected pore spaces, such as sands, gravels, and highly fractured bedrock. On the flip side, layers with smaller and less-connected pore spaces, such as clay, tend to impede groundwater flow and form the boundaries of aquifers.

FIGURE 2-11



(Sequences of pools, riffles, and runs: #a with bird's-eye-view, cross-section, and lateral points of view [source: USEPA 1997] and #b bird's-eye-view [planform] in both straight and sinuous streams [source: FISRWG 1998]. The "thalweg" is the deepest, fastest part of a stream/river channel.)

Maine differs from this general situation in some ways because of its glacial history and the deposition of materials as the continental glacier melted. Here, the unconsolidated glacial aquifers found in sand and gravel deposits, located over solid bedrock, have internal layering of materials that have different characteristics, but many of these deposits (eskers, ice marginal deposits, etc.) are not considered true "layers" by geologists. *("**Unconsolidated**" refers to materials that are loosely arranged or un-cemented.)* Additionally, Maine aquifers are generally isolated bodies as opposed to broad units overlaying the landscape. Most of our aquifers are not hydrologically-connected to other aquifers over broad areas, as may be the case in other parts of the United States.

So how does groundwater interact with rivers and streams? Depending on the elevation of the water table relative to a section of a stream, groundwater will either discharge into a stream or be recharged by a stream. A stream segment being fed by groundwater is termed a "gaining" segment while a segment losing water to the ground is called a "losing" stream segment **(Figure 2-13).** (The conditions of a given reach may vary seasonally.)

Groundwater has several important impacts on streams, particularly for gaining streams. Many streams which lack base flow provided by runoff would dry up in the summer without input from groundwater. This groundwater has the added benefit of being cool, allowing cold-water-adapted organisms to survive. Since they are hydraulically connected, the chemistry of the groundwater will affect the chemistry of a gaining stream.

On a smaller scale, groundwater interacts with streams through the **hyporheic zone.** This is the area beneath stream and river channels and floodplains where mixing of surface and groundwater occurs, resulting in unique environmental conditions. In these zones, water moves in and out of the subsurface in paths ranging from centimeters to meters, in most cases, within the river floodplain and beneath the channel. (Local geological conditions, such as depth and porosity of alluvium beneath

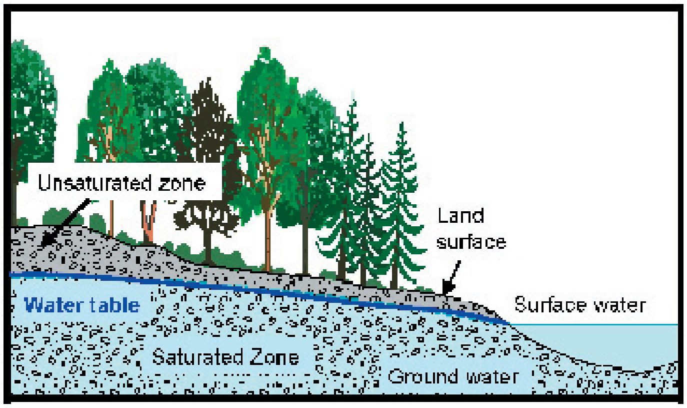


FIGURE 2-12

Basic groundwater terminology.

(Source: USGS "Water Science for Schools" webpage: http://ga.water.usgs.gov/edu/mearth.html)

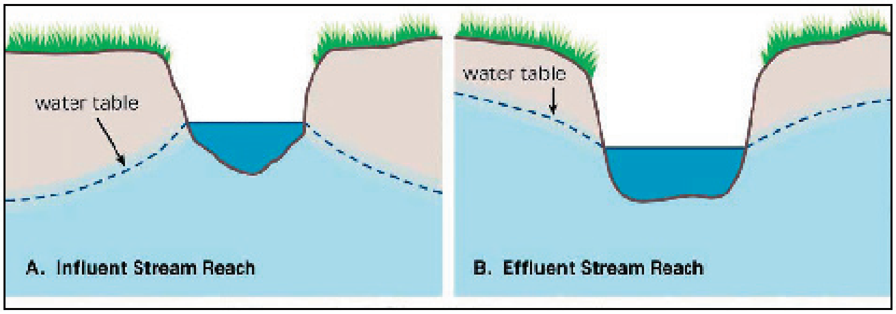


FIGURE 2-13

(Source: FISRWG 1998)

Cross-sections of (a) influent and (b) effluent stream reaches. Influent or "losing" reaches lose stream water to the aquifer. Effluent or "gaining" reaches receive discharges from the aquifer.

streams/rivers and floodplains, determine the extent, if any, of these hyporheic zones. **Alluvium** is an unconsolidated accumulation of stream-deposited sediments, including silts, clays, sands, or gravels. Stream bottoms comprised of bedrock or solid clay do not have hyporheic zones.)

I. Basic Fluvial Geomorphology Concepts

What is Fluvial Geomorphology?

Fluvial geomorphology is the study of the shape and stability of river and stream systems. It assesses not only the form of these watercourses, but also the associated contributing physical processes related to water and sediment transport. At the advanced level, this science applies natural channel design for restoring or rehabilitating channel reaches, and provides integration with aquatic biology to enhance habitat or community structure. This contributes greatly towards a more comprehensive understanding of channel stability, condition, and flow dynamics.

A number of factors combine and interact to determine a stream or river channel's dimensions (width and depth), pattern ("planform" or shape from a bird's eye view), and profile (slope). These factors include things such as climate (rain and snow inputs, etc.), valley characteristics (e.g., slope, width, bedrock and surficial geology, soils, and vegetation), and inputs of sediments from both surrounding lands and in-stream processes. The channel's dimensions are developed and maintained over time by the "channel-forming flow" and the sediment produced by the watershed. The channel forming flow, also called the bankfull flow, occurs roughly every 1.5 - 2.0 years in the northeastern United States. Because of its frequency, this particular flow event does the greatest amount of "work" on the channel (i.e., it transports the greatest volume of sediment over time and maintains the average bankfull channel dimensions over a long period of time).

Field Indicators of Bankfull Elevation

Before we go much further, it is useful to provide you with some suggested indicators of bankfull elevation (a.k.a. bankfull height) of a channel. (Keep in mind that this is one of the things that river scientists and managers argue over most in the field. It can be tricky to determine in some streams and rivers.)

Some field indicators of the location of the bankfull elevation include:

1) the first, flat depositional surface above the active channel's bars* (in many cases, this first flat surface is the floodplain);
2) the lowest extent of woody vegetation in the bank;
3) the top of the zone of washed roots (roots cleaned of soil and exposed in the bank);
4) a break (abrupt change) in the slope angle of the bank;
5) just above the tops of points bars* or other sediment deposits;
6) the elevation of float debris (carried and deposited by the last storm), if used in combination with the other seven features;
7) a change in size of substrate (usually a coarse to fine break);
8) the area of washed rock (scrubbed clean of vegetation or soil by flowing water action), if used in combination with the other seven features.

(Adapted from materials developed by L. Steffan,Natural Resource Conservation Service, Nebraska)

*(**An example of a channel bar is a point bar** — an accumulation of cobbles, gravels, sands, and silts deposited on the inside edge of a stream bend/meander. Some streams have them, others don't. The top of a point bar is usually considered to be the lowest possible elevation at which bankfull elevation could occur.)

For folks who are interested in learning more about bankfull height determination, one can obtain a video or DVD entitled *Identifying Bankfull Stage in Forested Streams in the Eastern United States by* visiting the USDA Forest Service's Stream Systems Technology Center at: http://www.stream.fs.fed.us/publications/videos.html. Also, FISRWG (1998) and Harrelson et al. (1994) provides a good review of various ways to determine bankfull elevation in the field.

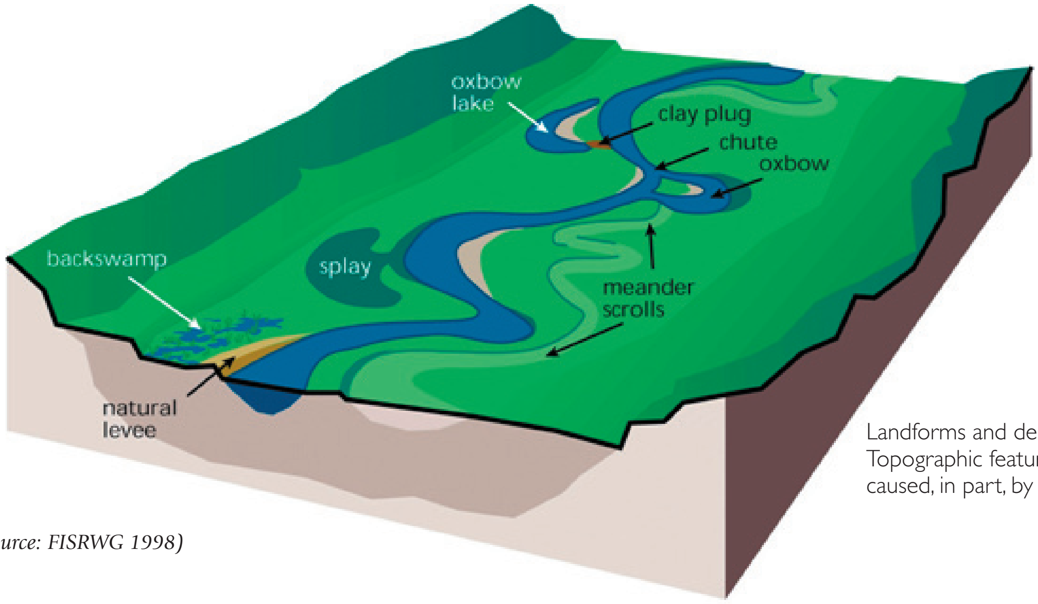
Stream and River Equilibrium and Morphological Responses to Natural and Human-Caused Disturbances

Streams often can be exposed to small- and (sometimes) medium-sized disturbances (i.e., small- to medium-sized storms and associated flows, or human-influenced disturbances) and still maintain a fairly stable channel form and size. This ability to continually return to fairly stable, relatively constant dimensions (width, depth, etc.) is known as "dynamic equilibrium". Once the stream's threshold to tolerate a given amount of disturbance has been exceeded, the system is said to be "unstable". Streams and their corridors then typically go through a series of adjustments over a usually long period of time in order to arrive at a new steady-state (dynamic equilibrium) condition.

Streams in equilibrium may still erode their banks, migrate over time across their valleys, and periodically experience small-scale lateral and/or vertical adjustments. **Figure 2-14** shows an example of how streams can change slowly over time and how one might observe where they may have existed in the past. Features such as oxbow lakes and meander scrolls indicate where channels probably existed prior to present-day location. Comparisons of historical series of aerial photographs often show how a given stream channel has changed over time.

Figure 2-15 illustrates how sediment volume, sediment particle size, water volume, and slope (or energy grade) of a river channel each contribute to its dynamic equilibrium and are naturally balanced, according to an equation called Lane's Balance Equation (Rosgen, 1996; after Lane, 1955). Channel equilibrium occurs when all four of these variables are in balance. If a change in any of these variables occurs, the balance will temporarily be tipped and equilibrium lost. The stream will then tend to experience a proportional increase or decrease in one or more of the other variables as it heads back towards an equilibrium condition. For example, if streamflow (discharge) increased and the slope stayed the same, sediment load or sediment particle size must increase to maintain channel equilibrium. Under this example's conditions, a stream seeking a new equilibrium would tend to erode more of its banks and bed, transporting larger particle sizes and a greater sediment load *(FISRWG, 1998)*.

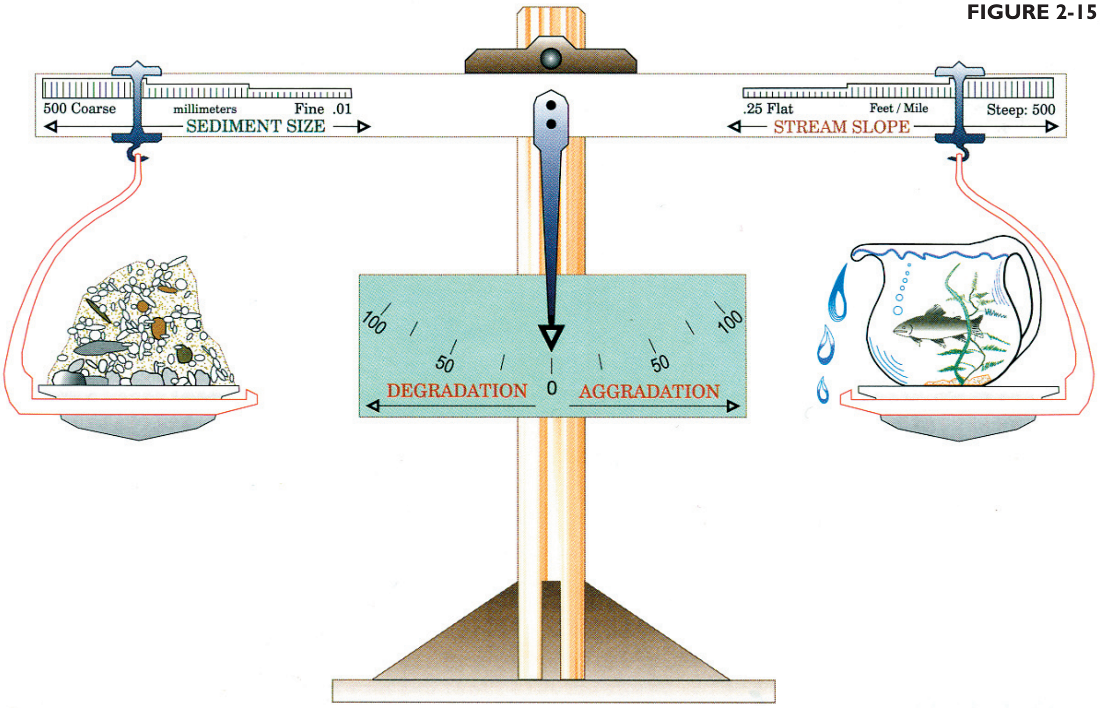
FIGURE 2-14



Landforms and deposits of a floodplain. Topographic features on the floodplain are caused, in part, by meandering streams.

(Source: FISRWG 1998)

FIGURE 2-15



$$(\text{Sediment LOAD}) \times (\text{Sediment SIZE}) \propto (\text{Stream SLOPE}) \times (\text{Stream DISCHARGE})$$

Schematic of the Lane relationship for qualitative analysis (after Lane, 1955).

(Source: Copyright D.L. Rosgen [1996] and Wildland Hydrology, Inc., Fort Collins, Colorado. Used with permission.)

One can use the Lane's Balance Equation to predict changes in the different variables as one follows a stream from steep headwaters to flatter lowland sections. Alternatively, one can use the equation to predict changes at a given site, if human-caused or naturally-caused disturbances impact a certain section of stream or river. Both natural events and human activities (e.g., increased sediment or water inputs due to land use changes, channel straightening, etc.) have the capability to change factors such as sediment load, water load, slope, etc., and tip the balance of the scale in a certain direction. Many types of land uses can impact the equilibrium condition of streams and rivers. Examples of land uses that can have an impact include poorly designed or maintained agriculture, forestry/log-driving, urbanization, and channel straightening, armoring (e.g., hardening with concrete or "riprap"), and dredging activities. These activities can increase sediment or water inputs into stream and river systems, which can "tip the (Lane) balance" of the stream and cause it to respond or react.

> (**NOTE:** The Lane's Balance Equation works for alluvial streams [streams having bed and bank materials that can be moved by the stream [e.g., cobble, gravels, sands, etc.]. The equation done not work well for non-alluvial streams [streambed and bank materials comprised of unmovable bedrock or ledge]. More discussion regarding alluvial versus non-alluvial streams in presented later in this unit. Also note that the Lane's Balance Equation is a good, simplistic, qualitative model, but that most professionals utilize more complicated, quantitative assessment tools when doing their analyses.)

Some examples of channel responses or reactions to disturbances include accumulation of sediments within the channel (**aggradation**), channel scour or incision (**degradation**; i.e., basically a lowering of the channel bed elevation and a steeping of its banks; the river cuts deeper into the land). Other channel responses, such as **channel widening** or **planform adjustmen**t (changes in the channel's shape from a bird's-eye point of view), may follow aggradation or degradation phases. *(These processes are illustrated in the Rapid Geomorphic Assessment Picture Key in Appendix J of Volume 1 [MDEP, 2008].)* Once the channel dimensions have changed enough to accommodate the new water and/or sediment loads, the scale (Lane's Balance) begins to return towards a balanced state.

Stable vs. Unstable Rivers

STABLE RIVERS: A "stable" riverbank changes very little, with minimal change in location from year to year. Stable rivers have no large deposits of sand or gravel. There is minor natural erosion, and the river has the ability to move its water and sediment load in balance.

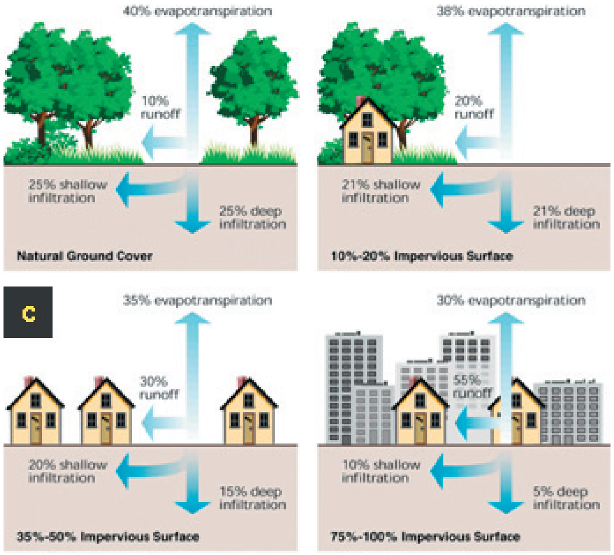
UNSTABLE RIVERS: "Unstable" river systems can change their course by many feet per year, and sometimes cut new channels altogether. Unstable river systems have large sections of collapsing banks; the river widens and/or cuts deeper into its channel, and sand and sediment fill natural pools. The deposited sediment chokes aquatic life and can re-direct the course of the river, causing even more erosion.

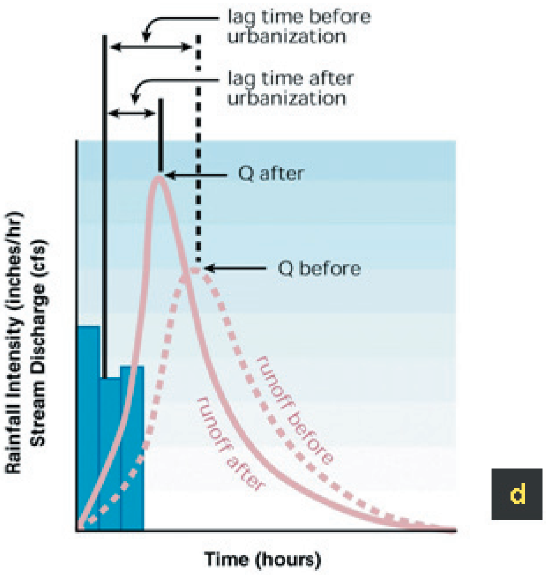
(from Vermont Agency of Natural Resources, 1999)

Urbanization Impacts on Stream Stability

In this manual, we use urbanization of a watershed as an illustration of land uses that can negatively impact streams and rivers if not designed and carried out in an environmentally-sensitive manner. In recent decades, urbanization has become a rapidly expanding threat to Maine's waterways. **Figure 2-16** illustrates how paving over portions of a watershed (urbanization) can increase the amount of its "impervious surface." *(Examples of impervious surfaces and a storm drain are shown in **Figures 2-16a** and **2-16b**.)* Impervious surfaces are materials

FIGURE 2-16





Urbanization impacts on streams. (#a-d). Changes in the landscape from pervious to increasing amounts of impervious surfaces reduce the amount of precipitation that infiltrates into the ground (source of baseflow) and increases the amount of precipitation that runs off into stream quickly. ["Q" represents stream flow/discharge in "d".] #e is an example of streambank degradation associated with increased (urban) runoff and a degraded riparian zone.

(photos #a, b, e by Jeff Varricchione [Maine DEP]; images #c, d from FISRWG 1998)

such as asphalt roads, parking lots, driveways, and rooftops that prevent rain or melting snow from slowly percolating into the ground where it could become groundwater that supplies baseflow to streams, rivers, and other waterbodies *(see **Figure 2-16c**)*. Instead, this water typically is quickly routed through storm drains and stormwater collection systems and dumped out through pipes into nearby streams, rivers, and other waterbodies. This quickly-arriving stormwater tends to come in much greater quantities over much shorter timespans than those seen in un-urbanized watersheds *(see **Figure 2-16d**)*, causing stream channels to expand their size (downcut or widen) in order to accommodate these flows *(see **Figure 2-16e**)*. Other negative effects include warmer water temperatures (as precipitation runs over hot asphalt surfaces) and increased loading of pollutants such as heavy metals, petroleum-related toxins, and excessive amounts of nutrients such as phosphorus and nitrogen. *(These pollutants are discussed later in this document.)* Recent shifts in stormwater management have acknowledged these impacts, which managers are beginning to reduce through creative stormwater treatment systems and lower impact design strategies for urban development.

Channel Classification Systems and Channel Evolution Models

A number of stream and river channel classification and channel evolution model systems are used today. These systems are very useful communication tools that provide people with a coding or naming system that enables the description of the many different types of channel and floodplain shapes, slopes, sizes, and channel bottom material types in a way that other trained people can understand fairly easily. This introductory manual is not the place to describe these various classification systems in detail, but it is appropriate to mention some of the more popular systems with which you may want to become more familiar if you get involved in stream/river research and restoration.

One popular stream classification system is that of Rosgen (1996), which utilizes measurements of a variety of channel and valley characteristics (e.g., channel width/depth ratios, sinuosity, entrenchment [a measure of how accessible a floodplain is to a stream], slope, bed material size, number of channels) to arrive at a certain designation within a specific coding system (e.g., channel type A5, C3, D1, etc.).

Channel evolution models, such as those proposed by Schumm et al. (1984) and Simon (1989), predict the sequence of changes to a stream's width/depth ratio, elevation, and access to its floodplain that typically occur in response to certain kinds of disturbances. **Figure 2-17** shows the basic channel evolution model proposed by Schumm et al. (1984). Chapter 7 of FISRWG [1998] provides a fairly comprehensive and straightforward summary of these various channel classification systems and channel evolution models.

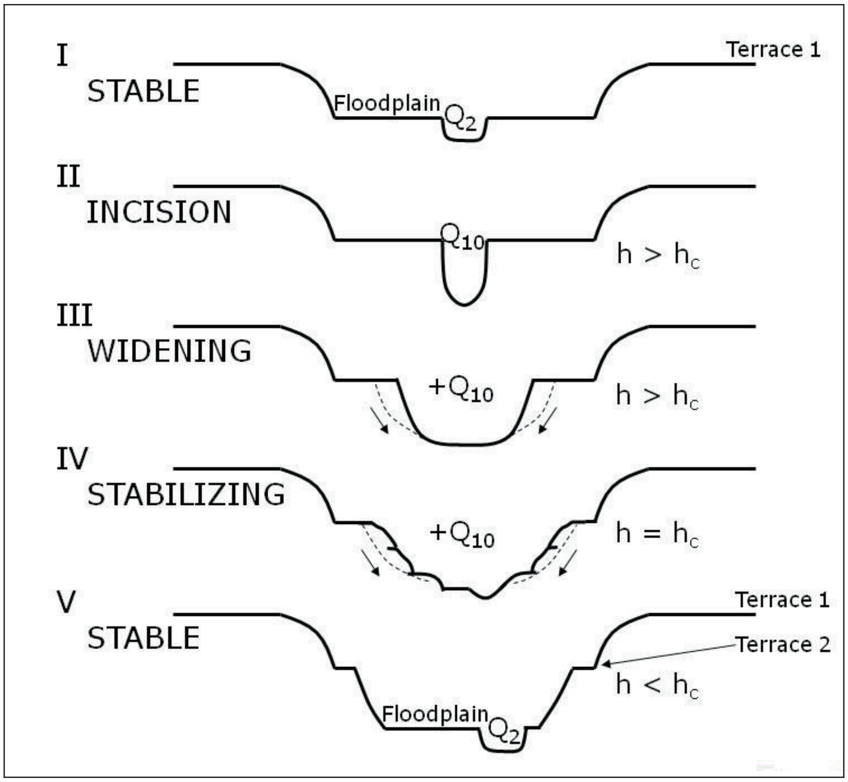


FIGURE 2-17

The channel evolution model. The value "h" represents streambank height and "hc" represents critical streambank height (where slope failure is imminent depending upon the strength of the soils in the bank). Q2 and Q10 represent 2-year and 10-year storms, respectively.

(Adapted from Schumm et al., 1984, and used with permission from Water Resources Publications, LLC, Littleton, Colorado.)

Glaciation and Alluvial vs. Non-Alluvial Streams

Recent glacial activity only took place in approximately the upper northern 1/3 of the United States. This glacial activity scraped off loose soils and other materials in many places around Maine, resulting in a significant number of areas where changes in river morphology are constrained by the presence of large amounts of exposed bedrock or ledge on river and stream bottoms. As a result, while many reaches of streams and rivers around Maine are alluvial channels, a significant amount of reaches are non-alluvial channels. **Alluvial** stream and river sections have channel beds and banks that are comprised of materials (cobbles, gravels, sands, silts, etc.) that can be transported by the river under current climate conditions. **Non-alluvial** sections, unlike alluvial sections, have channel beds and banks that are not able to freely adjust to watershed disturbances such as increased water or sediment loads (from human activities such as urbanization, agriculture, forestry, etc. or from natural events such as sea-level change). Non-alluvial sections of streams and rivers frequently are constrained by channel bed and bank materials that are bedrock (ledge).

Historically nationwide, fluvial geomorphology assessment and river restoration principles commonly focus on alluvial stream/river systems because they are more likely to respond to current restoration techniques. The fact that there are abundant non-alluvial river sections in Maine, which typically have limited river morphology responses to changes in a watershed, need to be considered when making observations about the geomorphology of Maine rivers and streams.

Additional Resources

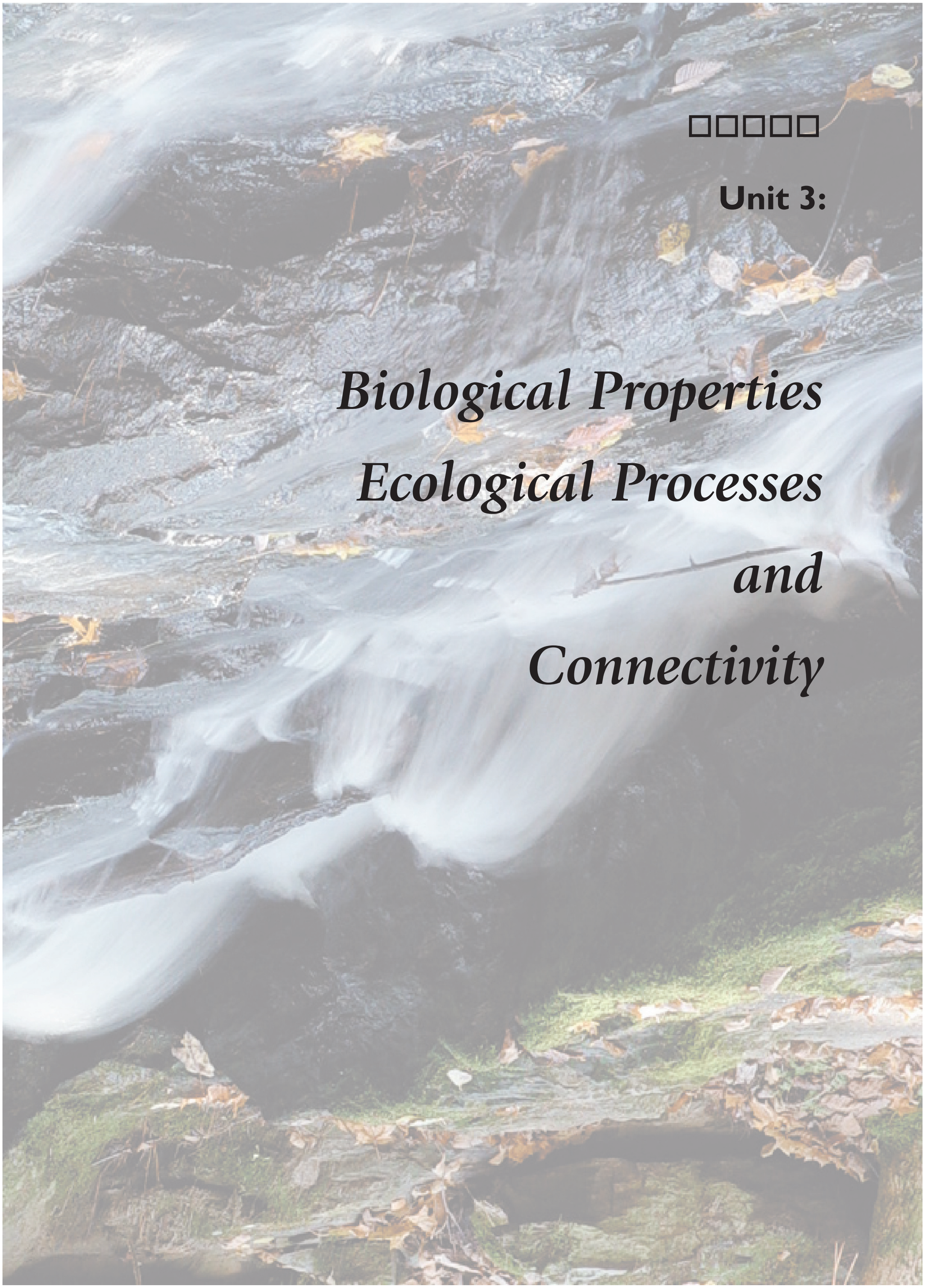
For more information and details about fluvial geomorphology principles and methods, consider taking a course in the subject matter or refer to resources listed in *Appendix L* such as:

- Federal Interagency Stream Restoration Working Group (1998)
- Leopold et al. (1964)
- Rosgen (1996)
- U. S. Environmental Protection Agency — Watershed Academy Web [various modules related to streams] http://www.epa.gov/watertrain/
- Vermont Agency of Natural Resources (2004)

Cautionary Note Regarding Fluvial Geomorphology Assessments and Stream/River Restoration Projects in Maine

Fluvial geomorphology is a science that helps stream and river managers understand the physical processes of these waterbodies and, with a reasonable degree of confidence, predict how human activities on or around them may cause them to react and change. In Volume I, we provide guidance on a screening-level assessment technique called a **Rapid Geomorphic Assessment** *(see Unit 5 and Appendix J)*. This tool does a good job of providing preliminary (screening-level) information on the relative stability of stream and river segments. It helps managers and local groups identify, in a relatively quick manner, which segments may be in fairly good (or excellent) shape versus other segments that may be fairly unstable and in need of more intensive, follow-up investigations and, possibly, restoration work.

Aside from completing simple, small- or medium-scale riparian buffer planting projects using only hand tools, it is strongly recommended that no stream or river restoration activities be designed or implemented without the assistance of professionals (e.g., consultants, federal/state agency staff) possessing significant fluvial geomorphology and/or restoration credentials. Even for buffer plantings, it is wise to involve experienced people.



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Unit 3:

Biological Properties Ecological Processes and Connectivity

Unit 3:
Biological Properties, Ecological Processes, and Connectivity

A. Introduction

This unit focuses on the organisms that inhabit streams and rivers and the ecological processes that take place in them. It also focuses on connections — laterally, between the water and adjacent lands; longitudinally, between upstream and downstream areas; and vertically, between different layers above and below the stream bottom surface. The organisms described in this unit are mostly general types of organisms that one might find in stream systems in most places around the world. Additionally, though, specific examples of organisms that one would find in Maine streams and rivers are provided to increase the usefulness of this unit to people living or visiting Maine.

B. Organisms

Native vs. Non-Native/Invasive Species

Before discussing various types of stream-related organisms, it is important to describe the difference between "**native**" and "**non-native**" or "**invasive**" species because we live in a world in which it is becoming increasingly easy to transport (intentionally or accidentally) species from one part of the world to another.

Maine is home to many native (historically naturally-occurring) plants and animals. Unfortunately, these native communities have been carelessly degraded over the past few centuries by the introduction of species that originated from other places in the world like Europe and Asia. In some cases, invasive species can out-compete native species, creating entirely new, sometimes dysfunctional ecosystems. These illegal introductions have had very serious impacts all over the United States, and they cause significant habitat disruption, loss or degradation of native plant and animal communities, loss of property values, reduced fishing and water recreation opportunities, and large public/private expenditures in Maine.

To learn about the problem of invasive species visit the following websites:

- Maine Department of Environmental Protection — Invasive Species Page
  http://www.maine.gov/dep/blwq/topic/invasives/index.htm
- Maine Department of Inland Fisheries & Wildlife — Invasive Species Pages
  http://www.maine.gov/ifw/fishing/illegalstocking.htm
  http://www.maine.gov/ifw/wildlife/milfoil.htm
- Maine Center for Invasive Aquatic Plants
  http://www.mciap.org/

Biofilm

Biofilm is a term applied to the complex mix of algae, bacteria, fungi, and associated materials (e.g., sugars, nutrients, etc.) that cover solid surfaces (e.g., rocks, logs, branches, leaves) in streams and rivers. Other organisms that may be in this "matrix" include protozoans (single-celled) and micrometazoans (multi-cellular), which are small organisms that have animal-like traits. Another term sometimes applied to this community is a German word: "*aufwuchs*." (The term "*periphyton*" is sometimes used by scientists to describe this community. They use this term recognizing that they are emphasizing the algae since they usually are the most visible component of biofilms.)

These communities form a complex community within which much of the various organisms' biomass and waste products are eaten or recycled by other members of the community. As discussed later, these organisms can be an important food source for larger stream and river organisms.

Algae

Algae are microscopic plants that can exist in either a single-celled or multi-celled, aggregate (cluster) form. Some algae in streams and rivers float in the water column and are considered to be **phytoplankton.** These algae can play a significant role in the ecology of large, deep rivers, but usually play only a relatively minor role in swift, shallow streams. In these smaller systems, algae that are attached to rocks, logs, sticks, and plants, are known collectively as **periphyton.**

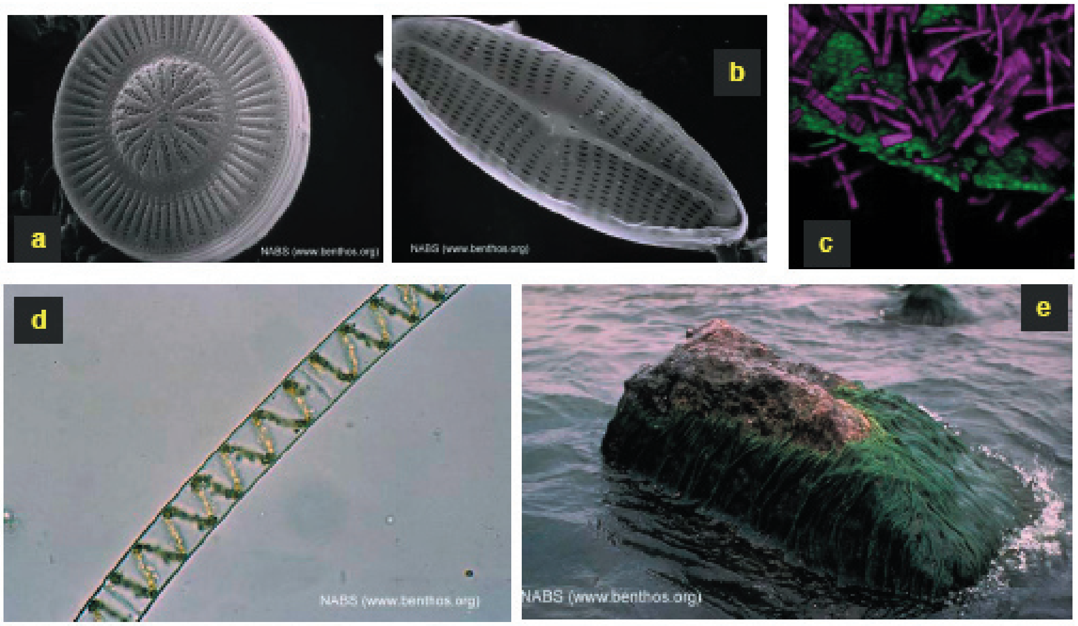
As discussed later, algae are one type of food source for other stream and river organisms, and they grow through a process known as **photosynthesis.** Photosynthesis is a process by which these organisms use power from sunlight to convert carbon dioxide and water into sugars, carbohydrates, and other organic carbon compounds. These organic compounds are then used to fuel the production of other materials necessary for plant growth and reproduction.

Many kinds of algae are not obvious to the casual observer. For example, some rocks in streams may be slippery because they are coated with a number of single cells or colonies of microscopic organisms including diatom algae or cyanobacteria. Green algae typically are seen in a "filamentous" (hair-like) form, often forming mats that sway in the water current. Streams receiving too much nutrient pollution, including excess phosphorus or nitrogen, can sometimes produce large, green mats of algae. When these plant materials die, bacteria and other microbes decompose (rot) these materials and use up dissolved oxygen in the process. Low dissolved oxygen conditions can stress aquatic organism communities. *(More details about nutrient pollution, other types of pollution, and the importance of dissolved oxygen are included in Unit 4.)*

Photographs of representative kinds of algae are shown in *Figure 3-1a*. Some examples of algae species commonly found in Maine include:

- *Achnanthidium minutissimum*, *Gomphonema parvulum*, and *Navicula cryptocephala* (diatoms; class Bacillariophyceae);
- *Chroococcus minor, Oscillatoria spp.*, and *Phormidium spp.* (*cyanobacteria;* class Cyanophyceae [formerly classified as blue-green algae, now actually considered to be bacteria]); and
- *Mougeotia spp.*, *Oedogonium spp.*, and *Spirogyra spp.* (green algae; class Chlorophyceae).

FIGURE 3-1a



Representative types of algae found in streams and rivers (though some of these species are not necessarily found in Maine). Examples of diatoms: a - b) *Discostella stelligera* and *Navicula tripunctata* [p.c.: i] and c) CLSM image of live diatoms (pseudo-colored in purple) growing on a moss leaf (pseudo-colored in green) [p.c.: ii]. Examples of green algae: d) *Spirogyra* [p.c.: iii] and e) *Cladophora* [p.c.: iv].

The algae in images a-d are microscopic in size.

Photo credits [p.c.]: i) David Johnson; ii) photography: Chad Larson, color editing: Sophia Passy, contributed by: Sophia I. Passy; iii) Rex Lowe; iv) Tina Larson. All photos from the North American Benthological Society image website: http://www.benthos.org/imagelibrary/index.cfm.

For more information about algae in general, visit: USEPA Biological Indicators of Watershed Health at: http://www.epa.gov/bioindicators/html/indicator.html

"Didymo" (a.k.a. "Rock Snot"):

An Invasive Algae that is a Potential Threat to Maine's Pristine Rivers & Streams

With the recent discovery of the aquatic nuisance algae known commonly as "*Didymo*" or "rock snot" ***(Figure 3-1b)*** on the Vermont/New Hampshire Border in the Connecticut River region, the Maine Department of Inland Fisheries and Wildlife and the Maine Department of Environmental Protection are alerting boaters, anglers, kayakers, canoeists, and others to take action to prevent this new invasive threat to Maine's waters.

Didymo, which has the scientific name *Didymosphenia geminata*, can form extensive 'blooms' on the bottoms of rocky river beds, essentially smothering aquatic life forms such as macroinvertebrates (aquatic insects, mollusks, etc.), native algae, and other organisms. Additionally, the physical appearance of the bloom is aesthetically unpleasing, and can reduce the recreational values of a waterbody. Didymo uses stalks to attach to rocks and plants in a river system. This particular diatom creates these stalks, which can form masses 10-12 inches thick on the river bottom, and trail for lengths of 2-3 feet in the current.

Didymo can be spread by transporting a single cell, which can then multiply into dense mats. The ease with which it can be spread is a real concern for anyone who enjoys Maine's waters. All of Maine's rivers and streams are at risk. Both IFW and DEP are urging anglers and other water recreationists to use these procedures for preventing the introduction and spread of Didymo *(see inset)**.

There are currently no known methods for controlling or eradicating Didymo once it infests a water body. Preventing the spread of Didymo is Maine's best defense. As of 2008, Maine DEP had tested algae at more than 200 locations on Maine rivers and streams, and it has not yet been detected in Maine's waters.

Didymo is generally found in colder, low nutrient, high clarity streams. However, recently there have been discoveries of Didymo in rivers and streams in warmer climates, as well as streams with more nutrients, streams with moderate clarities and even some tannic (tea colored) waters. Didymo is currently found in Europe (Scotland, Poland) and it is spreading throughout the northwestern region of the US. It is also in Quebec, British Columbia and New Zealand.

FIGURE 3-1b

Photo of the invasive algae Didymo *(Didymosphenia geminata)*, a.k.a. "rock snot", found on top of a rock taken from a river.

Photo credit: Matapédia River Watershed Council (CBVRM) [Quebec, Canada].

Didymo Prevention: CHECK, CLEAN & DRY

CHECK:

Remove everything that sticks to fishing gear, boats, and trailers. Remove all visible clumps of algae and plant material from fishing gear, waders, clothing, water shoes and sandals, canoes and kayaks, and anything else that has been in the water. It takes a number of cells present before Didymo is visible to the human eye, so cleaning is also very important.

CLEAN:**

Use **HOT** tap water and lots of soap (a good squirt of dishwashing detergent). Scrub boats and other "hard" items thoroughly; scrub all gear at least one minute. Soak clothes, felt-sole waders and other "soft" items for 30 minutes!

DRY:

Allow cleaned items to dry until "dry to the touch". If cleaning is not practical, after the item is dry to the touch, leave it to dry for at least another 48 hours before using in another freshwater system.

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*If you feel that you have discovered Didymo, please contact the Maine Department of Environmental Protection at 1-800-452-1942 or email milfoil@maine.gov. For more information, visit the New Hampshire - Didymo webpages at: http://des.nh.gov/organization/divisions/water/wmb/exoticspecies/didymo/index.htm or USEPA's page at: http://www.epa.gov/Region8/water/didymosphenia/.

**Professional level decontamination methods can be found at: http://www.maine.gov/dep/blwq/docmonitoring/materials/sop_dea_decon.pdf

Bacteria and Fungi

The major role which bacteria and fungi play in stream ecosystems is the decomposition of dead organic material (cells, plants, animals, leaves, logs, etc.), and the conversion of it into their own biomass or inorganic nutrient molecules. As discussed later, the presence of these microbes on decaying leaves and branches can greatly increase their nutritional value for larger organisms such as aquatic insects and crustaceans.

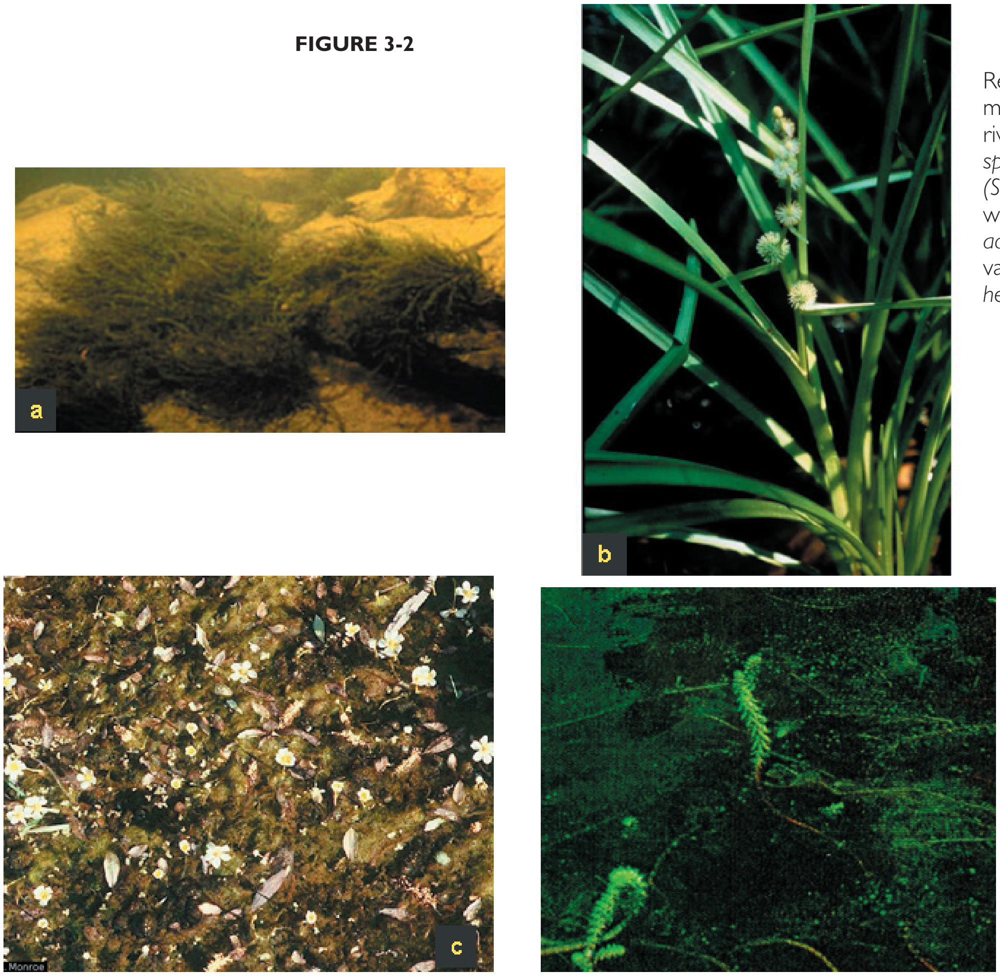
Macrophytes: Mosses, True Vascular Plants, Etc.

Macrophytes are large plants (as opposed to most algae). Types of macrophytes include mosses and liverworts (both are bryophytes) and flowering plants, among other things. Macrophytes can have various forms of attachment in streams, rivers, and other waterbodies. Mosses and liverworts are commonly attached to rocky surfaces such as boulders and usually are found in cold headwater streams. While most plants do best in sunny areas, many mosses do well in shaded areas. Duckweed is an example of a floating plant that does well primarily in slow, backwater sections of streams (in addition to ponds). The remainder of the macrophyte group is the rooted plant group, which tends to prefer slower sections of streams and rivers. Some of these rooted plants remain entirely submerged under water, while other types have parts that emerge out of the water.

Macrophytes play an important role in aquatic ecosystems by producing oxygen that is vital to aquatic animals, serving as a food source to some specially-adapted aquatic insects, and contributing their biomass as a food source to decomposer-type stream/river organisms after they have died.

***Figure** 3-2* shows some representative types of macrophytes.

FIGURE 3-2



Representative types of aquatic macrophytes found in streams and rivers: a) water moss *(Fontinalis spp.)* [p.c.: i]; b) American bur-reed *(Sparganium americanum)* [p.c.: ii]; c) white water crowfoot *(Ranunculus aquatilis)* [p.c.: iii]; and d) the 'invasive' variable-leaf milfoil *(Myriophyllum heterophyllum)* [p.c.: iv].

Photo credits [p.c.]: i) http://www.bio.umass.edu/biology/conn.river/plant_images/mossuw3.jpg ; ii) Robert H. Mohlenbrock at USDA-NRCS PLANTS Database / USDA SCS. 1991. Southern wetland flora: Field office guide to plant species. South National Technical Center, Fort Worth.; iii) Gary A. Monroe at USDA-NRCS PLANTS Database and iv) unknown Maine DEP source.

Some examples of native Maine macrophytes found in streams and rivers include: water moss *(Fontinalis spp.)*, ribbonleaf pondweed *(Potamogeton epihydrus)*, bulrush *(Schoenoplectus subterminalis)*, bur-reed *(Sparganium spp.)*, white water crowfoot *(Ranunculus aquatilis)*, and wild celery *(Vallisneria americana)*.

To date, the only invasive/non-native plants found in Maine streams and rivers has been variable-leaf milfoil *(Myriophyllum heterophyllum)*, though there is potential for other invasive species to make their way into these waterways.

Photographs, illustrations, and ecological information regarding aquatic plants can be found at:

- USEPA Biological Indicators of Watershed Health
  http://www.epa.gov/bioindicators/html/indicator.html
- Maine Center for Invasive Aquatic Plants
  http://www.mciap.org/
- USDA-NRCS PLANTS Database
  http://plants.usda.gov/index.html
- Center for Aquatic and Invasive Plants (University of Florida)
  http://plants.ifas.ufl.edu/ie6/index.html
- Maine DEP Invasive Aquatic Plant Page;
  http://www.maine.gov/dep/blwq/topic/invasives/index.htm

Invertebrates

Stream and river invertebrates can be broken down into two main categories based upon their size. Size breakdown may vary among scientists, but generally **meiofauna** are considered to be animals that are smaller than 0.5 mm (500 µm) and **macrofauna** are animals that are greater than 0.5 mm in size. This section focuses on invertebrates found in the benthic region of streams/rivers.

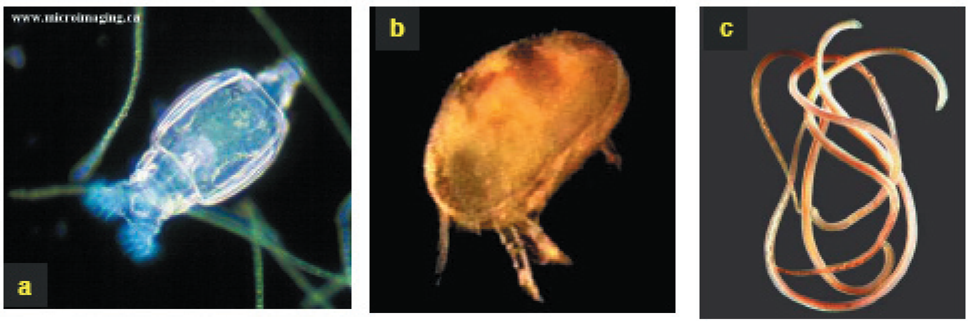


FIGURE 3-3

Representative types of meiofauna found in streams and rivers: a) rotifer [p.c.: i]; b) seed shrimp [p.c.: ii]; and c) oligochaete worm [p.c.: ii].

Photo credits [p.c.]: i) Ron Neumeyer http://www.microimaging.ca/ and ii) Charlie Drewes, Iowa State University, http://www.eeob.iastate.edu/faculty/DrewesC/htdocs/.

Some examples of meiofauna include protozoans, rotifers, nematode worms, oligochaete worms, and small (micro) crustaceans such as copepods and ostracods (seed shrimp). Meiofauna feed upon dissolved or decomposing organic matter, bacteria, fungi, small algae, or other meiofauna, and they serve as a food source for larger organisms. ***Figure 3-3*** shows some examples of meiofauna.

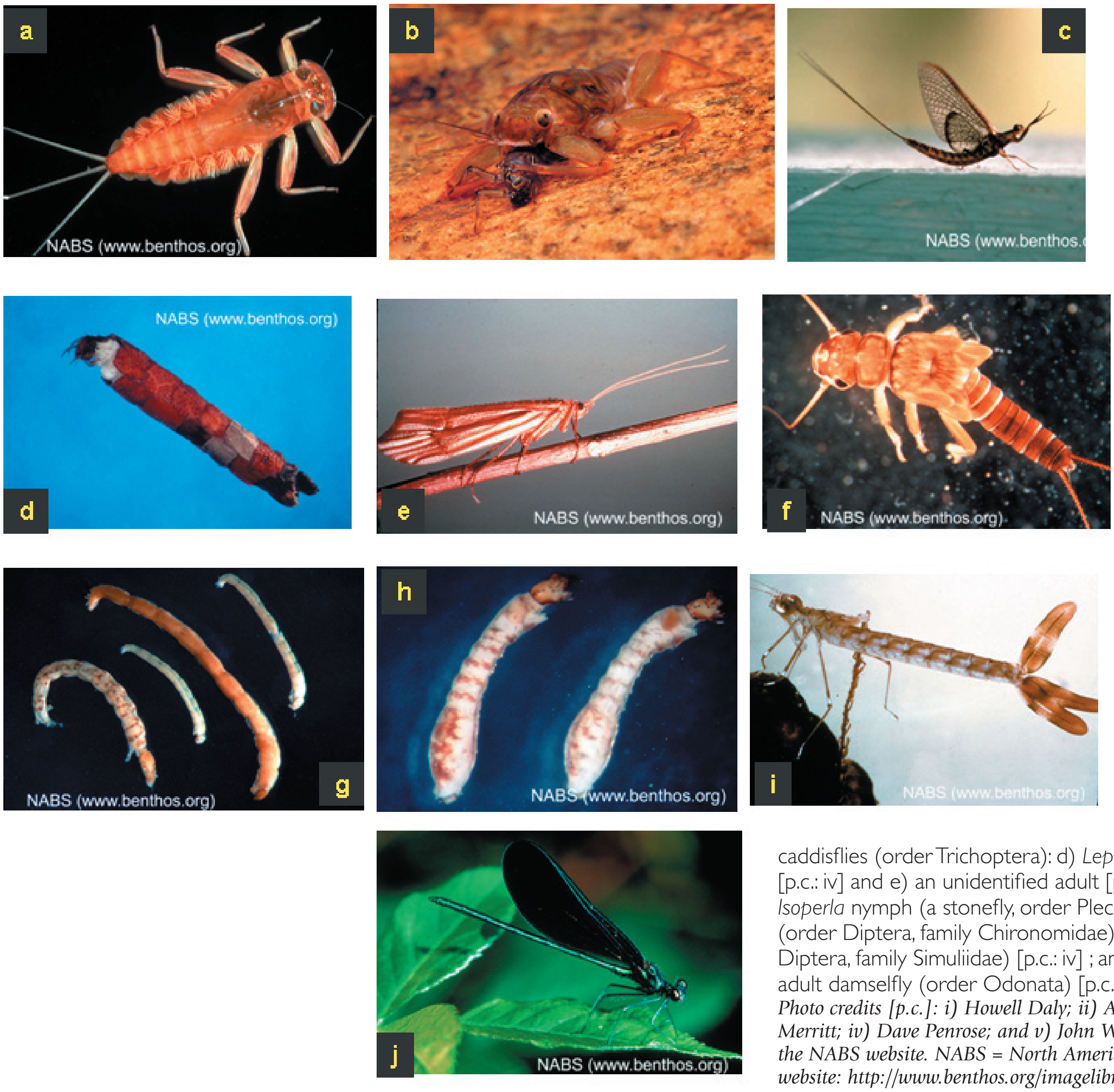
The term **macroinvertebrate** is frequently used by scientists and volunteer groups to refer to the easily-seen invertebrates they collect from stream and river bottoms, and usually refers to invertebrates larger than 0.5 mm (i.e., they are macrofauna) but typically not larger than about 80 millimeters (3.1 inches). Common macroinvertebrates include aquatic insects, mollusks (snails, limpets, clams, and mussels), and crustaceans (isopods, amphipods, and decapods [crayfish and shrimp]). Some less common kinds of stream and river macrofauna/macroinvertebrate categories include freshwater sponges, leeches, horse-hair worms, oligochaete worms, flatworms, and hydroids. ***Figure 3-4a*** and ***3-4b*** show some examples of various types of macroinvertebrates.

FIGURE 3-4a

Representative types of macroinvertebrates found in streams and rivers: a) leech [p.c.: i]; b) dwarf wedgemussel [p.c.: ii]; c) amphipod [p.c.: iii]; and d) crayfish [p.c. iv].

Photo credits [p.c.]: i) Ken Krieger and NABS; ii) USGS-New York; (http://ny.cf.er.usgs.gov/nyprojectsearch/projects/2457-A3J-1.html); iii) Mike Higgins and NABS; iv) photo: Eric Engbretson, U.S. Fish & Wildlife Service; Contributor: Division of Public Affairs, http://images.fws.gov/. NABS = North American Benthological Society image website: http://www.benthos.org/imagelibrary/index.cfm.

FIGURE 3-4b



Representative types of macroinvertebrates found in streams and rivers. Examples of different kinds of mayflies (order Ephemeroptera): a) nymph (juvenile) (of family Heptageniidae) [p.c.: i] ; b) a *Drunella* mayfly, which normally eats algae and other organic matter, eats a *Baetis* mayfly [p.c.: ii] ; and c) an adult [p.c.: iii] . Examples of caddisflies (order Trichoptera): d) *Lepidostoma* larva in its case [p.c.: iv] and e) an unidentified adult [p.c.: iii] . Examples of: f) an *Isoperla* nymph (a stonefly, order Plecoptera) [p.c.: iv] ; g) "midges" (order Diptera, family Chironomidae) [p.c.: iv] ; h) blackflies (order Diptera, family Simuliidae) [p.c.: iv] ; and i – j) a nymph [p.c.: iii] and adult damselfly (order Odonata) [p.c.: v] .

Photo credits [p.c.]: i) Howell Daly; ii) Angus McIntosh; iii) Rich Merritt; iv) Dave Penrose; and v) John Wallace. All photos located on the NABS website. NABS = North American Benthological Society image website: http://www.benthos.org/imagelibrary/index.cfm.

Aquatic insects are probably the most studied group of macroinvertebrates. Some types of aquatic insects spend their entire life cycle under water, but most begin as eggs, pass through various larvae or nymph stages, and eventually develop wings as they grow older so that they can emerge from the water to become adults. As adults, they mate, lay their eggs in the water, and the life cycle begins all over. Different species of macroinvertebrates prefer different habitats (e.g., riffles, pools, attached to plants or logs, burrowing in muds, etc.) and different food types (e.g., algae, bacteria- and fungi-covered organic matter such as leaves and twigs, other invertebrates, etc.), so macroinvertebrate community composition can be quite variable. At any given point in a stream system, the types and numbers of the macroinvertebrates found there depends upon factors such as habitat type and food resources available locally, as well as a number of other important factors such as water quality, temperature, and stream bottom composition, which are discussed elsewhere in this manual.

Scientists commonly sample macroinvertebrates, along with water chemistry and temperature, to gather a fairly comprehensive assessment of water quality at stream and river sites. Since invertebrates move relatively short distances (compared to fish) over time, and because different species of invertebrates have differing tolerances to certain types of pollution, invertebrate community composition can provide useful information about the health of streams and rivers. An overview of Maine DEP's "biomonitoring" (biological community monitoring) program, including methods, can be found at: http://www.maine.gov/dep/blwq/docmonitoring/biomonitoring/index.htm.

Thousands of species of aquatic insects, one of the major groups that make up stream and river macroinvertebrate communities, are known to exist in North American lotic (flowing) waterways. Within Maine, the Roaring Brook mayfly (*Epeorus frisoni,* order Ephemeroptera) is native to the Baxter State Park region of Maine and is listed as an endangered species. The Tomah mayfly (*Siphlonisca aerodromia;* order Ephemeroptera) is listed as a threatened species in Maine. The "Penobscot blackfly" (*Simulium penobscotensis*, order Diptera) was first discovered in the Piscataquis River watershed, a major tributary of the Penobscot River (Maine). Additionally, some more widely distributed aquatic insects that are commonly found in Maine streams include:

- *Stenonema* and *Baetis* (mayflies; order Ephemeroptera);
- *Acroneuria* (a stonefly; order Plecoptera);
- *Hydropsyche* and *Cheumatopsyche* (caddisflies; order Trichoptera);
- *Psephenus* (a "water penny"; beetle; order Coleoptera);
- *Boyeria* (a dragonfly; order Odonata [this also includes damselflies]); and
- *Polypedilum* (a midge or chironomid — under the "true flies" order Diptera).

For more information visit:

- Maine DEP Biomonitoring Program
  http://www.maine.gov/dep/blwq/docmonitoring/biomonitoring/index.htm
- USEPA Biological Indicators of Watershed Health
  http://www.epa.gov/bioindicators/html/indicator.html
- Nedeau, E. J., M. A. McCollough, and B. I. Swartz. 2000. The Freshwater Mussels of Maine. Maine Department of Inland Fisheries and Wildlife, Augusta, ME. 118 pp.

Maine Aquatic Biodiversity Project

Are you interested in learning more about the plant and animal species and communities in Maine's freshwater ecosystems? You are encouraged to visit the Maine Aquatic Biodiversity Project website. This website maintains information on over 1,500 species from almost 14,000 sites across the state. The website provides access to species checklists, distribution maps, and ecological summaries. The Project is a collaborative of the University of Maine, Maine Department of Inland Fisheries & Wildlife, and Maine Department of Environmental Protection.

For more information visit: http://pearl.maine.edu/windows/biodiversity/default.htm.

Fish

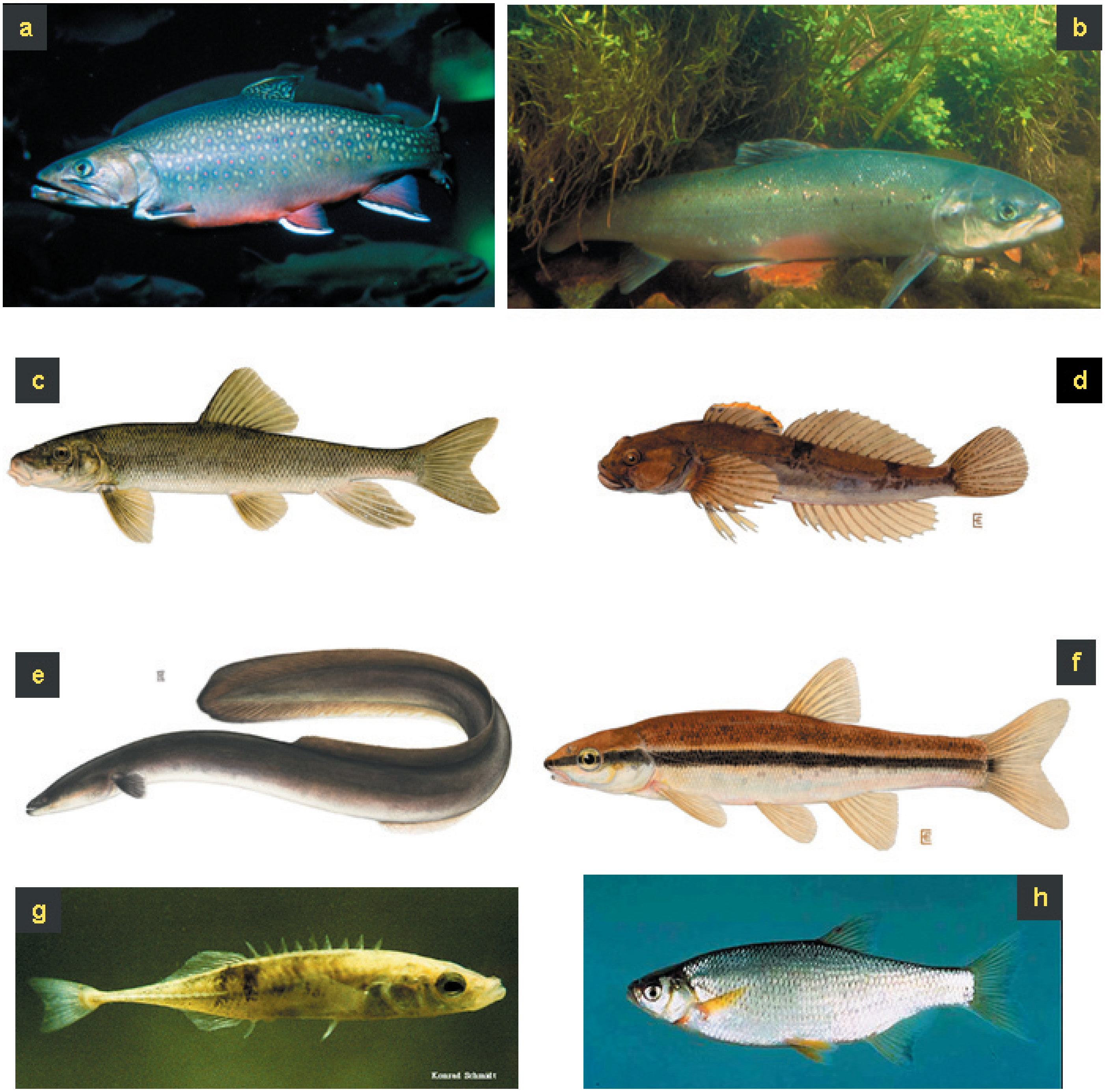
Fish is the group of organisms that most people envision when thinking about streams and rivers. As far as organisms that generally spend their entire lives under water, they are at the top of the "food chain" or "food web." Most fish spend some or all of their lives eating invertebrates. Some large fish eat other small fish, and a few species feed upon vegetation. Some fish are adapted to feeding along the bottom of stream/river channels, while others are specialized for feeding up in the water column, and their mouth parts (locations and shapes) typically reflect their food source preferences.

Different species thrive much better in certain habitat types versus others. While some fish species can do well in streams with bottom habitats that are muddy or with rocks that are embedded with silts, cold-water sport fish species in Maine, like Atlantic salmon and brook trout (of the family Salmonidae), do better in streams that have stream bottoms that are mostly gravel and cobble substrates with only small amounts of sand or silt. This is partly due to the need for egg-spawning gravels that permit the free-flow of oxygen laden waters through the cracks and gaps between the rocks. These stream beds with low amounts of fine sediments also allow for greater macroinvertebrate diversity, and thus a more thriving and plentiful food source for fish. Some fish spend their entire lives in streams and rivers. Some fish however, like Atlantic salmon, have **anadromous** life cycles, where they start as eggs and then juveniles in freshwater, migrate out to sea to feed and mature for a period of time, and then return to streams and rivers to spawn (deposit their eggs). Some other fish, like eels, have **catadromous** life cycles, where they reproduce and spend their early years at sea, then return to rivers to mature, and finally return to the sea to reproduce.

Figure 3-5 presents some example photographs and illustrations of fish found in Maine. Some examples of fish that are native to Maine streams and rivers include:

- Salmon Family *(Salmonidae)*
  - brook trout *(Salvelinus fontinalis)*
  - Atlantic salmon *(Salmo salar)*
- Minnow Family *(Cyprinidae)*
  - blacknose dace *(Rhinichthys atratulus)*
  - northern redbelly dace *(Phoxinus eos)*
  - golden shiner *(Notemigonus crysoleucas)*
  - creek chub *(Semotilus atromaculatus)*
- Herring family *(Clupeidae)*
  - alewife *(Alosa pseudoharengus)*
  - American shad *(Alosa sapidissima)*
- Sucker family *(Catostomidae)*
  - white sucker *(Catostomus commersoni)*
- Killifish Family *(Cyprinodontidae)*
  - banded killifish *(Fundulus diaphanus)*
- Stickleback Family *(Gasterosteidae)*
  - ninespine stickleback *(Pungitius pungitius)*
- Sculpin Family *(Cottidae)*
  - slimy sculpin *(Cottus cognatus)*
- Freshwater Eel family *(Anguillidae)*
  - American eel *(Anguilla rostrata)*

FIGURE 3-5



Representative types of fish found in streams and rivers: a) brook trout *(Salvelinus fontinalis)* [p.c.: i]; b) Atlantic salmon *(Salmo salar)* [p.c.: ii]; c) common/white sucker *(Catostomus commersoni)* [p.c.: iii]; d) slimy sculpin *(Cottus cognatus)* [p.c.: iii]; e) American eel *(Anguilla rostrata)* [p.c.: iii]; f) blacknose dace *(Rhinichthys atratulus)* [p.c.: iii]; g) ninespine stickleback *(Pungitius pungitius)* [p.c.: iv]; h) golden shiner *(Notemigonis crysoleucas)* [p.c.: iv].

Photo credit: i) photo by Eric Engbretson, (U. S. Fish & Wildlife Service Digital Images (USFWS DI), Contributor: Division of Public Affairs http://images.fws.gov/); ii) photo by William W. Hartley, (USFWS DI); iii) Fish images originally prepared by Ellen Edmonson and Hugh Chrisp as part of the 1927-1940 New York Biological Survey. Permission for use granted by the New York State Department of Environmental Conservation; iv) photo of stickleback by Konrad Schmidt; photographer of golden shiner unknown, (National Park Service; Isle Royale National Park; http://www.nps.gov/archive/isro/NR_Profile_Internal/NR_pages/fish.htm)

Maine is an important member of the United States when it comes to coldwater fisheries. Maine is remaining populations of wild Atlantic salmon in the U. S., and those populations remain at critically low numbers. Maine is an important habitat for Eastern brook trout populations in the U. S. A number of agencies, organizations, and volunteers around the state are working diligently to try to survey, restore, and maintain the populations of these fish, as well as other species such as alewives, shad, and American eel. Many of these organizations and individuals recognize that habitat and water quality are important factors that need to be studied, restored, and maintained before their fish species of interest can maintain healthy, sustainable populations. This understanding and these efforts result in better stream and river conditions overall, and thus benefit entire ecosystems rather than just target species.

Some examples of non-native/invasive species of fish in Maine include: northern pike *(Esox lucius)*, smallmouth bass *(Micropterus dolomieu)*, largemouth bass *(Micropterus salmoides)*, black crappie *(Pomoxis negromaculatus)*, bluegill sunfish *(Lepomis macrochirus)*, and green sunfish *(Lepomis cyanellus)*.

For more information, see:

- Downeast Salmon Federation
  http://www.mainesalmonrivers.org/
- Eastern Brook Trout Joint Venture
  www.easternbrooktrout.org or www.brookie.org
- Maine Atlantic Salmon Commission
  http://www.maine.gov/asc
- Maine Council of the Atlantic Salmon Federation
  http://www.mainecouncilasf.org/
  http://www.asf.ca/Overall/lifecycle.html (Wild Atlantic Salmon Life Cycle)
- Maine Department of Inland Fisheries & Wildlife — Fish Identification
  http://www.maine.gov/ifw/fishing/fishidentification/index.htm
- Maine Department of Marine Resources — Bureau of Sea Run Fisheries & Habitat
  http://www.maine.gov/dmr
- Project SHARE (Salmon Habitat and River Enhancement)
  http://salmonhabitat.org
- Trout Unlimited
  http://tumaine.org (Maine Council)
  http://www.tu.org (national organization)
- USEPA Biological Indicators of Watershed Health
  http://www.epa.gov/bioindicators/html/indicator.html

Other Vertebrate Animals That Frequent Streams and Rivers

A number of different vertebrate animals (those having a backbone/spine) can be found frequenting streams and rivers for various reasons. Most of these organisms spend some or most of their lives on land (they are terrestrial), but aquatic environments may play a vital role during some or all of their lives.

Reptiles and Amphibians

Turtles are probably the most commonly observed reptiles in or near Maine streams and rivers. Their diets vary, and mostly consist of plant material, though some species feed on other things like dead animal matter. They generally are not found in swift stream/river sections, but rather in slow waters. Some examples of turtles that might be found near or in a slow Maine stream include the eastern painted turtle *(Chrysemys picta)* and snapping turtle *(Chelydra serpentina)*.

Snakes, another type of reptile, can also be found near some streams and rivers. Some examples of snakes that might be found near streams in Maine include the northern water snake *(Nerodia sipedon)*, common garter snake *(Thamnophis sirtalis)*, and redbelly snake *(Storeia occipitomaculata)*. They eat primarily insects, crustaceans, amphibians, worms, and slugs. Additionally, garter snakes may eat small mammals or birds.

Amphibians such as salamanders, frogs, and toads are commonly found near aquatic environments such as streams and rivers. They may feed partly on algae, plants, or dead organic material when they are young, but as adults they feed mostly on small animals such as insects and other invertebrates, or smaller amphibians, fish, or reptiles. Aquatic environments are usually most important during the reproduction and early life stages of these organisms, though some may need to be near water during virtually all life stages. Examples of amphibians one might observe near a stream or river in Maine include the spring salamander *(Gyrinophilus porphyriticus)*, northern two-lined salamander *(Eurycea bislineata)*, and northern dusky salamander *(Desmognathus fuscus)*. *(See **Figure 3-6** for photographs of some reptile and amphibians.)*

For more information see:

- Maine Amphibian Monitoring Program
  http://www.maineaudubon.org/conserve/citsci/mamp.shtml
- Maine Herpetological Society
  http://www.maineherp.org/

Birds

Most birds visit a stream, river, or riparian environment at some point during their life. Raptors, diving birds, and wading birds, however, are groups of birds that commonly are found near aquatic environments because they often feed on aquatic organisms such as fish and invertebrates. Raptors, such as bald eagles *(Haliaetus leucocephalus)* or osprey *(Pandion haliaetus)*, can sometimes be seen diving from great heights in the air into rivers and streams to grab a fish swimming near the surface. Osprey feed mainly on fish, while eagles may sometimes scavenge dead animals or hunt waterfowl. Divers, such as cormorants, mergansers, and kingfishers feed primarily on fish, while ducks feed primarily on invertebrates and plant matter. The great blue heron *(Ardea herodias)* is one of the more recognizable riverine wading birds, and it commonly eats fish. *(See **Figure 3-7** for some example photographs of birds.)*

FIGURE 3-6

Representative types of reptiles and amphibians that frequent streams and rivers. Examples include: a) Eastern Painted Turtle *(Chrysemys picta)**; b) Wood Turtle *(Glyptemys insculpta)***; c) Northern Watersnake *(Nerodia sipedon)** ; d) Northern Redbellied Snake *(Storeria occipitomaculata)** ; e) Northern Dusky Salamander *(Desmognathus fuscus)**** ; f) Northern Two-lined salamander *(Eurycea bislineata)****.

** Photos "a," "c," and "d": Brookhaven National Laboratory's Upton Ecological and Research Reserve; http://www.bnl.gov/esd/reserve.*

*** Photo "b" by John Mosesso at National Biological Information Infrastructure; http://images.nbii.gov/*

**** Photo "e" and "f" by Pennsylvania (PA) Fish & Boat Commission; http://www.fish.state.pa.us/salamander.htm.*

FIGURE 3-7

Representative types of birds that frequent streams and rivers. Examples include a) bald eagle *(Haliaetus leucocephalus)* [p.c.: i]; b) osprey *(Pandion haliaetus)* [p.c.: ii]; and c) belted kingfisher *(Ceryl alcyon)* [p.c.: iii].

Photo credit: i) photo by Dave Menke, contributor: National Conservation Training Center — Publications, U.S. Fish and Wildlife Service Digital Library System (USFWS DLS), http://images.fws.gov/;

ii) http://www.nps.gov/acad/photos/osprey.htm, photographer unknown;

iii) photo by C. Schlawe; contributor: Alaska Maritime National Wildlife Refuge; USFWS DLS.

Mammals

Many types of mammals can occasionally be seen in streams or rivers. Some mammals that are more commonly seen in or around streams and rivers are described here. Moose *(Alces americana)*, the iconic symbol of Maine for some people, can sometimes be found in slower sections of streams and rivers feeding on aquatic plants. Bats (for example, *Myotis lucifugus* and *Lasionycteris noctivagans*) commonly are active at dusk or later in the night, feeding upon swarms of adult aquatic insects that have emerged from aquatic environments in addition to other habitats. Mink *(Mustela vison)* feed on a variety of organisms such as small mammals and birds, but they also feed upon aquatic invertebrates and fish. Muskrats *(Ondatra zibethica)* are large rodents that feed partly upon aquatic vegetation, invertebrates, and fish, and they build refuges with tunnels that typically have entrances under water but which burrow up into drier conditions in stream banks and other areas. River otters *(Lutra canadensis)* feed primarily on fish, though they also feed upon frogs, crayfish, insects, and sometimes even small birds and mammals. *(See **Figure 3-8** for some example photographs of these mammals.)*

FIGURE 3-8

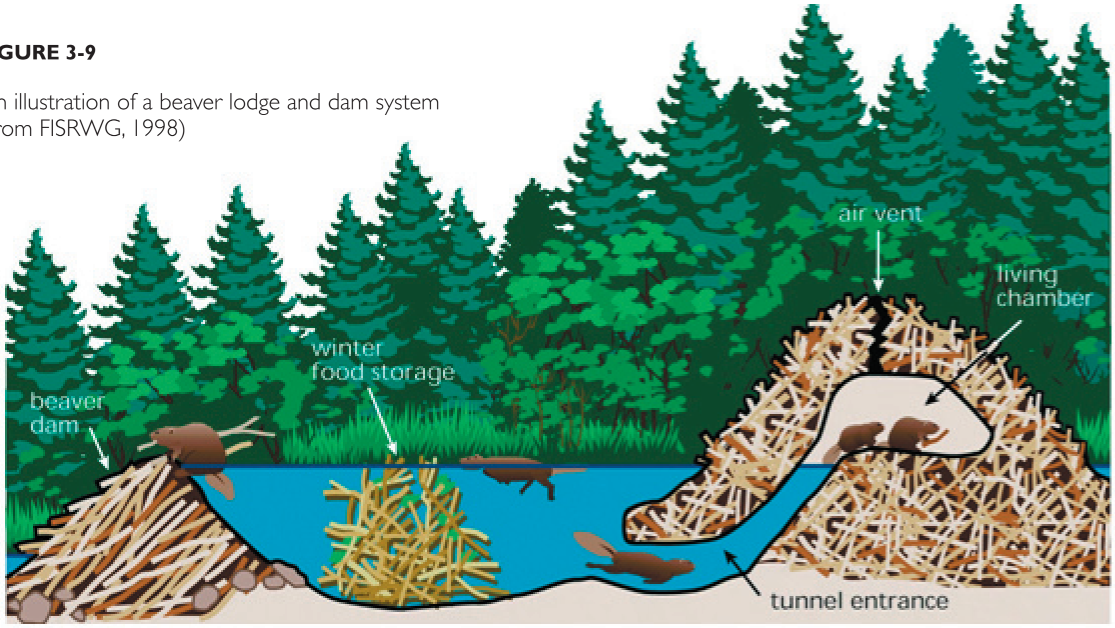
Representative types of mammals that frequent streams and rivers. Examples include:
a) river otter [p.c.: i]; b) beaver [p.c.: ii]; and c) moose [p.c.: iii].

Photo credits: All photos from U.S. Fish and Wildlife Service Digital Library System, Contributor: Division of Public Affairs, http://images.fws.gov/. Photos taken by i) Ron Singer; ii) Tom Smylie; and iii) Ralph Town.

Beaver *(Castor canadensis)* are considered to be the mammals that have the biggest influence on stream and river ecosystems, with one notable exception: humans! Beaver were trapped and hunted heavily for their fur when Europeans began to settle North America. For over a century, beaver were greatly reduced in numbers, and therefore there was a major decrease in the abundance of beaver-created dams, backwaters, and wetlands. Only recently have their numbers been starting to increase, as evidenced by increasing numbers of beaver dams. Beaver build dams and lodges (homes) of sticks and mud. Their dams add a lot of habitat diversity to stream and river ecosystems because waters in the ponds behind their dams are slowed, and nearby riparian areas and floodplains are flooded ***(Figure 3-9)***. In these wetland type habitats, sediments and organic matter (food) settle out, and slow-water, wetland-adapted organisms (certain invertebrates and young fish) begin to thrive. These areas locally retain some of the food and energy resources that may have been lost downstream due to otherwise quick currents. As for food themselves, beaver feed mainly on the inner bark of aspen, willow, and birch trees. Some people consider beaver to be a nuisance because of the alterations they make to stream corridors and human infrastructure. Other people greatly value the habitat diversity they bring to an area.

FIGURE 3-9

An illustration of a beaver lodge and dam system (from FISRWG, 1998)



For more information see:

- Maine Department of Inland Fisheries & Wildlife: http://www.maine.gov/ifw/wildlife/index.htm

C. Riparian Zones, Energy/Food Webs, and Wood

FIGURE 3-10

An example of a healthy riparian zone providing shade and organic matter to a stream in Maine. *(Photo taken by John Sowles.)*

Forests and other vegetated areas alongside streams, known as the **riparian zone,** should be considered part of the stream ecosystem *(see Figure 3-10 for an example of a healthy riparian zone)*. Riparian zones and streams interact in a variety of mutualistic ways:

Temperature: Riparian forests provide shade to keep stream waters cool. This is important because many of Maine's native fish require cold water habitats. The stream also cools and humidifies the adjacent riparian area.

Bank stability: Riparian vegetation root networks (especially those of trees) help to hold streambank soil in place.

Reducing the impact of very dry and very wet weather periods: Floodplain areas with riparian forests help to regulate stream flows during floods. They act as temporary storage areas for water distributed along the length of a stream so that overall flooding problems are less severe at downstream locations. Groundwater, which is stored within and slowly released from these streamside (as well as upland) areas into the stream, helps to maintain streamflow during dry summer months.

During dry periods, the stream can recharge soil moisture to the benefit of riparian vegetation.

Habitat: Riparian forests are critical habitats and travel corridors for many types of wildlife including moose, deer, otter, osprey, turtles, frogs, salamanders, and terrestrial forms of insects, to name a few. Additionally, flying adult forms of aquatic insects can be a significant food source for some of these animals — especially bats, birds, and spiders.

Leaves and twigs: Riparian forests introduce leaves and twigs into streams. These are important food sources for many stream organisms, including microbes and macroinvertebrates. These small creatures, in turn, become a food source for fish and other animals.

Large wood: Large wood (e.g., tree trunks, branches, and root wads) falls into streams as some of the trees in riparian forests die and fall over. (Large wood is sometimes referred to as "large woody habitat" or "large woody debris" [LWD].) When large pieces of wood land in a stream, they provide a number of important functions:

- **Storing food:** Fallen tree trunks and branches are important to streams because they retain food materials (leaves and twigs) in place so the small stream creatures can have a year-long food source ***(Figure 3-11).*** Organic matter such as leaves and twigs, which originates from terrestrial sources such as trees and plants, and which can serve as a food resource for stream organisms, is termed an allochthonous energy source.

- **Habitat diversity:** Piles of large wood act as cover, or resting/hiding places, for fish and other organisms. Large fallen trees also help to scour out pools, which are an important type of habitat in streams. This variety of habitat is important because, in general, greater biological diversity is associated with greater habitat diversity.

FIGURE 3-11

A fallen tree in a stream, also called large woody debris (LWD) or a "snag". This woody debris helps create habitat diversity (e.g., scoured pools; substrate for invertebrates; etc.) and also helps retain things like fallen leaves (a food resource for many aquatic invertebrates).

(Photo taken by John Sowles.)

- **Pollution prevention:** In most cases, riparian zones, with their uneven ground surfaces, vegetation, root networks, and "duff" (layers of fallen organic material such as leaves and needles) help filter out pollutants carried by stormwater. *(We'll discuss the role of vegetated riparian zones in reducing pollution more in the next unit.)*

Allochthonous energy sources are energy/food resources that are contributed to streams from *external* (e.g., terrestrial) sources. **Autochthonous** energy/resources originate from *internal* sources (i.e., from within the stream ecosystem itself.)

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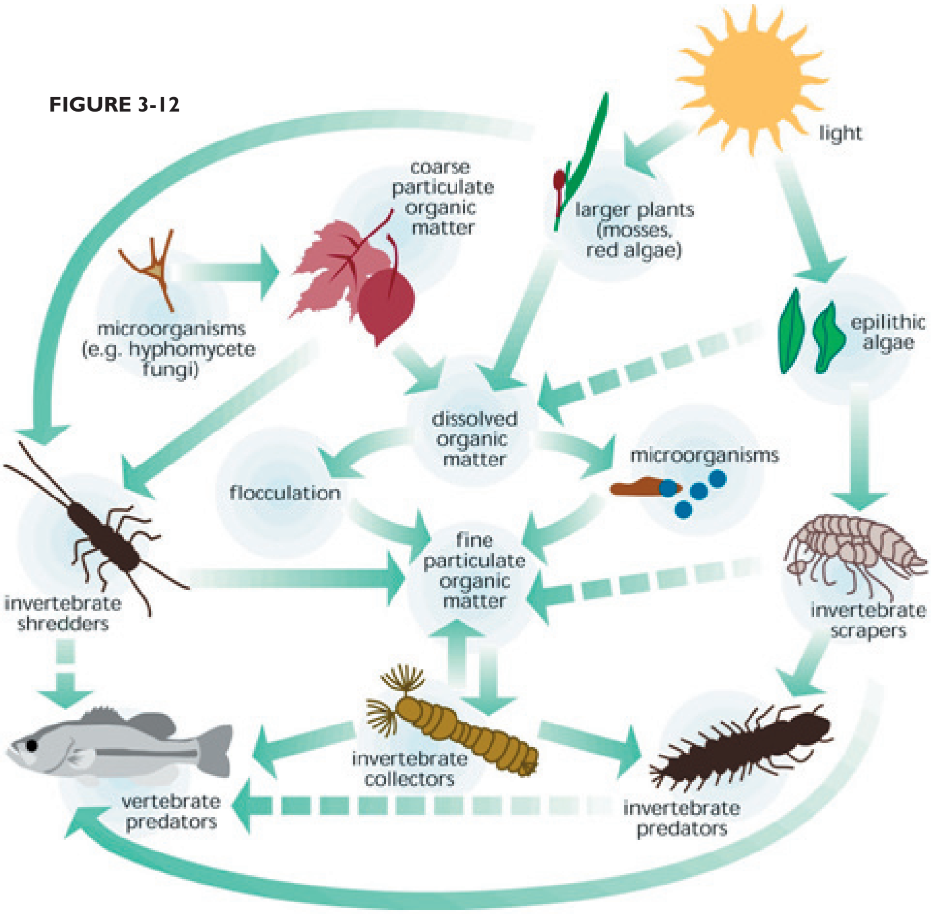
Aquatic organisms, like macroinvertebrates, can be separated into different groups called functional feeding groups based upon their different feeding habits or food preferences and how they process organic matter in stream systems. Examples of types of macroinvertebrate **functional feeding groups** include "shredders," "grazers/ scrapers," "collectors (gatherers/ filterers)," and "predators" and are based upon the shape of their mouthparts and their eating styles and food preferences.

FIGURE 3-12



Stream biota and food relationships typically found in streams. (From FISRWG [1998].)

Aquatic organisms, like macroinvertebrates, can be separated into different groups called functional feeding groups based upon their different feeding habits or food preferences and how they process organic matter in stream systems. Examples of types of macroinvertebrate **functional feeding groups** include "shredders," "grazers/scrapers," "collectors (gatherers/filterers)," and "predators" and are based upon the shape of their mouthparts and their eating styles and food preferences.

Figure 3-12 shows a very simplified food/energy web within a stream or river ecosystem, with energy pathways begin driven by either autochthonous or allochthonous energy sources. Both pathways depend upon the sun as their primary energy source, but the energy is captured and transferred in different ways. These two pathways can coexist in the same stream section, however one pathway is usually more dominant than the other as dictated by factors such as the local availability of sunlight and the amount of available organic matter of terrestrial origin (e.g., from riparian forests).

The **allochthonous** path begins with organic matter that originates from outside the stream. This coarse particulate organic matter, ("CPOM;" e.g., tree leaves, forest litter, etc.), is derived from trees and other vegetation harnessing the sun's energy. The allochthonous path continues with this material falling into the stream and becoming colonized by microorganisms such as fungi and bacteria ***(Figure 3-12).*** (Nutrient-rich microorganisms colonizing decaying leaves and twigs enhance the nutritional value of the organic matter for higher-level consumers such as macroinvertebrates.) These microorganisms, along with stream water action and shredder-type invertebrates, begin to chew up, ingest, and break down the organic matter into smaller sizes. (Those smaller sizes of organic matter pieces are referred to as fine particulate organic matter [FPOM] and dissolved organic matter [DOM]). These smaller organic materials serve as a resource for a variety of organisms including microorganisms and macroinvertebrate types known as collectors. Predatory types of macroinvertebrates then feed upon these shredders and collectors. Predatory fish feed upon many different types of macroinvertebrates (and sometimes other fish).

The **autochthonous** path relies upon stream-dwelling algae and plants to capture energy/food material ***(Figure 3-12).*** In this pathway, these producers either excrete nutrients and DOM (which can be used directly as an energy/food source), or they serve as a food source for higher-level consumers such as macroinvertebrate "scrapers." Predatory types of macroinvertebrates then feed upon these scrapers. Predatory fish feed upon many different types of macroinvertebrates (and sometimes other fish).

For a variety of information resources related to riparian zones, visit the Maine Stream Team Program's riparian webpage at: http://www.maine.gov/dep/blwq/docstream/team/riparian.htm.

D. Biological Communities in the Hyporheic Zone

The hyporheic zone, described earlier, serves some important functions. Its habitat is comprised of a blend of organisms commonly found in either surface water (high oxygen and light availability) or groundwater (low oxygen and light availability) environments. Generally, these organisms got into the hyporheic zone either by accident or they are a species with a wider tolerance for various environmental conditions than other species found in either strictly surface water or groundwater environments. (The term hyporheos is applied to organisms found in the hyporheic zone.) They may spend part ("occasional" hyporheos) or all ("obligate" or "permanent" hyporheos) of their life cycle in the hyporheic zone.

Since hyporheic zones are beneath streams and their floodplains, this habitat may serve as one potential source of colonists to re-establish local biological communities in streams that have recently gone through a heavy disturbance such as a catastrophic flood. Also, since the water has greater contact time with the sediments, hyporheic zones can also have a significant impact on nutrient cycles and potentially the removal of pollutants within streams through the activities of hyporheic bacteria and other microbes (sometimes called "biofilms") *(Harvey and Wagner, 2000)*. Relatively recent research across the globe has indicated that hyporheic zones and their biological communities can be quite extensive in some parts of the world (e.g., in the western U.S. some zones extend up to 2 km away from the edge of river channels [*Stanford et al., 1994; Boulton, 2000*]). In Maine, however, it is likely that these regions are not nearly as extensive or large as some of these other places due to local geological characteristics such as those described earlier. Hyporheic zones are generally expected to be found in stream segments in Maine that flow through floodplains (and over channel bottoms) comprised of unconsolidated sediments, and not in streams segments that are flowing directly over bedrock or solid clays.

Figures 3-13 and ***3-14*** illustrate both lateral and vertical interactions between streams and hyporheic zones (including both floodplain and sub-channel regions). In Maine, lateral interactions are probably more important than vertical ones, though both types of interactions may have

FIGURE 3-13

A schematic representation of changes in the direction of vertical hydrologic exchange (between hyporheic waters and surface waters; indicated by the arrows) in response to alterations in stream bed morphometry (e.g., transitions from riffle – pool – riffle bedforms). (After Hauer and Lamberti [1996], Vaux [1968], and White et al. [1987].)

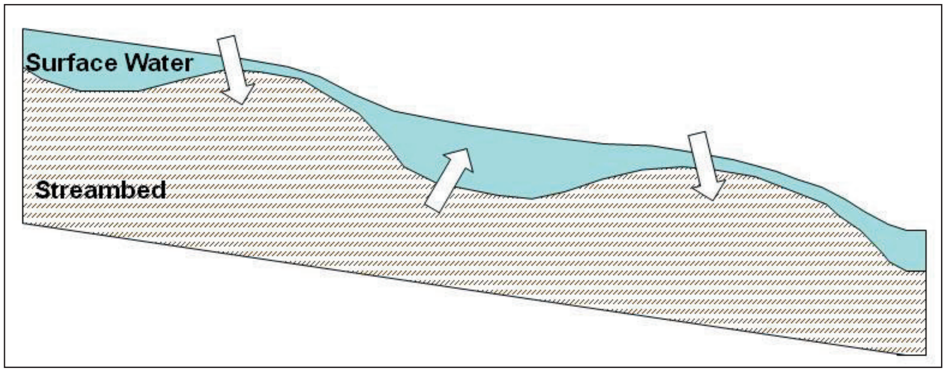
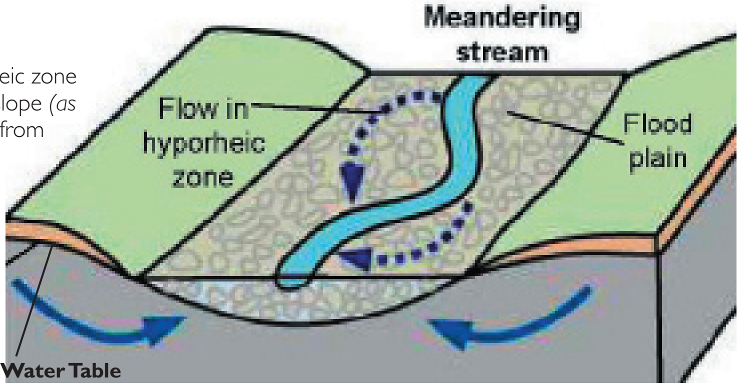


FIGURE 3-14

Surface-water exchange with ground water in the hyporheic zone is associated not only with abrupt changes in streambed slope *(as in Figure 3-13)*, but also with stream meanders. (Adapted from Winter et al. [1998].)



significant ecological effects. As far as vertical interactions, at the stream-reach scale there may be **"upwelling"** and **"downwelling"** water (if the streambed sediments are porous enough). In areas of upwelling, typically the upstream end of pools, one would more likely find abundant obligate hyporheos and "true" groundwater organisms in the hyporheic zone. In regions of downwelling, typically the upstream end of riffles, one would more likely find occasional hyporheos and "true" stream organisms in the hyporheic zone.

E. River Continuum

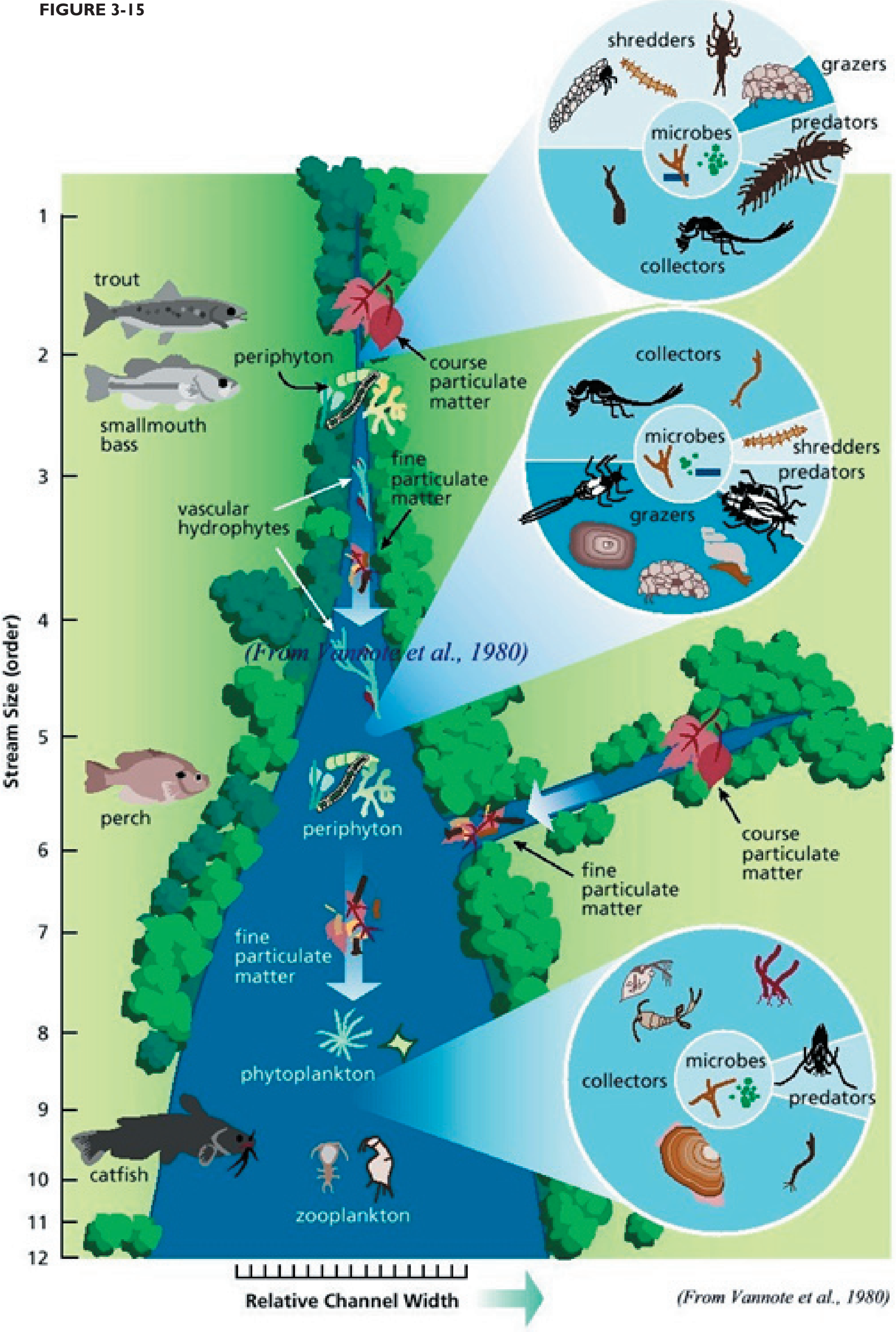
Theories and models are continually being developed to try to understand, explain, and predict changes in ecosystems that one might see at different locations of a stream or river within a river network. The River Continuum Concept (RCC) *(Vannote et al., 1980)* is one of the more commonly (though not universally *[FISRWG, 1998]*) studied and cited stream ecology theories. The RCC ***(Figure 3-15)*** attempts to explain, in very general terms, the relationship of a stream, its food and energy resources, and the inhabiting organisms to position in the watershed, general morphological (shape) changes of the channel, downstream transport of food and energy, and functional organization of the community.

One must remember that these are general predictions and that each stream/river watershed has its own unique geologic, topographic, hydrologic, climatic, and surrounding land-use conditions, which may explain deviations from the predictions of the RCC model. (For example, not every stream in Maine originates from densely forested, small headwater streams in mountains. Some streams originate from wetlands or ponds in low elevations.) Also, human activities, such as removing riparian vegetation or damming, can disrupt or reset the continuum pattern and thus RCC predictions. Still, the RCC helps scientists predict the types of biological communities they might expect to encounter while sampling, given that they know characteristics such as the local geology, surrounding land-cover and -use, elevations, etc. near their sampling site.

In the general RCC model stream system, headwater streams (1st - 3rd ["low"] order streams) are shaded by the riparian forest canopy. Because only limited amounts of sunlight reach the stream channel bottom, the growth of algae, periphyton, and aquatic macrophytes is limited. The local food web will be primarily based upon allochtonous organic energy/food source (e.g., macroinvertebrates feeding primarily upon leaves and other organic matter originating from outside the stream). Shredder-type macroinvertebrates tend to be more abundant in these types of streams, though other functional feeding groups are present too. Fish are mostly small and live close to and feed on bottom organisms. (**Note:** The "pie charts" in ***Figure 3-15*** show how the relative abundance of various functional feeding groups can change from headwaters down to large, deep rivers.)

As one moves downstream into mid-order order streams (4th - 6th order), the channels become wider and somewhat deeper. Silts and sand start to become more abundant (though substrates may still be predominantly large rocks), and water temperatures become more variable. Since the channels are wider, the forest canopy cover exerts less influence on the stream channel (decreased shade, input of leaves, etc.), and dissolved nutrients increase due to breakdown of organic matter upstream. This situation generally results in an increase in the relative abundance of periphyton and aquatic macrophytes, and thus, the relative importance of authocthonous food

FIGURE 3-15



The River Continuum Concept. The concept proposes a relationship between stream size and the progressive shift in structural and functional attributes. (From FISRWG [1998]. Original source: Vannote et al. [1980]. Used with the permission of NRC Research Press.)

pathways and consumers (e.g., macroinvertebrate scrapers/grazers) in the system. Also, because organisms like shredders have been so busy in the headwaters, they've broken down lots of large pieces of organic matter (CPOM) into smaller pieces (e.g., FPOM, DOM), so collectors can be relatively abundant. Because of the more varied types of food resources, diversity in these mid-order streams can be quite high.

The wider, deeper, typically slow-flowing river reaches (7th - 9th ["high"] order streams), tend to be more turbid because of higher suspended silt and sand loads. These conditions tends to reduce the amount of light that reach the channel bottom, thus reducing the growth of periphyton and macrophytes, and increasing the importance of suspended algae (phytoplankton) and macrophytes growing along the river's edges. The channel bottoms tend to be sandier/siltier in large rivers than the lower order stream reaches. Shredders and scrapers/grazers tend to be present in low numbers due to the lack of CPOM and periphyton. Collectors tend to be dominant in these reaches, with predators being the second-most dominant group. Fish are more pelagic (living in the water column) behaviorally and tend to be large in size.

NOTE: We attempt to keep the explanation of the RCC fairly simplified in this manual. For example, we do not discuss shifts in P/R ratios. The P/R ratio is the ratio of stream primary productivity (P) (e.g., photosynthesis by algae and macrophytes) to community respiration (R). According to the RCC, the P/R ratio varies as one moves along the river continuum. (For more detailed explanations of the RCC, refer to the following texts: Vannote et al. (1980), Cushing and Allan (2001), FISRWG (1998), Allan (1995, 2007).

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F. Stream / River Connectivity (Lateral, Longitudinal, and Vertical)

Connectivity (ability to freely exchange water, materials, organisms, etc.) between stream/river reaches and their surroundings is very important to the health and integrity of these ecosystems. Maintaining these connections as best as possible is an important goal in protecting and restoring streams and rivers.

Streams and rivers move water and other materials longitudinally from upstream areas to downstream areas. Some organisms are at the mercy of stream flows and floods, and mostly only stay within a small area or move in a downstream direction. Other organisms (e.g., fish) can often move freely in either an upstream or downstream direction. Human structures, like roads culverts *(especially "hanging" or "perched" culverts; see **Figure 3-16**)* and dams lacking fish passage structures, can disrupt **longitudinal** (upstream-downstream) connectivity and limit the passage of water, nutrients, large wood and other organic matter, and migratory aquatic animals such as fish, amphibians, and reptiles. Problems such as hanging/perched culverts can easily be identified by volunteers and brought to the attention of municipal officials, state/federal agency staff, and river protection groups. When it is time to replace deteriorating culverts, they can be replaced by better designed culverts (or preferably arches or bridges, which maintain natural stream bottom), improving upstream/downstream continuity. These upgrades may cost more in the short term, but they may have increased lifespans, along with better aquatic organism passage, that outweigh short-term costs.

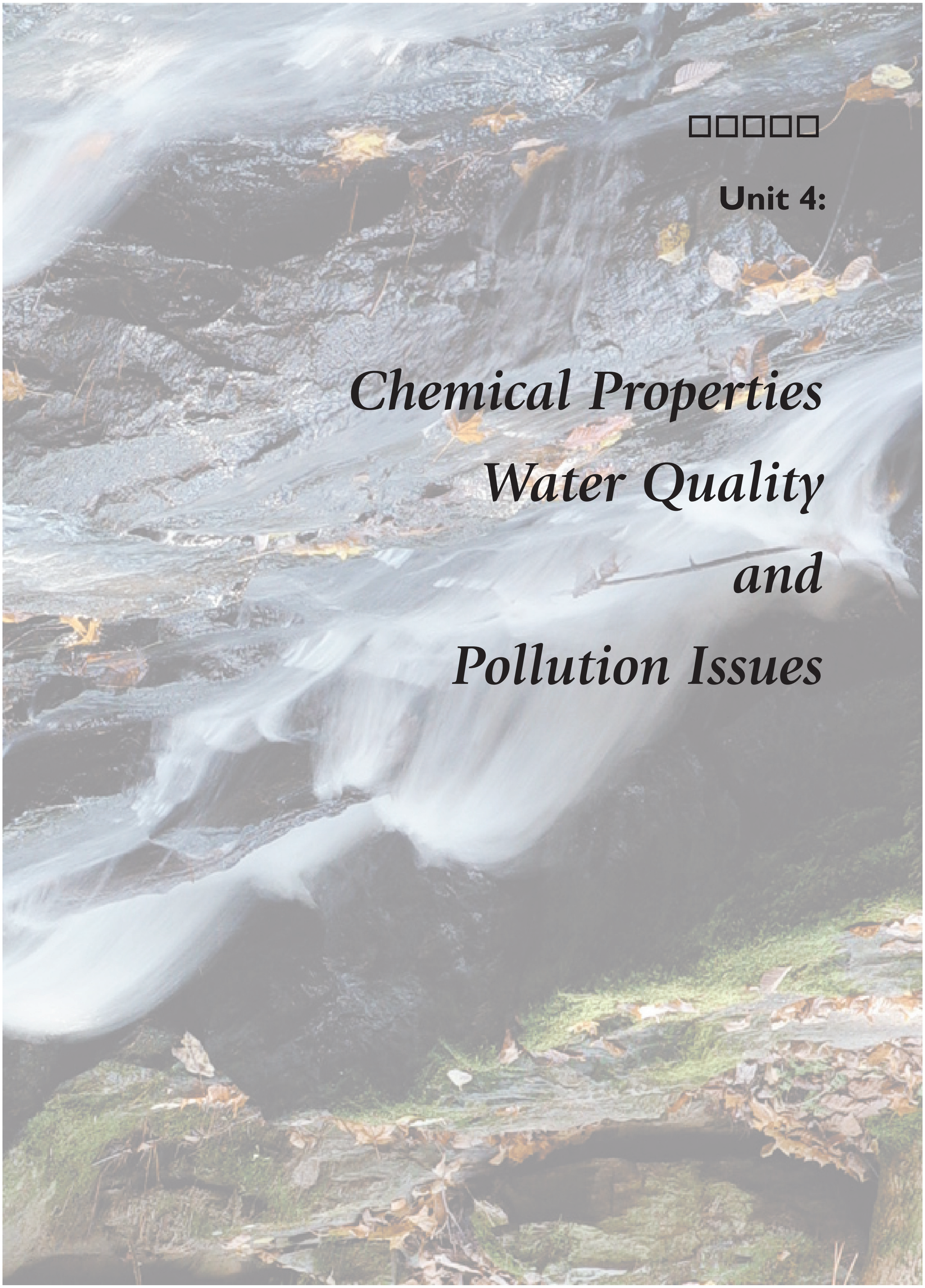
Streams and rivers also have **vertical** connections. Large rivers can be quite deep, and often have several types of communities that exchange materials (nutrients, gases, organisms, etc.) with one another: hyporheic, benthic, and pelagic. In shallow, turbulent areas, these two zones can mix and affect one another more than they would in very deep areas. In both shallow and deep streams/rivers, exchanges of materials (nutrients, gases, organisms, etc.) can take place between surface waters and

FIGURE 3-16

Images of "hanging" (a.k.a. "perched") culverts. *Photo source: Maine DEP.*

both hyporheic and groundwater environments. These connections can be severed or damaged by channelizing river sections and replacing their banks and bottoms with concrete (not very common anymore) or dredging activities. *(We will discuss the importance of various gases and nutrients to stream ecosystems in more depth in Unit 4.)*

Finally, streams and rivers have **lateral** connections with their surroundings. Streams/rivers are highly dependent upon their adjacent riparian areas (e.g., shade, leaves/twigs [food], habitat structures [large wood], etc.), which can be severed when riparian/shoreland vegetation is cleared. Floodplains, the lateral elements of stream corridors in many places, play an important role as temporary storage basins for floodwaters, and the thick vegetation on many floodplains provides a roughness that helps slow potentially-erosive floodwaters, both of which can reduce overall flood damage to human structures. Floodplains also contribute organic matter, nutrients, and organisms to stream and river ecosystems when they are flooded, and they are a place where sediments transported during high water events can settle out rather than flush downstream. Cutting off channels from their floodplains (e.g., with berms, other fill material, and/or encroaching development) can confine extra flood energy within the channel and cause the channel to widen or downcut/incise.



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Unit 4:

Chemical Properties Water Quality and Pollution Issues

UNIT 4:
Chemical Properties, Water Quality, and Pollution Issues

Water quality is the suite of environmental conditions in a stream or river which influence the types of aquatic organisms that can exist at a given location. When scientists and managers refer to water quality, they are referring mostly to various water chemistry conditions, but also usually to some important non-chemical factors such as water temperature and the amount of fine sediments (i.e., sands and silts) that exist on the stream bottom and in the water column. We begin this unit by providing an overview on Maine's Water Quality Classification System. Next, we discuss basic water chemistry, water quality, and pollution parameters and issues. Finally, we provide an overview of methods that can be used to protect streams and river from problems that can degrade water quality.

(**NOTE:** Refer to *Appendix O* for details about the various measurement units (e.g., mg/L, ppm, ppb, μm), including conversion tips, used in this unit.)

A. Overview of Water Quality and the Classification of Maine Waters

Purpose of Classification

Maine has had a water classification system since the 1950's. This classification system establishes water quality goals for the State. (More information about water quality is presented later in this document.) The classification system is used to direct the State in the management of its surface waters, protect the quality of those waters for their intended management purposes, and where standards are not achieved, direct the State to enhance the quality to achieve those purposes. The classification standards establish designated uses, related characteristics of those uses, criteria necessary to protect the uses, and establish specific conditions for certain activities such as the discharge of wastewater.

Water Quality Classes

The State has four classes for freshwater rivers, three classes for marine and estuarine waters, and one class for lakes and ponds. (We will just discuss streams and rivers here.) All attain the minimum fishable-swimmable standards established in the federal Clean Water Act. Table 4-1 provides an overview of the classification system for streams and rivers. Discussion of many of the parameters presented in the table can be found later in this unit.

The classification system should be viewed as a hierarchy of risk, more than one of use or quality, the risk being the possibility of a breakdown of the ecosystem and loss of use due to either natural or human-caused events. Ecosystems that are more natural in their structure and function can be expected to be more resilient to a new stress and to show more rapid recovery. Class AA involves little risk since activities such as waste discharge and impoundment are prohibited. The expectation to achieve natural conditions is high and degradation is unlikely. Class A waters allow impoundments and very restricted discharges, so the risk of degradation while quite small, does increase since there is some small human intervention in the maintenance of the ecosystem. Class B has fewer restrictions on activities but still maintain high water quality criteria. Finally, Class C has the least restrictions on use and lower (but not low) water quality criteria. Class C waters are still good quality, but the margin for error before significant degradation might occur in these waters in the event of an additional stress being introduced (such as a spill or a drought) is the least.

(**NOTE:** More detailed information about this classification program can be found at http://www.maine.gov/dep/blwq/docmonitoring/classification/index.htm. Information about Maine DEP's stream and river monitoring and assessment efforts can be found at http://www.maine.gov/dep/blwq/monitoring.htm.)

Table 4-1: Maine's water classification criteria for freshwaters.

*Percent saturation (% sat.) is the amount of oxygen in a liter of water relative to the total amount of oxygen that the water can hold at that particular temperature.

**These criteria refer to instantaneous (top number) and geometric mean (bottom number) measurements for *E. coli* bacteria of human or domestic animal origin occurring in the water between May 15 and September 30.

***Additional standards for monthly averages of dissolved oxygen concentration may also apply in Class C waters.

MAINE'S WATER CLASSIFICATION CRITERIA FOR FRESHWATERS

	Narrative Criteria		Numeric Criteria	
Statutory Water Class	Aquatic Life (Biological)	Habitat	Dissolved Oxygen*	Bacteria (E. coli)**
AA	as naturally occurs	free-flowing and natural	as naturally occurs	as naturally occurs
A	as naturally occurs	natural	7 mg/L; or 75% sat.	as naturally occurs
B	supports all aquatic species indigenous to the receiving water; no detrimental changes to the resident biological community	unimpaired	7 mg/L; or 75% sat.	236/100 mL 64/100 ml
C	supports all species of fish indigenous to the receiving waters and maintains the structure and function of the resident biological community	habitat for fish and other aquatic life	5 mg/L; or 60% sat.; ***	236/100 mL 126/100 ml

NOTE: This table is a simplified summary of basic minimum criteria for fresh surface waters that are not considered to be great ponds. Other criteria may apply in certain circumstances. Refer to the following website for the latest detailed, up-to-date information, particularly the sections entitled "465. Standards for classification of fresh surface waters" and "466. Definitions": http://www.maine.gov/dep/blwq/docmonitoring/classification/index.htm.

B. Water Chemistry, Water Quality, and Pollution

In this section we describe some basic water chemistry, water quality, and pollution parameters and issues that greatly influence the types and quality of aquatic organism communities found in streams and rivers.

DISSOLVED OXYGEN, BIOCHEMICAL OXYGEN DEMAND (BOD), AND TEMPERATURE

(**NOTE:** Temperature is a "physical attribute" of streams, but it frequently is considered a water quality parameter by stream scientists and managers, so it is included in this section.)

Dissolved oxygen (D.O.) is the amount of oxygen that is dissolved in the water. All living organisms, except for certain types of bacteria, need oxygen to survive. Organisms living in the water have the ability to use this dissolved oxygen to "breathe" (or respire). Oxygen levels (concentrations) that are too low severely reduce the diversity and population of aquatic communities. Therefore the amount of D.O. in the water is very important to stream life. Dissolved oxygen is one of the measures used in the Maine Water Classification Program to distinguish rivers and streams as either Class AA, A, B, or C ***(Table 4-1).***

All living organisms, except for certain types of bacteria, need oxygen to survive. Organisms living in the water have the ability to use this dissolved oxygen to "breathe" (or respire). Oxygen levels (concentrations) that are too low severely reduce the diversity and population of aquatic communities. Therefore the amount of D.O. in the water is very important to stream life.

Oxygen enters rivers and streams in several ways: by diffusion from the atmosphere at the water surface, by mixing with the atmosphere as the water tumbles over natural water falls, riffles (shallow, rocky areas), and dams, and from the release of oxygen by algae and plants during photosynthesis.

Generally, there is enough oxygen in streams for both the decomposition of leaves, twigs, and other materials which fall or are washed into the stream, and also for organisms living in the stream, such as fish and aquatic insects. However, if a stream experiences an increase in organic matter from sources such as runoff of manure or a failing septic system, bacteria (decomposers) may increase in numbers and activity, which can use up available oxygen needed by other stream organisms. Low oxygen can stress organisms so that they will not be able to successfully reproduce or grow. In rare, extreme cases, very low dissolved oxygen concentrations can kill aquatic organisms. Water with less than 1 milligram per liter (mg/L) of oxygen is considered anoxic (little or no oxygen present); less than 5 mg/L of oxygen is generally considered stressful - many fish and aquatic insects would avoid these areas. Even levels of 5-7 mg/L are stressful to some coldwater species of fish if the % saturation is low. (Percent saturation provides a measure of the capacity for oxygen to cross gill membrane barriers and enter the bloodstream of an organism.) Greater than 7 mg/L is considered desirable for all aquatic life.

Biochemical oxygen demand (BOD) is a laboratory test estimating the amount of oxygen-demanding substances in water samples. The oxygen depletion of a water sample is measured over a time increment — typically a five-day test (BOD_5). Examples of oxygen-demanding substances include naturally occurring organic matter (e.g., leaves, dead aquatic organisms), organic matter discharged from wastewater treatment plants (e.g., sewage, industrial/processing wastes), and ammonia.

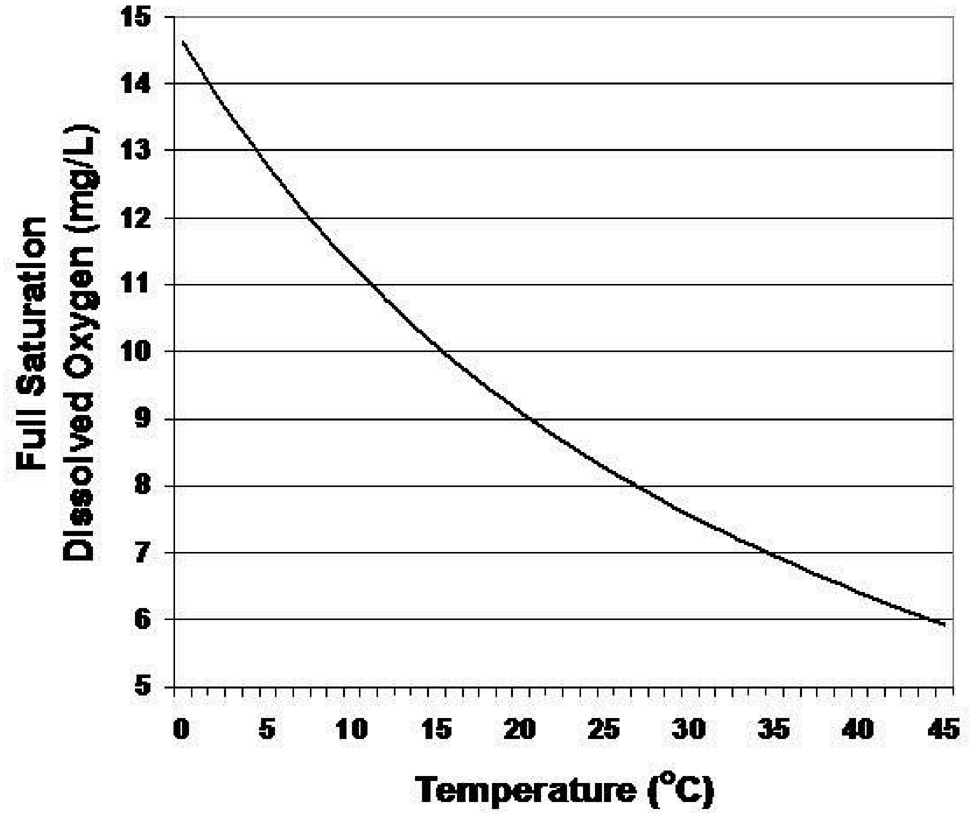
These substances are usually decomposed or converted to other compounds by bacteria if there is sufficient oxygen present in the water. If the BOD level is high, it might reduce dissolved oxygen concentrations in a stream or river enough to stress aquatic organisms such as fish and macroinvertebrates. Respiration by organisms can also elevate BOD, as commonly occurs in waterbodies experiencing excessive algae growth.

Temperature is the measure of heat in the water and it can affect stream water chemistry and biology. For example, the amount of oxygen water can hold is directly related to the temperature of the water. The lower the temperature the more oxygen the water can hold; inversely, the warmer the water the less oxygen the water can hold. The amount of oxygen water can hold under ideal (full saturation) conditions, called the saturation level, can be determined by using solubility tables, charts ***(Figure 4-1)*** or the percent saturation function of some water quality meters. The actual amount of oxygen measured in a stream can be higher, lower, or the same as the oxygen values in the table. The percent (%) saturation of dissolved oxygen (D.O.) in water can be computed by dividing the "measured" D.O. by the full saturation D.O. concentration expected at the water temperature of the sample.

Percent saturation can also be useful in determining causes of oxygen decline in rivers and streams. Oxygen will naturally decline during the summer months as water temperatures rise. However, % saturation should stay about the same (in most cases, fairly close to 100%) even though water temperature may rise and the amount of D.O. in the water drops. If the % saturation declines substantially below 100%, it can be an indication that biological activity (e.g., respiration by excessive amounts of algae at night, microbial decomposition of excessive amounts of organic matter) in the water is using up the available oxygen. (There are some situations where percent saturation of dissolved oxygen levels can exceed 100%. This is called "super-saturation" and typically occurs in streams with lots of algae or aquatic plants that are producing large amounts of dissolved oxygen during daylight hours.)

In Maine, % saturation of oxygen is a measure used to classify rivers and streams into the different classes ***(Table 4-1).***

FIGURE 4-1



Full (100%) saturation dissolved oxygen concentrations at various water temperatures.
To calculate the % saturation, one divides the measured dissolved oxygen concentration of one's sample by the full saturation dissolved oxygen concentration expected at the temperature of the sample. (Adapted from information in USEPA, 1997).

In addition to its effects on dissolved oxygen levels, temperature is important because it affects the amount of biological activity (e.g., the metabolisms of individual organisms) occurring in the stream environment. Cold water slows down biological activity, and thus dissolved oxygen depletion is seldom a problem during the winter. Late summer is usually the most stressful time for aquatic animals due to higher temperatures, relatively low dissolved oxygen levels, and high metabolic demand for oxygen.

Temperature can also determine the kinds of plants and animals found in the stream. For example, salmonids (trout & salmon) generally prefer temperatures below 20 °C (68 °F) but can tolerate slightly higher temperatures for short periods of time. However, constant exposure to temperatures greater than 20 °C may result in the fish being more susceptible to diseases or toxins or having reduced reproduction success. (Some sensitive species may migrate away from these stressful conditions to where conditions are more favorable such as stretches with cool groundwater inputs.) ***Table 4-2*** shows some temperature tolerance values for selected species of fish.

Temperature changes naturally over time as a result of change in weather, season, or time of day, and it can vary from place to place because of cool groundwater seeps or inflows in certain locations. Human activities can alter stream water temperatures at various locations in a watershed. Some examples of these activities include the removal of (shading) streambank vegetation, the creation of impoundments (a body of water confined by a barrier, such as a dam), discharge of cooling process water, and inputs of urban stormwater from sun-heated parking lots and roads.

Table 4-2.
Maximum average temperatures for growth and short-term maximum temperatures for selected fish (°C and ° F).
(Adapted from USEPA [1997]; originally from Brungs and Jones [1977]).

Species	Max. weekly average temp. for growth (juveniles)	Max. temp. for survival of short exposure (juveniles)	Max. weekly average temp. for spawning [a]	Max temp. for embryo survival
Atlantic salmon	20 °C (68 °F)	23 °C (73 °F)	5 °C (41 °F)	11 °C (52 °F)
Brook trout	19 °C (66 °F)	24 °C (75 °F)	9 °C (48 °F)	13 °C (55 °F)
Rainbow trout*	19 °C (66 °F)	24 °C (75 °F)	9 °C (48 °F)	13 °C (55 °F)
Smallmouth bass*	29 °C (84 °F)	--- ---	17 °C (63 °F)	23 °C (73 °F)
Largemouth bass*	32 °C (90 °F)	34 °C (93 °F)	21 °C (70 °F)	27 °C (81 °F)
Common carp*	--- ---	--- ---	21 °C (70 °F)	33 °C (91 °F)

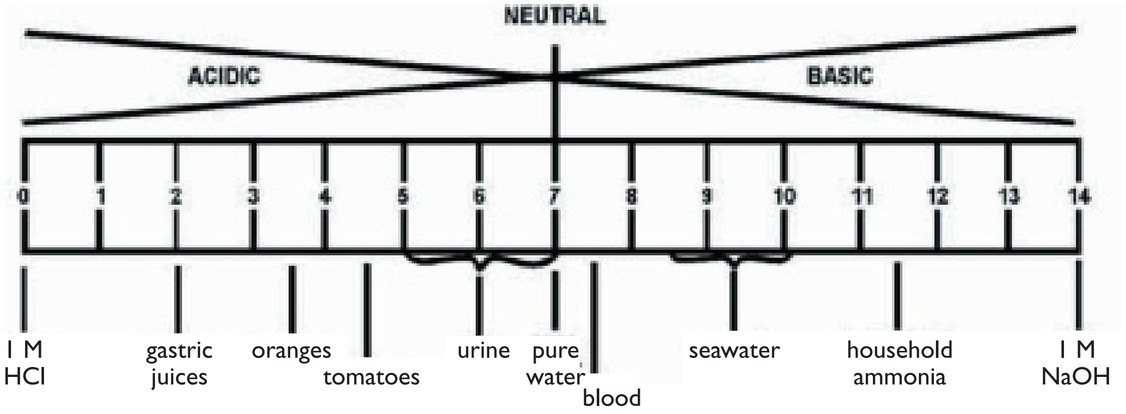
[a] - Optimum or mean of the range of spawning temperatures reported for the species
[b] - Upper temperature for successful incubation and hatching reported for the species
* = not native to Maine

pH

The term "pH" is used to indicate the alkalinity or acidity of a substance as ranked on a scale from 1.0 to 14.0. pH comes from the French term "puissance d'Hydrogene", or the strength of hydrogen. Acidity increases as the pH gets lower. ***Figure 4-2*** presents the pH of some common liquids. The pH scale measures the logarithmic concentration of hydrogen (H^+) and hydroxide (OH-) ions, which make up water ($H^+ + OH^- = H_2O$). When both types of ions are in equal concentration, the pH is 7.0 or neutral. Below 7.0, the water is acidic (there are more hydrogen ions than hydroxide ions). When the pH is above 7.0, the water is alkaline, or basic (there are more hydroxide ions than hydrogen ions). Since the scale is logarithmic, a drop in the pH by 1.0 unit is equivalent to a 10-fold increase in acidity. Thus, a water sample with a pH of 5.0 is 10 times as acidic as one with a pH of 6.0, and pH 4.0 is 100 times as acidic as pH 6.0. Pure, distilled water, at 25 °C, has a neutral pH of 7.0. Natural, unpolluted rain water tends to have an acidic pH of about 5.6 because it absorbs carbon dioxide as it falls through the atmosphere, forming carbonic acid. As rain washes over and through soils and rocks, it dissolves materials such as carbonates that help raise the pH up to (typically) the 6.5 to 8.0 range (in unpolluted watersheds).

pH is an important parameter that affects many chemical and biological processes in the water. Maine water quality standards allow a pH range of 6.0 to 8.5 for all freshwater quality classes (i.e., AA, A, B, and C). pH outside this range reduces the diversity in the stream because it stresses the physiological systems of most organisms and can reduce reproduction success. Low pH can also allow toxic elements (e.g., aluminum) to become mobile and/or "available" for uptake by aquatic organisms. Changes in acidity can be caused by atmospheric deposition (acid rain, acid snow melt), local geology, inputs of natural organic acids from the decomposition of organic matter (e.g., leaves), photosynthesis and respiration of aquatic plants and algae (through the uptake and release of carbon dioxide), and certain wastewater discharges.

FIGURE 4-2



The pH values of common liquids. (From USEPA, 1997)

ALKALINITY AND HARDNESS

ALKALINITY

Alkalinity is a measure of the capacity of water to neutralize acids and is also known as the buffering capacity. It is due primarily to the presence of naturally variable bicarbonate (HCO_3^-), carbonate (CO_3^{-2}), and hydroxide (OH^-) ions, with bicarbonate being the major form. Sources of alkalinity include rocks and soils, salts, algal activity, and even certain wastewater discharges.

Like alkalinity, hardness is primarily a function of the geology of the area with which the surface water is associated. Watersheds containing large amounts of limestone are prone to hard water because rainfall and groundwater continually dissolves the rock and carries the dissolved materials to the water system.

In Maine, alkalinity is generally highest in the northern part of the State (the "limestone belt"), and lowest in the southern and coastal parts of the State. (Limestone is sedimentary rock comprised primarily of calcium carbonate [$CaCO_3$].) Even in Maine, there are wide natural variations due to the depth and type of soil material in a watershed. Rivers with alkalinity values less than 10 milligrams per liter are considered poorly buffered. Alkalinity results are typically reported as milligrams per liter of calcium carbonate (mg/L $CaCO_3$).

Measuring alkalinity is important in determining a river's ability to neutralize acidic pollution from rainfall, acid deposition (polluted rain and snow), and other pollutants that may affect the strength of acids in a stream. Because alkalinity varies according to soils and bedrock, certain areas of the State may not have much capacity to neutralize acid inputs. In these cases, rivers are then susceptible to pH shifts, which may eliminate certain species of fish, aquatic insects, amphibians, etc. Spring snowmelts are suspected of damaging the fisheries in some Maine rivers because of sudden shifts in acidity in rivers with low alkalinity.

HARDNESS

Hardness is a characteristic of water caused mainly by the salts of calcium and magnesium, such as bicarbonate, carbonate, sulfate, chloride and nitrate. Like alkalinity, hardness is primarily a function of the geology of the area with which the surface water is associated. Watersheds containing large amounts of limestone are prone to hard water because rainfall and groundwater continually dissolves the rock and carries the dissolved materials to the water system.

The U. S. Geological Survey[1] uses the following guidelines to define water hardness: "soft" = 0 to 60 mg/L (expressed as calcium carbonate [$CaCO_3$]), "moderately hard" = 61 to 120 mg/L, "hard" = 121 to 180 mg/L, and "very hard" = more than 180 mg/L. If the water one uses is "hard", then more soap, detergent or shampoo is necessary to raise a lather. Hard water can produce scale deposits in pipes and water heaters. Additionally, the freshwater toxicity of several common metals such as copper, lead, nickel, silver, and zinc depends on the hardness of the water. Generally, the harder the receiving water, the less toxic the metal will be.

DISSOLVED ORGANIC CARBON, HUMICS, AND TANNINS

Dissolved organic carbon, or "DOC", is composed primarily of two categories of substances: "non-humic" substances — a class of compounds that includes carbohydrates, proteins, peptides, fats, pigments and other low molecular weight compounds that typically are easily degraded, and "humic" substances — a class of compounds that forms most of the organic matter in waters, and which consists of medium- to high-weight acidic complexes that are hydrophilic (having a strong affinity for water) and more persistent (than non-humics).

Tannins are humic substances. They are a diverse class of polyphenolic plant compounds that precipitate proteins, bind to metals, and complex with other compounds. Tannins are common in certain fruits (e.g., grapes, persimmon, blueberry), trees and shrubs (e.g., oaks, fir, some willows, birch, alder, hemlock), plants (e.g., tea, bearberry, heather, bloodroot, alfalfa, sweet gale), and some grasses. Humics, including tannins, usually make their way directly into streams via the decomposition of plant or tree matter (e.g., leaves, wood) that has fallen into streams or indirectly via outflows from wetlands. Humic and tannin substances also often have natural acids associated with them, which can influence pH levels in streams. These substances are often what are responsible for the yellow, tea-brown, or black colors seen in stream and lake waters.

NUTRIENTS AND POLLUTION BY EXCESS NUTRIENTS

Nutrients

Examples of nutrients important in stream and river ecosystems include calcium (Ca^{+2}), sodium (Na^{+1}), potassium (K^{+1}), magnesium (Mg^{+2}) (the *cations*), and chloride (Cl^{-1}), sulfate (SO_4^{-2}), nitrate (NO_3^{-1}), and phosphate (PO_4^{-3}) (the *anions*). For example, both phosphorus and nitrogen are essential nutrients for the plants and animals that make up the aquatic food web. Another example, calcium, is an essential nutrient for the metabolic processes of aquatic organisms in general as well as an important component of structural/skeletal materials of fish, crustaceans, insects, and mollusks in streams and rivers. These elements are sometimes referred to as nutrients because, in small to moderate amounts, they are essential to healthy aquatic life such as plants and animals.

A nutrient that is the least abundant relative to a plant's need for it is called the limiting nutrient. Limiting nutrients limit the growth and reproduction of organisms. Phosphorus is usually the primary limiting nutrient for algae growth in freshwater, such as streams, rivers, and lakes. (Nitrogen is usually the primary limiting nutrient for growth of algae in marine waters.)

PHOSPHORUS

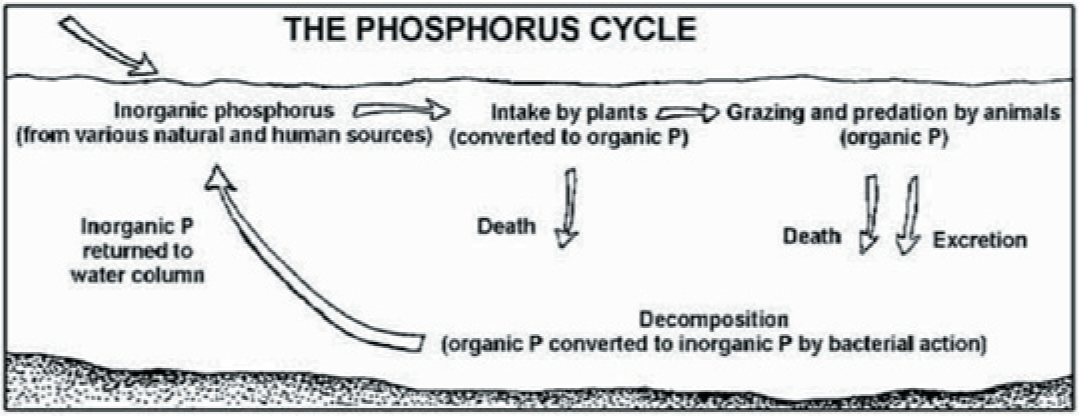
Forms of Phosphorus

Phosphorus has a complicated story. Pure, "elemental" phosphorus (P) is rare. In nature, phosphorus usually exists as part of a phosphate molecule (PO_4). Phosphorus in aquatic systems occurs as organic phosphate and inorganic phosphate. Organic phosphate consists of a phosphate molecule associated with a carbon-based molecule, as in plant or animal tissue. Phosphate that is not associated with organic material is inorganic. Inorganic phosphorus is the form required by plants. Animals can use either organic or inorganic phosphate. Both organic and inorganic phosphorus can either be dissolved in the water or suspended (often attached to particles such as eroded soil) in the water column.

The Phosphorus Cycle

Phosphorus cycles through the environment, changing form as it cycles ***(Figure 4-3)***. Aquatic plants take in dissolved inorganic phosphorus and convert it to organic phosphorus as it becomes part of their tissues. Animals get the organic phosphorus they need by eating either aquatic plants, other animals, or decomposing plant and animal material. As plants and animals excrete wastes or die, the

FIGURE 4-3



A simple diagram of the phosphorous cycle in freshwater systems. (from USEPA, 1997) organic phosphorus they contain sinks to the bottom, where bacterial decomposition converts it back to inorganic phosphorus, both dissolved and attached to particles. This inorganic phosphorus gets back into the water column when the bottom is stirred up by animals, human activity, chemical interactions, or water currents. Then it is taken up by plants and the cycle begins again.

In the field of water quality chemistry, phosphorus is described using several terms. Some of these terms are chemistry based (referring to chemically based compounds), and others are methods-based (they describe what is measured by a particular method). The term "orthophosphate" is a chemistry-based term that refers to the phosphate molecule all by itself. "Reactive phosphorus" is a corresponding method-based term that describes what you are actually measuring when you perform the test for orthophosphate. Because the lab procedure isn't quite perfect, you get mostly orthophosphate but you also get a small fraction of some other forms. More complex inorganic phosphate compounds are referred to as "condensed phosphates" or "polyphosphates". "Total phosphorus" is a measure of all the forms of phosphorus in the sample (orthophosphate, condensed phosphate, and organic phosphate).

Excess Phosphorus Pollution

The presence of algae and other aquatic plants in stream ecosystems is a natural condition, especially when adequate sunlight is available. When extra phosphorus from human activities enters freshwaters, it may, given the right conditions (e.g., adequate sunlight), fuel excess growth of algae and aquatic plants. In some extreme cases, decomposition of dead algae and plants by bacteria, and the low dissolved oxygen levels resulting from this unnatural amount of decomposition, can stress aquatic organism communities (e.g., fish, macroinvertebrates). Streams that are well shaded by trees usually are protected against excessive plant growth problems. In some situations, streams can be significant contributors of phosphorus, so they are good place to investigate when a lake is experiencing excessive phosphorus loading and algae growth.

There are many sources of phosphorus, both natural and human. Phosphorus enters freshwaters from human activities such as:

- agricultural sites (e.g., eroding soil, chemical fertilizer, manure, organic matter);
- residential areas (e.g., eroding soil, lawn fertilizer, pet waste, failing septic systems);
- urban developments (e.g., eroding soil, roads, parking lots, automobiles); and
- waste discharges (e.g., untreated or treated wastewater and sewage).

NITROGEN

Forms of Nitrogen

Nitrogen can be found in several different forms in terrestrial and aquatic ecosystems, including ammonia (NH_3), total Kjeldahl[2] nitrogen (TKN), nitrites (NO_2), and, most commonly, nitrates (NO_3). Nitrates are essential plant nutrients.

Excess Nitrogen Pollution

In excess amounts, various forms of nitrogen (NH_3, NO_2, NO_3, TKN) can cause significant water quality problems. In extreme cases, given the right conditions (e.g., adequate sunlight), excessively high amounts of nitrates, together with phosphorus, fuel excess growth of algae and other aquatic plants and can eventually lead to the low dissolved oxygen problems described above for phosphorus. Additionally, excess amounts of nitrates can become toxic to warm-blooded animals (e.g., human infants) at higher concentrations (10 mg/L or higher) under certain conditions. High levels of ammonia (NH_3) can be toxic to some fish including trout.

Excess nitrogen can enter freshwaters from human activities such as:

- agricultural sites (e.g., chemical fertilizer, manure, organic matter);
- residential areas (e.g., lawn fertilizer, pet waste, failing septic systems);
- urban developments (e.g., chemical fertilizer); and
- waste discharges (e.g., untreated or treated wastewater and sewage).

Interestingly, certain blue-green algae (cyanobacteria) are capable of fixing atmospheric nitrogen, especially when there is an ample supply of phosphorus, therefore increasing the supply of nitrogen in some aquatic ecosystems.

SEDIMENT POLLUTION, SUSPENDED SOLIDS, AND TURBIDITY

(NOTE: Sediment pollution, suspended solids, and turbidity are "physical attributes" of streams, but they frequently are considered water quality parameters by stream scientists and managers, so they are included in this section.)

Sediment Pollution

Streams and rivers naturally transport certain amounts of sediments (sand, silt, other soil particles) though their systems, as discussed in *Unit 2* (section I, Basic Fluvial Geomorphology Concepts). Above-normal amounts of sediment, usually resulting from human activities done carelessly, that enter into and are suspended, transported, and deposited within streams and rivers, are harmful in several ways. (*Figure 4-4* shows a Maine river carrying a high sediment load.) These excess sediments:

- fill in the spaces between gravels and other rocks in stream bottoms, eliminating spawning areas of many fish, suffocating any eggs present, and eliminating habitats for fish food such as aquatic insects (e.g., stoneflies, mayflies, etc.) and other invertebrates;
- reduce visibility, which interferes with fishes' ability to feed;
- raise water temperature, which reduces the amount of oxygen in the water;
- clog the feeding apparatus of filter feeders;
- damage fish and aquatic insect gills;
- block sunlight, which impairs photosynthesis of aquatic plants; and
- carry nutrients adsorbed to sediment particles.

Total Solids, Total Suspended Solids, and Suspended Sediment Concentration

"Total solids" is a measure of dissolved solids plus suspended and "settleable" solids in water. In stream water, dissolved solids consist of calcium, chlorides, nitrates, phosphates, iron, sulfur, and other ion particles, as well as humics and tannins, that will pass through a filter with very small pores. Suspended solids include sand, silt, and clay particles; plankton; algae; fine organic debris; and other particulate matter. These are particles that will not pass through a 2 µm filter[3].

FIGURE 4-4

An example of Maine river water having a high sediment load. (Photo source: Maine DEP.)

"Total suspended solids" (TSS) and "suspended-sediment concentration" (SSC) are measurements of suspended sediments (e.g., soil particles, sands, clays) originating both from outside and from within a stream. These suspended sediments can have many detrimental effects on stream and river ecosystems such as those listed earlier for sediments. The analytical methods for TSS and SSC differ. TSS data are obtained by several methods, most of which involve measuring the dry weight of sediment from a known volume of a *subsample* of the original sample. SSC data are obtained by measuring the dry weight of all the sediment from a known volume of a water-sediment mixture (sample). Due to the sub-sampling procedures that typically are used with the TSS method, and associated error problems, some agencies (including Maine DEP) are beginning to recommend that SSC be measured instead of TSS[4].

In addition to problems for ecosystems, a high concentration of suspended solids will make drinking water unpalatable and might have an adverse effect on people who are not used to drinking such water if it is unfiltered. Levels of suspended solids that are too high can also reduce the efficiency of public drinking water utilities and wastewater treatment plants, as well as the operation of industrial processes that use raw water. Total solids, total suspended solids, and suspended sediment concentration are typically measured in milligrams per liter (mg/L) or parts per million (ppm).

Turbidity

Turbidity is a measure of water clarity, or how much the material suspended in water decreases the passage of light through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, and other substances. These materials are typically in the size range of 0.004 mm (clay) to 1.0 mm (sand). Turbidity also can affect the color of the water. Generally, turbidity is relatively low in undisturbed watersheds (e.g., < 30 NTU); however, after a rainstorm, turbidity can increase significantly (e.g., > 100 NTU), especially if substantial erosion is occurring in the river's watershed. (NTU stands for Nephelometric Turbidity Units.) (Note that these values are generalities and that a wide range of values can actually occur for "clean" water.)

Sources

Sources of total solids, suspended solids/sediments, and turbidity include, but are not limited to:

- in-stream sources such as the channel bottom and stream banks due to normal amounts of in-stream erosion (as described in Unit 2);
- soil erosion from upland areas and usually as a result of human activities and land uses such as:
  - construction projects that leave soil exposed during and after construction;
  - bare soil areas on residential lots;
  - logging or farming too close to waterbodies without proper precautions;
  - wastewater discharges; and
  - polluted urban stormwater runoff (including eroded soil and winter sand).

CONDUCTIVITY / SPECIFIC CONDUCTANCE

Conductivity is a measure of the ability of water to carry an electrical current and is directly related to the dissolved ions (charged particles) present in water. Specific conductance is conductivity that has been adjusted to the conductivity that would be present in a water sample if it were held at a water temperature of 25 °C. Generally, specific conductance is the preferred monitoring/reporting method because it standardizes among different temperature conditions. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate (*anions;* ions that carry a negative charge) or sodium, magnesium, calcium, iron, aluminum (and other metals) (*cat-*

ions; ions that carry a positive charge). Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity and specific conductance is measured in micromhos per centimeter (µmhos/cm) or microsiemens per centimeter (µs/cm). Distilled water has conductivity values in the range of 0.5 to 3.0 µS/cm.

The values for Maine undisturbed rivers and streams are generally low (30 to 50 µS/cm). Values significantly greater than 100 may be indicating that there is a potential pollution problem in the stream. Some degraded urban streams having serious pollution problems can have specific conductance values in the range of 300 – 400 µS/cm or even higher.

Conductivity can successfully and inexpensively be used to track down many kinds of pollution sources. Also, fishery biologists use conductivity values to calculate fish yield estimates. Recently, there has been a growing concern in the northeastern United States about potentially significant increases in chloride concentrations in freshwater surface and groundwater supplies, primarily from winter road and parking lot safety maintenance (salting) activities (Kaushal et al., 2005; Mullaney et al., 2009). Though conductivity is not a direct measurement of chloride concentrations, high chloride concentrations are frequently associated with high specific conductance measurements, thereby making specific conductance a valuable screening tool for these types of problems.

E. COLI BACTERIA AND PATHOGENIC ORGANISMS

Esherichia coli (E. coli) is an intestinal bacteria, which occurs in high numbers in warm-blooded animals. Studies have shown a close correlation between high *E. coli* counts and the incidence of stomach illnesses at swimming beaches (USEPA,1986). Although *E. coli* do not generally cause serious disease, their presence signals the possible presence of human wastes which might contain pathogenic organisms (organisms which can cause disease) such as other types of bacteria, viruses, and other microorganisms that cause gastrointestinal illness, *Giardiaisis* ((e. g., from the microbe *Giardia*), etc.

Although *E. coli* counts in drinking water should be zero, *E. coli* usually are present in all aquatic ecosystems. Limits have been set by resource managers to determine the amount of bacteria allowable in each water classification for certain levels of risk for activities such as swimming. See ***Table 4-1*** for information on Maine's standards.

Some sources of *E. coli* bacteria and pathogenic organisms include malfunctioning septic systems, overboard discharge systems, combined sewer overflows (CSOs), discharges from boats, improperly stored animal manure, pet waste, and publicly owned treatment works (POTWs) that are not working properly. (POTWs are heavily regulated and usually do good job of treating and disinfecting wastewater.)

E. coli counts can increase right after a storm event (heavy thundershower or continuous rain). *E. coli* are found in all warm-blooded animals so run-off from farmland, urban areas, and lawns of pet owners will cause an increase in the number of bacteria found. Following storms, expect some bacteria to be present in the rivers and streams you visit because naturally-occurring local wildlife, plus pet and livestock waste, can introduce some bacteria. For that reason alone, we recommend that you never intentionally drink the water without proper treatment, even though many waterbodies in Maine are generally safe for swimming.

Remember that the standard used for bacteria specifies *E. coli* of human and domestic animal origin. Since all warm blooded animals contain *E. coli,* finding high *E. coli* counts does not necessarily mean you have foun*d E. coli* of human or domestic animal origin. Further testing may be necessary in some cases, but those tests can sometimes be expensive.

Other organic toxins such as pharmaceutical drugs and antibiotics can make their way into waterways via wastewater and septic systems and then damage aquatic ecosystems. Because these pollutants are found so universally among households, they remain a formidable challenge for pollution reduction.

TOXICS

Toxics are chemicals that can kill or may have sub-lethal effects such as affecting the growth or limiting the reproduction of aquatic (or terrestrial) organisms. A harmless substance can become toxic if its chemical form, quantity, or availability is changed. For instance, certain trace metals could be a nutritional requirement for an organism in small amounts, yet toxic if consumed in higher concentrations.

Lead, mercury, arsenic, cadmium, silver, nickel, selenium, chromium, zinc, and copper are heavy metals that can be toxic in fresh and marine waters. Metals can be transported into water bodies, and their sources include vehicle emissions, automobile parts, industrial processes, and improper use or disposal of paints and pesticides. Metals also occur naturally in rocks and minerals and can leach into the environment over time. Soil disturbance can accelerate the release of metals into the aquatic environment. For example, acid precipitation (e.g., acid rain) can leach aluminum from soils, which can potentially be washed into aquatic ecosystems and cause toxicity problems for the organisms living there.

Many petroleum products are toxic, particularly polycyclic aromatic hydrocarbons (PAHs). PAHs enter the water through events or processes such as oil spills and burning of fossil fuels. Polychlorinated biphenyls (PCBs, formerly used in electrical transformers and other products), chlorinated pesticides, and dioxin are other major toxics found in Maine's aquatic environments. PCBs and many pesticides are now banned because of their toxic properties. They take a long time to degrade, and their persistence in the environment means they will continue to cause problems for a long time. Significant efforts are being made to reduce or eliminate some of the toxins mentioned above from Maine's waterways through various water and air pollution management programs. Other organic toxins such as pharmaceutical drugs and antibiotics can make their way into waterways via wastewater and septic systems and then damage aquatic ecosystems. Because these pollutants are found so universally among households, they remain a formidable challenge for pollution reduction.

Significant quantities of metals and organic toxins can inhibit the growth, reproduction, and immune systems of aquatic organisms. In some degraded waterways, these contaminants accumulate in sediments and are consumed by bottom-feeding organisms. Fish and crustaceans eat the bottom-feeding organisms (e.g., aquatic insects and mollusks), further accumulating the contaminants. Birds, humans, and other organisms may eat these fish and crustaceans and, with them, the accumulated contaminants. Fortunately, many efforts are underway in Maine to reduce or eliminate the amounts of toxins that make their way into aquatic ecosystems.

PATHWAYS OF POLLUTION INTO STREAMS AND RIVERS

Land and Water Pathways

In the past, rivers, streams, and other waterbodies were disposal areas for untreated industrial and manufacturing wastes and raw sewage through point source pollution discharges. People thought that these waters had a limitless ability to dilute pollutants. However, years of discharging pollutants in some areas of the country led to waters that were toxic to aquatic life and humans. Point source pollution discharges were addressed when the Federal Clean Water Act was passed in the early 1970s. As mentioned in this volume's introduction, the objective of the Clean Water Act was, and is today, to restore and maintain the chemical, physical, and biological integrity of the Nation's (including Maine's) waters. (More background information about the Federal Clean Water can be viewed at < http://www.epa.gov/watertrain/cwa >.) Industrial and municipal wastewater discharges were regulated, pollutant loads were reduced, and municipalities constructed sewage treatment plants with federal funds. State programs, such as the Small Community Grants Program and Overboard Discharge Program, have funded the removal of untreated discharges and the elimination of overboard discharge pipes (and combined sewer overflows [CSOs]). These changes have resulted in great improvements to the water quality of Maine's waters.

Today, it is nonpoint source pollution (also known as polluted runoff, polluted stormwater, or stormwater runoff; ***Figures 4-5, 4-6)*** that poses the greatest threat to Maine's waters. This type of pollution originates from a variety of land uses including agriculture, forestry, urban and suburban areas.

Agricultural and forestry activities, when done without paying much attention to pollution prevention techniques, contribute nonpoint source pollution to our waterways. Common pollutants related to agriculture and forestry activities include eroded soil (and any phosphorus that may be attached to it) and fertilizers and pesticides (and the excess phosphorus, nitrogen, and toxins associated with them).

In many areas of Maine there is significant and/or growing urban and suburban development, which can stress and degrade waterways when not planned and built with environmentally sensitive designs. When development occurs on a landscape, many acres of natural forestland, grassland, and wetland are often converted into impervious surfaces like asphalt, concrete, metal, and compacted-soil lawns. There is a much greater quantity of stormwater coming off these surfaces when it rains than what comes off forestland ***(Figure 2-16).*** In forestland, most rainfall slowly soaks into the ground and eventually reaches streams and ponds, by way of springs and groundwater seepage, as clean and cool water. Only a fraction of this rainfall runs immediately into streams and ponds. Alternatively, in urban and suburban areas, most rainfall lands on impervious surfaces. Usually, this water flows into storm drains that connect directly to a nearby stream or pond. (Some developments have on-site structures that capture and treat stormwater before releasing it to a nearby waterway. More recent designs of these structures, and better site planning, tend to be more effective at minimizing the impacts of stormwater than older designs.)

First, the effect of the change in land use means that rainstorm and snowmelt events are much more "flashy" — water starts flowing across surfaces quickly and hard. The effect of the high flows from these urban landscapes can sometimes trigger severe erosion in stream channels. This erosion can harm the aquatic life by covering up fish nursery areas with sediments, irritating fish/insect gills that can lead to injury and death, and smothering other stream life, as described earlier in this manual. Second, there are more sources of pollution to be moved by that water. Most homeowners contribute pollution to waterways in the form of bare soil, fertilizers, pesticides, oil & grease from cars, and pet waste.

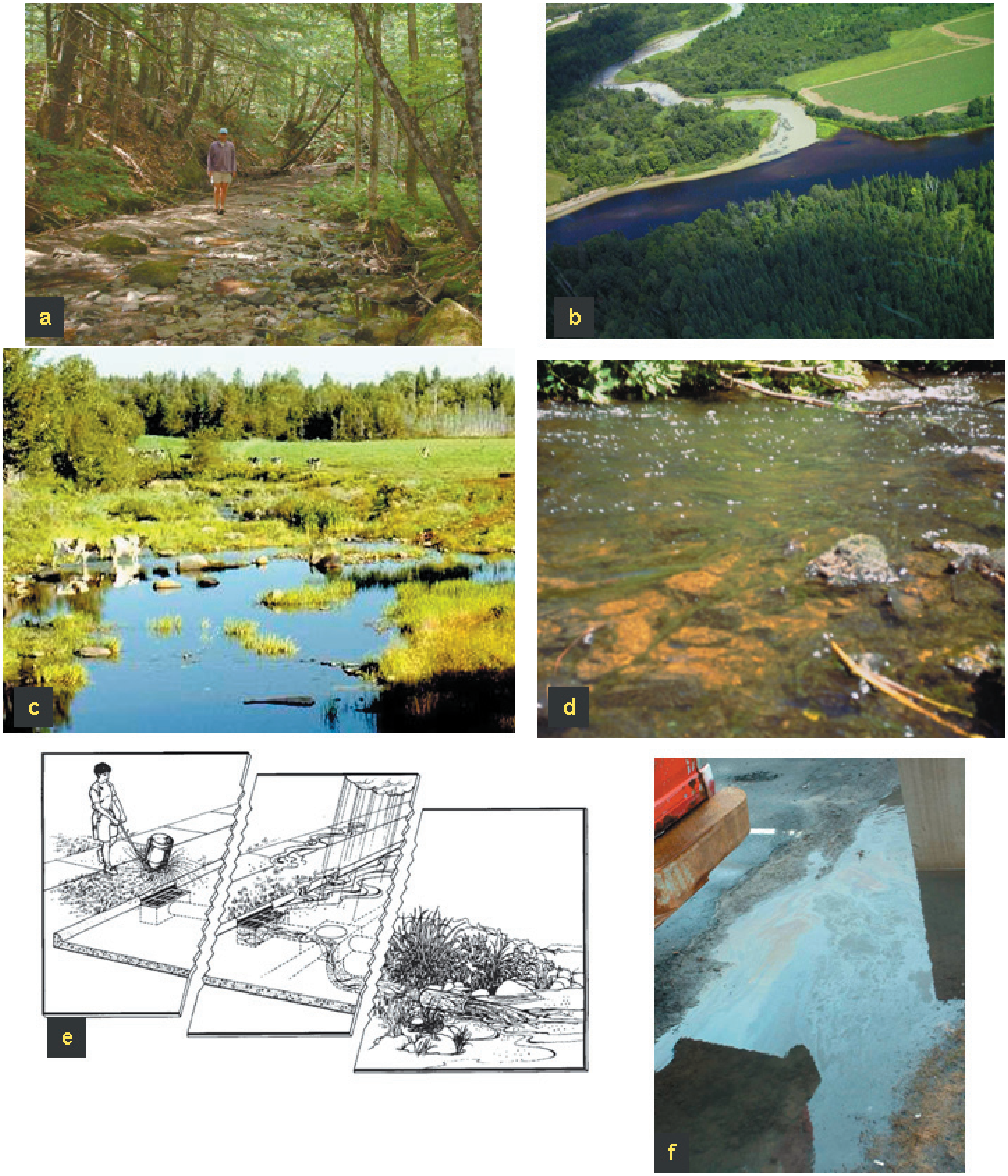
These pollutants and changes in the hydrology of our land threaten the health of our environment, our people and our economy. The investment we can make to prevent pollution is minimal compared to the potential costs of losing our water resources.

FIGURE 4-5

Examples of nonpoint source pollution problems (primarily erosion and sedimentation).

(photos sources: a) Maine DEP, b) Sunday River Watershed Interest Group, and c – e) Jeff Varricchione (Maine DEP).

FIGURE 4-6



Examples of nonpoint source pollution problems: a-b) erosion and sedimentation, c-d) nutrient pollution (from cows and resulting filamentous algae bloom, e) lawn fertilization (nutrients and runoff into storm drain system and eventually a waterbody, and f) automobile leakage of petroleum.

Photo sources: a, f) Jeff Varricchione (Maine DEP); b, c) Maine DEP; d) Mary-Ellen Dennis (Maine DEP).

Atmospheric Pathways

Atmospheric deposition can also be a significant source of pollutants to waterbodies such as streams and lakes. Atmospheric deposition is airborne pollution that falls onto land or water surfaces in the form of precipitation (either rain or snow), as a component of dust, or simply due to gravity. This type of pollution can make its way into waterbodies by *directly* being deposited into surface waters. It can also make its way into waterbodies *indirectly* by being deposited onto land surfaces and then being picked up and carried to waterbodies via stormwater runoff (keeping in mind that it originated from atmospheric sources). Common types of atmospherically-deposited pollutants include nitrogen compounds, sulfur compounds, mercury, and pesticides. Some sources of these pollutants can be natural (e.g., volcanoes and forest fires), while other sources can be human-related (e.g., combustion of fossil fuels, releases from industrial smokestacks and agricultural processes, and waste incineration).

C. Methods to Protect Water Quality

We will not take the time to review all the various types of methods that exist to help minimize impacts of development and other land uses on Maine's waterways. We refer you to *Appendix B* for resources and links related to these methods (also known as Best Management Practices or BMPs). We will take the time, however, to explain a very important BMP that any landowner can implement on their land: vegetated riparian buffers.

VEGETATED RIPARIAN ZONES — A Water Quality Protection Tool

Recall that riparian zones are areas adjacent streams, rivers, and other waterbodies, and include streambanks and floodplains. They are areas of trees, shrubs, and other vegetation between an upland area, that often is developed, and a waterbody. Vegetated riparian zones are important components of stream (and other waterbody) ecosystems that are highly valuable towards keeping water clean.

Vegetated riparian "buffers" are tools that watershed managers and landowners manage or restore in landscapes altered by humans, to protect streams and other waterbodies. These buffers can include trees, shrubs, bushes, and ground cover plants. The irregularities and depressions of the ground in natural buffers retain and treat polluted runoff, because water is allowed to percolate into the ground.

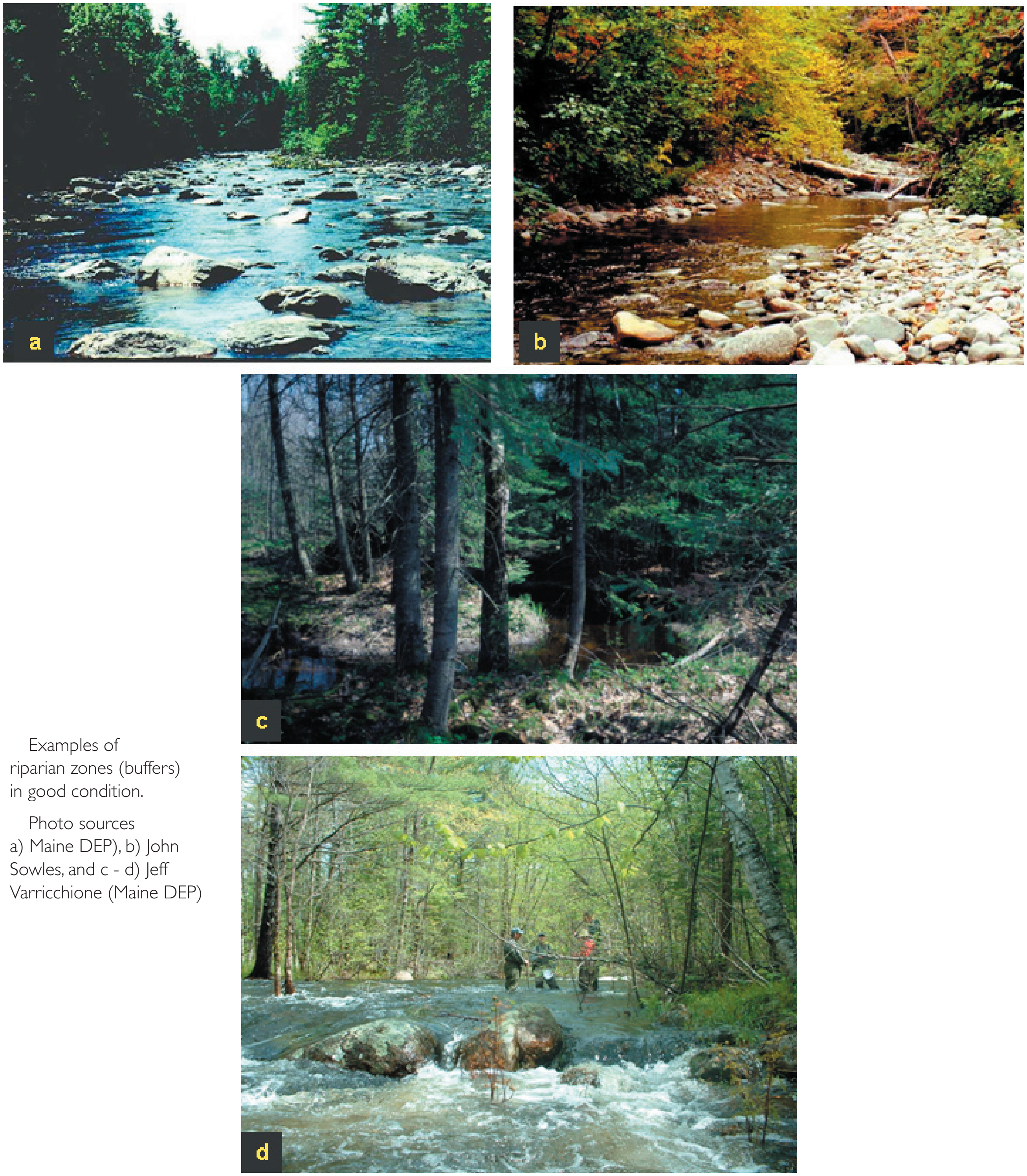
Forested areas are most effective in the retention of stormwater because of the duff layer (thick, soft layer) of decomposing pine needles, bark, leaves, and other organic material that has fallen on the ground. The duff layer in forests can be up to several inches thick — an incredible natural sponge! Over time, planted buffers can be as effective as natural ones.

Buffers prevent pollutants from reaching surface waters in several ways: they filter pollutants out of stormwater, they slow the flow rate of stormwater runoff, and they reduce the volume of stormwater runoff. Additionally, vegetated riparian zones (or managed "buffers") along rivers and streams also provide values such as shading, habitat diversity (e.g., fallen logs and the associated scour pools and cover for fish), and food sources for wildlife and aquatic organisms.

Figure 4-7 shows shorelands with healthy, stable riparian zones. *Figure 4-8* shows shoreland riparian areas that are in poor condition and which likely are unstable. These areas likely are contributing or allowing excess nonpoint source and solar heat pollution to reach the stream and river waters. *Figure 4-8* shows a riparian zone that has been modified by the addition of armoring with riprap (hard materials - typically large rocks).

The Maine Stream Team Program has assembled a list of resources and links related to riparian zones and vegetated buffers. Check out the following link for additional useful information and buffer design tips: http://www.maine.gov/dep/blwq/docstream/team/riparian.htm.

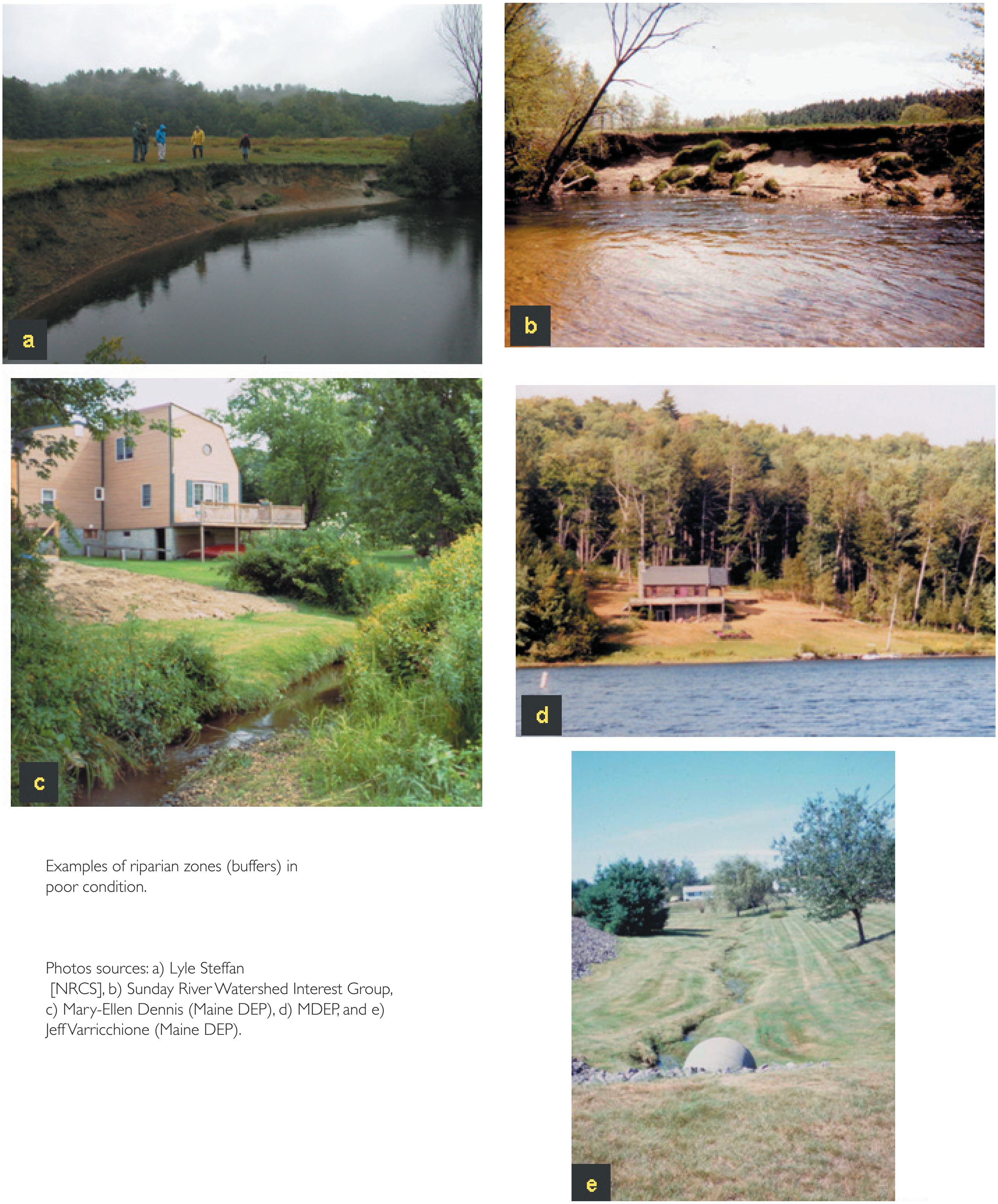
FIGURE 4-7



Examples of riparian zones (buffers) in good condition.

Photo sources a) Maine DEP), b) John Sowles, and c - d) Jeff Varricchione (Maine DEP)

FIGURE 4-8



Examples of riparian zones (buffers) in poor condition.

Photos sources: a) Lyle Steffan [NRCS], b) Sunday River Watershed Interest Group, c) Mary-Ellen Dennis (Maine DEP), d) MDEP, and e) Jeff Varricchione (Maine DEP).

Advantages and disadvantages associated with using riprap as a bank stabilization technique

■ Some of the advantages of using riprap ***(Figure 4-9)*** may include:

- a relatively low cost compared to other bank protection techniques (except the use of vegetation in manycases);
- relatively simple construction techniques with no special equipment or construction techniques necessary; and
- they are easily repaired by adding stone to damaged areas.

■ Some of the disadvantages may include:

- a prevention of lateral migration of stream in the vicinity of the riprap placement, thus affecting the morphologic evolution processes of the stream system;
- a potential increase in the amount of streambank/channel scour and erosion in areas downstream of riprap structures; and
- potentially increased local water temperatures because of a decrease in the presence of vegetation and an increase in the presence of heat absorbing material (i.e., rock).

There is a general trend in Maine and elsewhere to try to avoid or minimize the use of riprap in streams and rivers whenever possible, recognizing that it may be necessary in certain situations, in favor of stabilization strategies that use more natural techniques such as planting unstable areas with vegetation. A more detailed analysis of the pros and cons associated with riprap can be found in Fischenich (2003). That publication stresses the importance of recognizing that advantages and disadvantages of riprap vary widely depending on local site and watershed characteristics and that those characteristics must be taken into account. They also stress that modifications can be made to riprap designs that can help minimize impacts.

FIGURE 4-9

Example of a riprap stabilization technique used in streams and rivers.

Photo source: City of Norfolk, VA; Utilities-Water Resources (http://www.norfolk.gov/Utilities/resources/riprap.jpg).

ENDNOTES (Unit 4)

[1] U. S. Geological Survey. "Explanation of Hardness." < http://water.usgs.gov/owq/Explanation.html >. Accessed on August 19, 2008.

[2] Total Kjeldahl Nitrogen (TKN) is the sum of organic nitrogen and ammonia (NH_3) in a water body. Sources of TKN include the decay of organic material, such as plant material and animal wastes, and urban and industrial disposal of sewage and organic waste.

[3] Many organizations use a pore size of 2 µm (0.0002 cm) as the cut-off between solid and dissolved substances, while some others use a pore size of 0.45 µm.

[4] Gray, J. R, G. D. Glysson, L. M. Turcios, and G. E. Schwarz. 2000. Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data. U. S. Geological Survey. Water-Resources Investigations Report 00-4191. Reston, Virginia. 14 pp.