GEORGIA ENVIROTHON

AQUATIC ECOLOGY

STUDY GUIDE

Aquatic Ecology Curriculum Guidelines

1. Know the processes and phases for each part of the water cycle and understand the water cycle's role in soil nutrient erosion, salinization of agricultural lands, and climatic influences.
2. Understand the concept and components of a watershed. Know the features of a healthy watershed and an unhealthy watershed.
3. Understand why and how aquatic organisms and water quality are affected by the physical, chemical and biological conditions of the water.
4. Understand how energy and matter flow within an aquatic ecosystem.
5. Understand the concept of carrying capacity for a given aquatic ecosystem, and be able to discuss how competing water usage may affect the ability of the system to sustain wildlife, forestry and anthropogenic needs.
6. Identify aquatic and wetland environments based on their physical, chemical and biological characteristics.
7. Know characteristics of different types of aquifers, and understand historical trends and threats to groundwater quantity and quality.
8. Understand societal benefits and ecological functions of wetlands.
9. Understand the functions and values of riparian zones and be able to identify riparian zone areas.
10. Interpret major laws and methods used to protect water quality as well as federal and state agencies that provide oversight of water resources.
11. Identify global and local sources of point and non-point source pollution as well as methods to reduce point and non-point source pollution.
12. Understand the interaction of competing uses of water for water supply, hydropower, navigation, wildlife, recreation, waste assimilation, irrigation, and industry as well as how it may affect the ability of the system to sustain wildlife, forestry and anthropogenic needs.
13. Know the meaning of and methods for water conservation.

Skills to Know- Aquatic Ecology

1. Be able to identify by common name aquatic macroinvertebrates listed on the specimen list with or without a key at the order level from pictures, drawings, and preserved or live specimens. Be able to choose the scientific (order) name from a provided list

2. Be able to calculate a stream quality rating when provided a tolerance category list.

3. Be able to run commonly used chemical tests using Lamotte test kits. Instructions are provided. Tests to know are pH, temperature, and dissolved oxygen.

4. Be able to use either a secchi disk or an imhoff cone to evaluate turbidity.

5. Be able to delineate a watershed on a USGS quad sheet from a point marked on the map. Be able to determine direction of flow for lotic systems on the map.

6. Be able to label a stream diagram with Strahler stream orders

7. Identify common, rare, threatened and endangered aquatic species as well as aquatic nuisance species (ANS) with the use of a key

Specimen list

Be able to identify by common name the following aquatic macroinvertebrates (primarily larvae) at the order level

Mayfly
Stonefly
Caddisfly
Dragonfly
Dobsonfly
Damselfly
Snipefly
Cranefly
Water Penny
Crawfish
Blackfly
Mosquito
Aquatic worm
Leech
Gilled Snail
Pouch Snail
Midge
Riffle beetle

Also know these fish from the wildlife specimen list

Channel catfish
Brown Bullhead
White Crappie
Black Crappie
Bluegill
Redbreast Sunfish
Redear Sunfish
Largemouth Bass
White Bass
Striped Bass
Hybrid Bass
Rainbow Trout
Brown Trout
Brook Trout
Walleye

GEORGIA ADOPT-A-STREAM: Macroinvertebrate Form (page 2)

METHODS

Stream Type: ☐ Rocky Bottom Stream ☐ Muddy Bottom Stream

Method Used: ☐ Kick seine (2 x 2 ft area) ☐ D-Frame net (1 x 1 area) **Total Area Sampled:** ________ft^2

Habitats Sampled: ☐ Leaf Packs/Woody Debris ☐ Vegetated Bank Margin ☐ Riffle ☐ Streambed with silty area (very fine particles) ☐ Streambed with Sand or small gravel

Directions: ***Consult the macroinvertebrate monitoring manual for sampling guidelines***

1. Separate the macroinvertebrates into the different taxa groupings listed in the table below.

2. Note which **taxa** are present and their **abundance code** based on the number of individuals present in your sample. Enter these codes in the boxes below for each taxa. *Abundance Codes:* **R** (rare)=1-9, **C** (common)=10-99, and **D** (dominant)=100 individuals or greater

TAXA GROUPS

SENSITIVE TAXA	SOMEWHAT SENSITIVE TAXA	TOLERANT TAXA
☐ Stonefly Nymphs	☐ Common Net Spinning Caddisflies	☐ Midge Fly Larvae
☐ Mayfly Nymphs	☐ Dobsonfly/Helgrammite & Fishfly	☐ Black Fly Larvae
☐ Water Penny Larvae	☐ Dragonfly & Damselfly Nymphs	☐ Lunged Snails
☐ Riffle Beetle Larvae/Adults	☐ Crayfish	☐ Aquatic Worms
☐ Aquatic Snipe Flies	☐ Crane Flies	☐ Leeches
☐ Caddisflies	☐ Aquatic Sow Bugs	
☐ Gilled Snails	☐ Scud	
	☐ Clams & Mussels	
☐ # of taxa groups times 3 =____	☐ # of taxa groups times 2 =____	☐ # taxa groups times 1 =_

WATER QUALITY INDEX/RATING

Now add together the three index values to get your **Water Quality Index Score** =_______
Use this score to find out your **Water Quality Rating** for your stream (below).
Good water quality is indicated by a variety of different kinds of taxa/organisms, with no one kind making up a majority of the sample.

Water Quality Rating

☐ *Excellent (>22)* ☐ *Good (17-22)* ☐ *Fair (11-16)* ☐ *Poor (<11)*

OTHER

Optional: Do you see any of the following in your samples? Please count number of individuals.

☐ Fishes # : ______ ☐ Tadpoles # : ______
☐ Asian Clams # : ______ ☐ Nonnative Crayfish Which species?
☐ Salamanders # : ______ ______________________________

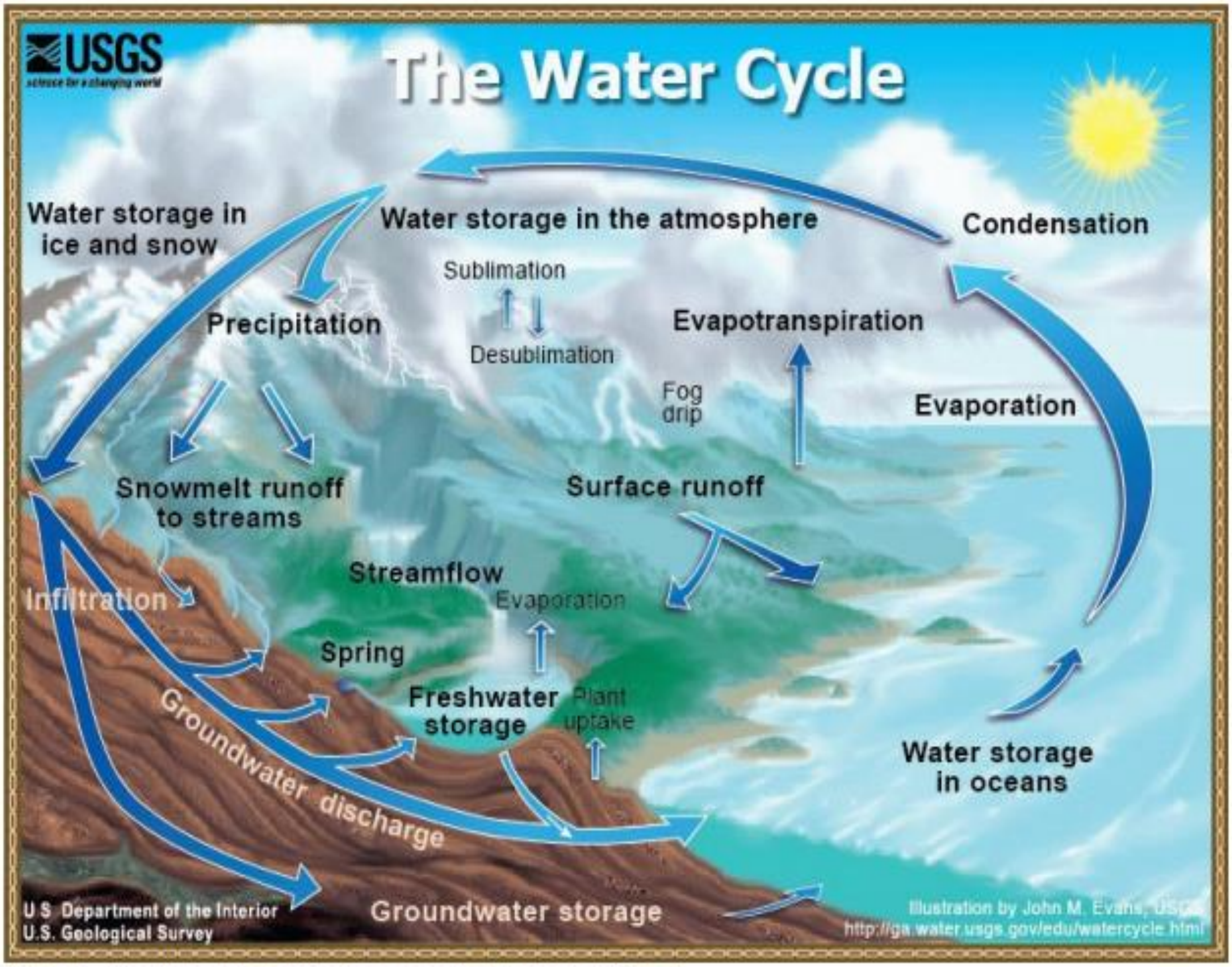


Figure 1. The Water Cycle (also known as the Hydrologic Cycle.)

Georgia Envirothon competitors should be conversant in all parts of the water cycle pictured above

Evapotranspiration is defined as the process by which water is discharged to the atmosphere as a result of evaporation from the soil and transpiration by plants. Transpiration rates vary widely depending on weather conditions, such as temperature, humidity, sunlight availability and intensity, precipitation, soil type and saturation, wind, and land slope. During dry periods, transpiration can contribute to the loss of moisture in the upper soil zone, which can have an effect on vegetation and food-crop fields. The amount of water that plants transpire varies greatly geographically and over time.

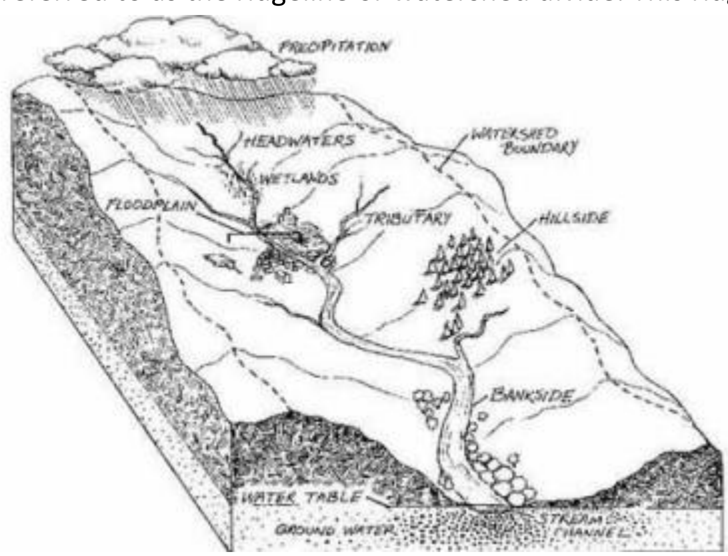
There are a number of factors that determine transpiration rates: **Temperature**: Transpiration rates go up as the temperature increases. Higher temperatures cause the stoma, or plant cells which control the openings where water is released to the atmosphere, to open, whereas colder temperatures cause the stoma to close. **Relative humidity:** As the relative humidity of the air surrounding the plant rises the transpiration rate falls. Water more easily evaporates into drier air than into more saturated air. **Wind and air movement:** Increased movement of the air around a plant results in a higher transpiration rate. **Soil-moisture availability:** Dry conditions can prompt senescence or aging, which can result in leaf loss and less transpiration. **Type of plant:** Different plants transpire water at different rates. Some plants which grow in arid regions, such as cacti and succulents, conserve water by transpiring less than other plants

What is a Watershed? A watershed is the land that water flows across or through on its way to a stream, river, or lake. A watershed can be very large, draining thousands of square miles to a major river, or very small, such as a 20-acre watershed that drains to a pond. A small watershed that nests inside of a larger watershed is sometimes referred to as a subwatershed. Watersheds provide our drinking water, habitat for wildlife, soil for agriculture, and the waterways we use for fishing, boating and swimming. Everyone lives in a watershed so we all benefit from a healthy watershed.

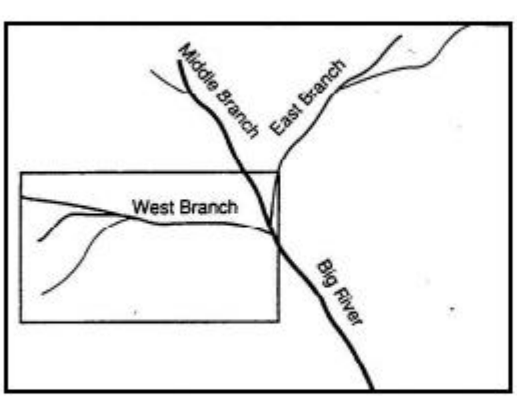
Why Should Watersheds Be Protected? Healthy watersheds and effective watershed protection can provide environmental, economic, and public health benefits. By using a preventive approach, water treatment and reservoir maintenance costs can be reduced, public health problems such as mercury exposure can be minimized, and stream baseflow for dependable water supply can be maintained. An effective watershed program:

(1) maintains natural water storage;
(2) prevents the production of water pollutants;
(3) controls the transport of any pollutants that may be produced;
(4) minimizes the loading of pollutants into water bodies;
(5) supports a vibrant ecosystem.

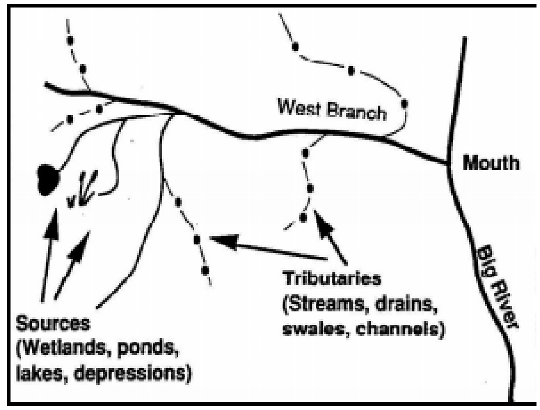
Watershed Delineation (From the Dept. of Environmental Protection Stream Survey Manual)
The first step in understanding your watershed is to delineate its boundaries.
Imagine a watershed as an enormous bowl. As water falls onto the bowl's rim, it either flows down the inside of the bowl or down the outside of the bowl. The rim of the bowl or the watershed boundary is sometimes referred to as the ridgeline or watershed divide. This ridge line separates one watershed from another.



Topographic maps created by the United States Geological Survey (USGS 7.5 minute series) can help you to determine a watershed's boundaries. Topographic maps have a scale of 1:24,000 (which means that one inch measured on the map represents 24,000 inches [2000'] on the ground). They also have contour lines that are usually shown in increments of ten or twenty feet. Contour lines represent lines of equal elevation, which typically is expressed in terms of feet above mean sea level. As you imagine water flowing downhill, imagine it crossing the contour lines perpendicularly.



Here's how you can delineate a watershed:
STEP 1: Use a topographic map to locate the river, lake, stream, wetland, or other water bodies of interest.



STEP 2: Trace the watercourse from its source to its mouth, including the tributaries This step determines the general beginning and ending boundaries. **STEP 3:** Examine the brown lines(contour lines) on the topographic map that are near the watercourse. • The dark brown contour lines (thick lines) will have a number associated with them, indicating the elevation. • The light brown contour lines (thin lines) are usually mapped at 10 (or 20) foot intervals, and the dark brown (thick) lines are usually mapped at 50 (or 100) foot intervals. Be sure to check the map's legend for information on these intervals. • To determine the final elevation of your location, simply add or subtract the appropriate contour interval for every light brown (thin) line, or the appropriate interval for every dark brown (thick) line. Figure D-3 shows a point (X) at an elevation of 70 feet above mean sea level.

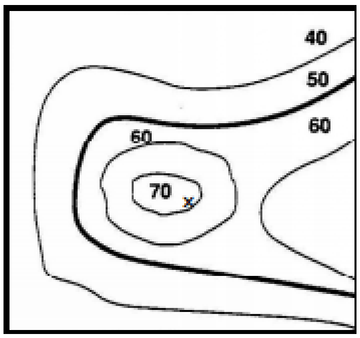


Figure D-3: Contour lines and an example point (X) at an elevation of 70 feet above sea level.

STEP 4: • Contour lines spaced far apart indicate that the landscape is more level and gently sloping (i.e., flat areas). Contour lines spaced very close together indicate dramatic changes in elevation over a short distance (i.e., steep areas) (Figure D-4).

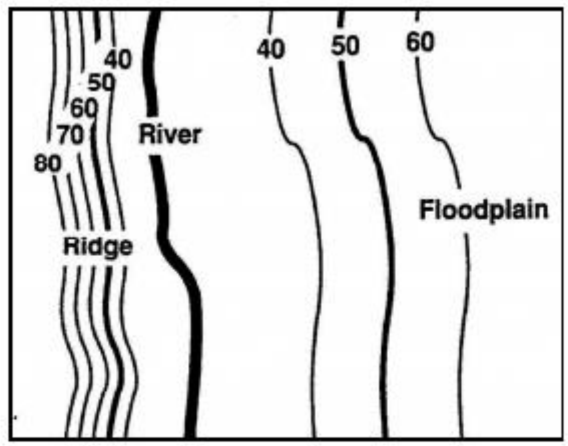


Figure D-4: Floodplains and ridges

STEP 5: Check the slope of the landscape by locating two adjacent contour lines and determine their respective elevations. The slope is calculated as the change in elevation, along a straight line, divided by the distance between the endpoints of that line. • A depressed area (valley, ravine, swale) is represented by a series of contour lines "pointing" towards the highest elevation (Figure D-5). • A higher area (ridge, hill) is represented by a series of contour lines "pointing" towards the lowest elevation (Figure D-5).

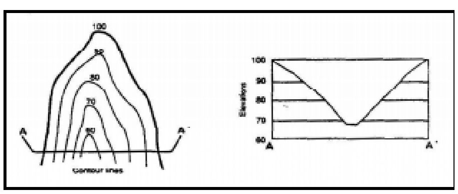
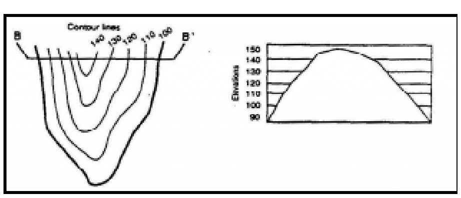


Figure D-5: Valley



STEP 6: Determine the direction of drainage in the area of the waterbody by drawing arrows perpendicular to a series of contour lines that decrease in elevation. Stormwater runoff seeks the path of least resistance as it travels

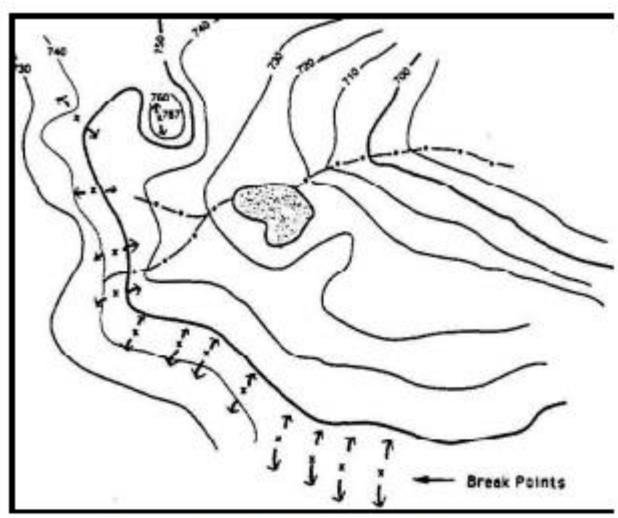


Figure D-7: Direction of drainage

downslope. The “path” is the shortest distance between contours, hence a perpendicular route (Figure D-7).
STEP 7: Mark the break points surrounding the waterbody. The “break points” are the highest elevations where half of the runoff would drain towards one body of water, and the other half would drain towards another body of water (Figure D-8).

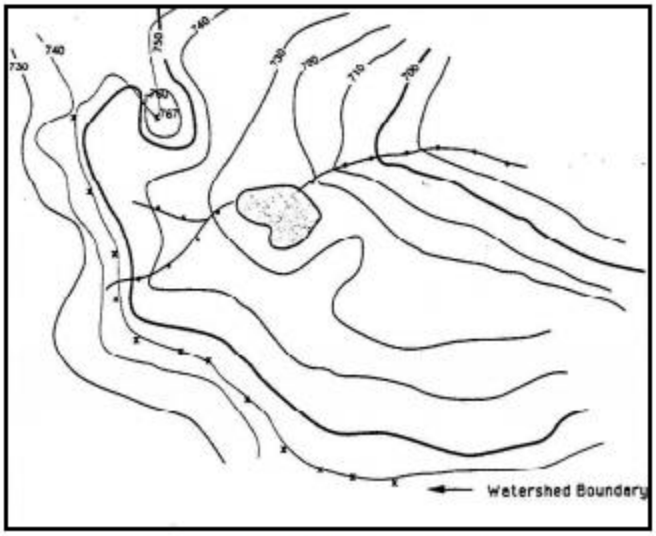


Figure D-8: Watershed Boundary

STEP 8: Connect the break points with a line following the highest elevations in the area. The completed line represents the boundary of the watershed (Figures D-8 and D-9).
STEP 9: Once you’ve outlined the watershed boundaries on your map, imagine a drop of rain falling on the surface of the map. Imagine the water flowing down the slopes as it crosses contour lines at right angles. Follow its path to the nearest stream that flows to the water body you are studying. Imagine this water drop starting at different points on the watershed boundaries to verify that the boundaries are correct.
STEP 10: Watersheds sometimes have subwatersheds within them. Rivers, large streams, lake, and wetland watershed often have more than one subwatershed (usually smaller tributary watersheds) within them. Generally, the larger the water body you are examining, the more subwatersheds you will find. Your watershed map can be further divided into smaller sections or subwatersheds.

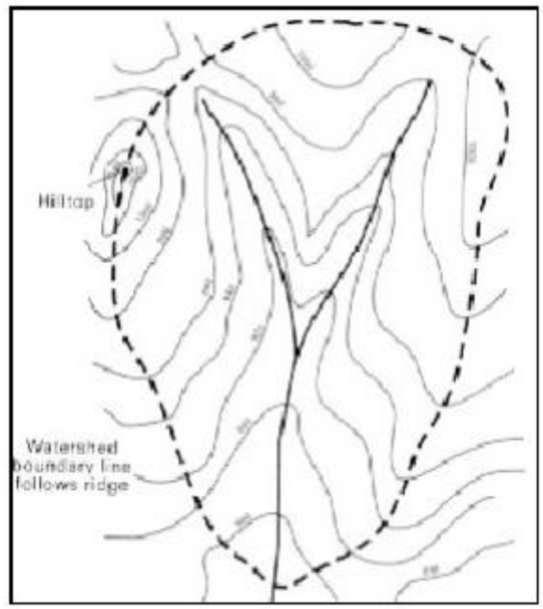


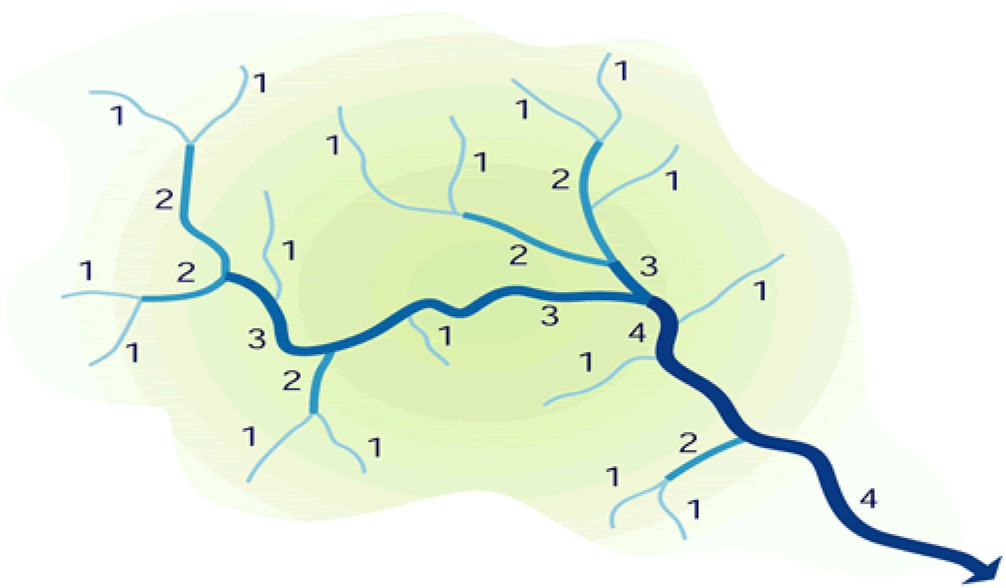
Figure D-9: Idealized Watershed Boundary

Stream Order and Classification
Classifying stream order is important because indicates the size and strength of specific waterways within stream networks- an important component to water management. In addition, classifying stream order allows scientists to more easily study the amount of sediment in an area and more effectively use waterways as natural resources. Stream order also helps determine what types of life might be present in the waterway. For example, different plants live in sediment filled, slower flowing rivers like the lower Mississippi than can live in a fast flowing tributary of the same river.

When using stream order to classify a stream, the sizes range from the smallest, a first order stream, all the way to the largest, a 12th order stream. A first order stream consists of small tributaries. These are the streams that flow into and "feed" larger streams but do not normally have any water flowing into them. In addition, first and second order streams generally form on steep slopes and flow quickly until they meet the next order waterway and slow down. First through third order streams are also called headwater streams and constitute any waterways in the upper reaches of the watershed. More than 80% of the world’s waterways are estimated to be headwater streams.

Increasing in size and strength, streams classified as fourth through sixth order are medium streams and anything larger is considered a river. For example, to compare the relative size of these different streams, the Ohio River in the United States is an eighth order stream while the Mississippi River is a tenth order stream. The world's largest river, the Amazon in South America, is a 12th order stream. Unlike the headwater streams, these medium and large rivers are usually less steep and flow slower. They tend to have larger volumes of runoff and debris as it collects from the smaller waterways flowing into them.

When studying stream order, recognizing the pattern associated with the movement of streams up the hierarchy of strength is important. It takes two first order streams joining to form a second order stream.



When two second order streams join, they form a third order stream, and when two third order streams join, they form a fourth and so on. If two streams of different order join, neither increases in order. For example, if a second order stream joins a third order stream, the second order stream simply ends by flowing its contents into the third order stream, which then maintains its place in the hierarchy. In other words, the order increases only when streams of equal order meet. When unequally ordered streams meet, the stream that continues takes the higher order number

In addition to the ordering system, streams may be classified, by the period of time during which flow occurs:

- Perennial flow indicates a nearly year-round flow (90 percent or more) in a well-defined channel. Most higher order streams are perennial.
- Intermittent flow generally occurs only during the wet season (50 percent of the time or less).
- Ephemeral flow generally occurs during and shortly after extreme precipitation or snowmelt. Ephemeral channels are not well defined and are usually headwaters or low order (1-2) streams.

Watershed Ecology.

Understanding watershed structure and natural processes is crucial to grasping how human activities can degrade or improve the condition of a watershed, including its water quality, its fish and wildlife, its forests and other vegetation, and quality of life for people who live there. Knowing these watershed structural and functional characteristics and how people can affect them sets the stage for effective watershed management.

<u>The Physical Template</u>

- Climatology, the science of climate and its causes, is important in understanding regional issues in watershed science. Climate influences watershed vegetation communities, streamflow magnitude and timing, water temperature, and many other key watershed characteristics.

- Geology is defined as the study of various earth structures, processes, compositions, characteristics, and histories. Geomorphology, refers specifically to the study of the landforms on the earth and the processes that change them over time. Fluvial geomorphology, referring to structure and dynamics of stream and river corridors, is especially important to understanding the formation and alteration of the stream or river channel as well as the flood plain and associated upland transitional zone.
- Hydrology is the science of water as it relates to the hydrologic cycle, including its distribution, circulation and behavior, and its chemical and physical properties, together with the reaction of the environment, including all living things, on water itself.

The Biological Setting

Concepts of basic ecology provide us with the vocabulary to understand and describe the biological setting of watersheds and the interaction of biotic components with the physical template. Working knowledge of the basic ecological terms and concepts is important.

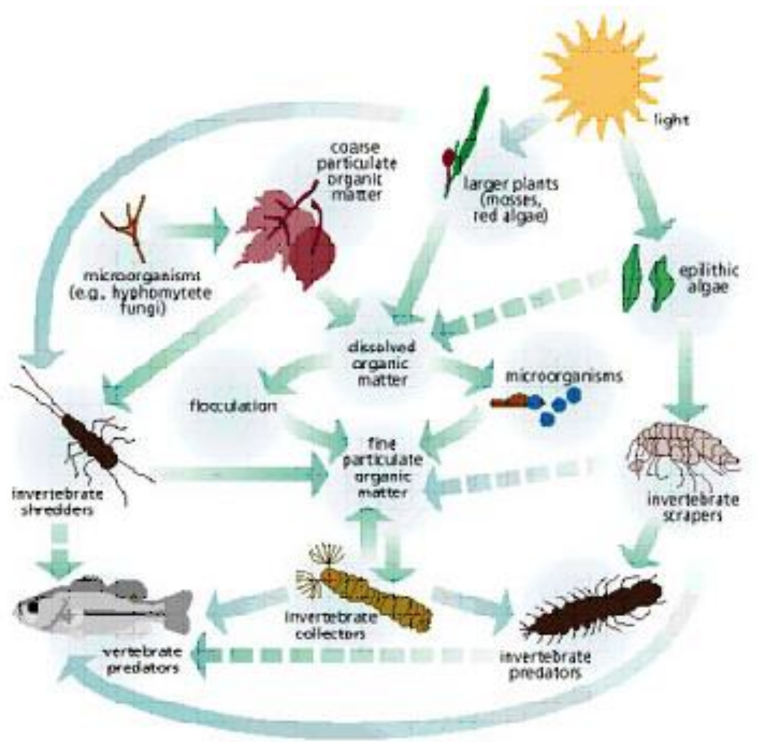
- Species (organism level). An organism which has certain characteristics of a given population and is potentially capable of breeding with the same population defines a member of a species. This definition does not apply to asexually reproducing life forms.
- Population. This term applies to all organisms of the same species that inhabit a specific area.
- Community. A community is an aggregate of all populations occurring within a given area.
- Habitat. A habitat is an area where a specific animal or plant is capable of surviving; usually characterized by climate, physical features, or the presence of certain animals or plants.
- Niche. This term applies to an organism's physical location and, most importantly, functional role (much like an occupation; what the organism specifically does) within an ecosystem.
- Ecosystem. As defined previously, a functioning natural unit with interacting biotic and abiotic components in a system whose boundaries are determined by the cycles and flux of energy, materials and organisms.
- Ecotone. An ecotone is a boundary ecosystem, specifically the ecosystem which forms as a transition between two adjacent systems. It may possess characteristics of both bordering ecosystems, while developing a suite of its own characteristics. Examples: Riparian zones, coastal forests.
- Biosphere. This is the surface zone of the planet earth, extending from within the earth's crust up into the atmosphere, within which all known life forms exist.

Ecological Concepts

- Life History Strategies refers to the selective processes involved in achieving fitness by certain organisms. Such processes involve, among other things, fecundity and survivorship; physiological adaptations and; modes of reproduction.
- Carrying capacity (K) is the level at which the population growth of a species ceases. Theoretically, the term implies that a population at K has reached equilibrium with its environment, from a resource allocation standpoint, or the maximum number of individuals the current environment can support.
- Competition occurs when two or more species or organisms that are engaged in an active or passive struggle for resources. Intraspecific competition refers to competition within a species (e.g., two chipmunks quarreling over a cache of acorns). Interspecific competition refers to competition between species (e.g., a female chum salmon fighting with a female pink salmon for access to a spawning redd).
- Symbiosis literally means "living together." This term has several subcategories. *Mutualism* refers to an interaction between two organisms in which both organisms benefit (e.g., mycorrhizae). *Commensalism*, another form of symbiosis, implies a relationship where one species benefits, while the other experiences no effect (e.g., Spanish moss). *Parasitism* and *predation* are symbiotic types whereby one species benefits and one is adversely affected.

Trophic Ecology

Terrestrial and aquatic ecosystems have characteristic trophic (feeding) patterns that organize the flow of energy in, through, and out of the watershed ecosystem and support the growth of organisms within the system. Food "chains" are rarely linear, hence the term food web, often used to describe the trophic interactions of organisms within an ecosystem



Within a food web, organisms interact and may directly or indirectly affect other organisms. The example pictured is a simple, aquatic-only food web; when the whole watershed's terrestrial components are also considered, food webs can be very complex with numerous interactions among land-based and water-based species. Food webs also often recognize the different roles species play by terming them producers (organisms that generate food, primarily through photosynthesis), consumers (first-order consumers are vegetarians, second-order consumers feed on first-order, etc.), and decomposers (which feed on dead tissue and return nutrients and energy to other parts of the cycle), among other terms.

The Natural Systems Concept

Thus far, you have been introduced to the physical template from which watersheds develop, and the biological setting which then becomes established upon and integrated with the physical template. The interactions and natural processes that link these abiotic and biotic components of watersheds (note here the similarity to the definition of ecosystem) exhibit what can be called system-like behavior. The dictionary defines a system as "a group of interrelated, interacting, or interdependent constituents forming a complex whole."

We have seen that natural systems such as watersheds have interacting components that together perform work (e.g., transport sediment, water, and energy) and generate products (e.g., form new physical structures like floodplains or channels, and form biological communities and new energy outputs). In a natural system, interactions make the whole greater than the sum of its parts.

The natural systems concept is key to watershed management because it emphasizes that a watershed, as a natural system, is more than just a variety of natural resources coincidentally occurring in one place. Severely degraded watersheds may have lost several of their components and functions and provide fewer benefits to human and natural communities as a result. Thus it is clear that recognizing the natural system and working toward protecting the system's critical components and functions are key to sustainable watershed management.

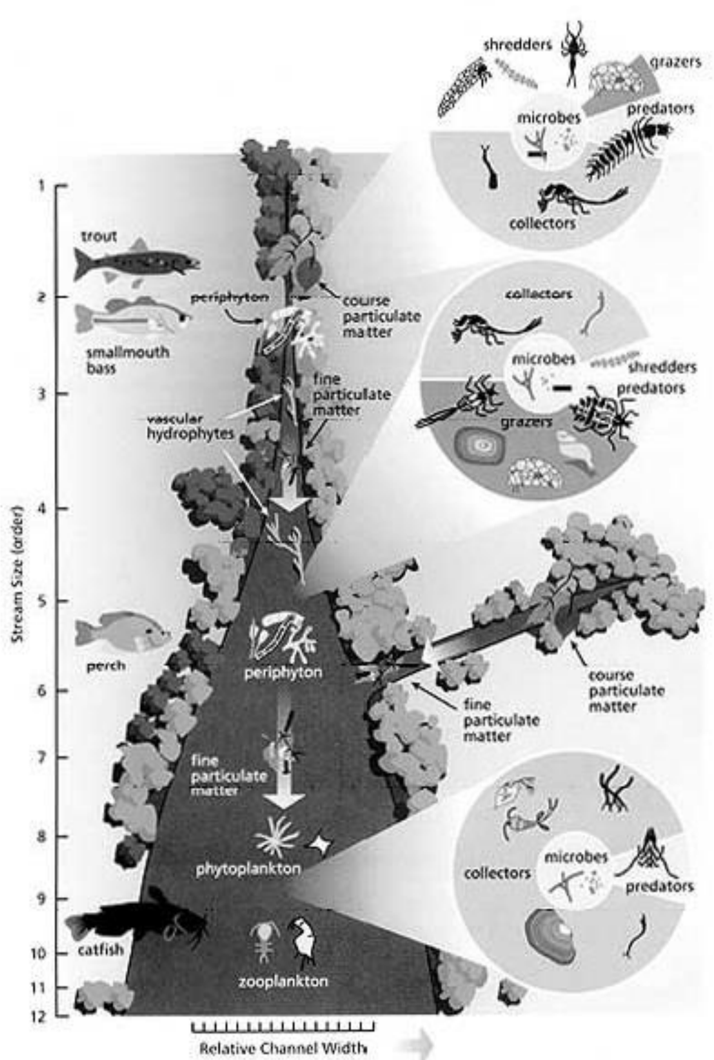
Other ecological concepts and theories help explain the idea of natural systems. These include:

Disturbance Theory.

Whereas natural systems have a certain degree of organization and order, they also exhibit constant change and disturbance at varying levels. Disturbance ecology often centers around a concept known as the intermediate disturbance hypothesis. This hypothesis explains why diversity is often highest in systems with intermediate levels of disturbance. Few species are capable of colonizing an area that either experiences high frequency or intensity of disturbance (e.g. frequent or intense flooding). In areas of low or infrequent disturbance, a small number of species optimally suited to local conditions establish themselves and outcompete other potential colonizers, so here too diversity tends to be lower. The importance of natural disturbances in shaping landscapes and influencing ecosystems is well-documented in the scientific literature. Ecologists generally distinguish between relatively small, frequent disturbances and large, infrequent, so-called "catastrophic" disturbances. Much has been recently learned of the former, while a relative paucity of data exists on the latter. Examples of small, frequent disturbances include seasonal floods, periodic grassland fires, and mild to moderate storms which periodically influence the landscape (e.g., wind-created forest canopy gaps). Examples of the large, infrequent disturbances include volcanic eruptions, hurricanes, and major wildfires.

The River Continuum Concept.

This concept is a generalization of the physical and biological patterns often seen in different zones of rivers from source to mouth. Conceptually, from headwaters to outlet, there exists in a river a gradient of physical conditions – width, depth, velocity, flow volume, temperature, and other factors. Geomorphologists have shown that lotic (flowing water) systems show patterns, or adjustments, in the relationship of a number of physical characteristics (e.g., stream width, depth, velocity, bedload) along their entire length. Biotic characteristics in each zone reflect the influence of the physical influences they exist under; in other words, similar natural systems often develop under similar conditions. And as we move from the headwaters to a downstream reach, we see a continuum of physical conditions and a subsequent response in expected biota within these aquatic systems.



The River Continuum Concept is based on the idea that a watercourse is an open ecosystem that is in constant interaction with the bank, and moving from source to mouth, constantly changing. Basis for this change in the overall system is due to the gradual change of physical environmental conditions such as the width, depth, water, flow characteristics, temperature, and the complexity of the water. Structural and functional characteristics of stream communities are selected to conform to the most probable position or mean state of the physical system. As a river changes from headwaters to the lower reaches, there will be a change in the relationship between the production and consumption (respiration) of the material (P/R ratio).

The continuous differences of properties within the river are dependent primarily on the specific composition of the organisms in different sections of the water. Throughout the continuum of the river, the proportion of the four major feeding groups; shredders, collectors, grazers (scrapers) and predators change. With the exception of the predators, all these organisms feed directly from plant material.

Shredders

Shredders are organisms that feed off of coarse particulate organic material(CPOM) such as small sections of leaves. They ingest the organic matter along with volunteer organisms (fungi, microorganisms) attached to the source. The preferred size of the CPOM is about one millimeter, therefore shredders must break it up into a finer particulate. In the process of shredding, much of the now finer organic matter is left in the system, making its way further downstream. .

Collectors

Collector organisms are designated by their use of traps or other adaptive features to filter and catch organic matter. The preferred particle size for collectors lies between 0.5 and 50 micrometers (UPOM = Ultrafine particulate organic matter and FPOM = fine particulate organic matter).

Grazers

The grazers (scrapers) feed off of periphyton that accumulates on larger structures such as stones, wood or large aquatic plants.

Because of the differences in the structure of organic matter at different sections in a river, the make- up and frequency of these groups in a community vary. In the upper reaches of a river, shredders and collectors make up a large percentage of total macroinvertebrates due to the excess presence of coarse plant matter. In the midreaches of a stream or river, where more light is available, there is an increase in the proportion of grazers due to the presence of periphyton. Shredders only make up a small percentage of the total invertebrates due to the lack of coarse organic matter making its way downstream. In the lower reaches, organic matter has been shredded completely to the level of FPOM or UPOM (Ultra-fine Particulate Organic Matter). Due to the increase in fine particulate organic matter, collectors are the most abundant in the lower reaches, feeding off organic matter and surface films. The proportion of predators in all sections remains largely constant and only changes in species composition. The reason for the even distribution is that predators are not dependent on the size of the organic matter but on the availability of prey animals in the area Atypical changes in the composition of these groups of organisms within a watercourse, such as an increased number of shredders in a major river area (mid to lower reach) or a lack of these organisms in the upper reaches, suggest a possible disturbance

The river continuum concept assigns different sections of a river into three rough classifications. These classifications apply to all river waters, from small streams to medium-sized and large rivers.

Headwaters (Stream order 1 to 3)

The creek area in the upper reaches or headwaters of a water system is usually very narrow and lined by thick shore vegetation. This prevents the penetration of sunlight, in turn decreasing the production of organic material through photosynthesis in the water. The majority of the organic matter that does make its way into the system is in the form allochthonous plant material that falls into the river, such as leaves and sticks. In this section, respiration (consumption) outpaces production (P/R<1). Here shredders play a major role in breaking down coarse plant material. In this area, the largest diversity of organic material can be expected

Midreaches (Stream order 4-6)

In the midreaches of a river, river structures such as rocks and trees play an important role as a supplier of organic material such as periphyton and other autochthonous organic materials. The photosynthesis to respiration ratio is larger in this section and amounts to P: R> 1. The percentage of shredders in this area is less than that of the headwaters, due to lack of coarse plant particulate. Collectors and grazers make up a majority of the macro invertebrate structure in this area, with the predator's share remaining unchanged.

Lower reaches (Stream order >6)

In the lower reaches, there is a large flux in particulate material and also a decrease in production through photosynthesis, due to an increase in water cloudiness (turbidity) and surface film from suspended FPOM.

Here, like the headwaters, respiration outpaces photosynthesis, making the ratio again less than 1 (P: R <1). The living community in these areas is made up of almost exclusively collectors, as well as a small share of predators

The continuous changes down the water route are due to various factors. As described above, at its beginning, the river is very strongly influenced by material from outside the system, especially organic material which is consumed by various macroinvertebrates (mainly shredders). As you go further down the system there is an increase in autochthonous (i.e., within the system) production of organic material such as periphyton. The extent of this production varies depending on the amount of sunlight present. The last area is less dependent on the outside but still very much influenced by the degradation processes. In a continuous system without interference, such as by inflows, this development is possible in all river systems, with some variations occurring due to seasonal changes and other environmental factors (especially temperature)

Watershed Structure

Flowing (Lotic) Systems

The US has more than 3.5 million miles of flowing water systems, which include springs and seeps, rivers, streams, creeks, brooks and side channels. The Four-Dimensional Concept recognizes that lotic systems' structure exists in a four-dimensional framework, as follows:

1. Longitudinal (in an upstream and downstream direction) - Flowing water systems commonly go through structural changes en route from their source to mouth. Three zones are usually recognized –

- headwaters, where flow is usually lowest of any where along the system, slope is often steepest, and erosion is greater than sediment deposition
- transfer zone, the middle range of the stream where slope usually flattens somewhat, more flow appears, and deposition and erosion are both significant processes
- depositional zone, where flow is highest but slope is minimal and deposition of sediment significantly exceeds erosion most of the time.

2. Lateral (across the channel, floodplains and hillslopes) - Again, significant variation occurs among stream types, but a common pattern includes the channel, the deepest part of which is called the thalweg; low floodplains that are flooded frequently, and higher floodplains (e.g., the 100-year or 500-year) that are rarely inundated; terraces, which are former floodplains that a down-cutting stream no longer floods; and hillslopes or other upland areas extending up-gradient to the watershed boundary.

3. Vertical (surface waters, ground water and their interactions) - It is always important to recognize that water bodies are not purely surface features; rivers and streams constantly interact with groundwater aquifers and exchange water, chemicals, and even organisms. Over its entire length, a stream often varies between influent reaches where surface water leaks downward into the aquifer and effluent reaches where the stream receives additional water from the aquifer.

4. Temporal (through time, from temporary response to evolutionary change) - The dimension of time is important because rivers and streams are perpetually changing. Structure as described in the other three dimensions above should never be considered permanent, and watershed managers should always think of structure not just as what is there now, but in terms of the structural changes in progress and their rates of occurrence.

Still (Lentic) Waters

Lentic systems generally include lakes and ponds. A lake's structure has a significant impact on its biological, chemical, and physical features. Some lentic systems may be fresh water bodies, while others have varying levels of salinity (e.g., Great Salt Lake). Most basin-type wetlands are also generally grouped within lentic systems; these are areas of constant soil saturation or inundation with distinct vegetative and faunal communities. Lakes and ponds are almost always connected with streams in the same watershed, but the reverse is not nearly as often true.

The method of lake formation is the basis for classifying different lakes. Natural processes of formation most commonly include glacial, volcanic, and tectonic forces while human constructed lakes are created by dams or excavation of basins. Of the processes that form these lakes, glacial activity has been the most important mechanism for their formation in North America. Although on human time scales we may think of lakes as permanent, they are ephemeral features on the landscape. They are found in depressions in the earth's surface in regions where water is available to fill the basin. Over time, lakes fill with sediments and organic material while outlets tend to erode the lake rim away.

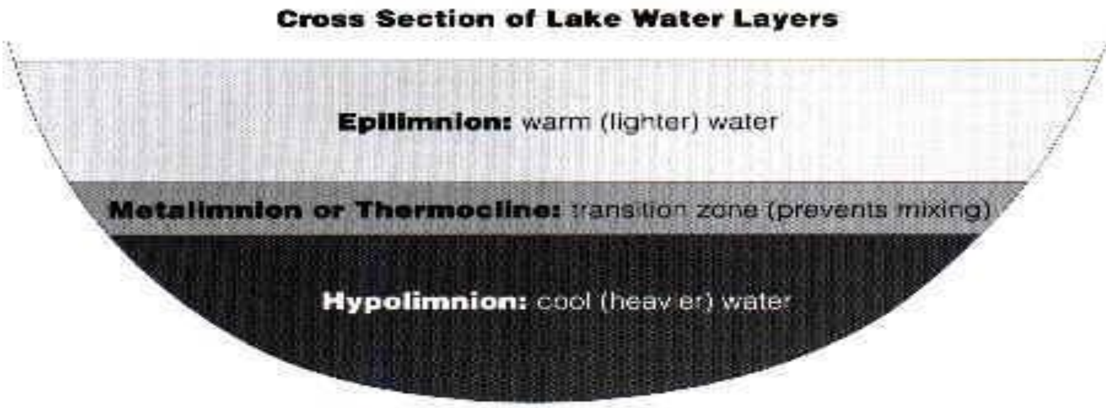
Lake Types

- Glacial Lakes. Most of North America's lakes including the Great Lakes were formed during the most recent cycle of glacial activity (approx. 10,000 to 20,000). Although glaciers can form lakes through several unique processes, most basins are carved out by the glacier's weight and movement, or created when glacial debris forms dams. Glacial moraine dams are responsible for a number of lakes in North America. Melting ice blocks left by retreating glaciers create kettle lakes.
- Tectonic Basins. These basins form or are exposed due to movements of the earth's crust. This can result from uplifting as when irregular marine surfaces that collect freshwater after elevation (e.g. Lake Okeechobee in Florida), and tilting or folding to create depressions that form lake basins. Lakes also form along faults (e.g. several lakes in California).
- % Volcanic Lakes. Several different volcanic processes can form lake basins. Craters form natural basins (Crater Lake in Oregon) well-known for their clear waters and lava dams can create basins in valleys.
- Landslides. Rockfalls or mudslides that dam streams or rivers can form lakes for periods as short as a year to several centuries.
- Solution Lakes. These lakes can be found in areas characterized by significant limestone deposits where percolating water creates cavities. These lakes are particularly common in Florida.
- Oxbow Lakes. Where rivers or streams have meandered across low gradients, oxbows can often form in areas where the former channel has become isolated from the rest of the river. Several examples can be found along the Mississippi River and other large rivers.
- Beaver-made and Human-made Lakes. Both humans and beavers create lakes when they dam rivers and streams. In addition to the many large dams, there are upwards of one million small dams impounding lakes and ponds across the lower 48 states.

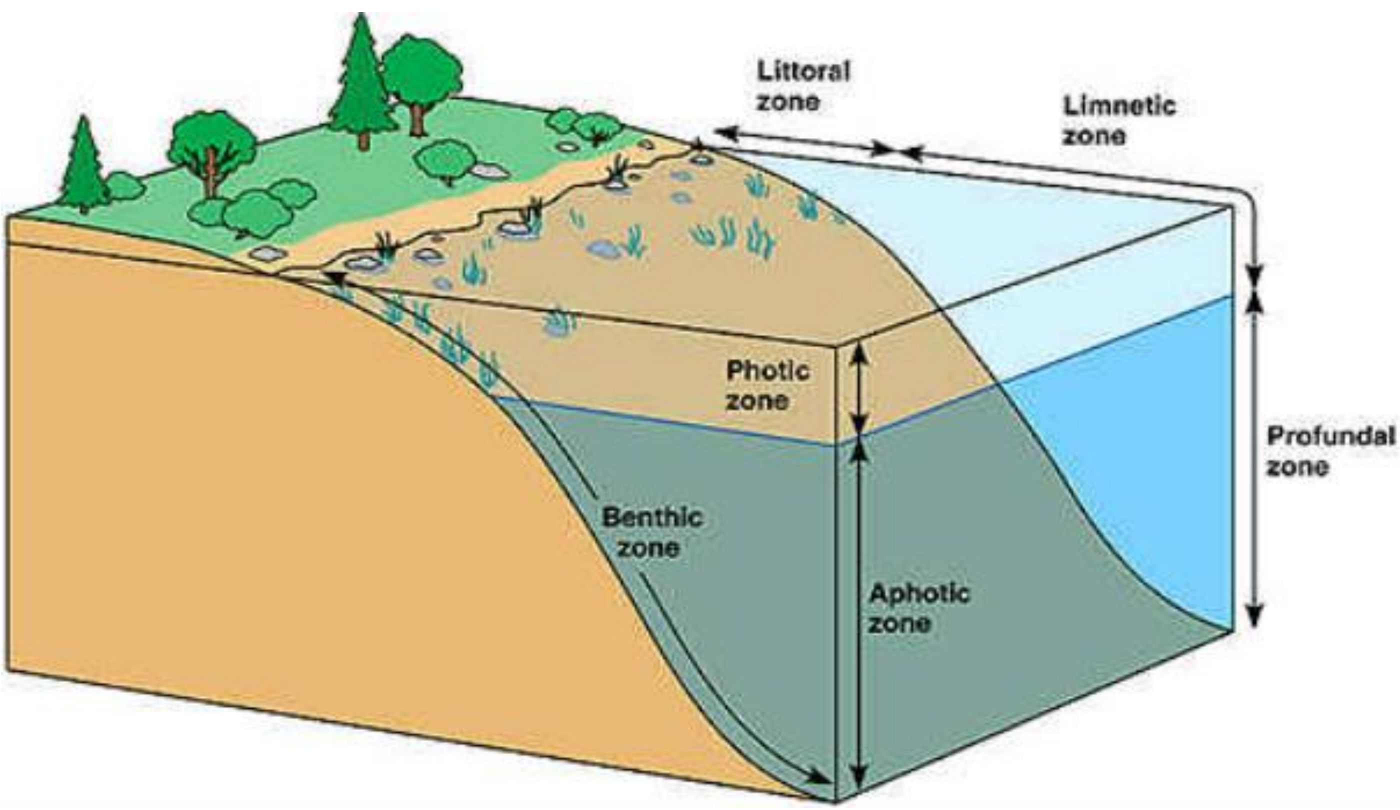
Lake Zones

A typical lake has distinct zones of biological communities linked to the physical structure of the lake.
The littoral zone is the near shore area where sunlight penetrates all the way to the sediment and allows aquatic plants (macrophytes) to grow. Light levels of about 1% or less of surface values usually define the deepest portion of this zone. The 1% light level also defines the bottom of the euphotic zone of the lake, which is the layer from the surface down to the depth where light levels become too low for photosynthesizers. In most lakes, the sunlit euphotic zone occurs within the epilimnion. However, in unusually transparent lakes, photosynthesis may occur well below the thermocline into the perennially cold hypolimnion. The higher

plants in the littoral zone, in addition to being a food source and a substrate for algae and invertebrates, provide a habitat for fish and other organisms that is very different from the open water environment.



The limnetic zone is the open water area where light does not generally penetrate all the way to the bottom. The bottom sediment, known as the benthic zone, has a surface layer abundant with organisms. This upper layer of sediments may be mixed by the activity of the benthic organisms that live there, often to a depth of 2-5 cm (several inches) in rich organic sediments. Most of the organisms in the benthic zone are invertebrates. The productivity of this zone largely depends upon the organic content of the sediment, the amount of physical structure, and in some cases upon the rate of fish predation. Sandy substrates contain relatively little organic matter (food) for organisms and poor protection from predatory fish. Higher plant growth is typically sparse in sandy sediment, because the sand is unstable and nutrient deficient. A rocky bottom has a high diversity of potential habitats offering protection (refuge) from predators, substrate for attached algae (periphyton on rocks), and pockets of organic "ooze" (food). A flat mucky bottom offers abundant food for benthic organisms but is less protected and may have a lower diversity of structural habitats, unless it is colonized by higher plants.

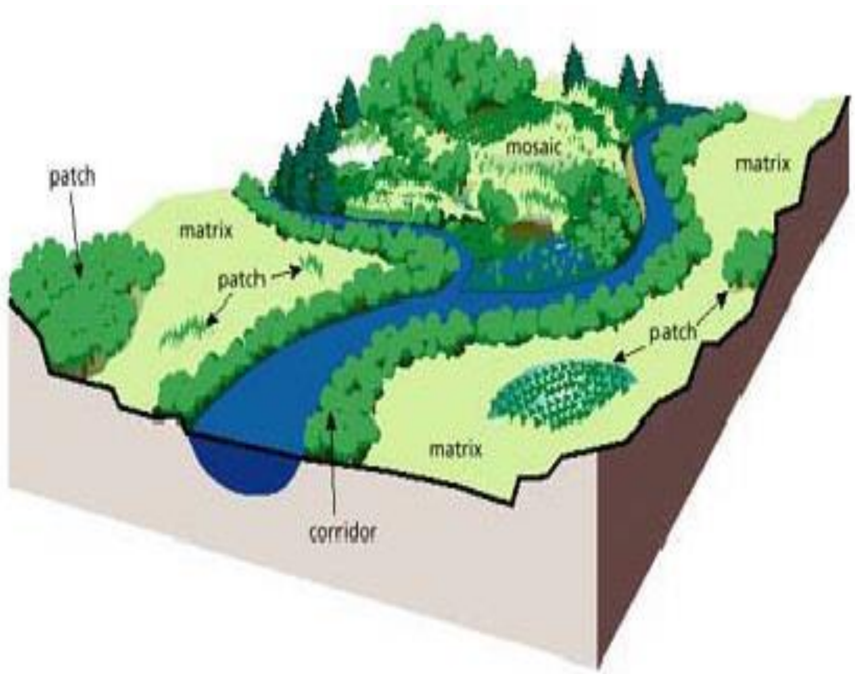


Basic Functional Differences Between Streams and Lakes

Differences between lake and stream dynamics are largely the result of differences in the location of energy fixation and the water residence time. Streams are primarily heterotrophic systems with energy fixed in the terrestrial environment rather than the stream itself and they are much more dependent on their watershed. Energy fixation and decomposition are spatially separated from each other. Although lakes are also dependent on their watersheds largely as the source of nutrients, most of the activity occurs in the water. In a lake, energy fixation and utilization of that energy by other organisms are not as spatially separated. Organisms in lakes and streams also tend to differ, due to the fact that stream organisms experience flowing water currents. The majority of producers and primary consumers in streams are benthic organisms that spend much of their time closely associated with the substrate. Because many lakes stratify, and have bottom waters that are limited in light and nutrients, the main challenge for organisms in many lakes is to remain suspended in the water column.

Landscape patterns.

Landscape ecology offers a simple set of concepts and terms for identifying basic landscape patterns: matrix, patch, and mosaic. The ecological term matrix refers to the dominant (> 60 percent) land cover, while a patch is a nonlinear area that is less abundant and different from the matrix. A mosaic is a collection of different patches comprising an area where there is no dominant matrix.



Landscape pattern change.

The individual patches in a landscape can change, and so can the entire landscape change in pattern and/or composition. Disturbances and various landscape processes maintain a constant dynamic, referred to as a shifting mosaic. Some landscapes remain in a “dynamic equilibrium” and, although changing steadily from place to place, retain an important quality called mosaic stability. A well-managed forestry operation, for example, would exhibit over the long term a constantly shifting set of locations where mature forest occurred, but at the same time sustains the relative proportions of forested and non-forested land in the area. Or, a landscape may evolve toward a new type of pattern and composition (e.g., via timber clearcutting, suburban sprawl, abandonment and succession of agricultural lands back to forest, or landscape change due to disease, fire, or global warming).

Vegetational patterns.

Upland vegetation structure varies spatially, following various biogeographical patterns based on climate, physiography, soils, disturbance regimes, and their interactions. Vegetation communities are areas where a few species of plants dominate and establish a characteristic form or structure, within which a potentially large number of less abundant organisms also exist. Nationwide, there are hundreds of vegetation community types; the Society of American Foresters recognizes over 80 forest types alone. As a first step in analyzing vegetational patterns, it is easier to recognize a few generalized upland vegetation types based on their growth form, including: forests (deciduous, evergreen and mixed), shrublands, grasslands, and forbs (broad-leaved herbs). Human activity has carved up and fragmented many of the natural vegetation patterns that formerly covered our watersheds. Without human influence, however, vegetation patterns would not be uniform due to different vegetation communities arising from different environmental conditions (e.g. variations in moisture and temperature due to slope and aspect) and events (e.g., fire, pest outbreak).

Land-use patterns.
Because multiple uses occur in many locations and some land uses are not in themselves a visible landscape feature, mappers often use the term land cover to describe the delineation of landscape structure and pattern formed by the dominant land uses and remaining vegetation communities. Some common land cover categories (indicating land uses within the areas) include: urban land (residential, commercial, industrial, mixed), agriculture (row crops, field crops, pasture), transportation (roads, railroads, airports), rangelands, silviculture, and, mining/extractive areas. Like vegetation patterns, the land use patterns in a watershed can be studied through GIS data or maps.

Watershed Functions
The essential functions that occur in most healthy watersheds include:

- Transport and storage (of water, energy, organisms, sediments, and other materials) Because a watershed is an area that drains to a common body of water, one of its main functions is to temporarily store and transport water from the land surface to the water body and ultimately (for most watersheds) onward to the ocean. But, in addition to moving the water, watersheds and their water bodies also transport sediment and other materials (including pollutants), energy, and many types of organisms
    - Transport and Storage. As matter physically moves through the watershed, there are a number of terms which arise relative to various stages of cycling. ***Availability*** refers not just to the presence of an element in a system, but also speaks to it's usability. ***Detachment*** refers to the release of matter from an anchoring point, and its subsequent movement. ***Transport***, a process most evident in stream channels, involves the movement of a material through a system. ***Deposition*** refers to a given endpoint within a cycle. ***Integration*** refers to the assimilation of matter into a site or organism following depositional processes.
    - Transport and storage of water. One can view a watershed as an enormous precipitation collecting and routing device, but transportation and storage of water actually involves a complicated mix of many smaller processes. Even before precipitation reaches the ground (Figure at right), it interacts with vegetation. Trees and other vegetation are responsible for interception and detention of some of the rainfall, leading to some evaporation and also slowing the amount reaching the ground via throughfall and giving it time for better infiltration to groundwater (one form of storage). Saturation of soils, occurring when precipitation exceeds infiltration, leads to overland flow and, over longer time frames, drainage network development. The consistent flow of water in channels affects and shapes channel development and morphology in ways that seek dynamic equilibrium with the job to be done (moving water downstream).

    - Transport and storage of sediments. Watersheds also collect and transport sediments as a major function.

Sediment related processes mostly involve erosion and deposition, but sediment transport and storage also play a longer-term role in soil development.

- Cycling and Transformation. Cycling and transformation are another broad class of natural functions in watersheds. Various elements and materials (including water) are in constant cycle through watersheds, and their interactions drive countless other watershed functions. Elements like carbon, nitrogen, and phosphorus comprise the watershed’s most important biogeochemical cycles. Cycling involves an element of interest’s transport and storage, change in form, chemical transformation and adsorption.
- Nutrient Spiraling. The flow of energy and nutrients in ecosystems are cyclic, but open-ended. True systems, in both an environmental and energetic context, are either “open” (meaning that there is some external input and/or output to the cyclic loop) or “closed” (meaning that the system is self-contained). In watersheds, streams and rivers represent an open-system situation where energy and matter cycles, but due to the unidirectional flow, the matter does not return to the spot from whence it came. Also, nutrients “spiral” back and forth among the water column, the bodies of terrestrial and aquatic organisms, and the soil in the stream corridor en route downstream. Hence, the concept of nutrient “spiraling” implies both movement downstream and multiple exchanges between terrestrial and aquatic environments, as well as between biotic and abiotic components of the watershed.
- Nitrogen (N). N_2 (gaseous state) is not usable by plants and most algae. N-fixing bacteria or blue-green algae transform it into nitrite (NO_2) or ammonia (NH_4). N fixation, precipitation, surface water runoff, and groundwater are all sources of nitrogen. Under aerobic conditions, NH_4+ is oxidized to NO_3- (nitrate) in the nitrification process. Losses of N occur with stream outflow, denitrification of nitrate (NO_3) to N_2 by bacteria, and deposition in sediments. Unlike P, inorganic N ions are highly soluble in water and readily leach out of soils into streams. NH_4+ (ammonium) is the primary end-product of decomposition.

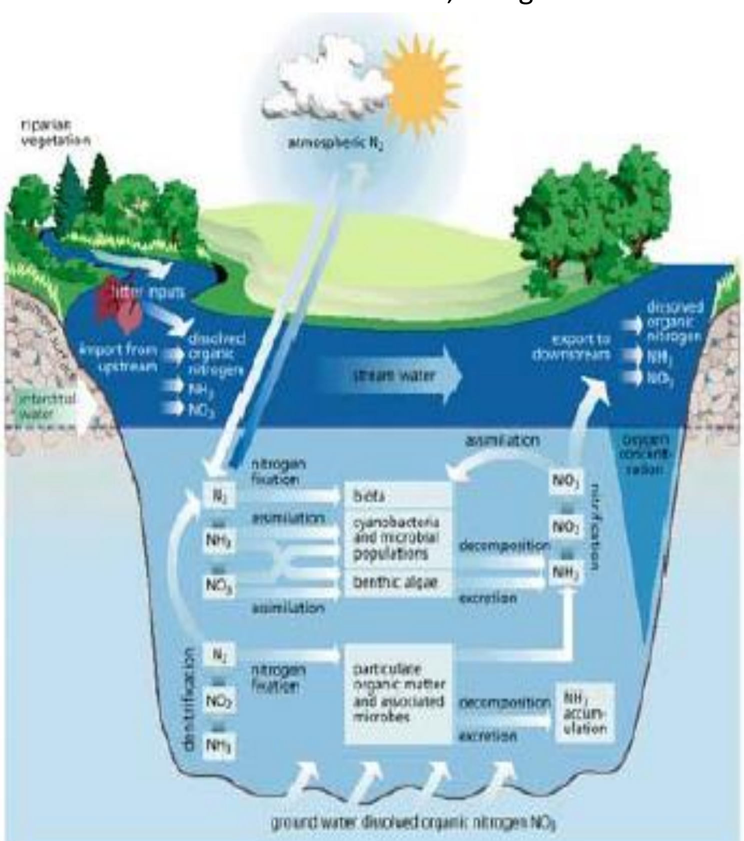


Figure 10 The nitrogen cycle.

- Phosphorus (P). Phosphorus in unpolluted watersheds is imported through dust in precipitation, or via the weathering of rock. Phosphorus is normally present in watersheds in extremely small amounts. Soluble reactive phosphorus (consisting of ionic orthophosphates) is the only significant form available to plants and algae and constitutes less than 5 percent of the total phosphorus in most natural waters. Phosphorus tends to exist in waters of a pH of 6-7. At a low pH (<6), P tends to combine readily with manganese, aluminum, and iron. At a higher pH (>7), P becomes associated with calcium as apatite and phosphate minerals. It is normally retained in aquatic systems by algae, bacteria and fungi.
- Nitrogen and Phosphorus limitation. Most watershed systems (both the aquatic and terrestrial realms) are either N or P limited, in that these are the required elements which are at the lowest availability. As a general rule, the N:P ratio should be 15:1. A lower ratio would indicate that N is

limiting, a higher ratio places P in that role. Commonly P is the limiting factor. Often, the slightest increase in P can trigger growth, as in algal blooms in an aquatic setting. In N and P limited systems, an input of either element above and beyond normal, “natural” levels may lead to eutrophication. The stream corridor is often a mediator of upland-terrestrial nutrient exchanges. As N and P move down through subsurface flow, riparian root systems often filter and utilize N and P, leaving less to reach the stream. This has a positive influence on those already nutrient overloaded bodies of water, but would not necessarily be a positive influence on organisms struggling to find food in very clean, nutrient-limited headwaters streams. Microbes also denitrify significant amounts of N to the atmosphere. Still, N-fixers, like alder, may serve as sources of N for the stream channel, and groundwater pathways between the stream and the streamside forest may provide significant quantities of nitrogen.

- Decomposition. Decomposition involves the reduction of energy-rich organic matter (detritus), mostly by microorganisms (fungi, bacteria, and protozoa) to CO_2, H_2O and inorganic nutrients. Through this process they both release nutrients available for other organisms and transform organic material into energy usable by other organisms. In lakes, much of the decomposition occurs in the waters prior to sedimentation. In the headwater reaches of streams, external sources of carbon from upland forests are a particularly important source of organic material for organisms and decomposition of microscopic particles occurs very rapidly. Decomposition is influenced by moisture, temperature, exposure, type of microbial substrate, vegetation, etc.
- Ecological Succession The classical ecological definition of plant succession involves a predictable set of vegetative changes through a series of discrete stages (seres). Recent challenges to the original succession concept suggest that succession does not necessarily involve a “climax” stage (after which additional changes in dominant species and structure do not normally occur).

Groundwater

Some water underlies the Earth’s surface almost everywhere, beneath hills, mountains, plains, and deserts. It is not always accessible, or fresh enough for use without treatment, and it’s sometimes difficult to locate or to measure and describe. This water may occur close to the land surface, as in a marsh, or it may lie many hundreds of feet below the surface, as in some arid areas of the West. Water at very shallow depths might be just a few hours old; at moderate depth, it may be 100 years old; and at great depth or after having flowed long distances from places of entry, water may be several thousands of years old. Ground water is stored in, and moves slowly through, moderately to highly permeable rocks called aquifers. The word aquifer comes from the two Latin words, aqua, or water, and ferre, to bear or carry. Aquifers literally carry water underground. An aquifer may be a layer of gravel or sand, a layer of sandstone or cavernous limestone, a rubbly top or base of lava flows, or even a large body of massive rock, such as fractured granite, that has sizable openings. In terms of storage at any one instant in time, ground water is the largest single supply of fresh water available for use by humans. Only a fraction of this reservoir of ground water, however, can be practicably tapped and made available on a perennial basis through wells and springs. The amount of ground water in storage is more than 30 times greater than the nearly 30,000 cubic-miles volume in all the fresh-water lakes and more than the 300 cubic miles of water in all the world’s streams at any given time.

The Nation’s total supply of water is large. Average annual streamflow in the conterminous (48) States is about 1,200 billion gallons a day or about three times the present water use. Much of the flow is sustained by discharge from ground-water reservoirs. The use of ground water increased steadily from 1950 to 1980 and generally has decreased since 1980. About 51 percent of the Nation’s population depends on ground water for domestic uses.

How Ground Water Occurs

It is difficult to visualize water underground. Some people believe that ground water collects in underground lakes or flows in underground rivers. In fact, ground water is simply the subsurface water that fully saturates pores or cracks in soils and rocks. Ground water is replenished by precipitation and, depending on the local climate and geology, is unevenly distributed in both quantity and quality. When rain falls or snow melts, some of the water evaporates, some is transpired by plants, some flows overland and collects in streams, and some infiltrates into the pores or cracks of the soil and rocks. The first water that enters the soil replaces water that has been evaporated or used by plants during a preceding dry period. Between the land surface and the aquifer water is a zone that hydrologists call the *unsaturated zone*. In this unsaturated zone, there usually is at least a little water, mostly in smaller openings of the soil and rock; the larger openings usually contain air instead of water. After a significant rain, the zone may be almost saturated; after a long dry spell, it may be almost dry. Some water is held in the unsaturated zone by molecular attraction, and it will not flow toward or enter a well. After the water requirements for plant and soil are satisfied, any excess water will percolate to the water table — the top of the zone below which the openings in rocks are saturated. Below the water table, all the openings in the rocks are full of water that moves through the aquifer to streams, springs, or wells from which water is being withdrawn. Natural refilling of aquifers at depth is a slow process because ground water moves slowly through the unsaturated zone and the aquifer. Aquifers can be replenished artificially. For example, large volumes of ground water used for air conditioning are returned to aquifers through recharge wells on Long Island, New York. Aquifers may be artificially recharged in two main ways: One way is to spread water over the land in pits, furrows, or ditches, or to erect small dams in stream channels to detain and deflect surface runoff, thereby allowing it to infiltrate to the aquifer; the other way is to construct recharge wells and inject water directly into an aquifer as shown on figure 12. The latter is a more expensive method but may be justified where the spreading method is not feasible. A well, in simple concept, may be

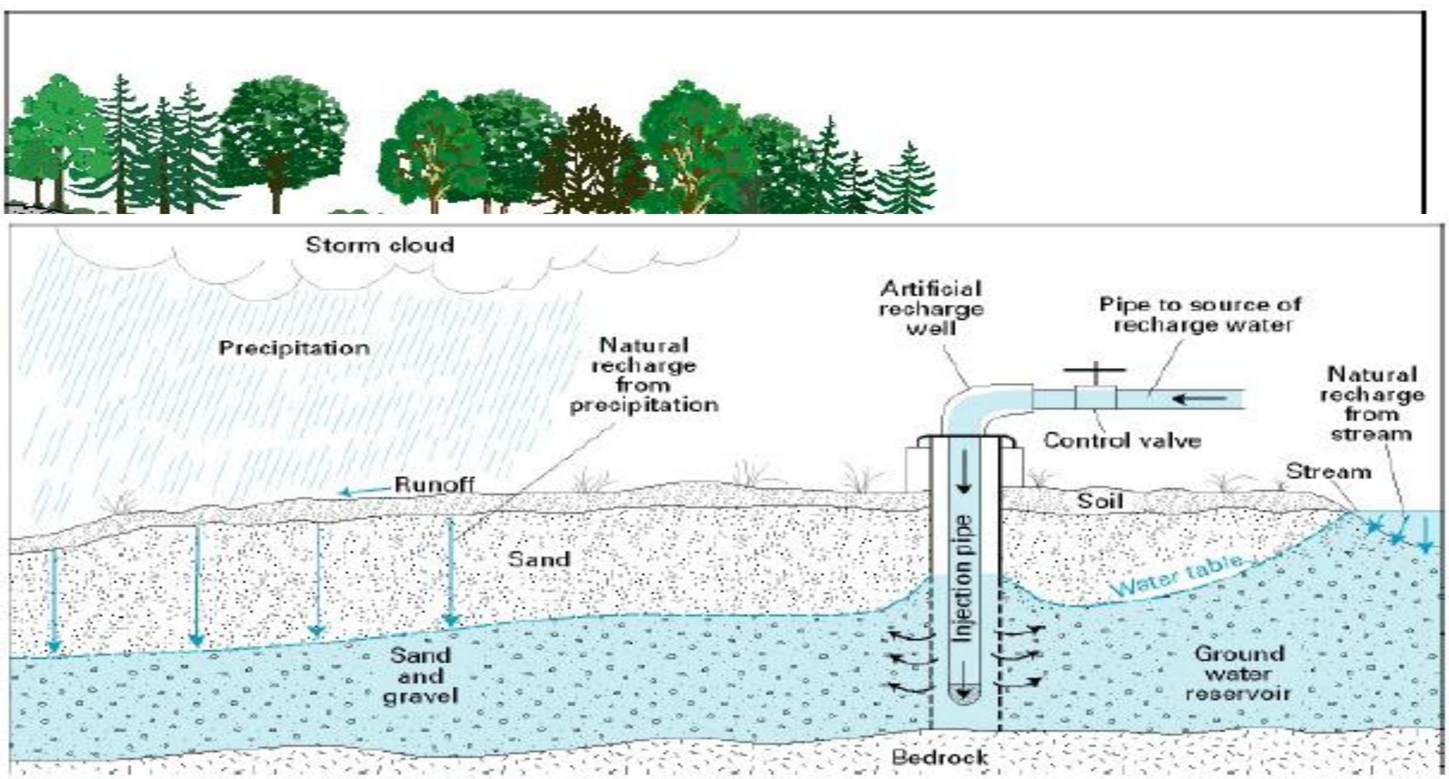


Figure 12 Natural and Artificial Recharge of an Aquifer.

regarded as nothing more than an extra-large pore in the rock. A well dug or drilled into saturated rocks will fill with water approximately to the level of the water table. If water is pumped from a well, gravity will force water to move from the saturated rocks into the well to replace the pumped water. The amounts of water that an aquifer will yield to a well may range from a few hundred gallons a day to as much as several million gallons a day. An aquifer may be only a few or tens of feet thick to hundreds of feet thick. It may lie a few feet below the land surface to thousands of feet below. It may underlie thousands of square miles to just a few acres. The Dakota Sandstone, for example, carries water over great distances beneath many States, including parts of North Dakota, South Dakota, Montana, Wyoming, Colorado, Nebraska, Kansas, New Mexico, and Oklahoma. On the other hand, deposits of sand and gravel along many streams form aquifers of only local extent. The quantity of water a given type of rock will hold depends on the rock's porosity — a measure of pore space between the grains of the rock or of cracks in the rock that can fill with water. For example, if the grains of a sand or gravel aquifer are all about the same size, or "well sorted," the water-filled spaces between the grains account for a large proportion of the volume of the aquifer. If the grains, however, are poorly sorted, the spaces between larger grains may be filled with smaller grains instead of water. Sand and gravel aquifers having well-sorted grains, therefore, hold and transmit larger quantities of water than such aquifers with poorly sorted grains. If water is to move through rock, the pores must be connected to one another. If the pore spaces are connected and large enough that water can move freely through them, the rock is said to be permeable. A rock that will yield large volumes of water to wells or springs must have many interconnected pore spaces or cracks. A compact rock almost without pore spaces, such as granite, may be permeable if it contains enough sizable and interconnected cracks or fractures.

After entering an aquifer, water moves slowly toward lower lying places and eventually is discharged from the aquifer from springs, seeps into streams, or is intercepted by wells. Ground water in aquifers between layers of poorly permeable rock, such as clay or shale, may be confined under pressure. If such a confined aquifer is tapped by a well, water will rise above the top of the aquifer and may even flow from the well onto the land surface. Water confined in this way is said to be under artesian pressure, and the aquifer is called an artesian aquifer. The level to which water will rise in tightly cased wells in artesian aquifers is called the potentiometric surface. Deep wells drilled into rock to intersect the water table and reaching far below it are often called artesian wells in ordinary conversation, but this is not necessarily a correct use of the term. Such deep wells may be just like ordinary, shallower wells; great depth alone does not automatically make them artesian wells. The word artesian, properly used, refers to situations where the water is confined under pressure below layers of relatively impermeable rock.

Where ground water is not confined under pressure, it is described as being under water-table conditions. Water-table aquifers generally are recharged locally, and water tables in shallow aquifers may fluctuate up and down directly in unison with precipitation or streamflow. A spring is the result of an aquifer being filled to the point that the water overflows onto the land surface. There are different kinds of springs and they may be classified according to the geologic formation from which they obtain their water, such as limestone springs or lava-rock springs; or according to the amount of water they discharge — large or small; or according to the temperature of the water — hot, warm, or cold; or by the forces causing the spring — gravity or artesian flow. Thermal springs are ordinary springs except that the water is warm and, in some places, hot. Many thermal springs occur in regions of recent volcanic activity and are fed by water heated by contact with hot rocks far below the surface. Even where there has been no recent volcanic action, rocks become warmer with increasing depth. In some such areas water may migrate slowly to considerable depth, warming as it descends through rocks deep in the Earth. If it then reaches a large crevice that offers a path of less resistance, it may rise more quickly than it descended. Water that does not have time to cool before it emerges forms a thermal spring. The famous Warm Springs of Georgia and Hot Springs of Arkansas are of this type. Geysers are thermal springs that erupt intermittently and to differing heights above the land surface. Some geysers are spectacular and world famous, such as Old Faithful in Yellowstone National Park.

There are two types of aquifers; confined and unconfined. All aquifers sit on an impermeable layer of clay or bedrock. A confined aquifer has a layer of impermeable clay or bedrock above it, as well, and an unconfined aquifer does not. Figure 13 illustrates the two types of aquifers, as well as the way in which the groundwater is connected to the surface. Artesian wells can be drilled into confined aquifers, because the great amount of pressure on the water (from the overlying ground) forces the water upwards. Unconfined aquifers can recharge nearby streams, during times of drought.

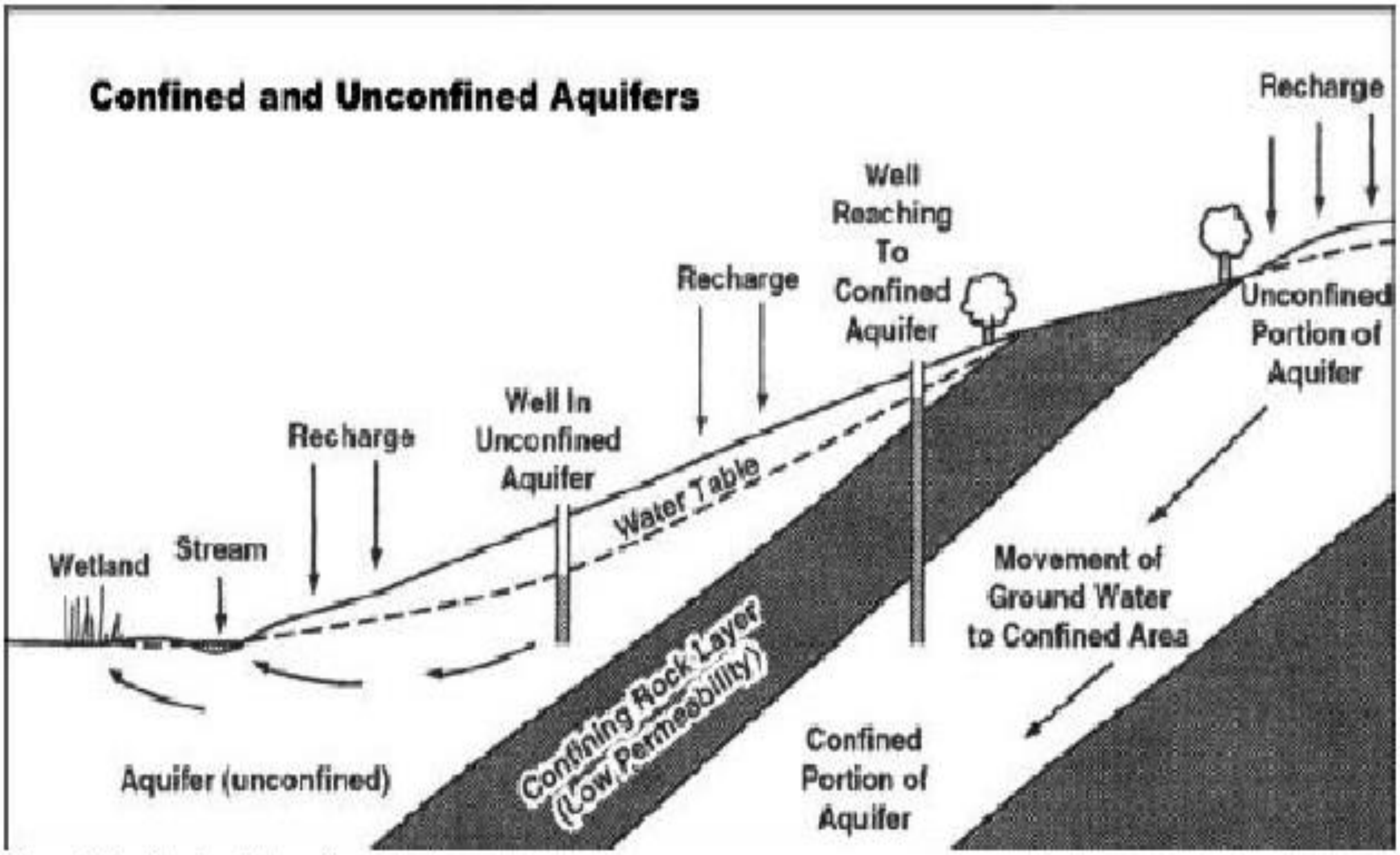


Figure 13 Confined and Unconfined Aquifers

Quality of Ground Water

For the Nation as a whole, the chemical and biological character of ground water is acceptable for most uses. The quality of ground water in some parts of the country, particularly shallow ground water, is changing as a result of human activities. Ground water is less susceptible to bacterial pollution than surface water because the soil and rocks through which ground water flows screen out most of the bacteria. Bacteria, however, occasionally find their way into ground water, sometimes in dangerously high concentrations. But freedom from bacterial pollution alone does not mean that the water is fit to drink. Many unseen dissolved mineral and organic constituents are present in ground water in various concentrations. Most are harmless or even beneficial; though occurring infrequently, others are harmful, and a few may be highly toxic. Water is a solvent and dissolves minerals from the rocks with which it comes in contact. Ground water may contain dissolved minerals and gases that give it the tangy taste enjoyed by many people. Without these minerals and gases, the water would taste flat. The most common

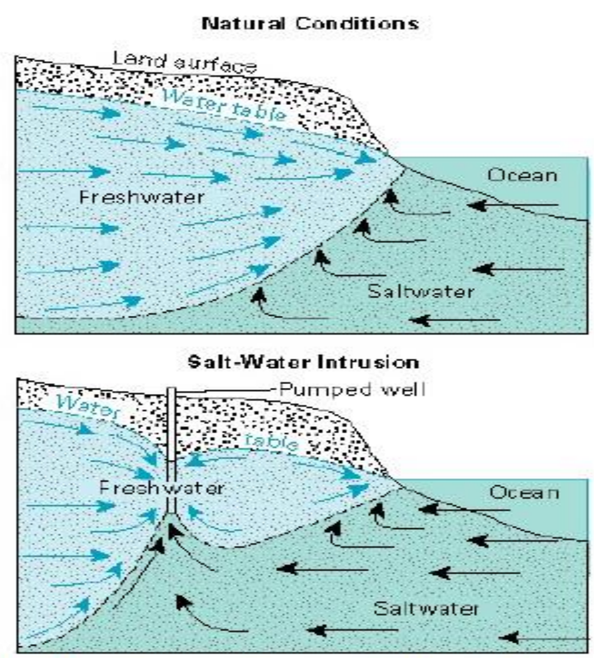


Figure 14 How intensive ground-water pumping can cause salt-water intrusion in coastal aquifers.

dissolved mineral substances are sodium, calcium, magnesium, potassium, chloride, bicarbonate, and sulfate.

Water typically is not considered desirable for drinking if the quantity of dissolved minerals exceeds 1,000 mg/L (milligrams per liter). Water with a few thousand mg/L of dissolved minerals is classed as slightly saline, but it is sometimes used in areas where less-mineralized water is not available. Water from some wells and springs contains very large concentrations of dissolved minerals and cannot be tolerated by humans and other animals or plants. Many parts of the Nation are underlain at depth by highly saline ground water that has only very limited uses. Dissolved mineral constituents can be hazardous to animals or plants in large concentrations; for example, too much sodium in the water may be harmful to people who have heart trouble. Boron is a mineral that is good for plants in small amounts, but is toxic to some plants in only slightly larger concentrations.

Water that contains a lot of calcium and magnesium is said to be hard. The hardness of water is expressed in terms of the amount of calcium carbonate-the principal constituent of limestone-or equivalent minerals that would be formed if the water were evaporated. Very hard water is not desirable for many domestic uses; it will leave a scaly deposit on the inside of pipes, boilers, and tanks. Hard water can be softened at a fairly reasonable cost, but it is not always desirable to remove all the minerals that make water hard. Extremely soft water is likely to corrode metals, although it is preferred for laundering, dishwashing, and bathing. Ground water, especially if the water is acidic, in many places contains excessive amounts of iron. Iron causes reddish stains on plumbing fixtures and clothing. Like hardness, excessive iron content can be reduced by treatment. According to U.S. Environmental Protection Agency criteria, water for domestic use should have a pH
between 5.5 and 9.

Saltwater Intrusion

Under natural conditions, the seaward movement of freshwater prevents saltwater from encroaching coastal aquifers, and the interface between freshwater and saltwater is maintained near the coast or far below land surface. This interface is actually a diffuse zone in which freshwater and saltwater mix, and is referred to as the zone of dispersion (or transition zone). Ground-water pumping can reduce freshwater flow toward coastal discharge areas and cause saltwater to be drawn toward the freshwater zones of the aquifer. Saltwater intrusion decreases freshwater storage in

Salinity

The presence of soluble salts in the soil, groundwater and surface water bodies is a major land degradation problem worldwide. Salinity exacts many economic and environmental costs. These include a reduction in agricultural productivity, a decline in the quality of water supplies for drinking, irrigation and industrial use, damage to urban infrastructure and the loss of biodiversity in both terrestrial and aquatic ecosystems.

Like many land degradation processes, salinity is a natural process. However land use practices, such as clearing and irrigation, have significantly increased the extent of the problem. The USDA estimates that, worldwide, 10 million hectares of arable land is lost to irrigation salinity every year..

What is salinity?

Salinity refers to the presence of soluble salts in the soil and water, including surface water and groundwater. Some soils and landscapes are saline in their natural state, for example inland salt lakes and soils formed from saline parent materials. This is called natural or primary salinity. Secondary salinity is due to human activities such as land clearing and over-irrigation. These activities result in groundwater rising to the surface, dissolving the salts and then depositing them in the soil.

Where does the salt come from?

Salt can be found in many old, highly weathered landscapes and originates from:

- weathering of rock minerals
- deposition of oceanic salt onto the landscape by wind or rain
- soils formed from marine sediments left behind by retreating seas.

In undisturbed landscapes, most of the salt is slowly leached into the subsoil, beyond the reach of plant roots

Irrigation salinity

Irrigation salinity is the accumulation of salts in the topsoil under irrigation. It is caused by over-irrigation of agricultural land, inefficient water use, poor drainage and the irrigation the aquifers, and, in extreme cases, can result in the abandonment of supply wells. Saltwater intrusion occurs by many mechanisms, including lateral encroachment from coastal waters and vertical upconing near discharging wells.

Competing uses for water (Statistics from 2010)

Since 1950, the U.S. Geological Survey (USGS) has compiled data on amounts of water used in homes, businesses, industries, and on farms throughout the United States, and has described how that use has changed with time. Water availability has emerged as an important issue for the 21st century. Between 1950 and 1980 there was a steady increase in water use in the United States. During this time, the expectation was that as population increased, so would water use. Contrary to expectation, reported water withdrawals declined in 1985 and have remained relatively stable since then in spite of a steady increase in United States population. Estimates of water use for 2000 indicate that about 408 billion gallons per day were withdrawn for all uses during the year. This total has varied less than 3 percent since 1985 as withdrawals have stabilized for the two largest uses—thermoelectric power and irrigation. Freshwater withdrawals were about 80 percent of the total, and the remaining 20 percent was saline water. Saline water is defined as water with 1000 mg/L or more of dissolved solids; it is usually undesirable for drinking and for many industrial uses.

Thermoelectric Water Use (45%)

Thermoelectric power accounts for about half of total water withdrawals. Most of the water is derived from surface water and used for once-through cooling at power plants. Almost 96 percent of saline-water withdrawals are for thermoelectric-power use.

Irrigation Water Use (32%)

Irrigation accounts for about a third of water use and is currently the largest use of fresh water in the United States. Irrigation water use includes water used for growing crops, frost protection, chemical applications, weed control, and other agricultural purposes, as well as water used to maintain areas such as parks and golf courses. Historically, more surface water than ground water has been used for irrigation. The percentage of total irrigation withdrawals from ground water has increased significantly in the last 50 years. The number of acres irrigated with sprinkler and microirrigation systems has continued to increase and now comprises more than one-half the total irrigated acreage.

Public Supply Water Use (12%)

Public-supply water is water withdrawn by public and private water suppliers, in contrast to self-supplied water, which is water withdrawn by a user. Public-supply water may be used for domestic, commercial, industrial, thermoelectric power, or public-use purposes. Approximately 85% of drinking water is from public supplies and accounts for 12% of water use in the US.

Industrial Water Use (4.5%)

Self-supplied industrial water withdrawals accounted for about 5% of water use. Industrial water use includes water used for fabrication, processing, washing, and cooling, and also includes water used by smelting facilities, petroleum refineries, and industries producing chemical products, food, and paper products.

Other Water Use (6%)

Combined withdrawals for self-supplied domestic, livestock, aquaculture, and mining activities represented about 6% total water withdrawals. Self-supplied domestic withdrawals include water used for household purposes which is not obtained from public supply. About 43 million people in the United States self-supply their domestic water needs, usually from wells.

Point and Nonpoint Source Pollution

Point Source

The U.S. Environmental Protection Agency (EPA) defines point source pollution as “any single identifiable source of pollution from which pollutants are discharged, such as a pipe, ditch, ship or factory smokestack”.

Factories and sewage treatment plants are two common types of point sources. When they discharge one or more pollutants in their discharged waters they are called effluents. An important point source is urban runoff in a combined sewer system. Runoff refers to stormwater that flows over surfaces like driveways and lawns. As the water crosses these surfaces, it picks up chemicals and pollutants. This untreated, polluted water then runs directly into a sewer system. When it rains excessively, a combined sewer system may not be able handle the volume of water, and some of the combined runoff and raw sewage will overflow from the system, discharging directly into the nearest waterbody without being treated. This combined sewer overflow (CSO) is considered point source pollution, and can cause severe damage to human health and the environment.

Whether a discharged chemical is harmful to the aquatic environment depends on a number of factors, including the type of chemical, its concentration, the timing of its release, weather conditions, and the organisms living in the area. Large farms that raise livestock, such as cows, pigs and chickens, are other sources of point source pollution. These types of farms are known as concentrated animal feeding operations (CAFOs). If they do not treat their animals' waste materials, these substances can then enter nearby waterbodies as raw sewage, radically adding to the level and rate of pollution. To control point source discharges, the Clean Water Act established the National Pollutant Discharge Elimination System (NPDES). Under the NPDES program, factories, sewage treatment plants, and other point sources must obtain a permit from the state and EPA before they can discharge their waste or effluents into any body of water. Prior to discharge, the point source must use the latest technologies available to treat its effluents and reduce the level of pollutants.

Nonpoint Source

Most nonpoint source pollution occurs as a result of runoff. When rain or melted snow moves over and through the ground, the water absorbs and assimilates any pollutants it comes into contact with. Following a heavy rainstorm, for example, water will flow across a parking lot and pick up oil left by cars driving and parking on the asphalt. When you see a rainbow-colored sheen on water flowing across the surface of a road or parking lot, you are actually looking at nonpoint source pollution. This runoff then runs over the edge of the parking lot, and most likely, it eventually empties into a stream. The water flows downstream into a larger stream, and then to a lake, river, or ocean. The pollutants in this runoff can be quite harmful, and their sources numerous. We usually can't point to one discreet location of nonpoint source pollution like we can with a discharge pipe from a factory.

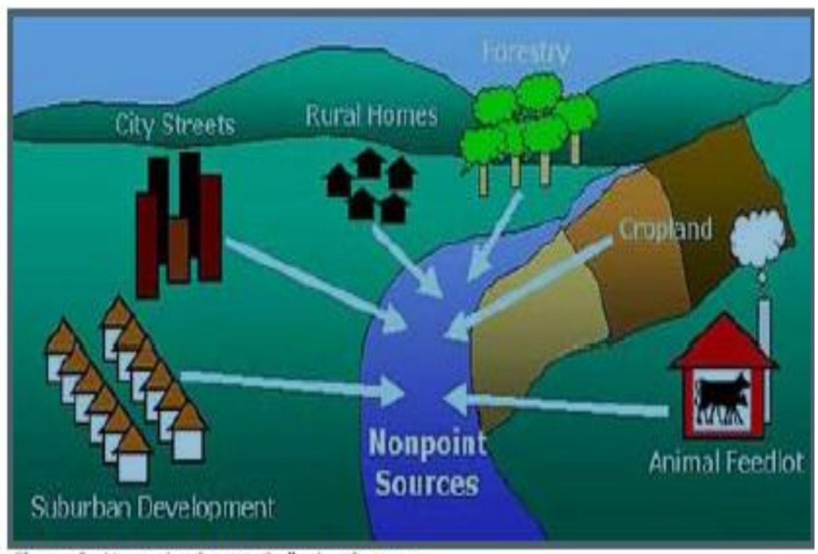


Figure 6. Nonpoint Source Pollution Sources

Nonpoint source pollution affects the beauty and health of coastal lands and waters. If the physical and environmental well-being of these areas is diminished, people will naturally find it less appealing to visit the coast and/or fish and boat. Beaches will not provide the tranquility and leisure activities many people expect to experience. You can see how nonpoint source pollution plays an indirect, though powerful role in tourists' contributions to a coastal community's economic status.

The population in many coastal communities is also increasing at a rapid rate, and the value of waterfront property often relies on environmental and aquatic conditions. Excess nonpoint source pollution impacts the overall quality of life, and subsequently can drive property values down. Although the concentration of some pollutants from runoff may be lower than the concentration from a point source, the total amount of a pollutant delivered from nonpoint sources may be higher because the pollutants come from many places. Nonpoint source pollution is difficult to control because it comes from multiple locations. It also varies over time in terms of the flow and the types of pollutants it contains.

Types of Nonpoint Source Pollution

- Urban and Suburban Areas

Runoff from urban and suburban areas is a major origin of nonpoint source pollution. Much of the urban environment is paved with asphalt or concrete, or covered with buildings. These surfaces are usually impervious, meaning that water runs off of them without being absorbed into the soil. These hard, impervious surfaces make it easier for stormwater to pick up, absorb, and carry pollutants. At construction sites, soil that has been disturbed or piled up without being contained can easily erode. Discarded construction materials (plastics, wood, oils, trash) can also be carried away from these sites by runoff waters. In suburban areas, the chemicals used in lawn care, and even pet wastes, often end up in runoff and contribute to nonpoint source pollution. In many towns and cities the water flowing into storm drains is not treated before emptying into nearby waterbodies. That's why many municipalities are painting words like "It Ends Up In The River" in large bright letters across their storm drains.

- Agricultural Operations

Agricultural operations account for a large percentage of nonpoint source pollution. In agriculture, large tracts of land are typically plowed to grow crops. Plowing the land exposes and disturbs the soil, making it more vulnerable to erosion during rainstorms. This increases the runoff that carries fertilizers and pesticides away from the farm and into nearby waters.

- Atmospheric Inputs

Industrial facilities often discharge pollutants into the atmosphere, typically through some type of smokestack. These airborne pollutants (hydrocarbons, metals, etc.) can travel long distances. The pollutants are then deposited on surfaces (dry deposition) or washed out of the atmosphere in rain or snowfall (wet deposition). Acid rain is a major concern in some areas of the United States. It is created when sulfur dioxide and nitrogen oxides are discharged from industrial plants that burn fossil fuels like coal, oil, and natural gas. These compounds react with water, oxygen, and other atmospheric compounds to form acid rain. Acid rain causes a cascade of effects that harm or kill fish and other aquatic organisms. As acid rain flows over and through soils, it releases aluminum into lakes and streams. Increased levels of aluminum are very toxic to fish. Acid rain also damages forests. Acid rain can damage the surfaces of leaves, reduce a tree's ability to withstand cold, and inhibit plant germination/ reproduction. Prolonged exposure can cause forest soils to lose valuable nutrients like calcium and magnesium. Lack of nutrients causes trees to grow more slowly or to stop growing altogether.

- Forestry and Mining Operations

Forestry operations such as logging can generate significant amounts of nonpoint source pollution. The heavy machinery used to remove vegetation and trees exposes the soil, increasing the risk of erosion. In addition, the improper construction and use of “skid trails” can contribute to nonpoint source pollution. Active mining operations are considered point sources of pollution, but drainage or runoff from abandoned mining operations often adds to nonpoint source pollution.

- Marinas and Boating Activities

Chemicals used on boats may spill into the water; spilled fuel can also contaminate waters around marinas. Chemicals used to maintain and repair boats, such as solvents, oils, paints, and cleansers, may spill into the water, or make their way into waterbodies via runoff. In addition, poorly maintained sanitary waste systems aboard boats or poorly maintained pump-out stations at marinas can significantly increase bacteria and nutrient levels in the water.

Pollutants from Nonpoint Sources

- Nutrients

There are many types of nonpoint source pollutants. When these accumulate in high enough concentrations in a waterbody, they can seriously affect the environment and the organisms living there.
The primary nutrients of concern in nonpoint source pollution are nitrogen and phosphorus. Both are essential for plant growth, but if too much of these substances enters a waterbody, it can lead to a condition called eutrophication. Eutrophication results in an overproduction of organic matter, particularly algae. This excess algae blocks the sunlight needed by native bottom-dwelling plants, often killing them. As the algae and bottom-dwelling plants die, they decay, using up oxygen in the water. This leads to a condition called hypoxia -- very low levels of oxygen in the water -- which makes it difficult for aquatic animals like fish and crabs to survive. In addition to hypoxia, eutrophication may be associated with conditions that result in harmful algal blooms (HABs). Although these organisms are not harmful in small quantities, too many of them can negatively affect the environment and people's health. When fish and shellfish feed on HABs, they can accumulate toxins that the algae produce. Consequently, when people eat seafood with algal toxins in it, they may get sick. The distribution, frequency, and intensity of HABs appears to be increasing worldwide. Nonpoint sources of nutrients can originate from agricultural activities, lawn fertilizers, and even pet wastes. Nitrogen and phosphorus also come from atmospheric inputs.

- Suspended Sediments

Runoff from agricultural fields, urban areas, and construction sites can carry away soil, producing cloudy or muddy water. Soil in the water, called suspended sediment, blocks out the sunlight that bottom-dwelling plants in lakes and rivers need to survive. If these plants, called submerged aquatic vegetation (SAV), are deprived of sunlight for extended periods, they will die. SAV is an important component of the ecosystem because it is not only a producer, but it provides habitat for aquatic organisms, manufactures oxygen, and traps sediment. Suspended sediments can also clog the gills of fish and other aquatic organisms.

- Pesticides and Toxic Chemicals

Pesticides typically enter a waterbody through surface water runoff, often from a farm field or from neighborhoods where they are applied on lawns. Pesticides can also enter a waterbody as a result of “spray drift.” This occurs when the pesticide is sprayed over an area, and the wind blows some of the spray into a nearby waterbody. Pesticides are designed to be toxic to a target organism, but they often kill other organisms as well. For the most part, today's pesticides do not build up in the tissues of animals to the extent that older compounds like DDT did. On the other hand, many of the compounds used today are toxic at very low concentrations. Toxic chemicals, such as spilled oils and fuels or combustion of fuels in automobiles and factories in cities eventually end up in the water through atmospheric deposition or runoff.

- Bacteria, Viruses and Trash

Runoff from agricultural areas where manure is either generated or spread on fields can be a source of bacteria and viruses, some of which may be pathogenic, leading to outbreaks of disease. Discarded trash can become a component of nonpoint source pollution runoff. Plastics, metals and other types of trash often harm animals and plants. Plastics and metals degrade very slowly over time and can leach harmful chemicals into the environment. In addition, trash simply degrades the beauty of an area.

Strategies used to decrease nonpoint source pollution.

- ✓ " Urban and Suburban Areas
    - Buffer strips are strips of vegetation located between and around impervious paving materials such as parking lots and sidewalks, and a body of water. The buffer strip absorbs soil, fertilizers, pesticides, and other pollutants before they can reach the water.
    - Retention ponds capture runoff and stormwater. Sediments and contaminants settle out of the water when they are trapped in the retention pond.

- Constructed wetlands are a recent innovation in which an area is made into a wetland; the land is then used to slow runoff and absorb sediments and contaminants. The constructed wetland also provides habitat for wildlife.
- Porous paving materials are used in parking lots and highways. The porous pavement allows rainwater and stormwater to drain into the ground beneath it, reducing runoff..
- Sediment fences, or knee-high black fabric fences, are often used at construction sites to trap large materials, filter sediment out of rainwater, and slow runoff.
- Grass planting and laying of straw around construction sites help reduce runoff and associated nonpoint source pollution.

✓ Agricultural Operations
- Buffer strips are located between a farm field and a body of water. The buffer strip absorbs soil, fertilizers, pesticides, and other pollutants before they can reach the water.
- Conservation tillage involves leaving some crop residue from a previous harvest while planting a new crop. Less erosion occurs because the field is not plowed, and nutrients or pesticides are more likely to stay where they are applied.
- Crop nutrient management involves applying fertilizers sparingly to prevent excess nutrient runoff.
- Beneficial insects can be used to control agricultural pests, reducing the need for pesticides.

✓ Forestry Operations
- The location and design of roads and skid trails are carefully planned prior to any logging operations. Skid trails are designed to follow the contour of the land and reduce erosion.
- Buffer strips are maintained between logging operations and nearby streams, lakes or rivers.
- Trees are replanted after logging to allow for regrowth and less erosion.

✓ Marinas
- Shutoff valves on fuel pumps on docks help limit spillage into the water.
- Pump-out stations at marinas allow boaters to safely empty their sanitary systems without dumping wastes into the water.
- Trash is placed in appropriate waste containers.

What You Can Do

Controlling and preventing nonpoint source pollution is every person's responsibility, including yours. There are many things you can do to reduce nonpoint source pollution, including:

Household Chemicals

- Follow directions when disposing of household hazardous waste.
- Select less-toxic alternatives or use non-toxic substitutes wherever possible.
- Buy chemicals only in the amount you expect to use, and apply them only as directed. More is not better.
- Take unwanted household chemicals to hazardous-waste collection centers; do not pour them down the drain.
- Never pour unwanted chemicals on the ground. Soil cannot purify most chemicals, and they could eventually contaminate runoff.
- Use low-phosphate or phosphate-free detergents.
- Use water-based products whenever possible.
- Do not indiscriminately spray leftover household pesticides, either indoors or outdoors, where a pest problem has not been identified. Dispose of excess pesticides at hazardous-waste collection centers.

Landscaping and Gardening

- Compost yard scraps and kitchen waste.
- Select landscaping plants that have low requirements for water, fertilizers and pesticides.
- Cultivate plants that discourage pests. Minimize grassed areas, which require high maintenance.

- Preserve existing trees, and plant trees and shrubs to help prevent erosion and promote infiltration of water into the soil.
- Use landscaping techniques, such as grass swales (low areas in the lawn) or porous walkways, to increase infiltration and decrease runoff.
- Install wood decking, bricks or interlocking stones instead of impervious cement walkways.
- Install gravel trenches along driveways or patios to collect water and allow it to filter into the ground.
- Restore bare patches in your lawn as soon as possible to avoid erosion.
- Grade all areas away from your house at a slope of one percent or more.
- Leave lawn clippings on your lawn so that nutrients in the clippings are recycled not sent to landfills.
- If you elect to use a professional lawn care service, select a company that employs trained technicians and follows practices designed to minimize the use of fertilizers and pesticides.
- Compost your yard trimmings. Compost is a valuable soil conditioner that gradually releases nutrients to your lawn and garden. (Using compost will also decrease the amount of fertilizer you need to apply.) In addition, compost retains moisture in the soil and thus helps you conserve water.
- Spread mulch on bare ground to help prevent erosion and runoff.
- Test your soil before applying fertilizers. Over-fertilization can leach into ground water or contaminate rivers or lakes. Avoid using fertilizers near surface waters. Use slow-release fertilizers on areas where the potential for water contamination is high, such as sandy soils, steep slopes, compacted soils and verges of waterbodies.
- Select the proper season to apply fertilizers—incorrect timing could encourage weeds or stress grasses. Do not apply pesticides or fertilizers before or during rain because of the strong likelihood of runoff.
- Calibrate your applicator before applying pesticides or fertilizers. As equipment ages, annual adjustments might be needed.
- Keep storm gutters and drains clean of leaves and yard trimmings. (Decomposing vegetative matter leaches nutrients and can clog storm systems and result in flooding.)

Septic Systems

- Proper septic system maintenance helps protect water quality. Improperly maintained septic systems can contaminate ground water and surface water with nutrients and pathogens. By following the recommendations, you can help ensure that your system continues to function properly.
- Pump out your septic system regularly. (Pumping out every three to five years is recommended for a three-bedroom house with a 1,000-gallon tank; smaller tanks should be pumped more often.)
- Do not use septic system additives. There is no scientific evidence that biological and chemical additives aid or accelerate decomposition in septic tanks; some additives can in fact be detrimental to the septic system or contaminate ground water.
- Do not divert storm drains or basement pumps into septic systems.
- Avoid or reduce the use of your garbage disposal. (Garbage disposals contribute unnecessary solids to your septic system and can also increase the frequency your tank needs to be pumped.)
- Don't use toilets as trash cans! Excess solids can clog your drain field and cause frequent pumping.

Water Conservation

- Purchase water-efficient products (identified by the EPA WaterSense).
- Reduce the volume of wastewater discharged to home septic systems and sewage treatment plants by conserving water.
- Use low-flow faucets, shower heads, reduced-flow toilet flushing equipment, and water-saving appliances such as dish- and clothes washers.
- Repair leaking faucets, toilets and pumps.
- Use dishwashers and clothes washers only when fully loaded.
- Take short showers instead of baths and avoid letting faucets run unnecessarily.

- Wash your car only when necessary; use a bucket to save water. Alternatively, go to a commercial carwash that uses water efficiently and disposes of runoff properly.
- Do not over-water your lawn or garden. It can increase leaching of fertilizers to ground water.
- When your lawn or garden needs watering, use slow-watering techniques such as trickle irrigation or soaker hoses.
- Pick up dog waste and dispose of it properly

More Water Conservation

No drips
A dripping faucet can waste 20 gallons of water a day. A leaking toilet can use 90,000 gallons of water in a month. Get out the wrench and change the washers on your sinks and showers, or get new washerless faucets. Keeping existing equipment well maintained is probably the easiest and cheapest way to save water.
Install new fixtures
New, low-volume or dual flush toilets, low-flow showerheads, water-efficient dishwashers and clothes washing machines can all save a great deal of water and money. Aerators on your faucets can significantly reduce water volume; water-saving showerheads can cut the volume of water used down to 1.2 gallons per minute or less, and some even have a "pause button" to let you stop the water while soaping up or shampooing. Splurging on a low-flow toilet could save another 50-80 gallons of water a day.
Cultivate good water habits
All the water that goes down the drain, clean or dirty, ends up mixing with raw sewage, getting contaminated, and meeting the same fate. Try to stay aware of this precious resource disappearing and turn off the water while brushing your teeth or shaving and always wash laundry and dishes with full loads. When washing dishes by hand, fill up the sink and turn off the water. Take shorter showers.
Stay off the bottle
By many measures, bottled water is a scam. In most first-world countries, the tap water is provided by a government utility and is tested regularly. Taste tests have shown that in many municipalities, tap water actually tastes better. Bottled water is not as well regulated and studies have shown that it is not even particularly pure. Not only is it more expensive per gallon than gasoline, bottled water incurs a huge carbon footprint from its transportation, and the discarded bottles are a blight. If you want to carry your water with you, get a bottle and fill it.
Go beyond the lawn
Naturalize it using locally appropriate plants that are hardy and don't need a lot of water. If you have to water, do it during the coolest part of the day or at night to minimize evaporation. *Xeriscaping* is a method of landscaping that utilizes only native and low water plants.
Harvest your rainwater
Put a rain barrel on your downspouts and use this water for irrigation. Rain cisterns come in all shapes and sizes ranging from larger underground systems to smaller, freestanding ones.
Harvest your greywater
Water that has been used at least once but is still clean enough for other jobs is called greywater. Water from sinks, showers, dishwashers, clothes washers and air conditioners are the most common household examples. (Toilet water is often called "blackwater" and needs a different level of treatment before it can be reused.) Greywater can be recycled with practical plumbing systems, or with simple practices such as emptying the captured water in the garden instead of the sink. Avoid putting water down the drain when you can use it for something else.
Don't spike the punch
Water sources have to be protected. In many closed loop systems like those in cities, waste water is returned to the same waterbody that the fresh water comes out of. Don't pour chemicals down drains, or flush drugs down toilets; it could come back in diluted form in your water.

Stream monitoring *(Poster Guide- Georgia Adopt-A-Stream)*

Macroinvertebrate Monitoring *(From Georgia Adopt-A-Stream Monitoring Manual Chapter 1)*
Macroinvertebrate monitoring involves identifying and counting macroinvertebrates. The purpose of macroinvertebrate monitoring is to quickly assess both **water quality and habitat**. Macroinvertebrates are organisms that lack a backbone and can be seen with the naked eye, including aquatic insects, crustaceans, worms, and mollusks. The organisms that are being sampled for are benthic macroinvertebrates meaning that they live in the substrate, or bottom of a waterbody. Macros live in various stream habitats and derive their oxygen from water. They are used as indicators of stream quality. These organisms are impacted by all the stresses that occur in a stream environment, both man-made and naturally occurring.
Aquatic macroinvertebrates are good indicators of stream quality because:

- They are affected by the physical, chemical and biological conditions of the stream.
- They are not very mobile. They can't escape pollution and show effects of short and long-term pollution events.
- They are relatively long lived. The life cycles of some sensitive macroinvertebrates range from one to several years.
- They are an important part of the food web, representing a broad range of trophic levels.
- They are abundant in most streams. Some 1st and 2nd order streams may lack fish, but they generally have macroinvertebrates.
- They are a food source for many recreationally and commercially important fish.
- They are relatively easy to collect and identify with inexpensive materials.

The basic principle behind the study of macroinvertebrates is that some species are more sensitive to pollution than others. Therefore, if a stream site is inhabited by organisms that can tolerate pollution, and the pollution-sensitive organisms are missing, a pollution problem is likely. This brings up both the advantage and disadvantage of the biosurvey. The advantage is that it tells us very clearly when the stream ecosystem is impaired due to pollution or habitat loss. It is not difficult to realize that a stream full of many kinds of crawling and swimming "critters" is healthier than one without much life. Different macros occupy different ecological niches within the aquatic environment, so diversity of species generally means a healthy, balanced ecosystem. The disadvantage of the biosurvey, on the other hand, is it cannot definitively tell us why certain types of creatures are present or absent. Thus a biosurvey should be accompanied by an assessment of habitat and water quality conditions in order to help explain biosurvey results.

If you find:	**You may have:**
Variety of macroinvertebrates, lots of each kind	Healthy stream
Little variety, with many of each kind	Water enriched with organic matter
A variety of macroinvertebrates, but a few of each kind, or **NO** macroinvertebrates, but the stream appears clean	Toxic pollution
Few macroinvertebrates and the streambed is covered with sediment	Poor habitat from sedimentation

Chemical Monitoring *(From the Georgia Adopt-A-Stream Monitoring Manual Chapter 2)*

Some general recommendations are listed below.
1. Measure air and water temperature in the shade. Avoid direct sunlight.
2. Rinse glass tubes or containers twice with stream water before running a test.
3. Collect water for tests in a well-mixed area of flowing water, one foot below surface. If water is less than one foot deep, collect approximately one-third of the way below surface. Collect samples at stream base flow.
4. Read values on plastic titrators on the liquid side of the disc around the plunger tip. If you are using a glass syringes, read values at the plunger's tip.
5. For dissolved oxygen and pH, run two tests. If the tests are not within duplicate precision of each other, run another test to ensure accuracy.

Chemical testing allows investigators to gather information about specific water quality characteristics at a specific time. A variety of water quality tests can be performed in fresh water - including temperature, dissolved oxygen, pH, water clarity, ammonia, hardness, phosphorus, nitrogen, chlorine and alkalinity.

Temperature Water temperature is one factor in determining which species may or may not be present in the system. Temperature affects feeding, respiration, and the metabolism of aquatic organisms. A week or two of high temperatures may make a stream unsuitable for sensitive aquatic organisms, even though temperatures are within tolerable levels throughout the rest of the year. Not only do different species have different requirements, optimum habitat temperatures may change for each stage of life. Fish larvae and eggs usually have narrower temperature requirements than adult fish.
Measuring Temperature A thermometer protected by a plastic or metal case should be used to measure temperature in the field. Temperature is recorded in degrees Celsius. First, measure air temperature by placing the dry thermometer in the shade until it stabilizes. Record the temperature of the air before measuring water temperature. To measure water temperature, submerge the thermometer in a sample of water large enough that it will not be affected by the temperature of the thermometer itself, or hold it directly in the stream.

- State Standards Water temperatures should be less than 32.2°C (90°F) to meet Georgia state standards.
- Significant Levels Temperature preferences among species vary widely, but all species can tolerate slow, seasonal changes better than rapid changes. Thermal stress and shock can occur when water temperatures change more than 1 to 2 degrees Celsius in 24 hours. Many biological processes are affected by water temperature. Temperature differences between surface and bottom waters help produce the vertical water currents, which move nutrients and oxygen throughout the water column.

What Measured Levels May Indicate Water temperature may be increased by discharges of water used for cooling purposes (by industrial or utility plants) or by runoff from heated surfaces such as roads, roofs and parking lots. Cold underground water sources, snow melt, and the shade provided by overhanging vegetation can lower water temperatures.

pH The pH test is one of the most common analyses in water testing. An indication of the sample's acidity, pH is actually a measurement of the activity of hydrogen ions in the sample. pH measurements are on a scale from 0 to 14, with 7.0 considered neutral. Solutions with a pH below 7.0 are considered acids and those above 7.0 considered bases. The pH scale is logarithmic, so every one-unit change in pH actually represents a ten-fold change in acidity. In other words, pH 6 is ten times more acidic than pH 7; pH 5 is one hundred times more acidic than pH 7.
Measuring pH pH is measured by adding a reagent to a sample of water which dyes the sample based on its pH level. The color of the water sample is then matched to a color comparator to determine the pH level. Take

two samples for duplicate precision. The two samples must be within ±0.25. If the tests are not within duplicate precision of each other, run another test until two are within that range.

- State Standards pH levels should fall between 6.0 and 8.5 to meet Georgia state standards.
- Significant Levels A range of pH 6.5 to pH 8.2 is optimal for most aquatic organisms. Rapidly growing algae or submerged aquatic vegetation remove carbon dioxide (CO_2) from the water during photosynthesis. This can result in a significant increase in pH levels, so the water becomes more basic. Low or high pH can affect egg hatching, kill sources of food for fish and insects, or make water uninhabitable for any aquatic life. In Georgia, mountain and piedmont streams will have pH ranges of 6.0 to 8.0. Black water streams of coastal and south Georgia will naturally have more acidic conditions, with pH values as low as 3.5. In coastal waters, normal pH levels fall within state standards and increase (becomes more basic) with increasing salinity. In other regions of Georgia, pH readings outside of the acceptable levels may be the result of mine drainage, atmospheric deposition or industrial point discharges.

Dissolved Oxygen (DO) Like land organisms, aquatic animals need oxygen to live. Fish, invertebrates, plants, and aerobic bacteria all require oxygen for respiration. Dissolved oxygen is measured in parts per million (ppm) or milligrams per liter (mg/L).
Sources of Dissolved Oxygen Oxygen dissolves readily into water from the atmosphere at the surface until the water is "saturated". Once dissolved in water, the oxygen diffuses very slowly, and distribution depends on the movement of aerated water by turbulence and currents caused by wind, water flow and thermal upwelling. Aquatic plants, algae and phytoplankton produce oxygen during photosynthesis.
Dissolved Oxygen Capacity of Water The dissolved oxygen capacity of water is limited by the temperature and salinity of the water and by the atmospheric pressure, which corresponds with altitude. These factors determine the highest amount of oxygen that is able to dissolve in the water. As water temperature changes, the highest potential dissolved oxygen level changes.

- At 0 degrees Celsius the saturation point for dissolved oxygen is 14.6 ppm
- At 32 degrees Celsius the saturation point for dissolved oxygen is 7.6 ppm

Lower temperature = Higher potential dissolved oxygen level
Higher temperature = Lower potential dissolved oxygen level

The temperature effect is compounded by the fact that living organisms increase their activity in warm water, requiring more oxygen to support their metabolisms. Critically low oxygen levels often occur during the warmer summer months when capacity decreases and oxygen demand increases. This is often caused by respiring algae or decaying organic material.
Measuring Dissolved Oxygen Dissolved oxygen is measured using the Winkler titration method. A sample bottle is filled completely so that no air is present in the sample. Reagents are added to produce a 'fixed' solution – the dissolved oxygen content cannot be influenced by external sources or changes. This fixed solution is then titrated until it reaches the 'endpoint' where the color of the solution changes to clear. The level of the remaining liquid in the direct-read titrator corresponds to the dissolved oxygen level in the sample. Take two samples for duplicate precision. The two samples must be within ±0.6 ppm or mg/L. If the tests are not within duplicate precision of each other, run another test until two are within that range.

- State Standards Dissolved oxygen levels must average 5mg/L and no less than 4mg/L to meet Georgia state standards.
- Significant Levels The amount of oxygen required by an aquatic organism varies according to species and stage of life. DO levels below 3 ppm are stressful to most aquatic organisms. DO levels below 2 or 1 ppm will not support fish; levels of 5 to 6 ppm are usually required for growth and activity. Fish and invertebrates that can move will leave areas with low dissolved oxygen and move to higher level areas.

What Measured Levels May Indicate A low dissolved oxygen level indicates a demand on the oxygen in the system. Pollutants, including inadequately treated sewage or decaying natural organic material, can cause such a demand. Organic materials accumulate in bottom sediments and support microorganisms (including bacteria), which consume oxygen as they break down the materials. Some wastes and pollutants produce direct chemical demands on any oxygen in the water. In ponds or impoundments, dense populations of active fish can deplete dissolved oxygen levels. In areas of dense algae, DO levels may drop at night or during cloudy weather due to the net consumption of dissolved oxygen by aquatic plant respiration. High dissolved oxygen levels can be found where stream turbulence or choppy conditions increase natural aeration by increasing the water surface area and trapping air under cascading water. On sunny days, high dissolved oxygen levels occur in areas of dense algae or submerged aquatic vegetation due to photosynthesis. In these areas, the lowest DO levels occur just before sunrise each morning and highest levels just after noon.

Wetlands

Wetland functions include surface and subsurface water storage, nutrient cycling, particulate removal, maintenance of plant and animal communities, water filtration or purification, and groundwater recharge. Characteristics of wetlands that are beneficial to society are called wetland values. Some examples of wetland values include reduced damage from flooding, water quality improvement, and fish and wildlife habitat enhancement.

Types of Wetlands

Each wetland differs due to variations in soils, landscape, climate, water regime and chemistry, vegetation, and human disturbance.

- **Marshes** Marshes are periodically saturated, flooded, or ponded with water and characterized by herbaceous (non-woody) vegetation adapted to wet soil conditions. Marshes are further characterized as tidal marshes and non-tidal marshes.
  - **Tidal** Tidal (coastal) marshes occur along coastlines and are influenced by tides and often by freshwater from runoff, rivers, or ground water. Salt marshes are the most prevalent types of tidal marshes and are characterized by salt tolerant plants such as smooth cordgrass, saltgrass, and glasswort. Salt marshes have one of the highest rates of primary productivity associated with wetland ecosystems because of the inflow of nutrients and organics from surface and/or tidal water. Tidal freshwater marshes are located upstream of estuaries. Tides influence water levels but the water is fresh. The lack of salt stress allows a greater diversity of plants to thrive.
  - **Nontidal** Nontidal (inland) marshes are dominated by herbaceous plants and frequently occur in poorly drained depressions, floodplains, and shallow water areas along the edges of lakes and rivers. Major regions of the United States that support inland marshes include the Great Lakes coastal marshes, the prairie pothole region, and the Florida Everglades.
    - Freshwater marshes are characterized by periodic or permanent shallow water, little or no peat deposition, and mineral soils. They typically derive most of their water from surface waters, including floodwater and runoff, but do receive ground water inputs.
    - Wet meadows commonly occur in poorly drained areas such as shallow lake basins, low-lying depressions, and the land between shallow marshes and upland areas. Precipitation serves as their primary water supply, so they are often dry in the summer.
    - Wet prairies are similar to wet meadows but remain saturated longer. Wet prairies may receive water from intermittent streams as well as ground water and precipitation.
    - Prairie potholes develop when snowmelt and rain fill the pockmarks left on the landscape by glaciers. Ground water input is also important.
    - Playas are small basins that collect rainfall and runoff from the surrounding land. These low-lying areas are found in the Southern High Plains of the United States.

  - Vernal pools have either bedrock or a hard clay layer in the soil that helps keep water in the pool. They are covered by shallow water for variable periods from winter to spring, but may be completely dry for most of the summer and fall.

- **Swamps** Swamps are fed primarily by surface water inputs and are dominated by trees and shrubs. Swamps occur in either freshwater or saltwater floodplains. They are characterized by very wet soils during the growing season and standing water during certain times of the year. Well-known swamps include Georgia's Okefenokee Swamp and Virginia's Great Dismal Swamp.
  - **Forested Swamps** Forested swamps are found in broad floodplains and receive floodwater from nearby rivers and streams. Common deciduous trees found in these areas include bald cypress, water tupelo, swamp white oak, and red maple.
  - **Shrub Swamps** - similar to forested swamps except that shrubby species like buttonbush dominate.
  - **Mangrove Swamps-** coastal wetlands characterized by salt-tolerant trees, shrubs, and other plants growing in brackish to saline tidal waters.
  - **Bogs-** Bogs are freshwater wetlands characterized by spongy peat deposits, a growth of evergreen trees and shrubs, and a floor covered by a thick carpet of sphagnum moss. These systems, whose only water source is rainwater, are usually found in glaciated areas of the northern United States. One type of bog, called a pocosin, is found only in the Southeastern Coastal Plain.
  - **Fens-** ground water-fed peat forming wetlands covered by grasses, sedges, reeds, and wildflowers.

Functions and Values
Wetland functions include water quality improvement, floodwater storage, fish and wildlife habitat, aesthetics, and biological productivity. The value of a wetland is an estimate of the importance or worth of one or more of its functions to society.

Water storage.
Wetlands function like natural tubs or sponges, storing water and slowly releasing it. This process slows the water's momentum and erosive potential, reduces flood heights, and allows for ground water recharge, which contributes to base flow to surface water systems during dry periods. Although a small wetland might not store much water, a network of many small wetlands can store an enormous amount of water. The ability of wetlands to store floodwaters reduces the risk of costly property damage and loss of life—benefits that have economic value to us.

Water filtration.
After being slowed by a wetland, water moves around plants, allowing the suspended sediment to drop out and settle to the wetland floor. Nutrients from fertilizer application, manure, leaking septic tanks, and municipal sewage that are dissolved in the water are often absorbed by plant roots and microorganisms in the soil. Other pollutants stick to soil particles. In many cases, this filtration process removes much of the water's nutrient and pollutant load by the time it leaves a wetland. Some types of wetlands are so good at this filtration function that environmental managers construct similar artificial wetlands to treat storm water and wastewater. Wetlands are considered valuable because they clean the water, recharge water supplies, reduce flood risks, and provide fish and wildlife habitat. In addition, wetlands provide recreational opportunities, aesthetic benefits, sites for research and education, and commercial fishery benefits.

Biological productivity.
Wetlands are some of the most biologically productive natural ecosystems in the world, comparable to tropical rain forests and coral reefs in their productivity and the diversity of species they support. Abundant vegetation and shallow water provide diverse habitats for fish and wildlife. Aquatic plant life flourishes in the nutrient-rich environment, and energy converted by the plants is passed up the food chain to fish, waterfowl, and other wildlife and to us as well. This function supports valuable commercial fish and shellfish industries.

The State of Our Wetlands
Approximately 100 million wetland acres remain in the 48 contiguous states, but they continue to be lost at a rate of about 60,000 acres annually. Draining wetlands for agricultural purposes is significant, but declining, while development pressure is emerging as the largest cause of wetland loss. Unfortunately, many remaining wetlands are in poor condition and many created wetlands fail to replace the diverse plant and animal communities of those destroyed. When a wetland functions properly, it provides water quality protection, fish and wildlife habitat, natural floodwater storage, and reduction in the erosive potential of surface water. A degraded wetland is less able to effectively perform these functions.

What Is Adversely Affecting Our Wetlands?
Common human activities that cause degradation include the following:
Hydrologic Alterations- A wetland's characteristics evolve when hydrologic conditions cause the water table to saturate or inundate the soil for a certain amount of time each year. Any change in hydrology can significantly alter the soil chemistry and plant and animal communities. Common hydrologic alterations in wetland areas include:

- ✓ Deposition of fill material for development.
- ✓ Drainage for development, farming, and mosquito control.
- ✓ Dredging and stream channelization for navigation, development, and flood control.
- ✓ Diking and damming to form ponds and lakes.
- ✓ Diversion of flow to or from wetlands.
- ✓ Addition of impervious surfaces in the watershed, increasing water and pollutant runoff into wetlands.

Pollution Inputs. Although wetlands are capable of absorbing pollutants from the surface water, there is a limit to their capacity to do so. The primary pollutants causing wetland degradation are sediment, fertilizer, human sewage, animal waste, road salts, pesticides, heavy metals, and selenium. Pollutants can issue from:

- ✓ Runoff from urban, agricultural, silvicultural, and mining areas.
- ✓ Air pollution from cars, factories, and power plants.
- ✓ Old landfills and dumps that leak toxic substances.
- ✓ Marinas, where boats increase turbidity and release pollutants.

Vegetation Damage. Wetland plants are susceptible to degradation if subjected to hydrological changes and pollution inputs.
Other activities that can impair wetland vegetation include:

- ✓ Grazing by domestic animals.
- ✓ Introduction of nonnative plants that compete with natives.
- ✓ Removal of vegetation for peat mining.

Riparian Buffers

Riparian buffers are one of the most effective tools to protect our water resources. These strips of grass, shrubs, natural vegetative area, and/or trees along the banks of streams, rivers, and lakes provide a necessary transition zone between water and human land use. The vegetation filters polluted runoff and holds soil in place to prevent erosion into the waterway. It also slows the stormwater flow and provides a pervious area for infiltration and groundwater recharge. Also, trees provide shade over the water, lowering its temperature and increasing its holding capacity of dissolved oxygen.
Functions of Buffers
Protect Stream Health The most general function of riparian forest buffer systems is to provide control of the stream environment. This function includes moderating fluctuations in stream temperature and controlling light quantity and quality; enhancing habitat diversity; modifying channel morphology; enhancing food webs and species richness; and protecting water resources from nonpoint source pollutants.

Reducing Water Pollution Non-point source pollution is responsible for most water pollution in the United States today. The most efficient and cost-effective way to keep these pollutants out of our water is to “trap” them by maintaining a buffer of natural plants along our streams and rivers to absorb and filter pollutants
Reducing Flooding and Drought During floods, undeveloped land surrounding rivers acts like a sponge, absorbing rising and falling water. Native plants in undisturbed areas help slow flood velocity, store water for future use, and slowly release water over a long period of time. Loss of floodplains and stream buffers increase the change of floods and can worsen flooding when it occurs. Intact buffers also store subsurface water and slowly release it to the stream channels, maintaining baseflow during dry spells.
Controlling and Reducing Erosion Much erosion can be controlled by keeping a buffer of natural plants along the banks of our streams and rivers to “trap” eroding silt, strengthen and stabilize stream banks, and help keep the water clean. Additionally, leaves, both living on trees and dead on the ground, protect streamside solids from splash erosion
Providing Nutrients Buffers supply up to 90 percent of the nutrients, in the form of shed leaves and fallen insects, for instream animals.
Aquatic Organisms Habitat The vegetation of the riparian buffer affects the type and amount of organic matter food sources available for stream organisms. Streamside vegetation also affects the amount of sunlight that reaches the stream and, in turn, the temperature of the water. In addition, the physical structure of the stream, such as the extent of pools and riffles, is affected by riparian vegetation.
Food Food sources for macroinvertebrates include detritus and algae. Detritus is organic matter such as leaves, stems, sticks, and logs that falls into the stream. Because their mouth parts are adapted for a particular food source, some macroinvertebrates eat primarily detritus and others eat only algae. Two types of algae found in streams are diatoms and filamentous algae.
Light Vegetation also affects the amount of light that reaches the stream, but this is also a function of stream order and stream width. For first to third-order streams, the riparian canopy of trees can block sunlight from reaching the water, thus affecting the types of algae in the stream
Temperature and light Vegetation type, canopy development, and directional orientation of the stream controls light energy and impacts stream temperature. A north-south oriented stream is less affected by buffer canopy shading. The vegetation on the north side of an east-west oriented stream may also have little effect on light penetration. For first through third-order streams, the majority of water flows through a shaded riparian buffer. For higher order streams, which are wide and open in cross-section, shading has less of an impact on water temperature. However, the loss of the buffer canopy on any stream, due to clearing, can increase water temperature substantially, causing a shift in macroinvertebrate and fish species.
Physical habitat (pools, riffles, etc.).
Roots of riparian vegetation stabilize the stream bank and prevent stream bank erosion and sedimentation. Stabilized stream banks also help maintain the geometry of the stream, including characteristics such as the meander length and profile. Preventing excess sedimentation helps prevent silt from covering large rocks and stones in the stream bed which serve as habitat for some macroinvertebrates. Pools can be vital parts of stream habitat for fish. Excess sediment can fill pools and eliminate habitat. Tree roots and woody debris are also important habitat features for macroinvertebrates and fish. Large woody debris provides critical macroinvertebrate habitat. Large woody debris can also create dams and trap sediment and detritus. Riparian forests may have the greatest enhancing effect on fish habitat on mid-order streams (i.e., stream order 3-6), with sufficient large woody debris structure and flow to support diverse populations.
Wildlife Habitat Wildlife species require food, water, and cover. Well managed riparian buffers generally support larger populations of wildlife because the buffer provides many habitat requirements. Riparian areas may also serve as corridors linking dryer, less diverse uplands to more moist, more diverse bottom lands.
Reduce Nitrogen Buffers help to reduce Nitrogen by absorbing, denitrifying, or adsorbing it.

Reduce Sediment Riparian buffers serve to slow water velocity, thus allowing sediment to settle out of the surface runoff water. The effectiveness of well-maintained grass riparian buffers for sediment may be as high as high as 90–95%.

Buffer Width

There isn't one generic buffer which will keep the water clean, stabilize the bank, protect fish and wildlife, and satisfy human demands on the land. The size and vegetation of the buffer should match the land use and topography of the site. The minimum acceptable width is one that provides acceptable levels of all needed benefits at an acceptable cost.

As a general rule, the area within 50' of the river/stream should be covered with native vegetation.

- Steeper slopes call for a wider riparian buffer below them to allow more opportunity for the buffer to capture pollutants from faster moving runoff.
- A wetter soil, a wider buffer is needed to get the same effect.

Buffer Vegetation

- In urban and residential areas, trees and shrubs do a better job at capturing pollutants from parking lots and lawn runoff and providing visual screening and wildlife habitat.
- Between cropland and waterways, a buffer of shrubs and grasses can provide many of the benefits of a forested buffer without shading crops, and trees can be used on the north side of fields.
- Trees have several advantages over other plants in improving water quality and offering habitat. Trees are not easily smothered by sediment and have greater root mass to resist erosion. Above ground, they provide better cover for birds and other wildlife using waterways as migratory routes. Trees can especially benefit aquatic habitat on smaller streams.
- Native vegetation is preferable to non-native plants.
- Turf grass is not an appropriate buffer vegetation. While turf grasses slow runoff, their root systems are too shallow to stabilize streambanks or shorelines. In fact, removing native vegetation and replacing it with turf grass usually results in accelerated streambank and shoreline erosion that degrades water quality.

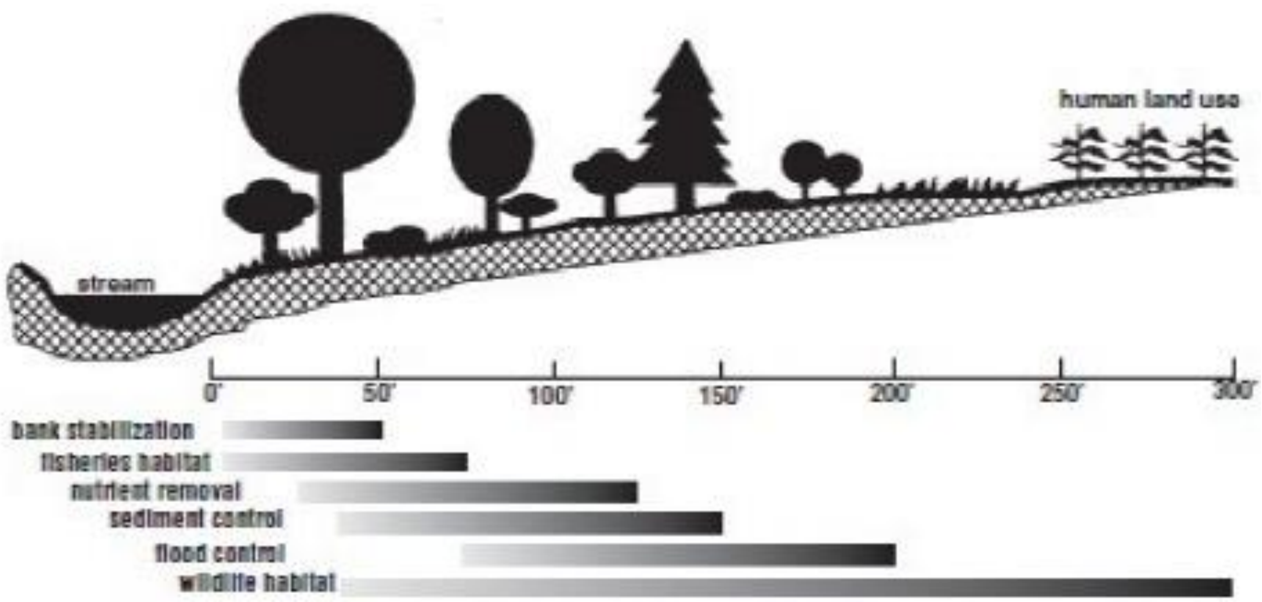


Figure 16 Recommended Buffer Widths

Introduced Species

Aquatic Nuisance Species (ANS) are nonindigenous species that threaten the diversity or abundance of native species, the ecological stability of infested waters, or any commercial, agricultural, aquacultural or recreational activities dependent on such waters.
Invasive species are any species or other viable biological material (including its seeds, eggs, spores) that is transported into an ecosystem beyond its historic range, either intentionally or accidentally, and reproduces and spreads rapidly into new locations, causing economic or environmental harm or harm to human health. ANS species can arrive through many different pathways or vectors, but most species considered invasive arrived as a direct result of human activity. It is often impossible to identify how an organism was introduced, which can make preventing or controlling the introduction of harmful species even more challenging.

- **Environmental Effects** The impacts of invasive species are second only to habitat destruction as a cause of global biodiversity loss. In fact, introduced species are a greater threat to native biodiversity than pollution, harvest, and disease combined. ANS cause severe and permanent damage to the habitats they invade by reducing the abundance of native species and altering ecosystem processes. They impact native species by preying upon them, competing with them for food and space, interbreeding with them, or introducing harmful pathogens and parasites. ANS may also alter normal functioning of the ecosystem by altering fire regimes, hydrology, nutrient cycling and productivity.
- **Economic Impacts** ANS are increasingly seen as a threat not only to biodiversity and ecosystem functioning, but also to economic development. They reduce production of agricultural crops, forests and fisheries, decrease water availability, block transport routes, choke irrigation canals, foul industrial pipelines impeding hydroelectric facilities, degrade water quality and fish and wildlife habitat, accelerate filling of lakes and reservoirs, and decrease property values. The costs to control and eradicate invasive species in the U.S. alone amount to more than $137 billion annually.
- **Public Health** Introduced birds, rodents and insects can serve as vectors and reservoirs of human diseases. Throughout recorded history epidemics of human diseases such as malaria, yellow fever, typhus, and bubonic plague have been associated with these vectors. Waterborne disease agents, such as Cholera bacteria (Vibrio cholerae), and causative agents of harmful algal blooms are often transported in the ballast water of ships. Cholera strains were also found in oyster and fin-fish samples, resulting in a public health advisory to avoid handling or eating raw oysters or seafood. Invasive mussels, may increase human and wildlife exposure to organic pollutants such as PCB's and PAHs as these toxins bio-accumulate in the food chain.
- **Alteration of Natural Flow Regimes** Human management of flow regimes has altered the timing and volume of inflow to some estuaries. Changes in the natural freshwater inflow to estuaries can have significant impacts on the health and distribution of plants and wildlife. Too much or too little freshwater can adversely affect fish spawning, shellfish survival, bird nesting, seed propagation, and other seasonal activities of fish and wildlife. In addition to changing salinity levels, inflow provides nutrients and sediments that are important for overall productivity of the estuary.

Important Parameters for Water Quality Monitoring

Alkalinity - how well a water body can neutralize acids. Alkalinity measures the amount of alkaline compounds in water, such as carbonates , bicarbonates, and hydroxides. These compounds are natural buffers that can remove excess hydrogen ions that have been added from sources such as acid rain or acid mine drainage. Alkalinity mitigates or relieves metals toxicity. Watersheds containing limestone will have a higher alkalinity than watersheds where granite is predominant.
Dissolved Oxygen (DO) is the amount of oxygen dissolved in the water. DO is a very important indicator of a water body's ability to support aquatic life. Fish "breathe" by absorbing dissolved oxygen through their gills. Human activities that affect DO levels include the removal of riparian vegetation, runoff from roads, and sewage discharge.

Fecal Coliform Bacteria are present in the feces and intestinal tracts of humans and other warm-blooded animals, and can enter water bodies from human and animal waste. If a large number of fecal coliform bacteria (over 200 colonies/100 ml of water sample) are found in water, it is possible that pathogenic (disease- or illness-causing) organisms are also present in the water. High concentrations of the bacteria in water may be caused by septic tank failure, poor pasture and animal keeping practices, pet waste, and urban runoff.
Flow is the volume of water moving past a point in a unit of time. Two things make up flow: the volume of water in the stream, and the velocity of the water moving past a given point. Flow is measured in units of cubic feet per second (cfs).
Hardness generally refers to the amount of calcium and magnesium in water. In household use, these cations (ions with a charge greater than +1) can prevent soap from sudsing and leave behind a white scum in bathtubs. In the aquatic environment, calcium and magnesium help keep fish from absorbing metals, such as lead, arsenic, and cadmium, into their bloodstream through their gills. Therefore, the harder the water, the less easy it is for toxic metals to absorb onto gills.
Nitrogen is required by all organisms for the basic processes of life to make proteins, to grow, and to reproduce. Excessive concentrations of nitrate, nitrite, or ammonia can be harmful to humans and wildlife.. Nitrate, nitrite, and ammonia enter waterways from lawn fertilizer run-off, leaking septic tanks, animal wastes, industrial waste waters, sanitary landfills and discharges from car exhausts.
pH measures hydrogen concentration in water and is presented on a scale from 0 to 14. Natural waters usually have a pH between 6 and 9. The pH of natural waters can be made acidic or basic by human activities such as acid mine drainage and emissions from coal-burning power plants and heavy automobile traffic.
Phosphorus is a nutrient required by all organisms for the basic processes of life. Its concentrations in clean waters is generally very low; however, phosphorus is used extensively in fertilizer and other chemicals, so it can be found in higher concentrations in areas of human activity. Phosphorus is generally found as phosphate. The primary sources of phosphates to surface water are detergents, fertilizers, and natural mineral deposits.
Specific Conductance **(conductivity)** is a measure of how well water can pass an electrical current. It is an indirect measure of the presence of inorganic dissolved solids, such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron. These substances conduct electricity because they are negatively or positively charged when dissolved in water. The concentration of dissolved solids, or the conductivity, is affected by the bedrock and soil in the watershed. It is also affected by human influences. For example, agricultural runoff can raise conductivity because of the presence of phosphate and nitrate.
Temperature controls the rate of metabolic and reproductive activities. Most aquatic organisms are "cold-blooded," which means they cannot control their own body temperatures. Their body temperatures become the temperature of the water around them. If water temperatures vary too much, metabolic activities can malfunction. Temperature also affects the concentration of dissolved oxygen and can influence the activity of bacteria in a water body.
Total Organic Carbon (TOC) affects biogeochemical processes, nutrient cycling, biological availability, chemical transport and interactions. It also has direct implications in the planning of wastewater treatment and drinking water treatment. Organic matter content is typically measured as total organic carbon and dissolved organic carbon, which are essential components of the carbon cycle.
"Total solids" refers to matter suspended or dissolved in water or wastewater, and is related to both specific conductance and turbidity. Total Solids includes both ***total suspended solids (TSS)*** , the portion of total solids retained by a filter, and ***total dissolved solids (TDS***) , the portion that passes through a filter. High levels of TDS or TSS can cause health problems for aquatic life.
Turbidity is a measure of the cloudiness of water- the cloudier the water, the greater the turbidity. Turbidity in water is caused by suspended matter such as clay, silt, and organic matter and by plankton and other microscopic organisms that interfere with the passage of light through the water. Turbidity is closely related to total suspended solids (TSS), but also includes plankton and other organisms.High turbidity can be caused by soil erosion, urban runoff, and high flow rates.

Laws to Protect Water Quality

Federal Law

Clean Water Act. The Clean Water Act's objective was to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The primary goals of the Act were that all waters were "fishable" and "swimmable" by 1983 and that discharge of pollutants into navigable waters was eliminated by 1985. The Environmental Protection Agency was the lead agency charged with development and implementing comprehensive programs for water pollution control

- *Section 404* of the Act, administered by the U.S. Army Corps of Engineers, is one of the two most important federal statutes regulating wetlands, particularly inland wetlands. Section 404 requires a permit for all discharges by point sources of dredged or fill materials into "navigable waters." "Navigable waters" is broadly defined as water of the United States including the territorial seas.
- *Section 303(d)* of the Clean Water Act requires states to identify waters that are impaired by pollution. For impaired waters, states must establish a ***total maximum daily load*** (***TMDL)*** of pollutants to ensure that water quality standards can be attained. A **TMDL** is the amount of a particular pollutant that a particular stream, lake, estuary or other waterbody can "handle" without violating state water quality standards. Once a TMDL is established, responsibility for reducing pollution among both point sources and diffuse sources is typically assigned to a city or county. Diffuse "sources" include, but are not limited to, run-off (urban, agricultural, forestry, etc.), leaking underground storage tanks, unconfined aquifers, septic systems, stream channel alteration, and damage to a riparian area.

Coastal Zone Management Act (CZMA). In 1972, Congress passed the CZMA to preserve and develop the resources of the coastal zone by providing funds to states that develop and implement programs for management of land and water uses consistent with the Act's standards.

Endangered Species Act (ESA). Passed in 1973, the ESA was intended not only to conserve and protect the endangered and threatened species themselves, but also to protect the ecosystems upon which such species depended. As a result, in addition to prohibitions against actions such as hunting of endangered or threatened species, the ESA also limits and regulates development which might cause the species any further harm.

Clean Air Act. The Clean Air Act requires all areas of the United States to attain and maintain health-based standards for ambient air quality, called National Ambient Air Quality Standards (NAAQS). These standards are important in the regulation of air pollutants that affect waterways via deposition.

National Environmental Policy Act (NEPA). NEPA requires preparation of an environmental impact statement (EIS) for any major federal project that has the potential to impact the environment. The agency must examine the need for, alternatives to, and environmental consequences of the action(s). NEPA also ensures that environmental information is available to public officials and citizens and that public input is considered before decisions are made and actions are taken.

Marine Protection, Research and Sanctuaries Act. This Act contains several parts, or Titles. Title I is known as the Ocean Dumping Act of 1972 and regulates the transport and disposal of material in U.S. coastal waters. Title III, known as the National Marine Sanctuaries Act, authorizes NOAA (National Oceanic and Atmospheric Administration) to preserve and protect marine areas that have special significance to the people of the United States. As of November, 1997 there were 12 sanctuaries in U.S. coastal waters. Gray's Reef National Marine Sanctuary off Georgia's coast was designated in 1981. Title V (Beach National Coastal Water Quality Monitoring Program) establishes a coastal water quality monitoring program administered by EPA and NOAA.

Safe Drinking Water Act (SDWA) The Act was originally passed by Congress in 1974 to protect public health by regulating the nation’s public drinking water supply. The law was amended in 1986 and 1996 and requires many actions to protect drinking water and its sources—rivers, lakes, reservoirs, springs, and ground water wells. (SDWA does not regulate private wells which serve fewer than 25 individuals.) SDWA authorizes the United States Environmental Protection Agency (US EPA) to set national health-based standards for drinking water to protect against both naturally-occurring and man-made contaminants that may be found in drinking water.

State Laws

Coastal Marshlands Protection Act. The Act protects the water quality of Georgia's coastal areas and tidal wetlands, including estuarine areas of the state by requiring permits for any alteration, including the erecting of structures, dredging, removing, draining, filling or any other alteration of these areas.

Shore Protection Act. The Shore Protection Act limits activities in shore areas and requires a permit for certain activities and structures on Georgia's shoreline, including sand dunes, beaches, sandbars and shoals, which collectively make up the sand-sharing system. Construction activity in sand dunes is limited to temporary structures such as crosswalks, which must be permitted by the Coastal Resources Division. The Act prohibits construction of docks, marinas or boat ramps in the dunes, as well as operation of motorized vehicles on or over the dynamic dune fields and beaches

Georgia Water Stewardship Act The Act creates a culture of conservation in Georgia by:

- encouraging every state department to look at its water conservation practices;
- standardized leak reporting by public water utilities;
- "submetering" of multifamily, commercial and industrial construction;
- high efficiency toilets, urinals and fixtures for all new construction;
- tracking unused water withdrawal permits for agriculture purposes, and establishing a process for those unused permits to revert back to the state;
- statewide scheduling of outdoor watering between 4:00 p.m. and 10:00 a.m., to avoid evaporative loss and waste during the hottest hours of the day.

Erosion and Sedimentation Act. This Act provides for the establishment and implementation of a statewide program to protect Georgia's waters from soil erosion and sediment deposition. The Act requires permits for "land disturbing activities" and prohibits development within 25 of most streams in Georgia and 50 feet for trout streams

Local Regulations

River corridor protection. Generally requires maintenance of a 100 foot vegetative buffers adjacent to identified rivers that meet a predetermined criteria and limits land uses within buffer.

Watershed protection. Purpose is to protect municipal drinking water supply watersheds through limiting the amount of impervious surface in the watershed, establishing buffers adjacent to reservoirs and tributaries upstream of a reservoir or drinking water intake. There is also some limitation of permitted land uses.

Groundwater recharge protection. Purpose is to protect aquifers through a limitation on impervious surfaces and permitted land uses within the recharge area, and requires larger lot sizes where public sewerage facilities are not available. –

Greenspace requirements. Vary widely among jurisdictions. However, the idea behind requiring a dedication of greenspace (also called open space) is to offer recreational facilities or preserve identified community natural or historic resources, or simply to provide a green area in a community which cannot be paved. Typical greenspace requirements may be associated with a river corridor, greenway, or hiking trail.

AQUATIC ECOLOGY GLOSSARY

Acid rain: rain containing pollutants that give it a pH that is generally below 5.

Algae: photosynthetic organisms with a one-celled or simple multicellular body plan.

Aquifer: a land, gravel or rock formation capable of storing or conveying water below the land surface

Benthos: bottom dwelling or substrate-oriented organisms.

Best Management Practices: a practice or combination of practices that provide an effective, practical means of preventing or reducing pollution from non-point sources.

Bioaccumulate: the practice of concentrating a particular substance over time in a food chain.

Biomonitoring: the use of organisms to assess or monitor environmental conditions.

Biochemical Oxygen Demand (BOD): a measure of the quantity of oxygen used by microorganisms in the aerobic oxidation of organic matter.

Buffer: a vegetated area of grass, shrubs or trees designed to capture and filter runoff from adjoining land

Cobble stone: 2-10 inch size stones where stream life can be found.

Coliform Bacteria: a group of bacteria found in cold and warm blooded animal intestines commonly used as indicators of pathogens.

Cultural Eutrophication: process whereby human activity increases the amount of nutrients entering surface waters.

Decomposition: the separating or decaying of organic or chemical matter.

Dendritic: a pattern of stream drainage that resembles the pattern of a tree.

Density of water: greatest at 4°(39.2°F).

Discharge: the flow of surface water in a stream or canal or the outflow of groundwater from a flowing artesian well, ditch or spring.

Discharge pipe: a pipe used to carry wastewater from a factory or other facility into a receiving water body

Dissolved oxygen: oxygen dissolved in water which is readily available to plants and animals.

Ecology: the science of the relationships between organisms and their environments.

Ecosystem: an ecological community together with its physical environment, usually considered as a unit.

Ephemeral Stream: a stream that flows only during wet periods or rainstorms.

Epilimnion: topmost layer of water in a lake.

Estuary: an arm of the sea that extends inland to meet the mouth of a river, usually characterized by tidal changes and rich diversity of aquatic life.

Fecal coliform: bacteria originating in the intestinal tract of warm blooded animals.

Floodplain: a low area of land, around streams or rivers, which holds water overflow during a flood.

Freshwater: water that is not saline or brackish.

Groundwater: water beneath the earth's surface.

Habitat: the area or environment in which an organism lives.

Hardness: a characteristic of water primarily caused by the presence of calcium and magnesium

Headwaters: the uppermost reaches of a river or stream.

Hydric soils: soils found in saturated, anaerobic environments usually characterized by gray or mottled appearance, found in wetlands.

Hydrologic cycle: the series of pathways the earth's water may take on its journey from the sea to the atmosphere to the land and ultimately back to the sea.

Hydrologic unit: all land and water within a drainage area.

Hypolimnion: lower layer of water in a lake.

Infiltration: the downward entry of water into the soil.

Intermittent stream: a stream which has an interrupted flow or does not flow continuously. (< 90%)

Lentic: standing water as in a lake.

Limiting factor: something that determines the presence, survival and success of an organism.

Limnology: the study of inland water: ponds, lakes and streams.

Littoral: region of shallow water where light reaches the bottom.

Lotic: running water as in a river.

Macroinvertebrates: an animal without a backbone visible to the naked eye or larger than 0.5 millimeters.

Meander: the circuitous winding or sinuosity of a stream, used to refer to a bend in the river.

Nonpoint source pollution (NPS): pollution that originates from many diffuse sources such as runoff from streets or agricultural areas.

Oligotrophic: a body of fresh water that contains few nutrients and few organisms.

Part per million (ppm): the quantity of one substance contained in one million units of another substance. Equivalent to milligram per liter (mg/l).

Perennial stream: a stream which flows continually. (> 90%)

Plankton: collective word for microscopic organisms that drift around in the upper level of a body of water.

Point source pollution: Pollution that is discharged through a pipe or other conduit

Pollutant: any substance or mixture of substances that defile or contaminate (causes harm to) the soil, water or atmosphere.

Pond: a quiet body of water so shallow that rooted plants usually grow completely across it.

Profundal: region of water below photosynthetic light penetration.

Receiving waters: all distinct bodies of water that receive runoff such as streams, lakes and estuaries.

Riffle: a shallow section of a stream where water bubbles over rocks, often found at the bend in a river.

Riparian: relating to the banks of a stream or river.

Run: the straight section in a river between riffles

Runoff: water, including rain and snow, which is not absorbed into the ground: instead it flows across the land and eventually runs into streams and rivers.

Secchi disk: a simple device for measuring turbidity.

Sediment: soil, sand, and materials washed from land into waterways.

Settling ponds: ponds constructed or used to hold storm water and other runoff where heavy materials can settle and the water can become clear before being discharged. (a.k.a. retention ponds)

Stream: a body of running water moving over the earth's surface in a channel or bed.

Streambank: the side of a stream.

Subwatershed: a small watershed that is part of a larger watershed

Surface water: Water that flows over or is found on the earth's surface.

Thermocline (metalimnion): intermediate (middle) layer of water in a lake.

Total solids: a term used to describe all the matter suspended or dissolved in water.

Tributary: a stream or river that flows into another larger stream or river.

Turbidity: a measure of water cloudiness caused by suspended solids.

Watershed: an area of land that drains into a particular river or body of water

Water table: the upper surface of groundwater.

Waterway: a natural or man-made place for water to run through (such as river, stream, creek, or channel)

Wetland: an area of land that is saturated at least part of the year by water