Lesson 10:
Water Resources and Pollution

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Penn State Biology - BISC 003: Environmental Science
• Review the importance of water to humans and other living creatures.
• Understand how water is used by human society and where water resources come from.
• Examine the major types of water pollution and how they impact both human and ecosystem health.
• Explore how we can continue the progress started in the 1960s towards conserving this precious resource both domestically and on an international level.

As pointed out earlier, water is absolutely essential for life—without water, no life could exist as we know it. Despite the universal need of living organisms for water, the stanza from The Ancient Mariner is true:

Water, Water, everywhere,
And all the boards did shrink;
Water, Water, everywhere,
Nor any a drop to drink.

The Rhyme of the Ancient Mariner By Samuel Taylor Coleridge

The ancient mariner would have done better to look to the fishes for water than the ocean. The spinal fluid of most fish is lower in salt concentration than the waters of the ocean. But trivia aside, water shortages are often cited as the next big environmental crisis. Though often neglected, the possibility of world water shortages is high and the potential for unrest and war as a result of these shortages is real. When we consider resource depletion, water is often forgotten.

So, exactly how many are the "drops" of water that are fit to drink? Even though the earth's surface is mostly water, the amount of fresh water that is available to life is shockingly small. Of all the water on earth, less than 3% of it is fresh water. Of that fresh water, less than 15% is liquid; most of the fresh water on earth is tied up in frozen ice and snow. Of the liquid fresh water, most of it (95%) is tied up in
ground water. So of all the fresh water on earth, less than 0.001% is readily available to humans and other terrestrial life.

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• Less than 3% of all water is fresh water
• Less than 15% of fresh water is in liquid form
• 95% of liquid fresh water is ground water
• Less than 0.001% of all water is readily available to humans and other terrestrial life.

And that fresh water is constantly cycled. Plants play a pivotal role in the cycling of water. Transpiration, which is the evaporation of water from plant surfaces, drive the daily tropical rains that set the world’s rainfall patterns across the globe. Water that moves into plant roots is, in most cases, surface ground water. Water enters the soil via infiltration and slowly percolates through the soil. Plant roots are found mostly in the top layers above the water table. Deeper ground water sources include aquifers, which are essentially layers of rocks, gravel or sand saturated with water well below the water table.

If you need a review of the water cycle, check out the video included in the video library: [http://www.dnatube.com/video/7385/Earth-Science-Week-Water-Water-Everywhere](http://www.dnatube.com/video/7385/Earth-Science-Week-Water-Water-Everywhere)
Some aquifers like those found in central Pennsylvania are recharged on a yearly basis, whereas others such as those under grasslands and desert regions represent the water equivalent of fossil fuels. In these areas, aquifers recharge very slowly and should be viewed as non-renewable resources. As can be seen in this map, the water level in some aquifers in the US South west have dropped more than 60 meters since humans started pumping water from these aquifers, essentially depleting these fossilized water supplies.
We, along with all other living organisms, need water to survive. We use water to meet domestic needs though the bulk of fresh water used by humans is for agriculture. On average, approximately 70% is used for agriculture worldwide. The majority of this water is use for irrigation of crops. Industrial uses of water take about 22-25% and domestic use 5-8% worldwide. Actual percentages for individual regions may vary significantly from this.

Conservation of water, like that of energy, does not need to be a hardship. Though domestic water use is only a small percentage of total water use, consider how the use of this water could be made more efficient. Two major sources of wasted water in private homes are lawns and toilets. Being OK with a less than percent lawn is a good place to start. Letting go of the lawn altogether and practicing xeriscaping, which is the planting of drought resistant plants in areas that are drought prone, is yet another step in the right direction.

Water saving plumbing devises has come a long way. The low flow toilets of today have been redesigned to efficiently flush with only 1.6 liter of water. A front-loading washing machine not only uses a fraction of the water of a top loader, it cannot become unbalanced and gets your clothes just as clean. For more water saving tips, review the “What can you do?” section in your textbook and share what you do (and don’t do) to conserve water in the discussion forum.
Supplying water for human needs relates to both quantity and quality of water. In the past, human society has relied on large-scale water projects to meet our needs. Dams and reservoirs, wells and aquifers, and even canals have all been used to satisfy human needs for water. Though the days of large dam building in the developed world are probably over, large-scale projects in the developing world progress, most notably the Three Gorges Dam and other larger dam projects in China. Dams are constructed to provide flood control, to produce hydroelectric power, and to provide a reservoir for drinking and agricultural water. All three are reasons for the building of the Three Gorges Dam. In the case of this dam, many argue that the alleged benefits are exaggerated and the dam itself is a prelude to disaster. Take a look at “What do you think? China’s south to north water diversion” in the text book. The other large-scale water projects, from withdrawal of ground water to canals and redistribution of water from water rich areas to water poor areas, are associated with their own set of problems.
Large Scale Water Projects

- Wells
- Canals and pipelines
- Dams and reservoirs
  - Flood control, hydroelectric power, reservoirs for drinking and agriculture
- Issues: ecosystem disturbances, water loss

Now pause to consider your own transportation impact and let’s take a look at how that compare to your classmates’ traveling.

What is the fuel efficiency of your primary vehicle? Approximately how many miles do you drive per week? And what is your primarily mode of transportation?

To complete the Cars Poll go to the ANGEL site, click on the Communicate Tab, Polls and the Cars Poll.

You can do this now and then come back to the lecture, or you can complete the poll when you have finished the lecture.

You will get two extra credit points for participating in this poll.

*Slide 9*
Other than ground water, the surface waters of the world are important sources of water for humans. Within the United States, we are blessed with an extensive network of fresh water. From the Great Lakes, the largest fresh water reservoirs on earth, to the extensive river ways, we are surrounded by an abundance of surface waters. Let’s briefly review the various fresh water and marine ecosystems.

Halfway between surface water and ground water are wetlands. Though once viewed as "useless" swamps, wetlands are now recognized as integral parts of a functioning ecosystem. Not only are they vital stop-over points for migratory birds, the ecological services provided by wetlands are truly astounding. Marshes, bogs, and swamps help filter and purify water as well as hold back water for natural flood control.

Another "halfway" ecosystem can be found at the mouths of rivers that empty into the oceans. The estuaries and bay lands of the world are among the most productive regions on earth. They serve as hatcheries for important game fish and shellfish. Ocean ecosystem range from the very productive coral reefs to the open oceans, the last great frontier on earth.

Surface waters may be stationary, like ponds, lakes, or reservoirs. These bodies of water are distinguished by their size and origins. A pond is small and shallow, shallow enough for rooted plants. Stagnation comes to mind, as a pond is too small to support significant wave action. Ponds are not stratified by temperature or other traits. Over time, the pond is doomed. Plants carried in by birds can
sprout, develop, and die. The plant debris accumulates and will decay. It forms layers of debris that build up over time. Ultimately, the pond turns to marsh that turns to swamp that turns to grassland or forest. This is called pond succession—the ultimate fate of a pond is to fill in.

Lakes are all about waves and layering. Natural lakes and man-made reservoirs are basically giant ponds, but size changes everything. Lakes are too large for rooted plants, except along the shore. Waves can form, and though mixing can occur, a lake is stratified or layered with respect to temperature, light, oxygen and nutrients.

Surface waters also include running rivers and streams. All rivers are fed by a network of streams and ground water. A watershed is a common set of streams and rivers and ground water that all drain into the same place. You can think of a watershed as a large drainage basin.

The water from the University Park campus in central PA for example ultimately drains into the Chesapeake Bay. Remember, whatever you dump onto the land and into the streams will ultimately end up in rivers and finally the ocean. Think about what happens if you urinate on the Continental Divide, shown as a red line on this map. You will be polluting both the Atlantic and the Pacific Ocean at the same time! To the East, all the waters ultimately feed into the Atlantic Ocean and to the West, the Pacific Ocean.
One final important concept to consider with respect to surface fresh water ecosystems is that of productivity. A fresh water body can be classified by trophic state. Productivity relates to plant life, the biomass of the producer and productivity is tied to nutrient level. Though humans view water clarity as a measure of quality, from a natural point of view, this is not always the case. In aquatic systems, crystal clear water means low productivity. Some lakes are naturally oligotrophic, meaning that they have low levels of nutrients and productivity. Other lakes are naturally eutrophic due to high levels of nutrients. Eutrophication of a water ecosystem can happen natural. In an aquatic system, the limiting factor to producer growth is the availability of nutrients. Excessive nutrients, and thus high productivity in an aquatic system can signal the death of that system. You can think of it as an overshoot of the carrying capacity by the producer with essentially a doomsday result. Cultural eutrophication occurs when there is an influx of nutrients from human activities, especially nitrogen and phosphorus from inorganic fertilizers that leads to massive algal growth. The populations of producers explode and what grows must die. After an algae bloom, all the algae die and fall to the bottom of the lake. This then provides food for decomposers. As the decomposer population explodes, oxygen is depleted from the water. If nutrients limit plant growth in aquatic systems, dissolved oxygen is certainly the limiting factor for most consumers. The oxygen depletion can result in killing off most of the life in the lake, and can also lead to lake fill in.

Eutrophication zones are not restricted to lakes. Run-off from agricultural lands combined with erosion has significantly contributed to the large dead zone off the mouth of the Mississippi river delta; a giant area with no oxygen and of no life. You can read more about that in “Exploring Science. Studying the Dead Zone” in your textbook.

Obviously, inorganic plant nutrients are significant pollutants that can be damaging to freshwater ecosystems. Our discussion of cultural eutrophication is a good lead into water pollution issues.
Water pollutants can be categorized as physical, biological, or chemical pollutants, or by their origin; human and natural sources, or by their source types; point or nonpoint sources.

The major classes of water pollutants as outlined in your text book are:

- **Infectious Agents** or disease-causing organisms. Sources include improperly treated human and animal waste. This type is the greatest risk to human health worldwide.

- **Sediments**: which are insoluble soil particles from eroded soil. This is the water pollutant with the greatest negative effect on fresh water ecosystems and tops in terms of total weight.

- **Inorganic Compounds**: includes inorganic fertilizer, primarily nitrogen and phosphorus, acids, heavy metals and salts. The main sources again are human activities: industry, leaching from mines, surface run-off, household wastes. The inorganic water pollutants also include radioactive isotopes.

- **Organic Compounds** include oil, plastics, solvents and volatile organic compounds (VOC’s). The source of these contaminates are also mostly due to human activity.

- **Oxygen Demanding Waste** is waste that can be decomposed. Sources include treated sewage, paper mill waste, food processing, and in some cases animal manure. Such pollutants as sewage and animal waste can have a double effect in that they can contain infectious agents as well as being, by nature,
oxygen demanding waste. So why are oxygen demanding waste a problem? As mentioned earlier, the limiting factor for aquatic consumers is often oxygen availability. Oxygen is needed for cellular respiration so pollutants that deplete the oxygen levels in water creates a problem for most organisms.

*Thermal Pollution* is heat from industrial cooling processes in power plants. Thermal pollution can either result in a direct kill of organisms if the temperature is too high, or heat can decrease oxygen and thus deplete this critical resource, because as temperature increases, oxygen solubility decreases.

### Water Pollution

- Physical, Biological, Chemical
- Human or Natural source
- Point source and Non-point source

**Major Water Pollutant Categories**

- **Infectious Agents** – disease causing organisms, improperly treated human and animal waste, biggest threat to human health worldwide
- **Sediments** – insoluble soil particles from eroded soil, largest in terms of weight and ecosystem impact
- **Inorganic compounds** – fertilizers, acids, heavy metals, salts, from agricultural run off and industry, radioactive isotopes
- **Organic compounds** – oils, plastics, solvents, pesticides, VOCs
- **Oxygen demanding wastes** – sewage, waste from paper mills, food processing, animal manure
- **Thermal pollution** – heat from industrial cooling processes, power plants, direct effects and oxygen depletion

So what can be done to solve our water pollution problems? When thinking about solutions to environmental problems, we usually have to choices, clean-up or prevention.

Let’s use eutrophication as an example. A body of water affected by eutrophication can be cleaned up through dredging and removing biomass and sediments or plants can be killed off using herbicides. A pond or lake can also be artificially aerated to speed up the decomposition process. However, all of these processes are pretty labor and energy intensive. The other tactic is to address these problems by prevention. Controlling erosion via conservation tillage in agriculture, and using best management practices in construction and forestry most effectively address reducing the load of sediment in the waterways. Remember how the practice of clear-cutting contributes to erosion? Too much plant nutrients can also be attacked at the source. A good place to start is changing large- and small-scale
agricultural and landscaping practices by replacing highly soluble inorganic fertilizers with organic alternatives.

Prevention has been the focus of legislation over the past few decades—especially the prevention of pollution from point sources. This approach has been highly effective. Surface waters of the U.S. have improved dramatically since the Clean Water Act was first passed in 1972.

**Solutions**

**Eutrophication**

**Clean-up**
- Dredge and remove biomass and sediments
- Herbicides to kill plants
- Artificial aeration to speed up decomposition
- Energy and labor intensive processes

**Prevention**
- Reducing erosion: conservation tilling, best practices in construction and forestry
- Limiting fertilizer run off: organic farming and landscaping

**Clean Water Act 1972**

As mentioned, the top pollutants in terms of human health are water-born infectious pathogens. The lack of safe drinking water is a major cause of disease in the world today. Water borne pathogens account for a large percentage of deaths of children in the developing world. The most important weapon against pathogens is prevention by proper treatment of human sewage. In addition, the emerging problem of animal waste must be addressed. As agriculture shifts to an industrial model, the old style methods of storing animal waste in lagoons on-site and using them for fertilizing fields is no longer practical or safe. If we insist on continuing to scale up animal production, the same rules that apply to human waste should be applied to animal waste to make sure that they do not contaminate our waterways with infectious agents and oxygen demanding waste.
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Human sewage can be treated in **septic tanks**, which are holding tank where waste is decomposed with the help of bacteria, and soil of the drain field is used to purify the waste water.

The alternative is conventional sewage treatment. Primary sewage treatment includes collection of solids through the use of screens and settling tanks. Most communities in the U.S. now rely on **secondary sewage treatment** where, after the collection of solid waste the remaining waste water is subjected to vigorous aeration, thus promoting the decomposition of oxygen demanding waste. Water from secondary sewage treatment plants is usually chemically sterilized prior to release to kill any remaining human pathogens. This is typically done with chlorine.

Though this approach is decades ahead of much of the developing world, there are some problems with the conventional treatment methods. Chlorination results in the formation of chlorinated hydrocarbons when the chlorine reacts with the remaining organic compounds. Chlorinated hydrocarbons are typically toxic. There are less toxic alternatives to chlorine, most notably ozone or ultra violet light, that can be used to kill any remaining human pathogens prior to release.

After secondary treatment, nitrates and other plant nutrients as well as toxic metals and persistent pollutants, which have a low rate of biodegradation, remain. Some of these can be removed through tertiary treatment.

**Issues with conventional sewage treatment**

- Chlorination – chlorinated hydrocarbons (toxic). Ozone and UV alternatives.
- Plant nutrients, toxic metals and persistent pollutants remain
- Sludge, used as fertilizer, buried or burned.
After conventional treatment, you are left with sludge in addition to more or less clean water. Though sludge can be used as fertilizer, sludge is sometimes too contaminated for use and is then usually buried or burned.

Bioremediation:
- plant-filled pools, “living machines” or wetland based
- plants and microorganisms acts as filters to clean up waste water

**Bioremediation examples:**
Arcata, California
Appleton, Canada