Colorado Envirothon
Aquatics Resource
Study Guide

This manual is divided into sections based on the 4 Key Points of the Colorado Envirothon Aquatics Curriculum.

Each section covers the Learning Objectives listed in the individual Key Point.

To prepare for the Colorado Annual Contest it is recommended that you use the information in this manual along with the PowerPoints and videos referenced on the website.

Go to https://www.coloenvirothon.org/aquatics-ecology.html to access the additional information you will need to be familiar with.

General Aquatic Ecology Resources

River Watch Website:
https://coloradoriverwatch.org/forms-copy/

Wetland function and values:
http://cfpub.epa.gov/watertrain/pdf/modules/WetlandsFunctions.pdf
https://www.epa.gov/watershedacademy

Lake Ecology:
http://cfpub.epa.gov/watertrain/pdf/limnology.pdf

Invertebrates:
http://www.dep.wv.gov/WWE/getinvolved/sos/Documents/Benthic/WVSOS_MacroIDGuide.pdf

Effects of Human Settlement on Bird Communities in Lowland Riparian Areas of Colorado
http://millerlab.nres.illinois.edu/pdfs/Effects%20of%20Human%20Settlement%20on%20Bird%20Communities%20in%20Lowland%20Riparian%20Areas%20of%20Colorado%20(USA).pdf

Note: pay attention to the concepts and findings of the study and don't get intimidated by the statistical methods.

Aquatics Ecology
Key Point 1—Abiotic factors

Learning Objectives:

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 and be able to identify stream orders and watershed boundaries. Know the features of a healthy watershed and an unhealthy watershed.
3. Know how to perform and interpret chemical water quality tests and understand why aquatic organisms and water quality is affected by the physical, chemical and biological conditions of the water.

Suggested Activities:

- Use topographic maps to investigate the concept of a watershed, identify a river's watershed system, and delineate the watershed of a given area. Be able to describe how different land uses and watershed characteristics can affect water runoff, water flow, types of stream habitats and management approaches.

  Find Watershed Delineation diagrams at the end of this resource

- Investigate and find out who is using the water in your watershed and become familiar with historic stream and river levels to learn if levels are increasing or decreasing. Use stream assessment data to determine the health of your watershed.
- Conduct chemical water quality tests to determine the temperature, dissolved oxygen, pH, phosphorus, alkalinity, nitrogen, and dissolved oxygen percent saturation of a water sample and explain why these test results are indicators of water quality and can be used to assess and manage aquatic environments.

Importance of Water

Water is essential for all life to survive. Everything is linked to water directly or indirectly. Water is a widespread life sustaining substance comprising 70-90% of all living materials and covering a similar percentage of the Earth's surface. Of the Earth's total moisture however, some 97% is contained in the oceans with less than .003% flowing in the rivers and streams.

The Hydrologic Cycle

The Earth is a closed system; all the water that is on earth has been here since its formation. Water moves around the world, changes forms, is taken in by plants and animals, but never really disappears. Water can assume the form of ice (solid), water (liquid), or water vapor (gas). Water can be found on the earth's surface as ponds, lakes, streams, rivers, and oceans or as ground water in aquifers. Water can also be found in ice caps or in the atmosphere. It "travels" in a large, continuous cycle through a number of reservoirs (the largest being the oceans). The process in which water moves between these places and changes from one form to another is known as the hydrologic cycle

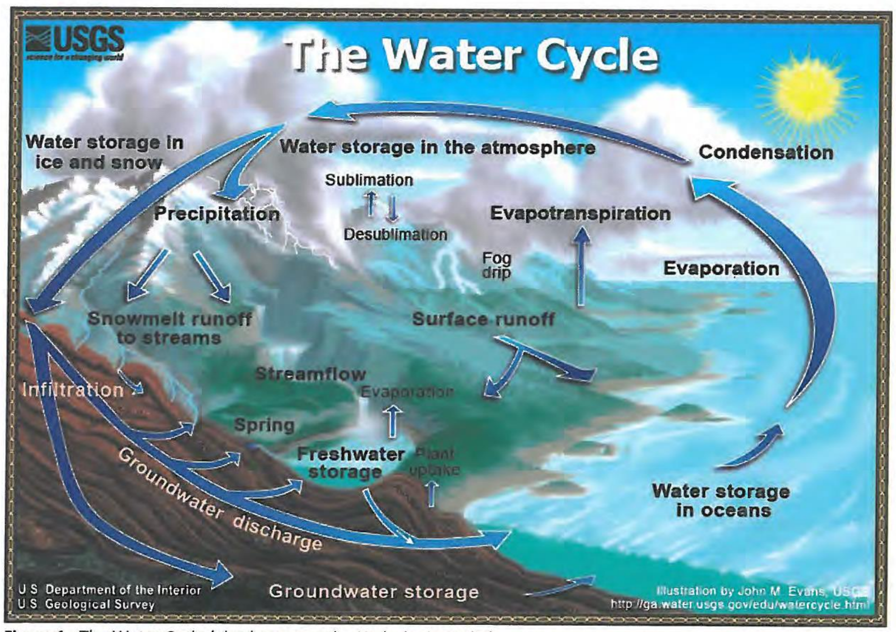

Figure 1. The Water Cycle (also known as the Hydrologic Cycle.)

The water cycle has no starting point. But, we'll begin in the oceans, since that is where most of Earth's water exists. The sun, which drives the water cycle, heats water in the oceans. Some of it evaporates as vapor into the air. Ice and snow can sublimate directly into water vapor. Rising air currents take the vapor up into the atmosphere, along with water from evapotranspiration, which is water transpired from plants and evaporated from the soil. The vapor rises into the air where cooler temperatures cause it to condense into clouds. Air currents move clouds around the globe, cloud particles collide, grow, and fall out of the sky as precipitation. Some precipitation falls as snow and can accumulate as ice caps and glaciers, which can store frozen water for thousands of years.

Snowpacks in warmer climates often thaw and melt when spring arrives, and the melted water flows overland as snowmelt. Most precipitation falls back into the oceans or onto land, where, due to gravity, the precipitation flows over the ground as surface runoff.

A portion of runoff enters rivers in valleys in the landscape, with streamflow moving water toward the oceans. Runoff, and groundwater seepage, accumulate and are stored as freshwater in lakes. Not all runoff flows into rivers, though. Much of it soaks into the ground as infiltration. Some water infiltrates deep into the ground and replenishes aquifers (saturated subsurface rock), which store huge amounts of freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater discharge, and some ground water finds openings in the land surface and emerges as freshwater springs. Over time, though, all of this water keeps moving, some to reenter the ocean, where the water cycle "ends" ... oops - I mean, "begins."

Evaporation

Evaporation is the process by which water changes from a liquid to a gas or vapor. Evaporation is the primary pathway that water moves from the liquid state back into the water cycle as atmospheric water vapor. The oceans, seas, lakes, and rivers provide nearly 90 percent of the moisture in the atmosphere via evaporation, with the remaining 10 percent being contributed by plant transpiration. Heat (energy) is necessary for evaporation to occur. Energy is used to break the bonds that hold water molecules together, which is why water easily evaporates at the boiling point (212° F, 100° C) but evaporates much more slowly at the freezing point.

Evaporation from the oceans is the primary mechanism supporting the surface-to-atmosphere portion of the water cycle though, a very small amount of water vapor enters the atmosphere through sublimation. After all, the large surface area of the oceans (more than 70 percent of the Earth's surface is covered by the oceans) provides the opportunity for large-scale evaporation to occur. On a global scale, the amount of water evaporating is about the same as the amount of water delivered to the Earth as precipitation. This does vary geographically, though. Evaporation is more prevalent over the oceans than precipitation, while over the land, precipitation routinely exceeds evaporation. Most of the water that evaporates from the oceans falls back into the oceans as precipitation. Only about 10 percent of the water evaporated from the oceans is transported over land and falls as precipitation.

Once evaporated, a water molecule spends about 10 days in the air. The process of evaporation is so great that without precipitation runoff, and groundwater discharge from aquifers, oceans would become nearly empty. Less evaporation takes place during periods of calm winds than during windy times. When t he air is calm, evaporated water tends to stay close to the water body; when winds are present, the more moist air close to the water body is moved away and replaced by drier air which favors additional evaporation.

Sublimation

Sublimation is the conversion between the solid and the gaseous phases of matter, with no intermediate liquid stage. For those of us interested in the water cycle, sublimation is most often used to describe the process of snow and ice changing into water vapor in the air without first melting into water. The opposite of sublimation is "deposition," where water vapor changes directly into ice-such a snowflakes and frost. Sublimation occurs more readily when certain weather conditions are present, such as low relative humidity and dry winds. Sublimation also occurs more at higher altitudes, where the air pressure is less than at lower altitudes.

What is a Watershed?

A watershed is simply the land that water flows across or through on its way to a common stream, river, or lake. A watershed can be very large (e.g. draining thousands of square miles to a major river or lake or the ocean), or very small, such as a 20-acrewatershed that drains to a pond. A small watershed that nests inside of a larger watershed is sometimes referred to as a subwatershed.

Everyone lives in a watershed! Watersheds provide our drinking water, habitat for wildlife, soil in which to grow our food, and the streams, rivers and lakes we use for fishing, boating and swimming. We all share a common interest in having a healthy watershed. The US Environmental Protection Agency has long promoted using a watershed approach to manage our land and water resources. The scientific basis for this approach is documented by research on the important connection between land use and watershed health.

During the land development process, forests are cleared, soils are compacted, natural drainage patterns are altered, and impervious surfaces such as roads, buildings and parking lots, are created. These changes increase the amount of polluted runoff that reaches our local waterways. As a result, stream banks begin to erode, critical in-stream habitats are washed away or filled in with sediment, downstream flooding increases, and water becomes too polluted to support sensitive fish and bugs or recreational activities.

Water Storage in the Atmosphere

The water cycle is all about storing water and moving water on, in, and above the Earth. Although the atmosphere may not be a great storehouse of water, it is the superhighway used to move water around the globe. Evaporation and transpiration change liquid water into vapor, which ascends into the atmosphere due to rising air currents. Cooler temperatures aloft allow the vapor to condense into clouds and strong winds move the clouds around the world until the waterfalls as precipitation to replenish the earthbound parts of the water cycle. About 90 percent of water in the atmosphere is produced by evaporation from water bodies, while the other 10 percent comes from transpiration from plants. There is always water in the atmosphere.

Evapotranspiration

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 goes. Higher temperatures cause the plant cells which control the openings (stoma) where water is released to the atmosphere to open, whereas colder temperatures cause the openings to close.
Relative humidity: As the relative humidity of the air surrounding the plant rises the transpiration rate falls. It is easier for water to evaporate into dryer air than into more saturated air.

Wind and air movement: Increased movement of the air around a plant will result in a higher transpiration rate.
Soil-moisture availability: When moisture is lacking, plants can begin to senesce (premature ageing, which can result in leaf loss) and transpire less water.
Type of plant: Plants transpire water at different rates. Some plants which grow in arid regions, such as cacti and succulents, conserve precious water by transpiring less water than other plants.

Transpiration and ground water

In many places, the top layer of the soil where plant roots are located is above the water table and thus is often wet to some extent, but is not totally saturated, as is soil below the water table. The soil above the water table gets wet when it rains as water infiltrates into it from the surface, but it will dry out without additional precipitation. Since the water table is usually below the depth of the plant roots, the plants are dependent on water supplied by precipitation. In places where the water table is near the land surface, such as next to lakes and oceans, plant roots can penetrate into the saturated zone below the water table, allowing the plants to transpire water directly from the groundwater system. Here, transpiration of ground water commonly results in a drawdown of the water table much like the effect of a pumped well.

Precipitation

Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail. It is the primary connection in the water cycle that provides for the delivery of atmospheric water to the Earth. Most precipitation falls as rain.

Stored Water

The water cycle describes how water moves above, on, and through the Earth. But, in fact, much more water is "in storage" at any one time than is actually moving through the cycle. By storage, we mean water that is locked up in its present state for a relatively long period of time. Short-term storage might be days or weeks for water in a lake, but it could be thousands of years for deep groundwater storage or even longer for water at the bottom of an ice cap, such as in Greenland.

Just because water in an ice cap or glacier is not moving does not mean that it does not have a direct effect on other aspects of the water cycle and the weather. Ice is very white, and since white reflects sunlight (and thus, heat), large ice fields can determine weather patterns. Air temperatures can be higher a mile above ice caps than at the surface, and wind patterns, which affect weather systems, can be dramatic around ice-covered landscapes.

Snowmelt Runoff to Streams

Runoff from snowmelt is a major component of the global movement of water. Of course, the importance of snowmelt varies greatly geographically, and in warmer climates it does not directly play a part in water availability. In the colder climates, though, much of the springtime runoff and streamflow in rivers is attributable to melting snow and ice. Mountain snowfields act as natural reservoirs for many western United States water-supply systems, storing precipitation from the cool season, when most precipitation falls and forms snowpacks, until the warm season when most or all snowpacks melt and release water into rivers. As much as 75 percent of water supplies in the western states are derived from snowmelt.

Surface Runoff

Surface runoff is precipitation runoff over the landscape. As with all aspects of the water cycle, the interaction between precipitation and surface runoff varies according to time and geography. Surface runoff is affected by both meteorological factors and the physical geology and topography of the land. Only about a third of the precipitation that falls over land runs off into streams and rivers and is returned to the oceans. The other two-thirds is evaporated, transpired, or soaks (infiltrates) into ground water. Surface runoff can also be diverted by humans for their own uses.

As more and more people inhabit the Earth, and as more development and urbanization occur, more of the natural landscape is replaced by impervious surfaces, such as roads, houses, parking lots, and buildings that reduce infiltration of water into the ground and accelerate runoff to ditches and streams. In addition to increasing imperviousness, removal of vegetation and soil, grading the land surface, and constructing drainage networks increase runoff volumes and shorten runoff time into streams from rainfall and snowmelt. As a result, the peak discharge, volume, and frequency of floods increase in nearby streams.

Streamflow

"Streamflow" refers to the amount of water flowing in a river and streamflow is always changing. Of course, the main influence on streamflow is precipitation runoff in the watershed. Rainfall causes rivers to rise, and a river can even rise if it only rains very far up in the watershed - remember that water that falls in a watershed will eventually drain by the outflow point. The size of a river is highly dependent on the size of its watershed. Large rivers have watersheds with lots of surface area; small rivers have smaller watersheds.

Likewise, different size rivers react differently to storms and rainfall. Large rivers rise and fall slower and at a slower rate than small rivers. In a small watershed, a storm can cause 100 times as much water to flow by each minute as during base-periods, but the river will rise and fall possibly in a matter of minutes and hours. Large rivers may take days to rise and fall, and flooding can last for a number of days. After all, it can take days for all the water that fell hundreds of miles upstream to drain past an outflow point.

Freshwater Storage

Earth's surface-water bodies are generally thought of as renewable resources, although they are very dependent on other parts of the water cycle. The amount of water in our rivers and lakes is always changing due to inflows and outflows. Inflows to these water bodies will be from precipitation, overland runoff, groundwater seepage, and tributary inflows. Outflows from lakes and rivers include evaporation and discharge to ground water. Humans get into the act also, as people make great use of surface water for their needs.

So, the amount and location of surface water changes over time and space, whether naturally or with human help. Surface water keeps life going. Water on the land surface really does sustain life. And, since ground water is supplied by the downward percolation of surface water, even aquifers are happy for water on the Earth's surface. You might think that fish living in the saline oceans aren't affected by freshwater, but, without freshwater to replenish the oceans they would eventually evaporate and become too saline for even the fish to survive.

Useable freshwater is very scarce. Freshwater represents only about three percent of all water on Earth and freshwater lakes and swamps account for a mere 0.29 percent of the Earth's freshwater. Twenty percent of all freshwater is in one lake, Lake Baikal in Asia. Another twenty percent is stored in the Great Lakes (Huron, Michigan, and Superior). Rivers hold only about 0.006 percent of total freshwater reserves. People have built systems, such as large reservoirs and small water towers (like this one in South Carolina, created to blend in with the peach trees surrounding it) to store water for when they need it. These systems allow people to live in places where nature doesn't always supply enough water or where water is not available at the time of year it is needed.

Infiltration

Anywhere in the world, a portion of the water that falls as rain and snow infiltrates into the subsurface soil and rock. How much infiltrates depends greatly on a number of factors. Some water that infiltrates will remain in the shallow soil layer, where it will gradually move vertically and horizontally through the soil and subsurface material. Eventually, It might enter a stream by seepage into the stream bank.

Some of the water may infiltrate deeper, recharging groundwater aquifers. If the aquifers are porous enough to allow water to move freely through it, people can drill wells into the aquifer and use the water for their purposes. Water may travel long distances or remain in groundwater storage for long periods before returning to the surface or seeping into other water bodies, such as streams and the oceans.

Factors affecting infiltration:

- The amount and characteristics (intensity, duration, etc.) of precipitation.
- Soil characteristics.
- The degree to which soil is saturated prior to the rainfall.
- Land cover.
- Topography.
- Evapotranspiration.

Subsurface water

As precipitation infiltrates into the subsurface soil, it generally forms an unsaturated zone and a saturated zone. In the unsaturated zone, the voids-that is, the spaces between grains of gravel, sand, silt, clay, and cracks within rocks-conta in both air and water. Although a lot of water can be present in the unsaturated zone, this water cannot be pumped by wells because it is held too tightly by capillary forces. The upper part of the unsaturated zone is the soil-water zone. The soil zone is crisscrossed by roots, openings left by decayed roots, and animal and worm burrows, which allow the precipitation to infiltrate into the soil zone. Water in the soil is used by plants in life functions and leaf transpiration, but it also can evaporate directly to the atmosphere. Below the unsaturated zone is a saturated zone where water completely fills the voids between rock and soil particles. Natural refilling of deep aquifers is a slow process because ground water moves slowly through the unsaturated zone and the aquifer.

Spring

A spring is a water resource formed when the side of a hill, a valley bottom or other excavation intersects a flowing body of ground water at or below the local water table, below which the subsurface material is saturated with water. A spring is the result of an aquifer being filled to the point that the water overflows onto the land surface. They range in size from intermittent seeps, which flow only after much rain, to huge pools flowing hundreds of millions of gallons daily.

Why Should Watersheds Be Protected?

Healthy watersheds can provide for stable local economies that enable people to enjoy a quality life and a quality environment. Water is important as a foundation for life and for its habitat. 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 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, and (5) supports a vibrant ecosystem. We must therefore not only look at the economic and public health benefits of a watershed but also protection of the ecosystem that the watershed supports.

Understanding Your Watershed

A watershed is a dynamic and unique place. It is a complex web of natural resources - soil, water, air, plants and animals. Yet, everyday activities can impact these resources, ultimately impacting our well-being and economic livelihood. Each watershed has many features that make it unique, including the river and its tributaries, dams, lakes and ponds, mountains, open fields forests, and wetlands, to name a few. Important features of a watershed are:

- ► Size of the watershed.
- ► Geographic boundary of the watershed.
- ► Topography (terrain).
- ► Soil type.

Whether your watershed drains into a stream or lake, the area nearest the water greatly affects water quality. This is why filter/buffer strips, wildlife habitat, wetlands and riparian areas are important aspects of your watershed. Both filter/buffer strips and wetlands utilize nutrients and tie up sediment to help Improve water quality. Wetlands also act as natural sponges to absorb peak flows of water and reduce flooding. Many fish and wildlife species rely on wetlands for rearing their young, and for food and shelter.

Watershed Delineation – see last pages of this resource for diagrams

The first step in understanding your watershed is to delineate the boundaries of your watershed. A watershed is the total area of land draining to a body of water such as a stream, river, wetland, estuary, or aquifer. Watersheds can range in size from a few acres that drain into a small creek to a large basin that drains an entire region into a major waterbody, such as the Mississippi River. See the the last pages of this resource to learn how to delineate a watershed.

Stream Order and Classification
Classifying stream order is important because it gives an idea of 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 in determining what types of life might be present in the waterway. Different types of plants for example can 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 a first order stream all the way to the largest, a 12th order stream. A first order stream is the smallest of the world's streams and 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 slow down and meet the next order waterway. **First through third order streams are also called headwater streams** and constitute any waterways in the upper reaches of the watershed. It is estimated that more than 80% of the world's waterways are these first through third order, or headwater streams.

Going up in size and strength, streams that are classified as **fourth through sixth order** are medium streams while *anything larger (up to 12th order) 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 considered a 12th order stream. Unlike the smaller order streams, these medium and large rivers are usually less steep and flow slower. They do however tend to have larger volumes of runoff and debris as it collects in them from the smaller waterways flowing into them.

When studying stream order, it is important to recognize the pattern associated with the movement of streams up the hierarchy of strength. The smallest tributaries are classified as first order. It then takes a joining of two first order streams to form a second order stream. When two second order streams combine, they form a third order stream, and when two third order streams join, they form a fourth and so on.

If however, 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 addition to the ordering system, streams may be classified, as follows, 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 (SO percent of the time or less).

➢ **Ephemeral flow** generally occurs during and shortly after extreme precipitation or snowmelt conditions. Ephemeral channels are not well defined and are usually headwaters or low order (1-2) streams.

➢ **Watershed Structure**

Watershed structure includes the structure of flowing waters (mainly rivers and streams with associated riverine wetlands and riparian zones), still waters (lakes and associated basin-type wetlands and shorelands), and upland areas of watersheds.

- **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 (Figure 7) recognizes that lotic systems' structure exists in a four-dimensional framework, as below:

Figure 7 A four-dimensional concept of watershed structure.

- **Longitudinal (**in an upstream and downstream direction) - Flowing water systems commonly go through structural changes enroute 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; and the downstream end's depositional zone, where flow is highest but slope is minimal and deposition of sediment significantly exceeds erosion most of the time.

- **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 floodedfrequently, and higher floodplains (e.g., the 100-year or 500-year) that are rarely inundated; terraces, which are former floodplains that a downcutting stream no longer floods; and hillslopes or other upland areas extending up-gradient to the watershed boundary.

- **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.

- **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 fauna I 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 lake. 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.

  Areas referred to as lake districts contain lakes created by similar processes. While the individual lakes in a lake district often share similar geologic features, the lakes themselves are often quite unique. In Northern Wisconsin and Minnesota for example many of the lakes were formed by the same glacial processes, but the individual biological, chemical, and physical characteristics of lakes even just a few miles apart can be dramatically different. In these lakes, landscape position of the basin, characteristics of the watershed, and morphometry of the basin are usually more important than method of basin formation for describing the biological features of a lake.

- **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 differentvolcanic 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.

- **Plunge pools**. Although somewhat rare, these lakes were formed when ancient waterfalls scoured out deep pools. They are often associated with glacial activity that diverted river flow.

- **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. Lake Mead and Lake Powell are two of the more dramatic examples of human-made lakes along the course of the Colorado River.In addition to the many large dams, there are upwards of one million small dams impounding lakes and ponds across the lower 48 states.

- **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 primary producers and 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.

- **Structure in Upland Areas of Watersheds**

The physical form of the uplands in watersheds can vary greatly. Here we focus only on the distribution of and variations in vegetation and land use, which together create the element of watershed structure called landscape pattern. Vegetation and land use patterns in watersheds are known to have many significant influences on the condition of the water bodies they drain into.

- **Landscape patterns.**

  Landscape ecology offers a simple set of concepts and terms for identifying basic landscape patterns: matrix, patch, and mosaic (Figure 8). 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). It is always important, when analyzing landscape pattern and landscape change, to remain aware that the spatial resolution of your information (how small a landscape feature you can detect) may or may not be sufficient to detect all the landscape changes of possible significance that may be occurring.

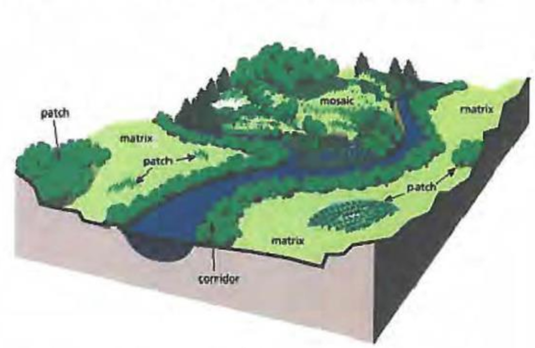

Figure 8 Useful units for describing landscape structure and pattern.

- **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). These categories are commonly found on land cover maps likely to be available in the GIS data for most watersheds, and can be consulted to give a general sense of vegetation patterns in the watershed.

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.**
  Increasingly, the landscape structure and pattern we see is the result of widespread human activity. In all fields of environmental management including watershed management, analysis of land use types, patterns, and trends is commonplace. 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. Human-dominated landscapes, just as natural landscapes, are shifting mosaics that often progress through a series of changes in what is dominant.

Watershed Functions

The essential functions that occur in most healthy watersheds include: transport and storage, cycling and transformation, and, ecological succession.

➢ **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. It is important when recognizing the transport function to also recognize temporary retention or storage at different locations in the watershed.

► Transport and Storage.

As matter physically moves through the watershed, there are a number of terms which arise re lative to various stages of cycling.Availability refers not just to the presence of an element in a system, but also speaks to the usability of a given agent. For instance, nitrogen gas may be plentiful in and around dam spillways, but N2 is not a usable form for most aquatic organ isms, and thus the availability of nitrogen is compromised. 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 9), 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).

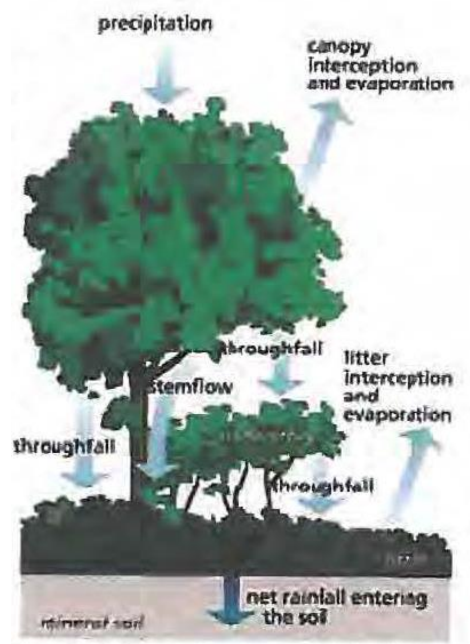

Figure 9 Dynamics of precipitation.

► Transport and storage of sediments.

Watersheds also collect and transport sediments as a major function. Sediment transport and storage is a complex network of smaller watershed processes, like the water processes described above, and actually is inseparable from water transport and storage. 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 enroute downstream. Hence, the concept of nutrient "spiraling" implies both movement downstream and multiple exchanges between terrestrial and aquatic environment, as well as between biotic and abiotic components of the watershed.

► The Cycling of Carbon and Energy.

In food webs, carbon and the subsequent synthesized energy is cycled through trophic (food web) levels. Energy transfer is considered inefficient, with less than 1 percent of the usable solar radiation reaching a green plant being typically synthesized by consumers, and a mere 10 percent of energy being typically converted from trophic level to trophic level by consumers.

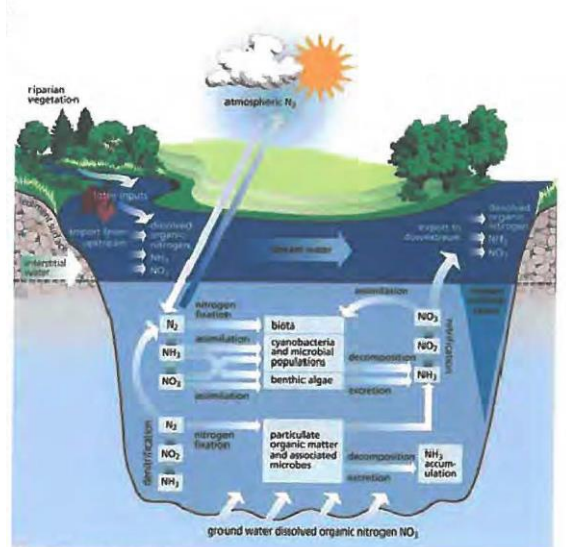

Figure 10 The nitrogen cycle.

► Nitrogen (N).

N2 (gaseous state) is not usable by plants and most algae. N-fixing bacteria or blue-green algae transform it into nitrite (NO2) or ammonia (NH4). N fixation, precipitation, surface water runoff, and groundwater are all sources of nitrogen. Under aerobic conditions, NH4+ is oxidized to NO3- (nitrate) in the nitrification process. Losses of N occur with stream outflow, denitrification of nitrate (NO3) to N2 by bacteria, and deposition in sediments. Unlike P, inorganic N ions are are highly soluble in water and readily leach out of soils into streams. NH4+ (ammonium) is the primary end-product of decomposition.

► **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; usually existing dissolved as inorganic orthophosphate, suspended as organic colloids, adsorbed onto particulate organic and inorganic sediment, or contained in organic water. 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 Pin 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 CO2, H2O 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. The bacteria and fungi modify the organic material through decomposition and make it an important food source for invertebrate and vertebrate detritivores, thereby reinserting these nutrients and materials into the watershed's aquatic and terrestrial food webs. Decomposition is

influenced by moisture, temperature, exposure, type of microbial substrate, vegetation, etc. Specifically, temperature and moisture affect the metabolic activity on the decomposing substrate. Nutritional value (as well as palatability) of the decomposing structure will also affect the time involved in complete breakdown and mineralization. Decomposition involves the following processes: the leaching of soluble compounds from dead organic matter; fragmentation; bacterial and fungal breakdown; consumption of bacterial and fungal organisms by animals; excretion of organic and inorganic compounds by animals; and clustering of colloidal organic matter into larger particles. The process of death and consumption, along with the leaching of soluble nutrients from the decomposing substrate, release minerals contained in the microbial and detrital biomass. This process is known as mineralization.

- **Ecological Succession**

The classical ecological definition of plant succession involves a predictable set of vegetative changes through a series of discrete stages (series). 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). Within the watershed, succession may vary with spatial scale, elevation, and topography. Modern successional theories view the landscape as being in a sort of dynamic equilibrium, in that various patches make up a shifting mosaic of various successional stages.

In watershed terms, succession is a process that circulates significant amounts of the watershed's energy, water and materials from the abiotic environment back into the biotic, and from one set of predominant organisms on to a subsequent set of dominant organisms. Characteristic forms of succession may be typical of specific parts of the watershed. Succession builds and gradually changes vegetational structure that serves many critical functions such as maintaining varied habitat (recall the earlier discussion of the highest biodiversity often being found in areas of intermediate disturbance) and reestablishing renewable resources for human use, like woodlots.

Water Quality Parameters

These parameters are used to find out if the quality of water is good enough for drinking water, recreation, irrigation, and aquatic life.

Alkalinity refers to how well a water body can neutralize acids. Alkalinity measures the amount of alkaline compounds in water, such as carbonates (CO_3^{2-}), bicarbonates (HCO_3^-), and hydroxides (OH^-). 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 by using available HCO_3^- and CO_3^{2-} to take metals out of solution, thus making it unavailable to fish. Alkalinity is affected by the geology of the watershed; 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. Oxygen enters the water by absorption directly from the atmosphere or by aquatic plant and algae photosynthesis. Oxygen is removed from the water by respiration and decomposition of organic matter. The amount of DO in water depends on several factors, including temperature (the colder the water, the more oxygen can be dissolved); the volume and velocity of water flowing in the water body; and the amount oforganisms using oxygen for respiration. The amount of oxygen dissolved in water is expressed as a concentration, in milligrams per liter (mg/l) of water. 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. Pathogens are typically present in such small amounts it is impractical to monitor them directly. 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 affects the concentration of dissolved oxygen, natural substances, and pollutants in a water body. 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 +l) 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. Nitrogen is very common and found in many forms in the environment. Inorganic forms include nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), and nitrogen gas (N_3) Organic nitrogen is found in the cells of all living things and is a component of proteins, peptides, and amino acids. Excessive concentrations of nitrate, nitrite, or ammonia can be harmful to humans and wildlife. High levels of nitrate, along with phosphate, can overstimulate the growth of aquatic plants and algae, resulting in high dissolved oxygen consumption, causing death of fish and other aquatic organisms. This process is called **eutrophication**. 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 O to 14. A solution with a pH value of 7 is neutral; a solution with a pH value less than 7 is acidic; a solution with a pH value greater than 7 is basic. 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. Phosphorus is a natural element found in rocks, soils and organic material. 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 isgenerallyfound as phosphate. High levels of phosphate, along with nitrate, can overstimulate the growth of aquatic plants and algae, resulting in high dissolved oxygen consumption, causing death of fish and other aquatic organisms. The primary sources of phosphates to surface water are detergents, fertilizers, and natural mineral deposits.

Specific Conductance 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 of water is a very important factor for aquatic life. It controls the rate of metabolic and reproductive activities. Most aquatic organisms are "cold-blooded," which means they can not control their own body temperatures. Their body temperatures become the temperature of the water around them. Cold-blooded organisms are adapted to a specific temperature range. 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): Organic matter plays a major role in aquatic systems. It 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. Turbidity itself is not a major health concern, but high turbidity can interfere with disinfection and provide a medium for microbial growth. It also may indicate the presence of microbes. High turbidity can be caused by soil erosion, urban runoff, and high flow rates.

Stream Monitoring

- **Biological Monitoring**

  Biological monitoring involves identifying and counting macroinvertebrates. The purpose of biological monitoring is to quickly assess both water quality and habitat. The abundance and diversity of macroinvertebrates found is an indication of overall stream quality.

  Macroinvertebrates include aquatic insects, crustaceans, worms, and mollusks that live in various stream habitats and derive their oxygen from water. They are used as indicators of stream quality. These insects and crustaceans 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 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. For example, stonefly nymphs, which are very sensitive to most pollutants, cannot survive if a stream's dissolved oxygen falls below a certain level. If a biosurvey shows that no stoneflies are present in a stream that used to support them, a hypothesis might be that dissolved oxygen has fallen to a point that keeps stoneflies from reproducing or has killed them outright.

This brings up both the advantage and disadvantage of the biosurvey. The advantage of the biosurvey is 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.

In the example presented above, the absence of stoneflies might indeed be due to low dissolved oxygen. But is the stream under-oxygenated because it flows too sluggishly, or because pollutants in the stream are damaging water quality by using up the oxygen? The absence of stoneflies might also be due to other pollutants discharged by factories or run off from farmland, water temperatures that are too high, habitat degradation such as excess sand or silt on the stream bottom has ruined stonefly sheltering areas, or other conditions. Thus a biosurvey should be accompanied by an assessment of habitat and water quality conditions in order to help explain biosurvey results.

Utilize the Aquatic Macroinvertebrate Field Guide, found in the last few pages of this resource, to identify and learn about macroinvertebrates.

- **Chemical Monitoring**

Chemical testing allows investigators to gather information about specific water quality characteristics at a specific time. A variety of water quality tests can be preformed in fresh water - including temperature, dissolved oxygen, pH, water clarity, ammonia, hardness, phosphorus, nitrogen, chlorine and alkalinity. The basic set oftests Adopt-A-Stream groups conduct include temperature, pH, settleable solids and dissolved oxygen. Advanced tests include alkalinity, conductivity, phosphate, ammonia and nitrate-nitrogen. These tests allow volunteers to check the "life signs" of their stream.

Water temperature is important in determining which species may or may not be present in a stream system. Temperature affects feeding, reproduction, and the metabolism of aquatic animals. Not only do different species have different requirements, but also the optimum temperature may change for each stage of life. Fish larvae and eggs usually have narrower temperature requirements than adults.

Oxygen is as important to the animals living in the water as it is to those living on land. Although oxygen does not dissolve very well in water, enough does to support a variety of living organisms. The solubility of oxygen in water depends on water temperature. Cool water can hold more oxygen than warmer water because gases are more soluble in cooler water.

Dissolved oxygen (DO), oxygen dissolved in water, is critical to many forms of aquatic life and is measured in parts per million (ppm). One ppm is equal to one milligram of oxygen dissolved per one liter of water. Streams that have a high velocity and flow over rocky areas (mountain streams) tend to have higher DO levels because the water mixes with the air more frequently. Also, colder water holds more dissolved oxygen than warmer water. The amount of dissolved oxygen (DO) may vary significantly from one place to another and during times of the day in aquatic habitats for a variety of reasons. The highest concentration of DO occurs at sunset. After sunset, plants respire (use oxygen). The lowest concentration of DO occurs at sunrise. This is the most likely time that a fish kill will occur. DO levels of 5 to 6 ppm are usually required for growth and activity. DO levels below 3 ppm are stressful to most aquatic organisms and DO levels below 2 ppm will not support fish.

However, nonpoint source pollution negatively impacts DO levels. Excessive nutrients from fertilizers, livestock wastes, leaking septic tanks, urban runoff and phosphate detergents entering the waterway via surface water runoff can accelerate plant growth or cause "algal blooms." Algal blooms can produce thick surface mats, turn the water green, stain boats, and may be toxic to animals that drink the water. When algae dies, oxygen is consumed by the decaying process which reduces the amount of oxygen remaining for use by aquatic animals.

Heavy rains can also affect DO levels by washing a variety of suspended materials into waterways. As sedimentation increases, light transmission decreases through the water, thus decreasing plant photosynthesis, a key process for adding oxygen back into the water. Sediment can also cause the temperature of the water to increase as individual particles absorb heat thus decreasing the amount of oxygen water can hold.

A **pH** test indicates the amount of hydrogen ions in the water. A pH range of 6.0 to 8.2 is optimal for most aquatic organisms. Rapidly growing algae or submerged aquatic vegetation that remove carbon dioxide (CO_2) from the water during photosynthesis can increase pH levels.

Phosphorous and **nitrogen** are nutrients found naturally in small amounts in streams. Unfortunately, many suburban and rural areas contribute excessive amounts of these nutrients to streams through fertilizer and livestock runoff. Too much phosphorous or nitrogen leads to algae blooms and fish kills.

Key Point 2—Biotic factors

Learning Objectives:

1. Understand the dependence of all organisms on one another and how energy and matter flow within an aquatic ecosystem.
2. 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.
3. Identify common, rare, threatened and endangered aquatic species as well as Aquatic Nuisance Species (ANS) through the use of a key.
4. Know how to perform biological water quality monitoring tests and understand why these tests are used to assess and manage aquatic environments.

Suggested Activities:

- Describe the habitat needs of three specific aquatic animals, and compare and contrast the flow of energy in three different aquatic food chains.
- Create a visual display of rare and endangered aquatic species. Explain how human activities are causing species imperilment and specify actions being taken to protect these species.
- Conduct a biological stream assessment by collecting macro-invertebrates. Stream Data sheets (key point 1, resource 4) should be used to record and analyze information. Explain why these organisms are biological indicators that help us determine the health of a stream or waterway.

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 the quality of community 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.

The Physical Template

Within the watershed, various forms of matter, including water, are in constant cyclic flow. Through these processes, an abiotic (nonliving) template of air, water, and soil is formed, upon which life can exist. The physical template of watershed structure is ultimately determined by varying combinations of climatic, geomorphic, and hydrologic processes. The three elements of the physical template and other factors also interact significantly in determining the structure and composition of a watershed and its biotic communities.

- **Climatology**, the science of climate and its causes, becomes important in understanding regional issues in watershed science. Though sometimes used synonymously with weather, climate is actually a dist inct term with important ecological ramifications. Climate refers to an aggregate of both average and extreme conditions of temperature, humidity, and precipitation (including type and amount), winds, and cloud cover, measured over an extended period of time. Weather refers to present day environmental conditions; current temperatures and meteorological events make up weather, not climate. Long-term weather trends establish averages which become climatic regimes. Climate heavily influences watershed vegetation communities, streamflow magnitude and timing1 water temperature, and many other key watershed characteristics.
- **Geology** is defined as the science centered around the study of various earth structures, processes, compositions, characteristics, and histories. Geomorphology, however, refers specifically to the study of t he 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 t ransitional zone; this is a critical discipline for effective, long-term watershed management.
- **Hydrology** is the science of water, as it relates to the hydrologic cycle. More specifically, it is the science of water in all its forms (liquid, gas, and solid) on, in and over the land areas of the earth, including its distribution, circulation and behavior, its chemical and physical properties, together with the reaction of the environment (including all living things) on water itself. One of the life-sustaining cycles we are most familiar with is the hydrologic cycle. This cycle is a natural, solar-driven process of evaporation, condensation, precipitation, and runoff.

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. It is important to have a working knowledge of the basic ecological terms and concepts.

- **Basic Ecological Terms**
    - **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 forms of life such as Monera, Protista, etc. Species can be considered the lowest (most specific) area of biological classification, but lower groupings are sometimes employed (e.g., subspecies, variety, race).
    - **Population.** This term applies to organisms of the same species which inhabit a specific area.
    - **Community.** A community is an aggregate of populations of different plant and animal species occurring within a given area.
    - **Habitat.** A habitat is an area where a specific animal or plant is capable of living and growing; usually characterized by 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 a biotic 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.

Example: Ecological Levels

Species: Cervus elaphus (Roosevelt elk)
Population: The sum total of all the elk in a given herd (e.g., migrating through the Greater Yellowstone Ecosystem)
Community: The elk, and other populations associated with them (e.g., wolf, grizzly, bison
Habitat: The place where these elk live -- the open t imberlands of Yellowstone NP
Niche: Primarily *browses* on shrubs, broad leafs, and new growth of conifers
Ecosystem: Yellowstone NP and surrounding forest, shrubland and grassland, extending to the limit of the elk range (ifwe defined *from* the elk's perspective)

- **Ecological Concepts**
  - **Life History Strategies.** The term life-history strategy in ecology *refers* to the selective processes involved in achieving fitness by certain organisms. Such processes involve, among other things, fecundity and survivorship; physiological adaptations; modes of reproduction
  - **Carrying capacity** (K). This term *refers* to 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.** This term refers to two or more species or organisms which 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).
    - **Amensalism** is a situation where one party is negatively affected while the other experiences no effect (examples are difficult to find in nature).
    - **Parasitism and predation** are symbiotic types whereby one species benefits and one is adversely affected.

- **Soil Ecology**

Soil is a complex mixture of inorganic materials (sand, silt, and clay), decaying organic matter, water, air, and a great array of organisms. Because of its abundance of living organisms, soil is discussed here along with other "biological setting" components, even though soil is sometimes incorrectly described as physical, non-living. Soil has three basic properties which aid in its identification and taxonomy: color, structure, and texture (see Definitions below). Soils often vary substantially from place to place within a watershed, and among different watersheds. To describe their differences, soils are classified into soil orders. Knowing the basic differences among types of soils can be useful for understanding why they vary in their suitability for supporting different land uses and ecological communities.

- **Definitions.**
  - **Color** refers to the soil's appearance. It is the first and most obvious clue in visually determining mineral composition, chemical make-up, relative amount of organic matter, and water content. For example, a soil which is red/maroon in

color may indicate the presence of ferric oxides; the soil in this case is actually "rusting," in lay terms.

- **Structure** refers to the way in which a soil will arrange itself in "peds" (large clumps or blocks). A soil's structure may be "structureless/granular" (beach sand) or "platy" (large blocks of soil which have been crushed, like peds which may form under the migration t rail of a large animal).
- **Texture** refers to the relative proportions of sand, silt, and clay, the three main particle sizes found as varying percentages of most soils.

➢ Food Webs and Trophic Ecology

Terrestrial and aquatic ecosystems have characteristic trophic (feeding) patterns that organize the flow of energy into, 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 (Figure 4).

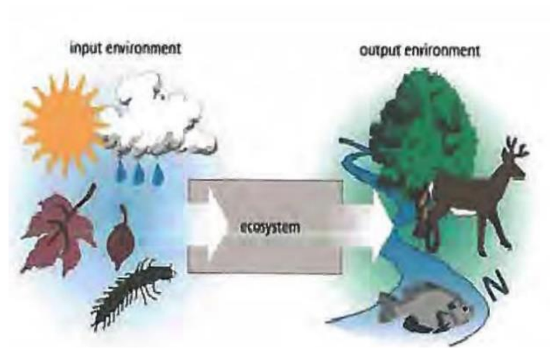

Figure 4 Ecosystems commonly have both inputs and outputs of energy, materials and

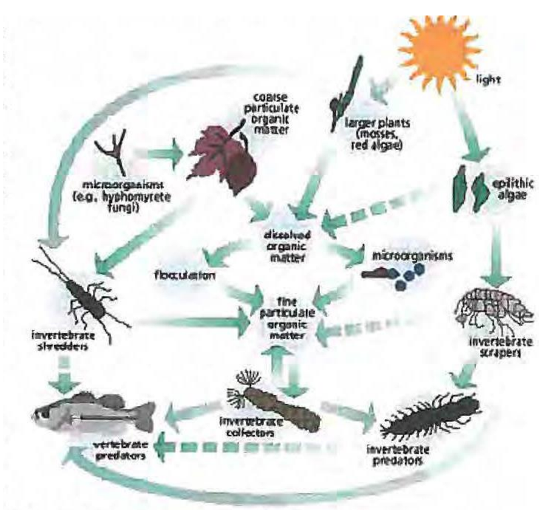

Figure 5 A simplified watershed food web.

Within a food web (Figure 5), organisms interact and, in the process, 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.

Species with especially far-reaching effects on an ecosystem are called **keystone species**. These species differ from dominant (i.e. abundant) species in that their effects are much larger than would be predicted from their abundance.They have a disproportionate effect on the composition of communities and ecosystem function. A keystone species' presence is often the lone reason for the presence of other organisms and/or the maintenance of unique ecological areas. The effects of keystone species are context-dependent, meaning that a species is not always a dominant controlling agent across its entire range, through all stages of its life cycle, or at all times of the year. The American Alligator is an example: it is not the most common species in southern swamplands and bayous, but it is an important predator that also modifies aquatic habitat structure by creating 'gator wallows'.

Indicator species are species whose presence or absence indicates an environmental change. 19th-Century coal miners used to keep a caged canary with them in the mine shaft; the especially-sensitive canary would signal the presence of dangerous, flammable gases by ceasing to sing, and dying. The ever-cognizant miners could evacuate upon noticing the death of the pet bird. This is the concept behind an indicator species: they are modern day canaries-in-a-coal mine. Watershed "canaries in a coal mine" include several types of aquatic invertebrates that are labeled "intolerant" of poor water quality, and amphibians such as frogs and salamanders.

➢ **Biodiversit**y (Genetic, Population, Species, Habitat)

- **Biodiversity** is a contemporary term which has several subcategories. In general, the term applies to the relative amount of biological elements existing within a given area.
- **Genetic biodiversity** refers to the total number of genotypes available within a given population. For example, whooping cranes were driven to the brink of extinction; at one point the total global population stood at 14 individuals. Today, the population has returned to a more comfortable level. Still, the current population is limited to the genetic material which was contained within those 14 birds, and it will take eons and many, many generations for genetic diversity to build up again. Populations with low genetic biodiversity may be more susceptible to certain diseases given the limited amount of genetic resistance potentially available. A "genetic bottleneck" refers to the loss of valuable survival traits from a population that has shrunk to a low level and then re-expanded.
- **Population biodiversity** refers to the total amount of population a given species has, worldwide. For instance, Pacific salmon are anadromous, meaning that they are born in freshwater, spend their adult life in the ocean, and then return to the fresh water from whence they originally came to reproduce and then expire. These fish rarely stray to other river systems, migrating in distinct populations from river to sea and then back to the same river. While the total number of pink salmon may be "healthy," given the number offish surviving in Alaska, population biodiversity may suffer if several rivers in southern British Columbia suddenly experience the loss of the runs of these fish.
- **Species biodiversity** is the total number of species found within a given area. In natural systems, as an example, species biodiversity is considered quite high in the tropical regions of the world, while the number may be quite moderate in temperate zones. In the woodlands of Pennsylvania, for instance, it is not uncommon to count on one hand the total number of tree species within an acre

of land. In the tropics, the number of t ree species found within an acre of land may be over 250.

- **<u>Habitat or ecological biodiversity</u>** refers to the number of different habitats or ecotypes found within a given region. In the Pacific Northwest, industrial forestry has reduced entire landscapes to monocultural tree plantations with a simple, homogeneous forest structure. On the other hand, in the region's natural systems there exists a much higher level of ecological diversity, given the various natural processes (e.g., wind, fire, flooding, disease, succession, competition) which create a mosaic of habitat types.

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 cosystem) 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 --each of the physical and biological components of watersheds if they existed separately would not be capable of generating the work and the products that the intact watershed system can generate.

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 wat ersheds 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 spatial and temporal scale, disturbance theory, and the river continuum concept, all discussed below.

➢ **Spatial and Temporal Scale**

Spatial and temporal scale are important parts of the natural systems concept. The spatial scale at which a system operates is an important factor in recognizing the system's key components, and in turn, the kind of management practices that may be appropriate. In general, systems at a larger spatial scale to have natural processes that operate on longer time frames.

- **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. Recent examples of these include the 1988 Yellowstone fires (which charred over 1,500 mi2 of predominantly forested National Park land), hurricanes Hugo and Mitch (which flattened trees and created landslides in Puerto Rico and Honduras, respectively), and Mount St. Helens, which erupted in May 1980 and affected more than 250 mi2 within the affected landscape, including areas of pyroclastic flow, debris avalanche, mudflow, blowdown, singe, and ash deposition.

- **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.

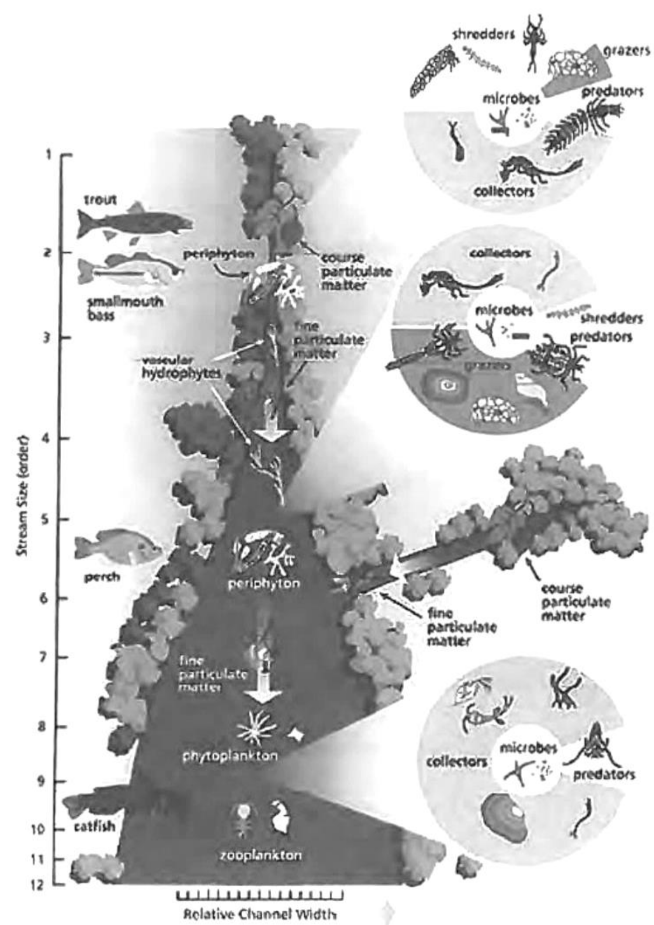

Figure 6 The River Continum Concept

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.

Colorado common, rare, threatened and endangered aquatic species

Go to https://cpw.state.co.us/learn/Pages/SpeciesProfiles.aspx to find up to date information about Colorado Aquatic species.

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. ANS include nonindigenous species that may occur within inland, estuarine or marine waters and that presently or potentially threaten ecological processes and natural resources. In addition to the severe and permanent damage to the habitats they invade, ANS also adversely affect individuals by hindering economic development, preventing recreational and commercial activities, decreasing the aesthetic value of nature, and serving as vectors of human disease.

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. This number is likely as underestimate as it does not consider ecosystem health or the aesthetic value of nature, which can influence tourism and recreational revenue. Estimating the economic impacts associated with **ANS** is further confounded as monetary values cannot be given to extinction of species, loss in biodiversity, and loss of ecosystem services.

- **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. More recently, West Nile Virus was introduced into the United States through an infected bird or mosquito. 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. Further, the effect of ANS on public health extends beyond the immediate effects of disease ·and parasites as chemicals used to control invasive species can pollute soil and water. Other ANS, such as invasive mussels, may increase human and wildlife exposure to organic pollutants such as PCB's and PAHs as these toxins accumulate in there tissues and are passed up the food chain.

Go to https://cpw.state.co.us/aboutus/Pages/ISP-ANS.aspx to find up to date info about Colorado Invasive and Aquatic Nuisance Species,

Stream Monitoring

- **Biological Monitoring**

Biological monitoring involves identifying and counting macroinvertebrates. The purpose of biological monitoring is to quickly assess both water quality and habitat. The abundance and diversity of macroinvertebrates found is an indication of overall stream quality.

Macroinvertebrates include aquatic insects, crustaceans, worms, and mollusks that live in various stream habitats and derive their oxygen from water. They are used as indicators of stream quality. These insects and crustaceans 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 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. For example, stonefly nymphs, which are very sensitive to most pollutants, cannot survive if a stream's dissolved oxygen falls below a certain level. If a biosurvey shows that no stoneflies are present in a stream that used to support them, a hypothesis might be that dissolved oxygen has fallen to a point that keeps stoneflies from reproducing or has killed them outright.

This brings up both the advantage and disadvantage of the biosurvey. The advantage of the biosurvey is 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.

In the example presented above, the absence of stoneflies might indeed be due to low dissolved oxygen. But is the stream under-oxygenated because it flows too sluggishly, or because pollutants in the stream are damaging water quality by using up the oxygen? The absence of stoneflies might also be due to other pollutants discharged by factories or run off from farmland, water temperatures that are too high, habitat degradation such as excess sand or silt on the stream bottom has ruined stonefly sheltering areas, or other conditions. Thus a biosurvey should be accompanied by an assessment of habitat and water quality conditions in order to help explain biosurvey results.

Utilize the Aquatic Macroinvertebrate Field Guide, found in the last few pages of this resource, to identify and learn about macroinvertebrates.

Key Point 3—Aquatic Environments

Learning Objectives:

1. Identify aquatic and wetland environments based on their physical, chemical and biological characteristics.
2. Know characteristics of different types of aquifers and understand historical trends and threats to groundwater quantity and quality.
3. Understand societal benefits and ecological functions of wetlands.
4. Understand the functions and values of riparian zones and be able to identify riparian zone areas.

Suggested Activities:

- Describe the physical, chemical and biological characteristics of a stream, river, pond, lake and wetland.
- Explain how different types of aquifers are indicators of water quantity and water quality. Describe how subsidence and salt water intrusion are related to the falling water table in many aquifers.
- Describe three functions of wetlands and explain how these functions are met in the absence of wetlands.
- Describe three functions of riparian zones and explain how the removal of or damage to the riparian zone would affect water quality and specific aquatic food chains.

Wetlands

Wetlands are among the most productive ecosystems in the world, comparable to rain forests and coral reefs. They also are a source of substantial biodiversity in supporting numerous species from all of the major groups of organisms - from microbes to mammals. Physical and chemical features such as climate, topography, geology, nutrients, and hydrology help to determine the plants and animals that inhabit various wetlands. The physical, chemical, and biological interactions within wetlands are often referred to as wetland functions. These functions include surface and subsurface water storage, nutrient cycling, particulate removal, maintenance of plant and animal communities, water filtration or purification, and groundwater recharge. Similarly, the 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.

It is important to maintain and restore wetland functions and values because wetlands contribute to the overall health of the environment.

➢ Types of Wetlands

Not all wetlands are the same? Think again. Each wetland differs due to variations in soils, landscape, climate, water regime and chemistry, vegetation, and human disturbance. Below are brief descriptions of the major types of wetlands found in the United States organized into four general categories: marshes, swamps, bogs, and fens.

- **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. Cattail, wild rice, pickerelweed, and arrowhead are common and help support a large and diverse range of bird and fish species, among other wildlife.

  - ✓ **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. Many vernal pools fill with water in fall or spring.

- **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. Swamps are classified as forested, shrub, or mangrove.

► **Forested Swamps** are found in broad floodplains of the northeast, southeast, and south-central United States 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** are similar to forested swamps except that shrubby species like buttonbush and swamp rose dominate.
► **Mangrove Swamps** are coastal wetlands characterized by salt-tolerant trees, shrubs, and other plants growing in brackish to saline tidal waters. These tropical and subtropical systems have a North American range that extends from the southern tip of Florida along the Gulf Coast to Texas.
► **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** are ground water-fed peat forming wetlands covered by grasses, sedges, reeds, and wildflowers. Willow and birch are also common. Fens, like bogs, tend to occur in glaciated areas of the northern United States.

➢ 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. For example, a value can be determined by the revenue generated from the sale of fish that depend on the wetland, by the tourist dollars associated with the wetland, or by public support for protecting fish and wildlife.

Although large-scale benefits of functions can be valued, determining the value of individual wetlands is difficult because they differ widely and do not all perform the same functions or perform functions equally well. Decision makers must understand that impacts on wetland functions can eliminate or diminish the values of wetlands.

- **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**

The National Audubon Society notes that bird populations continue to decrease as wetlands are destroyed. In the past 15 years alone, the continental duck breeding population fell from 45 million to 31 million birds, a decline of 31 percent. The number of birds migrating over the Gulf of Mexico, which rely on coastal wetlands as staging areas (especially in Louisiana and Mississippi), has decreased by one-half since the mid-1960s. 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. For this reason, wetland degradation is as big a problem as outright wetland loss, though often more difficult to identify and quantify.

➢ **What Is Adversely Affecting Our Wetlands?**

Human activities cause wetland degradation and loss by changing water quality, quantity, and flow rates; increasing pollutant inputs; and changing species composition as a result of disturbance and the introduction of nonnative species. 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, thereby 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 wet-land degradation are sediment, fertilizer, human sewage, animal waste, road salts, pesticides, heavy metals, and selenium. Pollutants can originate from many sources, including:
  - ► 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.

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.

Ground water has been known to humans for thousands of years. Many ancient chronicles show that humans have long known that much water is contained underground, but it is only within recent decades that scientists and engineers have learned to estimate how much ground water is stored underground and have begun to document its vast potential for use. An estimated one million cubic miles of the world's ground water is stored within one-half mile of the land surface. 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.

Water-use specialists at the U.S. Geological Survey report that about 341 billion gallons of freshwater a day was used in the United States in 1995 for public supplies, rural domestic and livestock uses, irrigation, industrial and mining uses, and for thermoelectric power. About 22 percent of this water, or 76.4 billion gallons a day, was ground water that was obtained from wells and springs. The use of ground water in seven States - Arkansas, Florida, Hawaii, Kansas, Mississippi, Nebraska, and Oklahoma - exceeded the use of surface water. Five western States - California, Idaho, Kansas, Nebraska, and Texas - used about 35 billion gallons per day of ground water. This average daily water use of 35 billion gallons accounts for about 46 percent of the total volume of ground water used in the Nation during 1995. 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.

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 distribution of water in both space and time is irregular, and some areas already face serious regional water shortages because of using some water faster than it is naturally replenished. Further development of energy, mineral, and agricultural resources is dependent largely upon adequate water supplies. Therefore, ground-water resources will become even more valuable in the years ahead as the Nation copes with growing natural-resource and environmental problems and increased water demands.

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. Similar forces hold enough water in a wet towel to make it feel damp after it has stopped dripping.

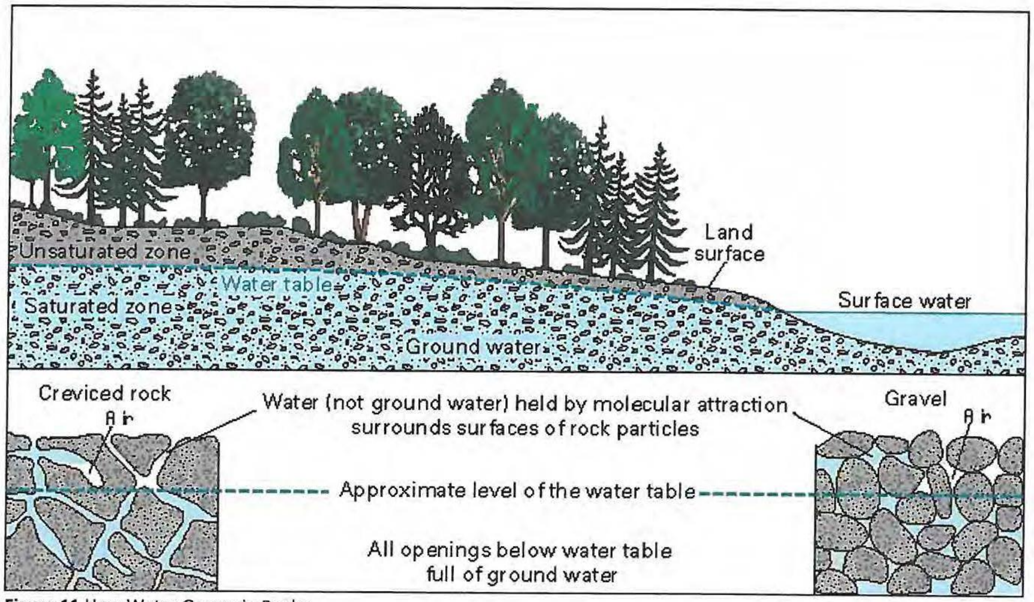

Figure 11 How Water Occurs in Rocks

After the water requirements for plant and soil are satisfied, any excess water will infiltrate 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. The rate of recharge is also an important consideration. It has been estimated, for example, that if the aquifer that underlies the High Plains of Texas and New Mexico - an area of slight precipitation - was emptied, it would take centuries to refill the aquifer at the present small rate of replenishment. In contrast, a shallow aquifer in an area of substantial precipitation may be replenished almost immediately.

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.

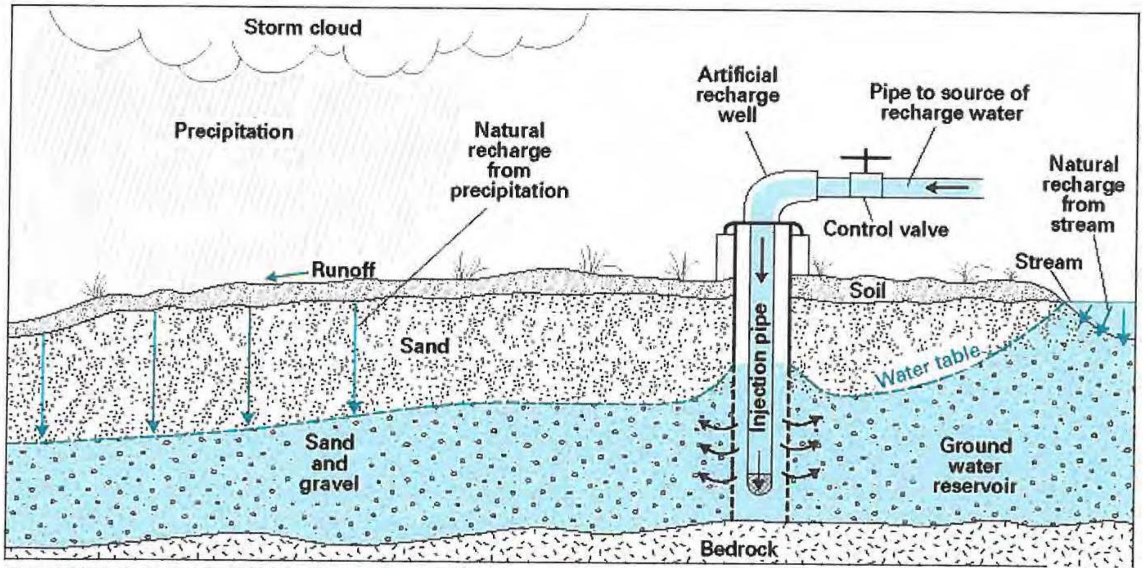

Figure 12 Natural and Artificial Recharge of an Aquifer.

The latter is a more expensive method but may be justified where the spreading method is not feasible. Although some artificial recharge projects have been successful, others have been disappointments; there is still much to be learned about different ground-water environments and their receptivity to artificial-recharge practices. A well, in simple concept, may be 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. This leads to the question: Will water be forced in fast enough under a pumping stress to assure a continuing water supply? Some rock, such as clay or solid granite, may have only a few hairline cracks through which water can move. Obviously, such rocks transmit only small quantities of water and are poor aquifers. By comparison, rocks such as fractured sandstones and cavernous limestone have large connected openings that permit water to move more freely; such rocks transmit larger quantities of water and are good aquifers. 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. Nearly all consolidated rock formations are broken by parallel systems of cracks, called joints. These joints are caused by stresses in the Earth's crust. At first many joints are hairline cracks, but they tend to enlarge through the action of many physical and chemical processes. Ice crystals formed by water that freezes in rock crevices near the land surface will cause the rocks to split open. Heating by the Sun and cooling at night cause expansion and contraction that produce the same result. Water will enter the joints and may gradually dissolve the rock or erode weathered rock and thereby enlarge the openings.

A relationship does not necessarily exist between the water-bearing capacity of rocks and the depth at which they are found. A very dense granite that will yield little or hO water to a well may be exposed at the land surface. Conversely, a porous sandstone, such as the Dakota Sandstone mentioned previously, may lie hundreds or thousands of feet below the land surface and may yield hundreds of gallons per minute of wo1ter. Rocks that yield fresh water have been found at depths of more than 6,000 feet, and salty water has come from oil wells at depths of more than 30,000 feet. On the average, however, the porosity and permeability of rocks decrease as their depth below land surface increases; the pores and cracks in rocks at great depths are closed or greatly reduced in size because of the weight of overlying rocks.

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 aqu ifers 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 underwater-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. Such are the thermal springs in Yellowstone National Park. 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.

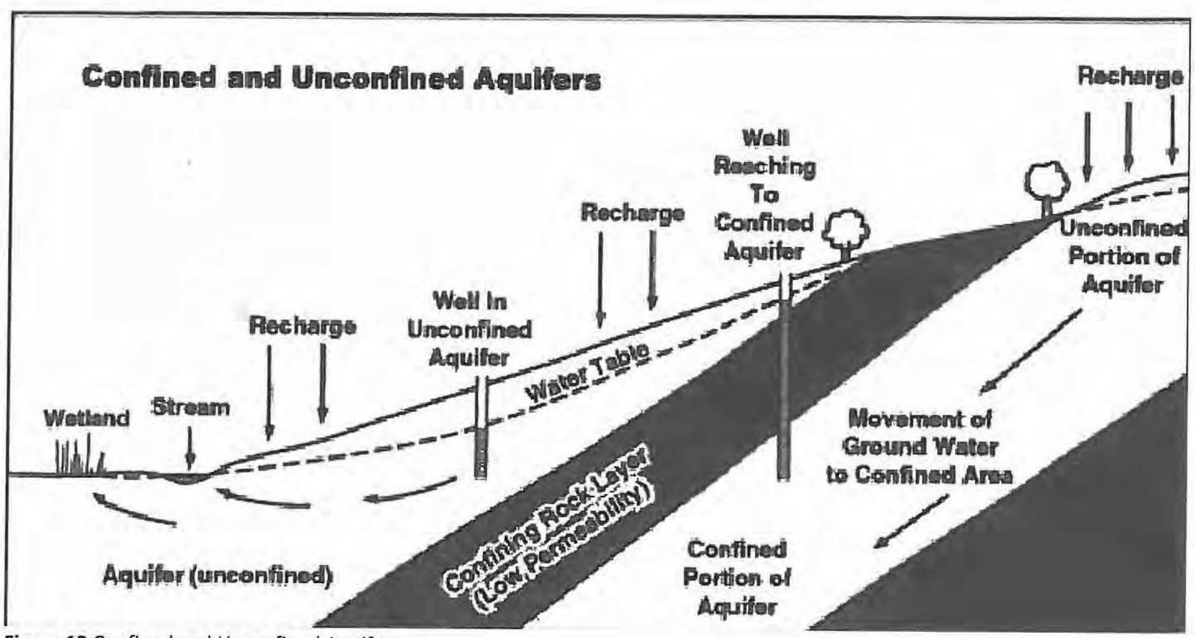

Figure 13 Confined and Unconfined Aquifers

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. streams, during times of drought. overlying ground) forces the water upwards. Unconfined aquifers can recharge nearby streams, during times of drought.

- **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 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.

In recent years, the growth of industry, technology, population, and water use has increased the stress upon both our land and water resources. Locally, the quality of ground water has been degraded. Municipal and industrial wastes and chemical fertilizers, herbicides, and pesticides not properly contained have entered the soil, infiltrated some aquifers, and degraded the ground-water quality. Other pollution problems include sewer leakage, faulty septic-tank operation, and landfill leachates. In some coastal areas, intensive pumping of fresh ground water has caused salt water to intrude into fresh-water aquifers.

In recognition of the potential for pollution, biological and chemical analyses are made routinely on municipal and industrial water supplies. Federal, State, and local agencies are taking steps to increase water-quality monitoring. Analytical techniques have been refined so that early warning can be given, and plans can be implemented to mitigate or prevent water-quality hazards.

- **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 Figure 14 How intensive ground-water pumping can cause zone of dispersion (or transition zone). Ground-water pumping 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 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.

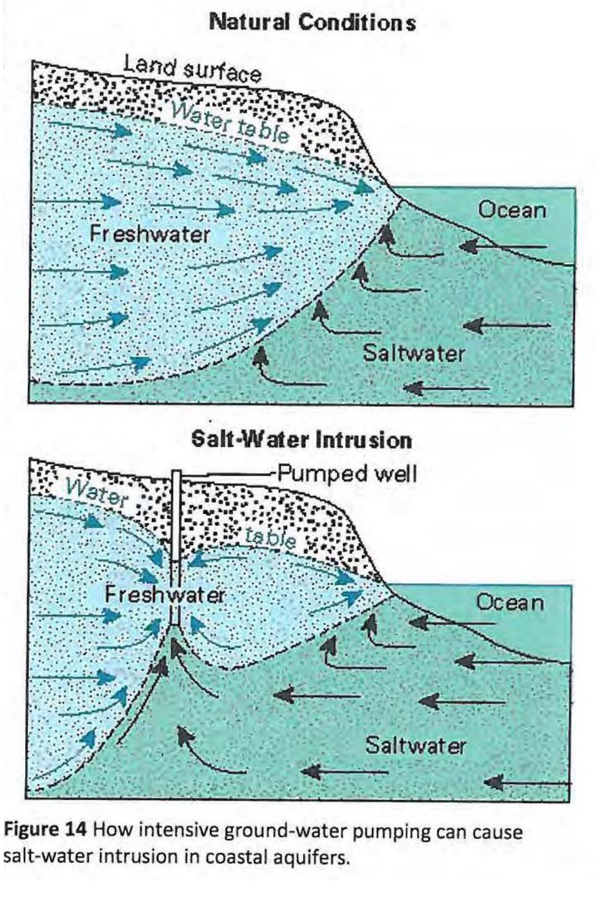

Figure 14 How intensive ground-water pumping can cause salt-water intrusion in coastal aquifers.

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. Buffers are complex ecosystems that provide habitat corridors for terrestrial organisms and, when roots or branches are submerged in the water, provide a habitat for aquatic organisms as well.

Natural riparian buffers have been lost in many places over the years. Restoring them is an important step forward for water quality, riverbank stability, wildlife, and aesthetics.

➢ **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, such as sediment and nutrients. The design specifications for forested riparian buffers should provide the desired function of the buffer at the particular location -whether it is being used to control nonpoint source pollution so that downstream waters do not deteriorate or to protect aquatic organisms.

- **Reducing Water Pollution** Non-point source pollution is responsible for most water pollution in the United States today. Oils, salt and sand from our roads; fertilizers used on lawns and farms; manure from livestock and other pollution can damage our rivers' health. 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 before they enter the water.

- **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 t ime. 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**
  Erosion results in serious environmental and economic damage. Loss of topsoil damages farms, homes and businesses, chokes clean streams, destroys fish and animal habitat, and eventually clogs our harbors and shellfish beds in bays and estuaries. 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 solid from splash erosion (i.e. the scattering of topsoil by raindrops as they hit the ground).

- **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 riparian buffer is an important feature of stream 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. Climate and watershed characteristics also affect aquatic life habitat. All of these factors influence species diversity and abundance.

  ✓ **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.

  The vegetation in the riparian buffer affects the type and quantity of detritus that occurs in the stream. It is likely that vegetation that falls into the stream generally does not move very far away so that the food benefits are highly localized to the immediate stream corridor. Older stratified forests may provide the greatest variation in quality of detritus food for macroinvertebrates.

  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-, second-, and third-order streams, the riparian canopy of trees can block sunlight from reaching the water. A shaded stream is likely to have more diatoms and less filamentous algae. A stream that runs through a cleared riparian buffer or one that has meadow vegetation is likely to have more filamentous algae. The detritus food source from the clearing of a riparian buffer is only temporary as detritus rapidly decays. For grassed riparian buffers, filamentous algae is likely to dominate. Also, large streams and rivers will receive a large portion of direct sunlight which encourages filamentous algal production in open areas. Near shore areas bordered by mature vegetation are likely to have diatoms and sufficient detritus.

- ✓ **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-, second-, and 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. Overhanging stream banks, stabilized by tree roots and large woody debris, can be important habitat for 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 fish and macroinvertebrate 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. In a stratified forest, different habitat zones exist vertically, including the soil-air interface, herbs and shrubs, intermediate height trees, and the canopy. Included with the leaf litter and rotting logs at the soil-water interface are insects, isopods, spiders,

and mites. These organisms are a food source for reptiles, mice, and birds. The herbs and shrubs provide habitat for insects, birds, and mammals. The intermediate zone and the canopy serve as habitat for birds, bats, squirrels, opossums, and raccoons. Bird habitat may be highly stratified and birds generally show a preference for certain layers that differ in habitat characteristics and food sources.

Riparian areas may also serve as corridors linking dryer, less diverse uplands to more moist, more diverse bottom lands. The width of riparian buffers needed for wildlife is not clear. This may be a function of the type of wildlife and their vegetation requirements. Upland game birds such as pheasant and bobwhite quail benefit from grasses. A stratified forested may be needed to maintain wrens and robins in a herbaceous zone and tree-creeping birds and robins in the canopy.

- **Reduce Nitrogen**
  In some geographic regions, most nitrogen enters surface waters from ground water as nitrate-nitrogen. As the shallow ground water moves through the riparian buffer, microorganisms change the nitrate-nitrogen to gaseous nitrogen via a process known as **denitrification**. When the soil is poorly aerated (anaerobic conditions), some microorganisms reduce nitrates to the gaseous components of nitrous oxide, nitric oxide, or free nitrogen gas.

  Denitrification is most effective in root-zone soil layers where carbon sources are available for the denitrifying bacteria. Numerous researchers have reported that it is the complex interaction between vegetation and below-ground environment that provides the appropriate conditions for denitrification to occur. The area of interaction within the riparian buffer is generally quite narrow -10 to 50 feet - from the field through the riparian buffer. The majority of denitrification that has been observed in riparian buffers occurred within the first 15 feet of the forested riparian buffer.

  Vegetation in riparian buffers also removes nitrogen and phosphorous through uptake. Some of these nutrients are sequestered in woody vegetation, whereas the nutrients absorbed into herbaceous materials, generally, are recycled as the vegetative matter dies.

  Although nitrogen uptake by the vegetative portion of the riparian buffer contributes to nitrogen reductions, denitrification is the primary process that removes nitrate from the shallow ground water that flows through riparian buffers.

- **Reduce Sediment and Phosphorus** Riparian buffers, both the grassed and forested portions, serve to slow water velocity, thus allowing sediment to settle out of the surface runoff water. The grassed portion of the buffer functions as a grass vegetated filter strip.

The effectiveness of well maintained grass riparian buffers for sediment may be as high as high as 90-95%. Likewise, nitrogen and phosphorus attached to the sediment and, to a lesser extent, dissolved nitrogen and phosphorus are abated. Frequently, the concentration of dissolved nutrients in the runoff passing over a grass filter does not change or may slightly increase. However, because some of the runoff water infiltrates in the buffer, less runoff water leaves the buffer than enters it. Because grass riparian buffers are designed to trap sediment, they require maintenance to remain effective.

- **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 with 50' of the river/stream should be covered with native vegetation. The ability of a buffer to remove pollutants is uncertain if it is narrower than 100'. A 100' buffer will generally remove 60% or more of pollutants, depending on local conditions. It will also provide food, cover and breeding habitat for many kinds of wildlife but only fulfill a few needs for others, such as travel cover.

  - **Topography**
    A buffer is more important for water quality in areas that collect runoff and deliver it to streams, and less critical on land that tips away from the water. Steeper slopes call for a wider riparian buffer below them to allow more opportunity for the buffer to capture pollutants from faster moving runoff.

  - **Hydrology and Soil**
    The ability of the soil to remove pollutants and nutrients from surface and ground water also depends upon the type of soil, its depth, and relation to the water table. On a wetter soil, a wider buffer is needed to get the same effect.

  - **Vegetation**
    The purpose(s) of the buffer will influence the kind of vegetation to plant or encourage. 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. Consequently, lawns mowed by the streams edge do little to control erosion. In fact, removing native vegetation and replacing it with turf grass usually results in accelerated streambank and shoreline erosion that degrades water quality.

Alteration of the Aquatic Habitat

Aquatic organisms are sensitive to any changes that may occur in their habitat and, like most other ecosystems on Earth, aquatic habitats are now changing with greater frequency due to the effects of human land use.

- **Sedimentation**
  One of the major changes that can occur in an aquatic habitat is sedimentation, or the erosion of tiny particles into a stream. Sediment can either remain suspended in the water or settle out to the stream bottom. The sediment that remains suspended in the water can affect several different aspects of stream life. It allows the water to absorb more solar radiation to heat the water, decreasing the holding capacity of dissolved oxygen. The particles also shade aquatic plants, reducing photosynthesis and increasing respiration. The sediment that accumulates on the stream bottom fills in gaps between rocks, decreasing habitat availability for benthic rnacroinvertebrates to live and for fish to lay their eggs, decreasing the populations of both. The sediment can accrue so much on the streambed that the depth is reduced, making the stream shallower and easier to heat up by the sun.

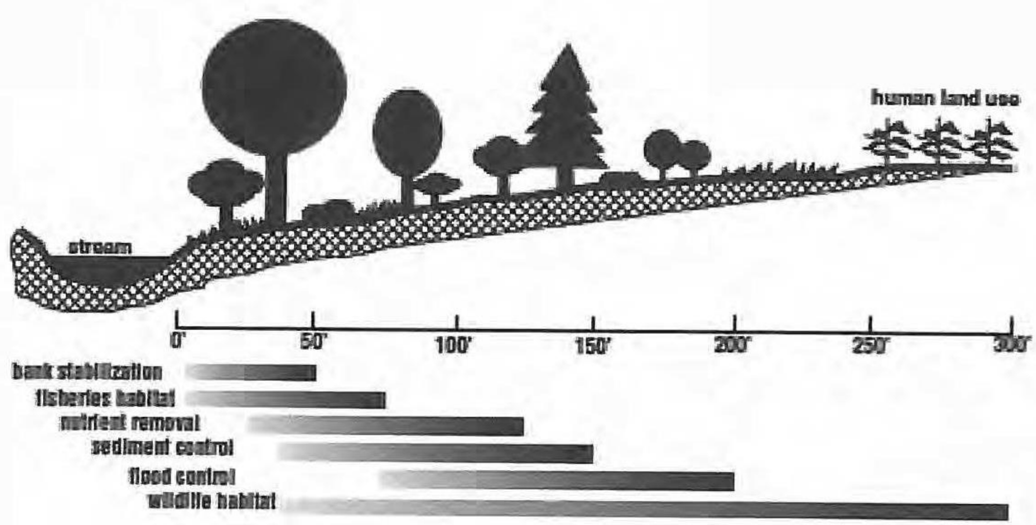

Figure 16 Recommended Buffer Widths

- **Nutrient Overloading**
  Nutrients such as nitrogen and phosphorus are necessary for growth of plants and animals and support a healthy aquatic ecosystem. In excess, however, nutrients can contribute to fish disease, red or brown tide, algae blooms, and low dissolved oxygen. The condition where dissolved oxygen is less than 2 parts per million is referred to as hypoxia. Many species are likely to die below that level-the level of healthy waters is 5 or 6 parts per million. Sources of nutrients include point and non-point sources such as sewage treatment plant discharges, stormwater runoff from lawns and agricultural lands, faulty or leaking septic systems, sediment in runoff, animal wastes, atmospheric deposition originating from power plants or vehicles, and groundwater discharges.

  Excessive nutrients stimulate the growth of algae. As the algae die, they decay and rob the water of oxygen. The algae also prevent sunlight from penetrating the water. Fish and shellfish are deprived of oxygen, and underwater seagrasses are deprived of light and are lost. Animals that depend on seagrasses for food or shelter leave the area or die. In addition, the excessive algae growth may result in brown and red tides which have been linked to fish kills, manatee deaths and negative impacts to scallops. Increased algae may also cause foul smells and decreased aesthetic value.

- **Pathogens**
  Pathogens are disease-causing organisms such as viruses, bacteria, and parasites. They are found in marine waters and can pose a health threat to swimmers, surfers, divers, and seafood consumers. Fish and filter feeding organisms such as shellfish concentrate pathogens in their tissues and may cause illness in persons consuming them. Pathogen contamination can result in the closure of shell fishing areas and bathing beaches. Sources of pathogens include urban and agricultural runoff, boat and marina waste, faulty or leaky septic systems, sewage treatment plant discharges, combined sewer overflows, recreational vehicles or campers, illegal sewer connections, and waste from pets or wildlife.

- **Toxic Chemicals**
  Toxic substances such as metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), heavy metals, and pesticides are a concern in the estuarine environment. These substances enter waterways through stormdrains; industrial discharges and runoff from lawns, streets and farmlands; sewage treatment plants; and from atmospheric deposition. Many toxic contaminants are also found in sediments and are resuspended into the environment by dredging and boating activities. Bottom-dwelling organisms are exposed to these chemicals and may pose a risk to human health if consumed. As a result, there may be fishery and shellfish bed closures, and consumption advisories.

- **Habitat Loss and Degradation**
  The continued health and biodiversity of marine and estuarine systems depends on the maintenance of high-quality habitat. The same areas that often attract human development

also provide essential food, cover, migratory corridors, breeding/nursery areas for a broad array of coastal and marine organisms. In addition, these habitats also perform other important functions such as water quality and flood protection, and water storage. Ecosystems can be degraded through loss of habitat- such as the conversion of a seagrass bed to a dredged material island-or through a change or degradation in structure, function, or composition. Threats to habitat include conversion of open land and forest for commercial development and agriculture, forestry, highway construction, marinas, diking, dredging and filling, damming, and bulkheading. Wetland loss and degradation caused by dredging and filling have limited the amount of habitat available to support healthy populations of wildlife and marine organisms. All of these activities may cause increases in the runoff of sediments, nutrients, and chemicals. Excess nutrients such as nitrogen can lead to algal blooms that deplete oxygen and block sunlight, killing submerged aquatic vegetation.

- **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. ANS include nonindigenous species that may occur within inland, estuarine or marine waters and that presently or potentially threaten ecological processes and natural resources. In addition to the severe and permanent damage to the habitats they invade, ANS also adversely affect individuals by hindering economic development, preventing recreational and commercial activities, decreasing the aesthetic value of nature, and serving as vectors of human disease.

  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. This number is likely as underestimate as it does not consider ecosystem health or the aesthetic value of nature, which can influence tourism and recreational revenue. Estimating the economic impacts associated with **ANS** is further confounded as monetary values cannot be given to extinction of species, loss in biodiversity, and loss of ecosystem services.

- **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. More recently, West Nile Virus was introduced into the United States through an infected bird or mosquito. 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. Further, the effect of ANS on public health extends beyond the immediate effects of disease and parasites as chemicals used to control invasive species can pollute soil and water. Other ANS, such as invasive mussels, may increase human and wildlife exposure to organic pollutants such as PCB's and PAHs as these toxins accumulate in their tissues and are passed up the food chain.

➢ **Alteration of Natural Flow Regimes**
Alteration of the natural flow regimes of tributaries can have significant effects upon the water quality and distribution of living resources in the receiving estuaries. Freshwater is an increasingly limited resource in many areas of the country. Human management of this resource 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.

- **Declines in Fish and Wildlife Populations**
  The distribution and abundance of estuarine fish and wildlife depend on factors such as light, turbidity, nutrient availability, temperature, salinity, and habitat, and food availability. Natural and human-induced events which disturb or change environmental conditions affect the distribution and abundance of estuarine species. Declines in fish and wildlife populations have resulted from fragmentation and loss of habitats and ecosystems; pollution and decreased water quality; overexploitation of resources; and introduced species.

  Habitat loss and degradation can lead to decreases in the stocks of sport and commercial fish and shellfish, changes in the populations of fur-bearing and waterfowl species, and decreased habitat for neotropical migratory birds and other species. Pollutants such as herbicides, pesticides, and other wastes pose a threat to living resources by contaminating the food chain and eliminating food sources. Runoff from farms and cities and toxic releases can alter aquatic habitat, harm animal health, reduce reproductive potential, and render many fish unsuitable for human consumption. Other threats to wildlife include oil spills, bioaccumulation of toxins, outbreaks of contagious and infectious diseases, and algal blooms such as red and brown tides. Overexploitation occurs when fisherman, trappers, hunters, or collectors take so many individuals of a species that their ability to maintain stable population levels is impaired. Introduced species compete with native species for food and habitat. Other causes of decline in fish and wildlife populations include agricultural and logging activities; trawling and bycatch; boat disturbances; entanglement from marine debris; and change in freshwater inflow.

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Key Point 4—Water Protection and Conservation

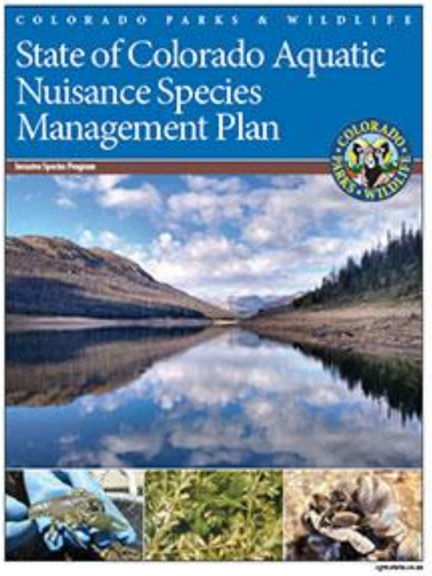
Learning Objectives:

1. Understand how education programs and enforcement agencies are working together to protect aquatic habitats and preventing those who use our waterways from inadvertently transporting Aquatic Nuisance Species ANS from one river to another.
2. Interpret major provincial and /or federal laws and methods used to protect water quality (i.e. surface and ground water). Utilize this information to propose management decisions that would improve the quality of water in a given situation.
3. Be familiar with the Federal, Provincial and state agencies that provide oversight of water resources, and understand that Geographic Information Systems (GIS) is a useful and important tool in the management of water resources.
4. Identify global and local sources of point and non-point source pollution and be able to discuss methods to reduce point and non-point source pollution.
5. Understand the interaction of competing uses of water for water supply, hydropower, navigation, wildlife, recreation, waste assimilation, irrigation, and industry.
6. Know the meaning of water conservation and understand why it is important every time you turn on a faucet.

Suggested Activities:

- List at least 3 Aquatic Nuisance Species ANS, and describe their effects on an aquatic ecosystem. Consider what can happen when predator ANS are imported, and develop a plan for the eradication of a target ANS.
- Site water protection laws at a mock hearing to decide whether a permit should be given to build a new shopping mall along a river.
- Explain how Geographic Information Systems (GIS) are being used to help communities assess water quality and watershed health information.
- Compare water usage in different regions of Canada and the United States and propose actions to help countries strike a balance between supply and demand in order to realize maximum benefit from our water resources.
- Design a comprehensive water conservation plan for your home and the watershed below your home. This should include groundwater replenishment, securing sediment on your property, managing non-point source pollution and following the path of good quality water as it leaves your property on its way to the sea.
- Many dams are used to provide low-cost electricity at the critical time of day when there is peak demand for electricity. Today a major issue is deciding which is more important to the economy, low cost energy or improving/restoring the ecology of a river. Evaluate the issue and develop recommendations for conservation groups and utility executives.

State of Colorado Aquatic Nuisance Species Management Plan



In Dec. 2020, the national Aquatic Nuisance Species Task Force approved the State of Colorado Aquatic Nuisance Species (ANS) Management Plan to protect Colorado waterways from invasive species.

Laws to Protect Water Quality

Numerous federal, state, and local laws facilitate protection of water quality. Major legislation is identified below

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 focus of the act from its inception has been on point source pollution from industrial and municipal discharges. 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 t he 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.

What is a TMDL? 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). Low-level ozone (03) and carbon monoxide (CO) are among the pollutants of particular concern to urban areas. *03* occurs as a photochemical reaction of water vapor, sunlight, and pollutants, principally volatile organic compounds (VOC) and oxides of nitrogen (NOX). More than 60 urban areas, including most of the nation's largest cities (and Atlanta), are not in attainment for CO or 03 standards.

• **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 their 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 conta ins 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 Ill, 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** (SOWA)
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. (SOWA does not regulate private wells which serve fewer than 25 individuals.) SOWA 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. US EPA, states, and water systems then work together to make sure that these standards are met.

Colorado State Law
Link to a Citizens Guide to Colorado Water Law
https://r.search.yahoo.com/_ylt=AwrNOd3bPqxmYAQA5q9XNyoA;_ylu=Y29sbwNiZjEEcG9zAzEEdnRpZAMEc2VjA3Ny/RV=2/RE=1723773916/RO=10/RU=https%3a%2f%2fwww.courts.state.co.us%2fuserfiles%2fFile%2fMedia%2fLaw_School%2fcfweCitizenGuideColoradoWaterLaw2Edition.pdf/RK=2/RS=CSLgFC8WaNSYZ5KMS_AgFiA8d9g-

GIS and Hydrology
GIS (Geographic Information Systems) is a powerful tool for developing solutions for water resources such as assessing water quality and managing water resources on a local or regional scale.

GIS improves calculations for watershed characteristics, flow statistics, debris flow probability, and facilitates the watershed delineation by using Digital Elevation Models (DEMs), a 3-D representation of a terrain's surface. It provides a consistent method for watershed analysis using DEMs and standardized datasets such as land cover, soil properties, gauging station locations, and climate variables.

GIS also provides the flexibility to combine watershed datasets from one map source with stream and river networks; hydrologic analysis such as calculating flow across an elevation surface, which provides the basis for creating stream networks and watersheds; calculating flow path length; assigning stream orders; and seamlessly integrating geological and temporal data from multiple sources, including field data collection.

Water quality involves careful management of both groundwater (recharge areas) and surface water (watersheds, aqu ifers). Because one sustains the other, cross-contamination is a key concern. GIS can be used to calculate loads to a surface water body or to monitor water quality changes within a water body such as a river or bay. A load is the product of flow and concentration, and it refers to how much mass of a chemical enters a system in a specified amount of time. Loads to a water body can result from point sources such as industrial discharges or nonpoint sources such as agricultural runoff. Once the loads to a water body are known, water quality models can be used to determine concentration changes within the water body.

Procedures that utilize a GIS have been developed for both types of load calculations and for water quality models.

GIS can also be used to help identify and map critical areas of land use and reveal trends that affect water quality, monitor water levels, water usage, and watch for trends to avoid overdraft and drawdown.

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. Factories, including oil refineries, pulp and paper mills, and chemical, electronics and automobile manufacturers, typically discharge one or more pollutants in their discharged waters (called effluents). Some factories discharge their effluents directly into a waterbody. Others treat it themselves before it is released, and still others send their wastes to sewage treatment plants for treatment. Sewage treatment plants treat human wastes and send the treated effluent to a stream or river.

Another way that some factories and sewage treatment plants handle waste material is by mixing it with 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 t reated. This combined sewer overflow (CSO) is considered point source pollution, and can cause severe damage to human health and the environment.

Unregulated discharges from point sources can result in water pollution and unsafe drinking water, and can restrict activities like fishing and swimming. Some of the chemicals discharged by point sources are harmless, but others are toxic to people and wildlife. 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 t hey 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.

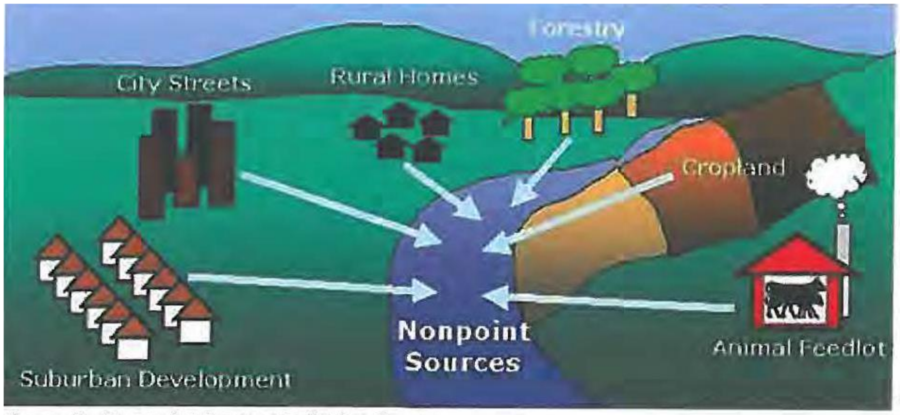


Figure 6. Nonpoint Source Pollution Sources

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. If necessary, a second, more stringent set of controls can be placed on a point source to protect a specific waterbody.

- **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.

Non point source pollution not only affects ecosystems; it can also have harmful effects on the economy. U.S. Coastal and marine waters support 28.3 million jobs, generate $54 billion in goods and services through activities like shipping, boating, and tourism, and contribute $30 billion to the U.S. economy through recreational fishing alone. If pollution leads to mass die-offs of fish and dirty-looking water, this area and others like it will experience deep financial losses.

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. 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 non point source pollution impacts the overall quality of life, and subsequently can drive property values down. If nonpoint source pollution continues to plague the waters surrounding coastal communities, their economies and social conditions may rapidly deteriorate.

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 non point sources may be higher because the pollutants come from many places. Non point 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 non point 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.

    Other environments in urban and suburban areas also add to nonpoint source pollution. 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. This reminds residents that their very own non point wastes, no matter how small, eventually contribute to polluting the rivers and streams.

- **Agricultural Operations**
  Agricultural operations account for a large percentage of nonpoint source pollution. In 2002, approximately 940 million acres of farmland existed in the United States. While the vast breadth of this land provides space for farming - an industry that provides the backbone of the U.S. economy, not to mention much of the food we eat-- it also creates numerous opportunities for 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). Although the pollutants may have originated from a point source of air pollution.

  Acid rain has also become a major concern in some areas of the United States. Acid rain 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. In addition, increased levels of aluminum cause fish to become chronically stressed. While chronic stress may not kill individual fish, it leads to lower body weight
  and smaller size, making the fish less able to compete for food and habitat.

  Acid rain also damages forests. For example, acid rain can damage the surfaces of leaves and needles, reduce a tree's ability to withstand cold, and inhibit plant germination and 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" -temporary paths used to transport logs out of the forest- can contribute to non point source pollution. Skid trails that are constructed against the natural contour of a hillside are especially prone to erosion.

  Active mining operations are considered point sources of pollution. But drainage or runoff from abandoned mining operations often adds to nonpoint source pollution. In strip mining, for example, the top layers of soil and vegetation are removed to reveal the desired ore. If an area where strip mining occurred has not been properly reclaimed after mining activities have ended (soil replaced and graded, vegetation replanted), erosion can occur. In addition, the mixing of air, water and sulfur-containing rocks can cause chemical reactions that lead to the formation of sulfuric acid and iron hydroxide. This acidic runoff dissolves heavy metals such as copper, lead and mercury. These metals, in turn, contaminate streams and other water bodies.

  Abandoned subsurface mines can also contribute significantly to nonpoint source pollution. The water that seeps out of them can become very acidic.

- **Marinas and Boating Activities**

  Boating can also contribute to nonpoint source pollution. Chemicals used on boats may spill into the water; spilled fuel can also contaminate waters around marinas. Marinas and boating activities can also contribute to nonpoint source pollution. 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. Spilling fuel (gasoline or oil) at marinas or discharging uncombusted fuels from engines also contribute to nonpoint source pollution. 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 water body, they can seriously affect the environment and the organisms living there as well as human health.

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 (pronounced you-tro-fi-kay-shun). Eutrophication results in an overproduction of organic matter, particularly the microscopic plants called algae.

You may have seen green masses of algae growing on a pond or lake. 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). Harmful algae are often small, single-celled organisms that live in aquatic environments. 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 often originate from agricultural activities. Excess nutrients applied to crops in the form of fertilizers are washed away in runoff, typically during rainstorms. Nutrients also originate from urban and suburban areas, from sources such as lawn fertilizers, and even pet wastes.

Nitrogen and phosphorus also come from atmospheric inputs. Scientists believe that the combustion of fossil fuels like oil and coal by power plants, large industries, and automobiles is a major source of nutrients in the atmosphere. Controlling nutrient inputs is proving to be very difficult because the nutrients frequently originate from multiple sources that are challenging to
identify and control.

- **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 provides a habitat for aquatic organisms, produces oxygen, and traps sediment. If **hypoxic conditions** occur - a state where the level of oxygen in the water is very low - the aquatic organisms living there must either move or die. Often, suspended sediments and excessive nutrients are both present, creating a harmful combination of **eutrophic conditions** - when there is an overproduction of organic matter - and cloudy water. 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 t issues 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 in cities, are often washed off streets, down storm drains, and into waterbodies. Combustion of fuels in automobiles and factories introduces hydrocarbons and metals into the environment. They eventually end up in the water through atmospheric deposition or runoff. Industrial facilities without the proper means to control runoff can also contribute toxic chemicals to the aquatic environment. The type of chemical that is released depends on the type of manufacturing done at a facility. Other chemicals, such as solvents, paints, cleaning solutions and others, originate from marinas and boating activities.

- **Bacteria, Viruses and Trash**

  Bacteria and viruses are naturally present in the environment. Some pathogenic (disease-causing) microbes are associated with human or animal activities. 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. Urban areas can also be a source of pathogenic bacteria and viruses. Asan example, outbreaks of cholera in urban areas have been blamed on inadequate sanitation.

  Discarded trash can become a component of nonpoint source pollution runoff. Plastics, metals and other types of t rash often harm animals and plants. Plastics and metals degrade very slowly over time and can leach harmful chemicals into the environment. These materials can also contribute to the transmission of disease. In addition, trash simply degrades the beauty of an area.

- **Research, Monitoring and Assessment**
  - **Research**

    Computer modeling is one technique used to better understand how non point source pollution affects waterbodies. A model, or simulation, is a computer program that allows scientists to predict how an environmental "system" like a river, lake, or coastal waterbody may change as a result of varying physical or chemical conditions. Models can also predict the progression and severity of such conditions. With this knowledge, scientists can develop techniques to prevent harmful environmental conditions before they occur.

    To develop models, scientists may concentrate on variables that are the most obvious indicators of nonpoint source pollution and potential eutrophication and then forecast the potential effects of eutrophication, as well as where it might occur.

  - **Monitoring**

    Research and the use of models provides important information that can be used to develop long-term monitoring programs. The data gathered from these monitoring efforts is then used to improve the accuracy of the original models.

  - **Assessments**

    Research using computer models combined with long-term monitoring allows assessment of conditions, determining the relationships between nonpoint source pollution and its impacts, and recommending standards and strategies to control pollution. Assessments are used to help plan control strategies.

- **Controlling Nonpoint Source Pollution**

  While research, monitoring, and assessment look at the larger environmental effects of nonpoint source pollution, taking measures to stop pollution before it begins is also essential for controlling the problem. This is especially true in coastal communities, where the majority of people live. With continued coastal population growth, the chances for more nonpoint source pollutants entering waterbodies via runoff increases.

  Even though the exact locations of nonpoint source pollution cannot be identified, it is known that certain environments and operations produce a high volume of pollution. Experts have developed systems to reduce and even eliminate pollution from these places. Listed below are some 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. In some cases, there is also a stone reservoir underneath the pavement to allow filtration of the water before it reaches the groundwater.
  ► **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. Common predators include ladybugs, praying mantises, and spiders, which feed on aphids, mites, and caterpillars. These natural predators help control infestations on valuable crops such as corn, soybeans, and tomatoes.

- **Forestry Operations**
  ► The location and design of roads and skid trails (temporary pathways used to shuttle logs out of the forest) 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.
► Many chemicals commonly used around the home are toxic. 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 and less yard waste goes 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. Also, 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-gaffon 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 dog your drainfiefd and necessitate more 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. If you have a septic system, by decreasing your water usage, you can help prevent your system from overloading and contaminating ground water and surface 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. Over-watering 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. (Such devices reduce runoff and are 20 percent more effective than sprinklers.)
► Pick up dog waste and dispose of it properly.

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 your existing equipment well maintained is probably the easiest and cheapest way to start saving 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 fess, 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. Together, those changes nearly cut in half the household's daily use, saving a considerable amount of water - and passing that savings on to your water bill, as well as your water heating bill."

- **Cultivate good water habits**
  All the water that goes down the drain, dean 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. If your water at home tastes funny, try an activated charcoal or ceramic filter.

- **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.

- **At the car wash**
  Car washes are often more efficient than home washing and treat their water rather than letting it straight into the sewer system. But check to make sure that they clean and recycle the water. Better yet, try the waterless car wash.

- **Keep your eyes open**
  Report broken pipes, open hydrants, and excessive waste.

- **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.

- **What are the Competing Uses of Water?**

Water is one of the most vital natural resources for all life on Earth. The availability and quality of water always have played an important part in determining not only where people can live, but also their quality of life. Even though there always has been plenty of fresh water on Earth, water has not always been available when and where it is needed, nor is it always of suitable quality for all uses. Water must be considered as a finite resource that has limits and boundaries to its availability and suitability for use.

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. These data, combined with other USGS information, have facilitated a unique understanding of the effects of human activity on the Nation's water resources. 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. Changes in technology, in State and Federal laws, and in economic factors, along with increased awareness of the need for water conservation, have resulted in more efficient use of the water from the Nation's rivers, lakes, reservoirs, and aquifers.

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/Lor more of dissolved solids; it is usually undesirable for drinking and for many industrial uses.

- **Thermoelectric Water Use**
  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. About 52 percent of fresh surface-water withdrawals and about 96 percent of saline-water withdrawals are for thermoelectric-power use.

- **Hydroelectric Water Use**
  Hydroelectric plants are the most widely used form of renewable energy. Hydroelectric plants capture the kinetic energy of falling water to make electricity. They do this with a dam. The dam forces the water level to go up so that the water will have more power when falling. The force of the falling water pressing against the turbines' blades cause them to spin. The spinning turbines transmit the kinetic energy of the falling water to generators. The generators spin when the turbines spin generating electricity that will be transmitted on the power lines to homes and businesses. World-wide, about 20% of electricity is generated by hydropower. In the U.S., about 10% of all the generated electricity is provided by hydropower.

- **Irrigation Water Use**
  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. However, the percentage of total irrigation withdrawals from ground water has continued to increase, from 23% in 1950 to 42% in 2000. Irrigated acreage more than doubled between 1950 and 1980, then remained constant before increasing nearly 7% between 1995 and 2000. The number of acres irrigated with sprinkler and micro irrigation systems has continued to increase and now comprises more than one-half the total irrigated acreage.

- **Public Supply Water Use**
  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 11% of water use in the US.

- **Industrial Water Use**
  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.

- **Recreation Water Use**
  Recreational water use is usually a very small but growing percentage of total water use. Recreational water use is mostly tied to reservoirs. If a reservoir is kept fuller than it would otherwise be for recreation, then the water retained could be categorized as recreational usage. Release of water from a few reservoirs is also timed to enhance white water boating, which also could be considered a recreational usage. Other examples are anglers, water skiers, nature enthusiasts and swimmers.

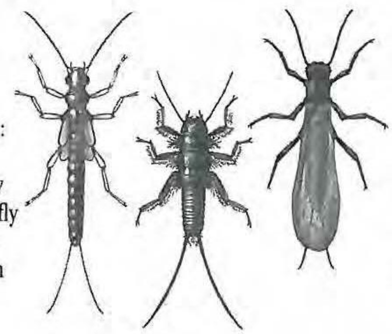
- **Other Water Use**
  Combined withdrawals for self-supplied domestic, livestock, aquaculture, and mining activities represented about 3% total water withdrawals. Self-supplied domestic withdrawals include water used for household purposes which is not obtained from public supply. About 43 million people in the United States self-supply their domestic water needs, usually from wells. Livestock water use includes watering, feedlots, and other on-farm needs for animals such as cattle, sheep, pigs, horses, and poultry. Aquaculture use is water used for fish hatcheries, fish farms, and shellfish farms. Mining water use encompasses water used for the extraction of minerals, including solids such as coal and ores, liquids such as crude petroleum, and gases such as natural gas. Also included is water used for processes done as part of the mining activity. Nearly all of saline ground-water withdrawals are for mining.

INSECTS

Stoneflies

Order: Plecoptera
Size: ½" to 1½"
Tolerance: Sensitive
Distinguishing Characteristics:

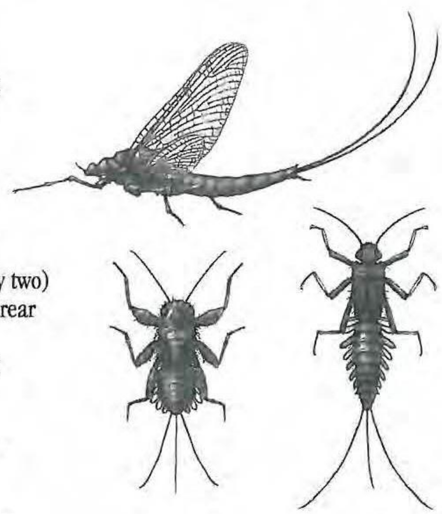
- Two hair-like tails
- No gills on rear half of body
- Structurally similar to mayfly nymphs, but have two tails instead of the usual three in mayflies
- 2 claws on each foot



Mayflies

Order: Ephemeroptera
Size: ¼" to 1"
Tolerance: Sensitive
Distinguishing Characteristics:

- Usually three long, hair-like tails (but sometimes only two)
- Gills present on the rear half of body
- 1 hook on each foot



Water Pennies

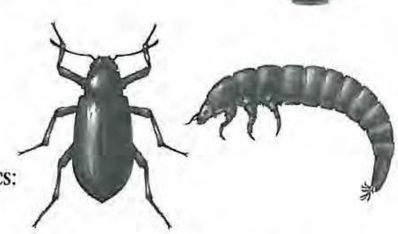
Order: Coleoptera
Size: up to ½"
Tolerance: Very sensitive
Distinguishing Characteristics:

- Looks like a flat, oval disc
- Plates extend from all sides
- Cannot survive on rocks covered with excessive algae or inorganic sediment

Riffle Beetles

Order: Coleoptera
Size: 1/16" to 1/8"
Tolerance: Sensitive
Distinguishing Characteristics:

- Very small
- Dark colored
- Adult riffle beetles will be found walking on the bottom of the stream



Aquatic Snipe Flies

Order: Diptera
Size: ¼" to 1"
Tolerance: Sensitive
Distinguishing Characteristics:

- Body is pale brown to green color
- Mostly cylindrical, with the front tapering to a cone-shaped point
- Larva have a number of mostly paired caterpillar-like prolegs
- Two stout, pointed tails with feathery hairs at back end

Caddisflies

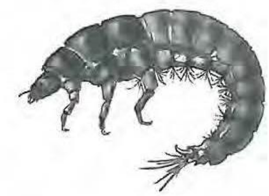
Order: Trichoptera
Size: ½" to 1 ½"
Tolerance: Sensitive
Distinguishing Characteristics:

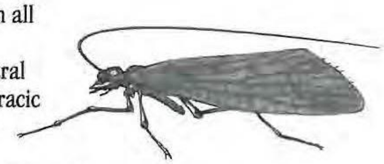
- Larva is caterpillar-like with three pairs of legs and tends to curl up slightly
- Two claws at posterior (rear) end
- May be found in a stick, rock, or leaf case with its head sticking out

Common Net Spinning Caddisflies

Order: Trichoptera
Family: Hydropsychidae
Size: up to 1"
Tolerance: Somewhat sensitive
Distinguishing Characteristics:

- Body is caterpillar-like with three pairs of legs and is strongly curved
- Dorsal plates (sclerites) on all three thoracic segments
- Branched gills on the ventral surface of the last two thoracic segments and most of the abdominal segments
- Usually have a bristle-like, setal tuft at the end of each anal proleg
- Color varies from bright green to dark brown

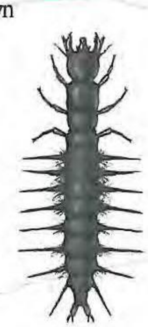




Dobsonflies/Hellgrammites and Fishflies

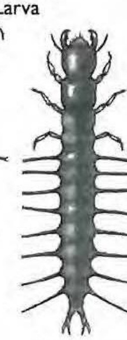
Order: Megaloptera
Size: ¾" to 4"
Tolerance: Somewhat sensitive
Distinguishing Characteristics:

- Stout body with large pinching jaws
- Eight pairs of pointed lateral appendages
- On the rear end of the body a pair of stubby, unjointed legs (prolegs), each with a pair of claws
- Dobsonflies/Hellgrammites have paired cotton-like gill tufts, fishflies lack these
- Fishflies have two short tube-like structures on the tail end



Dobsonfly Larva

Fishfly Adult



Fishfly Larva

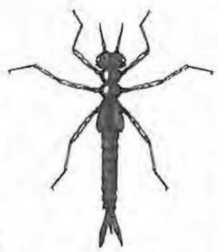
Damselflies and Dragonflies

Order: Odonata
Size: ½" to 2"
Tolerance: Somewhat sensitive
Distinguishing Characteristics:

- Both have large eyes, six legs, and a large lower lip that covers much of the bottom of the head
- Damselflies are slender and have three oar shaped tails (gills)
- Dragonflies have a stocky body without tails


Dragonfly Adult

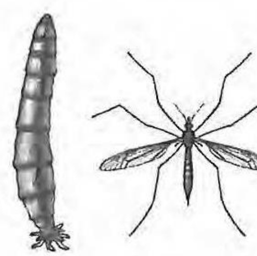

Dragonfly Larva


Damselfly

Crane Flies

Order: Diptera
Size: ⅓" to 2 ½"
Tolerance: Somewhat sensitive
Distinguishing Characteristics:

- Worm-like plump body
- Can be found in a variety of colors (clear, white, brown, and green)
- Segmented body with finger-like projections (gills) at the back end
- Head is usually pulled back into the front of the body



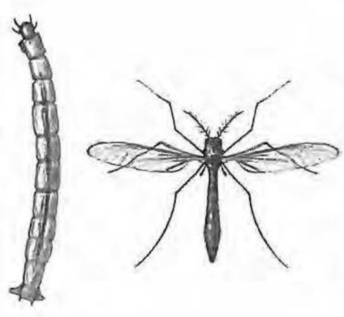
Midge Flies

Order: Diptera
Size: up to ¼"
Tolerance: Tolerant

- They can indicate poor stream health caused by pollution if found in large numbers

Distinguishing Characteristics:

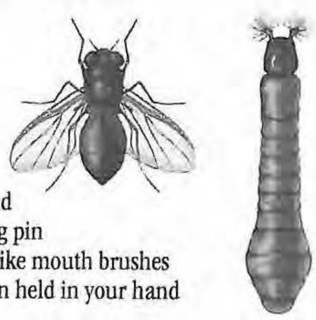
- Often whitish to clear, but occasionally bright red
- Segmented body
- Has distinct head with two small prolegs in the front of the body
- Display a spastic squirming action in the water



Black Flies

Order: Diptera
Size: up to ¼"
Tolerance: Tolerant
Distinguishing Characteristics:

- The body is larger at the rear end similar to the shape of a bowling pin
- The distinct head contains fan-like mouth brushes
- Often curl into a "u" shape when held in your hand



CRUSTACEANS

Crayfish

Order: Decapoda
Size: up to 5"
Tolerance: Somewhat sensitive

- Can withstand large ranges of pH and temperatures and is sensitive to toxic substances

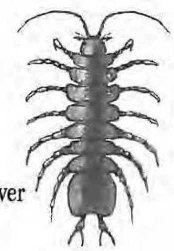
Distinguishing Characteristics:

- Resembles a lobster
- Has 10 legs and the two front legs have large claws or pinchers

Aquatic Sow Bugs

Order: Isopoda
Size: ¼"- ¾"
Tolerance: Somewhat sensitive
Distinguishing Characteristics:

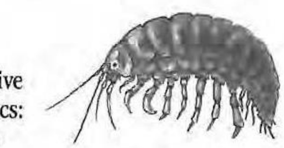
- Flat, segmented body
- Has an "armored" appearance
- Seven pairs of legs
- Can be confused with scuds, however they are flattened top to bottom



Scuds

Order: Amphipoda
Size: ⅛" to ¼"
Tolerance: Somewhat sensitive
Distinguishing Characteristics:

- Resemble a small shrimp
- Translucent body with silvery-gray or tan coloration
- Seven pairs of legs
- Unlike sow bugs, scuds are flattened side to side

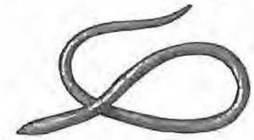


WORMS

Aquatic Worms

Class: Oligochaeta
Size: Usually 1" but up to 4"
Tolerance: Tolerant
Distinguishing Characteristics:

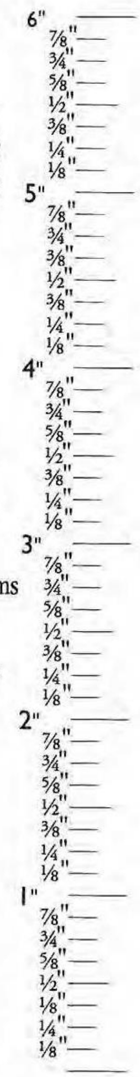
- Can be very tiny and slender or look similar to earthworms
- No legs, distinct head or any mouthparts
- Segmented body
- Aquatic worms can indicate organic pollution when they dominate the majority of the sample collection



Leeches

Class: Hirudinea
Size: ¼" to 2"
Tolerance: Tolerant
Distinguishing Characteristics:

- Somewhat slimy, soft, segmented body
- Two suckers on the underside of the body, one in the front and one in the rear
- Can be confused with a flatworm, however flatworms have no suckers and leeches have fine lines (annuli) across the body



MOLLUSKS

Gilled Snails

Class: Gastropoda
Size: ¼"-1"
Tolerance: Sensitive

- Gill breathing; therefore, they are more sensitive to low dissolved oxygen than lunged snails

Distinguishing Characteristics:

- Usually opens to the right when the narrow end is pointing upward
- Shell opening covered by a thick plate (operculum)
- When monitoring, do not count empty shells

Lunged Snails

Class: Gastropoda
Size: up to 2"
Tolerance: Tolerant

- They can tolerate severe organic or nutrient pollution that consumes oxygen in the water

Distinguishing Characteristics:

- Usually opens to the left when the narrow end is pointing upward
- Have no operculum and breathe oxygen from the air
- When monitoring, do not count empty shells

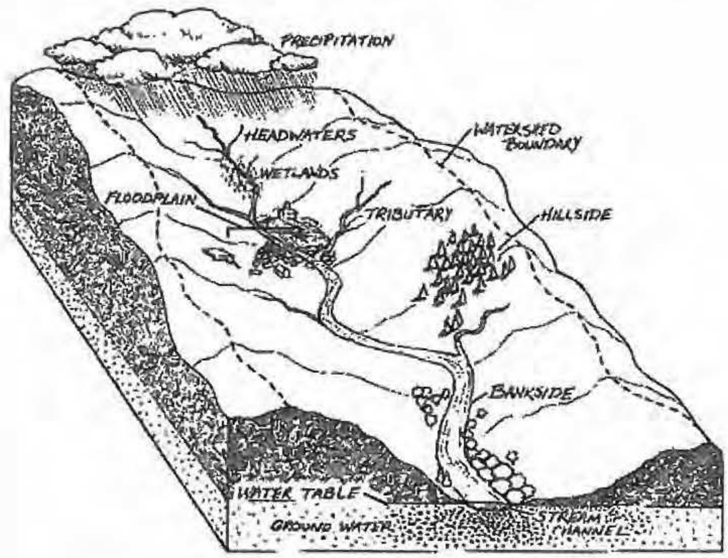
Clams and Mussels

Class: Bivalvia
Size: up to 5"
Tolerance: Somewhat sensitive

Distinguishing Characteristics:

- Fleshy body enclosed between two clamped shells
- If alive, the shells cannot be pried apart
- When monitoring, do not count empty shells

Watershed Delineation



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.

We describe basic topographic map concepts and symbols below, but more information can be found at the U. S. Geological Survey's website on Topographic Map Symbols:

- http://erg.usgs.gov/isb/pubs/booklets/symbols/index.html — or
- http://erg.usgs.gov/isb/pubs/booklets/symbols/topomapsymbols.pdf

Here's how you can delineate a watershed:

STEP 1:

Use a topographic map(s) to locate the river, lake, stream, wetland, or other waterbodies of interest. *(See the example, West Branch of Big River, in* ***Figure D-1.)***

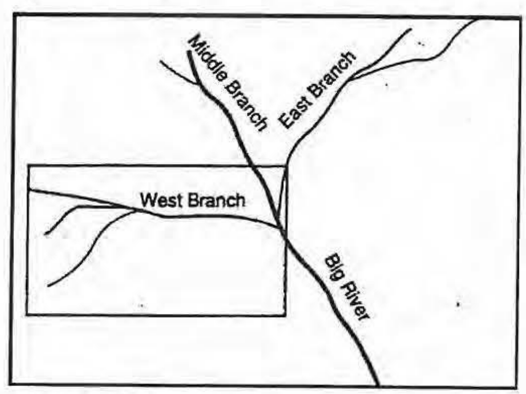


Figure D-1: West Branch of Big River

STEP 2:

Trace the watercourse from its source to its mouth, including the tributaries *(Figure D-2)*. This step determines the general beginning and ending boundaries.

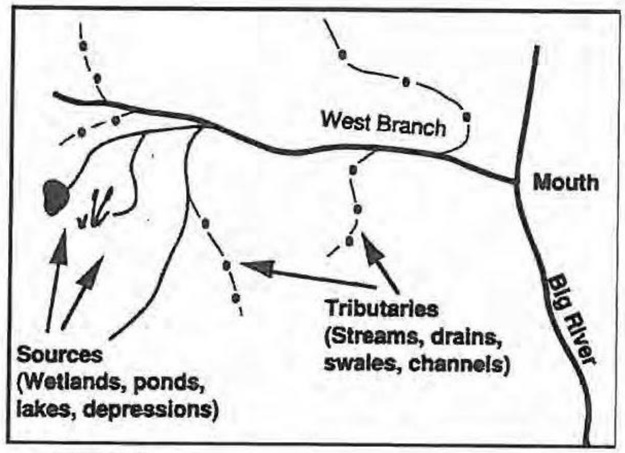


Figure D-2: West Branch subwatershed

STEP 3:

Examine the **brown lines** on the topographic map that are near the watercourse. These are referred to as contour lines. **Contour lines connect all points of equal elevation above or below a known reference elevation.**

- 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.

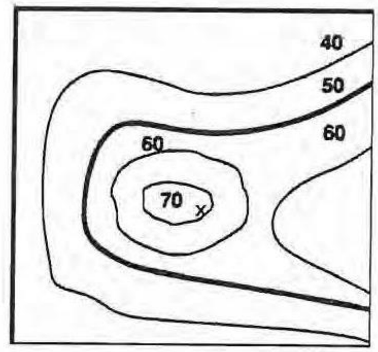


Figure D-3: Contour lines and an example point (X) at an elevation of 70 feet above sea level.

STEP 4:

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

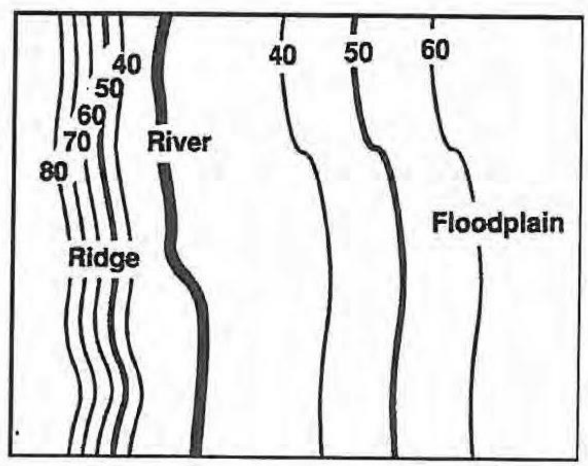


Figure D-4: Floodplains and ridges

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-6)*.

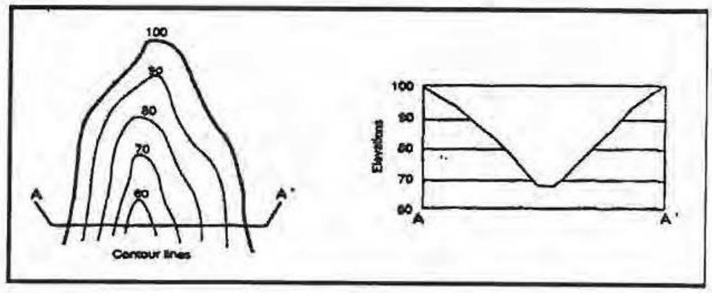


Figure D-5: Valley

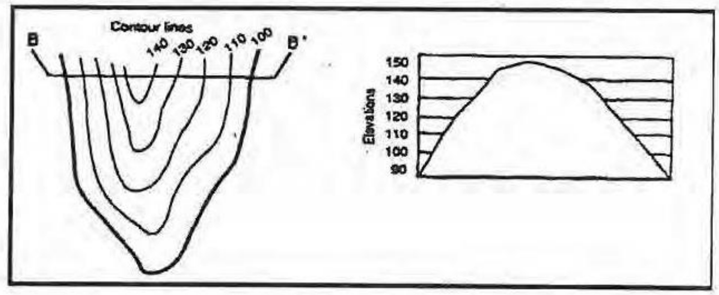


Figure D-6: Ridge

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 downslope. The "path" is the shortest distance between contours, hence a perpendicular route *(Figure D-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**).

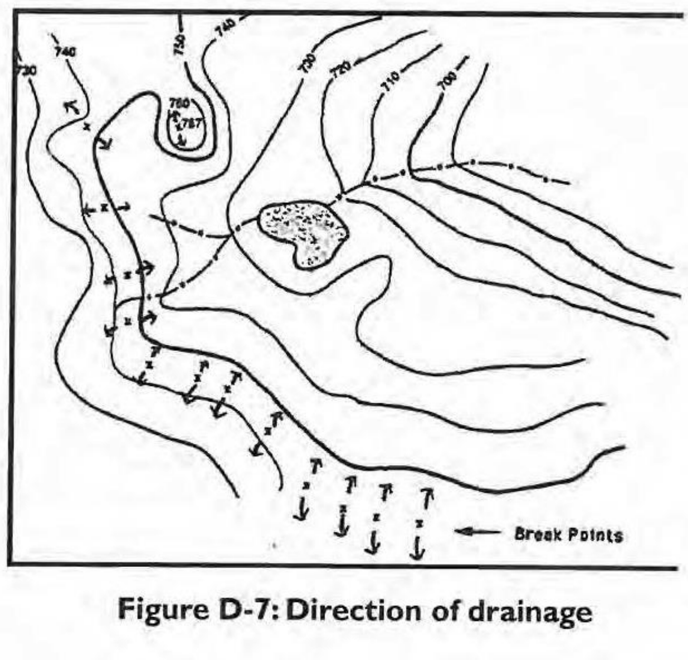


Figure D-7: Direction of drainage

STEP 8: IDENTIFY BREAK POINTS

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)*.

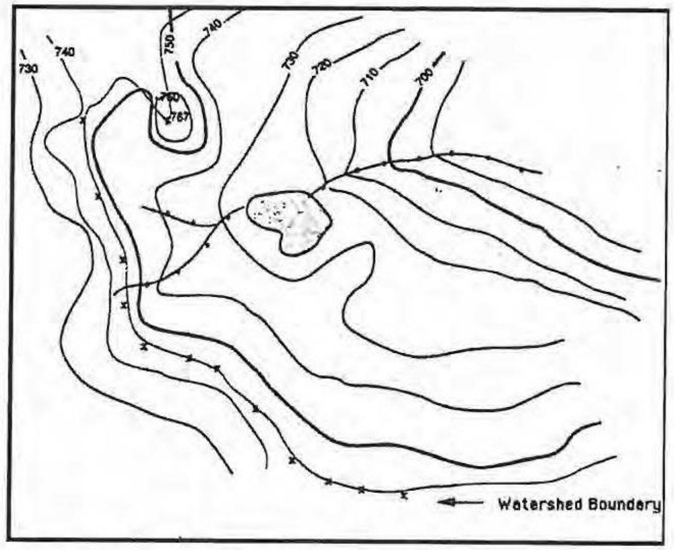


Figure D-8: Watershed Boundary

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:

Distribute copies of your watershed map to your group.

STEP 11:

Watersheds sometimes have what are termed 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 waterbody you are examining, the more subwatersheds you will find. Your watershed map can be further divided into smaller sections or subwatersheds if it helps organize your study better.

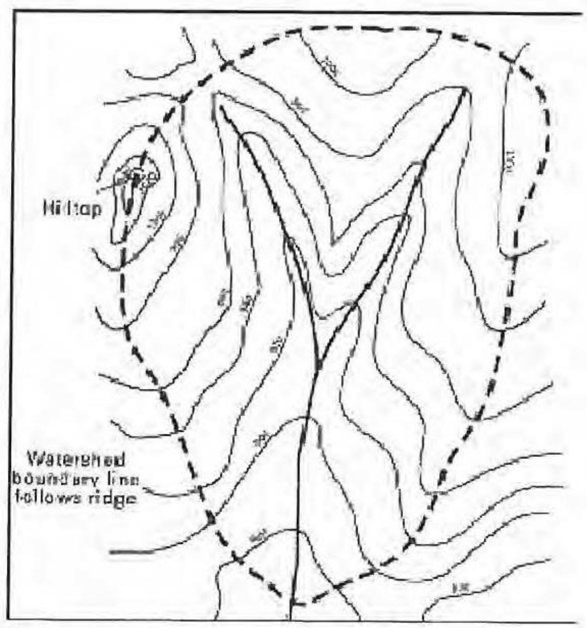


Figure D-9: Idealized Watershed Boundary

(Adapted from Ammann, Allen, and Amanda Lindley Stone, Method for the Comparative Evaluation of Nontidal Wetlands in New Hampshire. 1991, from New Hampshire Department of Environmental Services.)

STEP 12:

Once the watershed and subwatershed (optional) boundaries have been delineated on the map, your team can verify them in the field, if necessary.