-Forest Environment-
Soils, Water & Cycles

Adapted from the on-line Teachers Guide
http://mff.dsisd.net

MICHIGAN STATE UNIVERSITY EXTENSION

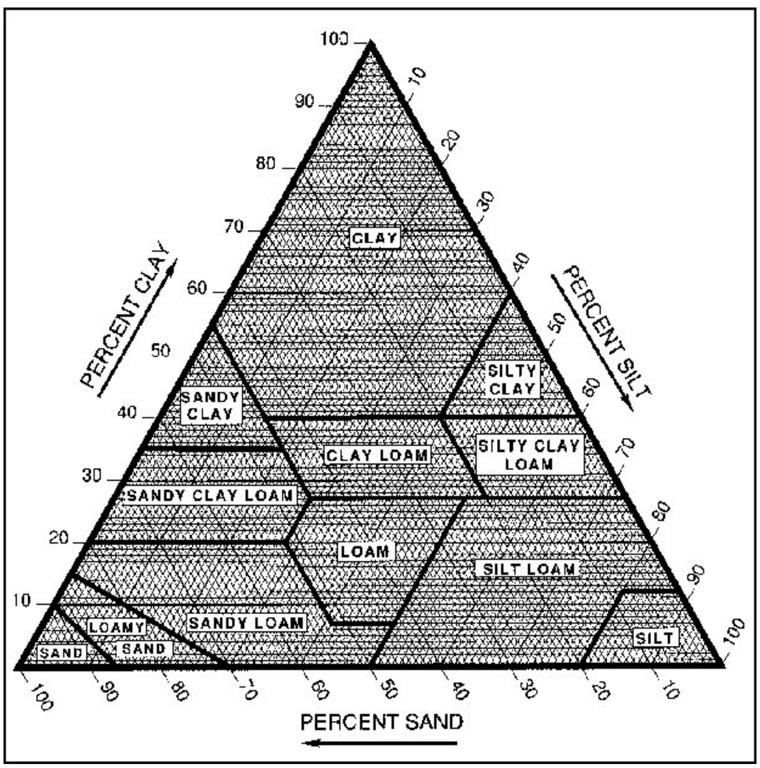
FOREST SOILS AND WATER & NUTRIENT CYCLING

Soil Types, Particle Sizes, and Soil Textures

According to the Natural Resource Conservation Service, there are about 475 soil types in Michigan. A soil type is defined by characteristics such as soil structure, moisture, soil genesis, particle size, and texture. Different soils are capable of producing certain levels of biological productivity, or so much biomass per year. Soil is one of the foundations of forest ecology. Because soil takes thousands of years to develop, conservation of soils is critical. Recovery from land abuse and excessive erosion cannot be easily overcome. There are many historical examples of collapsed societies due, at least in part, to abusive land practices. For a classic 28 page paper on the topic, read the essay by ***W.C. Lowdermilk***.

"Soil texture" determined by the relative composition of soil particle sizes. There four soil particle size classes.

- Gravel: particles over one millimeter in diameter.
- Sand: 0.05 to one millimeter.
- Silt: microscopic, from 0.002 to 0.05 of a millimeter.
- Clay: particles less than 0.002 millimeter in diameter.



Soil texture is a key soil descriptor. Particle sizes can be ascertained in a laboratory to determine what proportion a particular sample is due to sand, silt, and/or clay. The chart above illustrates how various mixtures of sand, silt, and/or clay make up soil textural classifications.

Most soils have a combination of soil particles sizes. There is usually a component of ***"organic matter"***, which is derived from decomposing plant and animal remains. A ***"loam soil"*** is a mix of sand, silt, and clay that optimizes agricultural productivity. The texture of a soil determines much about the water retention properties. A ***"coarse soil***", mostly sand & gravel, has large pore spaces and allows water to easily run through it beyond the reach of roots. These soils tend to be drought-prone. Additionally, sand and gravel have relatively little surface area for the particle volume, reducing the potential for nutrient weathering. A ***"fine soil"*** has large components of silt and clay, making it "muddy" when wet. Pore spaces are smaller and hold more water. However, when clay soils begin to dry, they may still hold large quantities of water, but due to the small particle size and adhesive & cohesive properties of water, most of it will be unavailable for root uptake.

The rock or original source of soil particles is called ***"parent material"***. The nature of parent material has a lot to do with soil quality. Glacial outwash sands tend to be rather infertile, or hold few minerals and nutrients important for tree growth. Soils derived from other sources may be relatively rich in minerals and nutrients. Usually a combination of weathered parent materials (often re-worked by glacial action in Michigan) and organic matter make a soil. Weathering or erosive actions include those from heating/cooling, freezing/thawing, glaciers, water, wind, chemistry, and plants & animals.

Distribution of Kalkaska Sands in Michigan

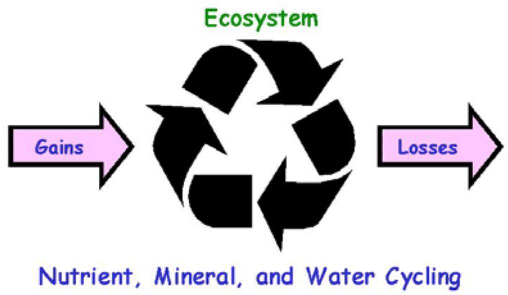
A ***"soil profile"*** is a look at the layers of soil in a particular place. Each layer is called a ***"horizon"***.   The *A-horizon* usually contains most of the organic matter and soil goodies. It is usually thin, maybe a few inches or less. The *B-horizon* contains much of the nutrients that are leaching out of the A-horizon. It generally lacks any organic matter. Accumulations of iron or other minerals may create ***"hardpan"***, which is a feature water and roots have difficulty penetrating. The *C-horizon* is raw soil, weathered parent material. This horizon defines a soil's mineral and acidic properties. A granite-based soil will be acid and weather slowly. A limestone-based soil will be much more alkaline and weather rather quickly. The *D-horizon* is unweathered rock formed from basic geological processes such as volcanism and sedimentation.

Soil profile of a Kalkaska Sand, Michigan's State Soil Courtesy of the NRCS

The U.S. Department of Agriculture, Soil Conservation Service publishes detailed soil surveys for each county. These documents are rich sources of information about not only soils, but other information as well. The soil surveys are available at no cost. On-line soil maps are also available through the USDA Natural Resource Conservation Service at [*http://websoilsurvey.nrcs.usda.gov/app*].

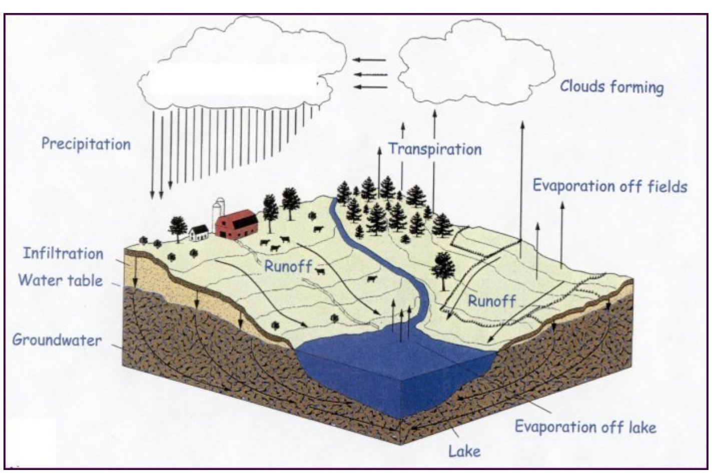
WATER AND NUTRIENT CYCLES

It is easy to get caught into the complexity and chemistry of water and nutrient cycles. As with most things in the natural world, multiple factors interplay with each to produce an immense array of conditions. However, there are some fundamental factors and basic ideas that are good to understand.



- Climate zones are important.
- Soils are the primary medium where "cycles" happen, in terms of their affect on living organisms.
- Stuff enters a system.
- Stuff gets held within a system.
- Stuff is lost from a system.
- A ***"closed system"*** is one where little comes in, little leaves, and most of the "goodies" are held within tissues of plants and animals.
- An ***"open system"*** is where "goodies" tend to have flow in and out of plant and animal tissues.
- Temperate climate systems generally tend to be open systems with a fair amount of cycling.
- There is a difference between the total amount of water or a nutrient in a system and the amount *available* to organisms.
- Chemistry has a great deal to do with what nutrients are available.
- Composition of soils have a tremendous influence on chemistry and nutrient & water movement.

Hydrologic Cycle



The hydrologic cycle is the natural sequence through which water passes into the atmosphere as water vapor precipitates to Earth in liquid or solid form, and ultimately returns to the atmosphere through evaporation and transpiration. The biotic community is only one part of the cycle. The oceans also have large biotic communities, mostly phytoplankton.

Scientists believe the total amount of water on Earth has remained unchanged for millions of years. They estimate the amount at 326 *million cubic miles* or about 358,026,240,000,000,000,000 gallons!

Water moves about the Earth. Water movements, especially how they affect the biota, are called the ***"hydrologic cycle"***. At any one time, only about 0.005 percent of the supply is actually moving through the cycle, which is a LOT of water. This cycle is solar-driven. The three main theaters are land, air, and ocean. Water is stored in various reservoirs for various periods of time. Water in glacial ice has been there a long time. Water held by trees soon goes somewhere else. There are many connections between the reservoirs and processes described below. Measuring the relative importance of each helps define a particular ecosystem.

Reservoir	Volume (cubic miles)	Percent of Total	Percent of Freshwater
Oceans	166,520,000	96.5	-
Ice	5,774,000	1.74	68.7
Groundwater	5,614,000	1.7	30.1
Permafrost	72,000	0.022	-
Lakes-fresh	21,800	0.007	0.26
Lakes-saline	20,500	0.006	-
Soil Moisture	4,000	0.001	0.05
Atmosphere	3,100	0.001	0.04
Swamps	2,800	0.0008	0.03
Rivers	500	0.0002	0.006
Biological	300	0.0001	0.003
Total	332,546,000	100.0	100.0

Source: Gleick, P.H. 1996.
Note: Estimates of Earth's water and where it lies are difficult to make, especially for groundwater. This table shows a total amount different than cited by Owen, 1971.

Oceans hold about 97.2 percent of Earth's water. If the surface of the Earth were smooth, that's enough water to cover the entire surface under 800 feet of water.

Surface and Groundwater includes lakes, rivers, marshes, and the water in the soil and underground aquifers. This is the water that most people are directly concerned about, although it comprises only a tiny fraction of a percent of all the water on Earth. In the USA, we have over three million miles of rivers that carries 1.2 trillion gallons each day. Surface water satisfies about 80 percent of human needs for water. Groundwater may be closer to the surface in ***"water tables"*** or deeper down in rock strata called ***"aquifers"***. The speed of groundwater movement is much less than that of surface water, ranging from a few feet to a few miles each year. Contamination of groundwater is a serious matter because of the long time required to "flush" the system out.

The Great Lakes contain one-fifth of the world's surface freshwater, and Michigan has shorelines on four of the five big lakes! They contain 5,473 cubic miles of fresh water, or six *quadrillion* gallons. Note that this volume of water is only 0.00167 percent of Earth's water! Lake Superior holds the largest amount of water, more than the other four put together. The next largest Great Lakes, in terms of water volume, are Michigan, Huron, Ontario, and Erie. More information on the Great Lakes can found at the end of this chapter.

The ***atmosphere*** contains water that has evaporated, primarily from the oceans. The amount of atmospheric water is constant. If water didn't return to the oceans, they would lose 39 inches of water each year. This atmosphere is what keeps heat around the Earth, which would otherwise drop to temperatures around -300 degrees Fahrenheit.

The ***biota***, or plants and animals, store and process water. However, the amount is only 0.003 percent of all freshwater, which is only a few percent of all water on Earth. Nevertheless, this is the water that we most directly concern ourselves with.

Precipitation is what brings water back to the Earth from the atmosphere. Nearly 90 percent falls back into the oceans. Precipitation (rain, snow, sleet, hail, fog, dew) is very unevenly distributed across the landscape and plays a critical role in the distribution of plants and animals. The average *daily* amount of precipitation in the USA is 4.3 *trillion* gallons. Enough precipitation falls in the USA in an average year to cover the surface of the country with 30 inches of water.

Evaporation moves precipitation right back into the atmosphere. Evaporation occurs from the surface of plants, from soils, and from oceans, lakes, and streams. Evaporation rates are higher in forested areas because of the huge amount of leaf surface area.

Transpiration is the process where plants move water from the soil to their above-ground parts, and then loses it to the atmosphere. One tree may transpire 100 gallons per day. An acre of corn might transpire 4,000 gallons in a day.

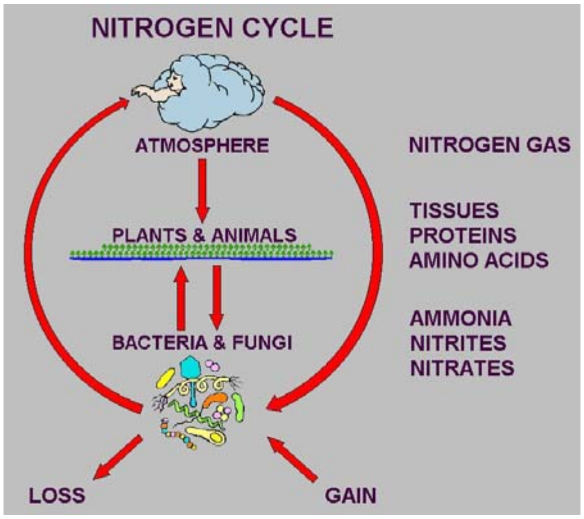
Evapo-transpiration is a combined term that includes both evaporation and transpiration. These processes send back 70 percent of annual precipitation in the USA.

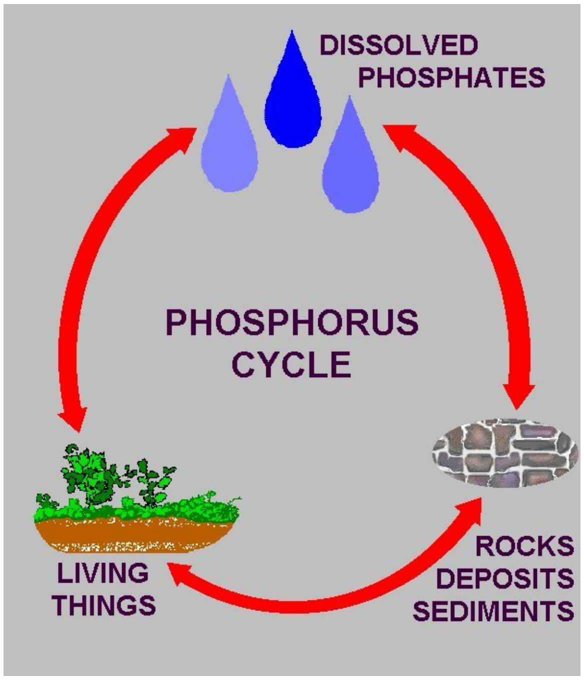
Nutrient Cycles

All minerals and nutrients cycle through soils and living systems. The amount *available* to plants and animals is what is important, not necessarily how much there is in the environment. The processes that influence the availability of nutrients vary from location to location and over time.

As mentioned in the Tree Physiology chapter, the most common minerals of life are carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulfur, calcium, iron, and magnesium. You might be able to remember this by a jingle formed using the abbreviations for these elements: C H O P K N S Ca Fe Mg . . . "see hopkins café, mighty good." Usually, the most limiting minerals are nitrogen, phosphorous, and potassium. These are the three main ingredients of most fertilizers. Decomposers (bacteria and fungi) play a critical role in keeping nutrients within the living system and slowing losses to the open cycles we find in north temperate zones.

The primary reservoir of phosphorus and potassium is the soil. As rock is weathered, soil particles are formed, and minerals become available to plants. Weathering is affected by factors such as freeze-thaw events, pH, wind and water movement, and actions by plants. Phosphorus and potassium are converted to "organic" forms that can be absorbed and utilized by plants.





The primary reservoir of nitrogen is the atmosphere. Nitrogen must be converted from atmospheric forms to forms that plants can use. This process is called ***"nitrogen-fixing"*** and is largely done by certain forms of bacteria and algae. Certain groups of plants, especially those in the legume family, have specialized root nodules containing nitrogen-fixing bacteria in a *symbiotic* relationship. Lightning fixes some amounts of nitrogen. Annual nitrogen fixation averages between one and six pounds per acre. There are several forms of nitrogen, but it is the nitrate form that is useable to plants.

Two dominant factors in nutrient availability are water and pH. Most chemical forms of nutrients available to trees are in a soluble state, meaning they dissolve in water. As water moves through and across soils, it carries valuable nutrients. As a landscape captures water, so too, will it capture many of the nutrients dissolved in the water. This is the very important connection between the hydrologic cycle and nutrient cycles.

pH is simply a scale that measures the acidity and alkalinity of water solution. The scale runs from 0 to 14, with low numbers being acid and high numbers being alkaline. Seven is neutral. Most soils exist in a natural state of acidity. As a soil pH changes, so does the chemical forms of many nutrients. A change in pH may work to the benefit or detriment of plants on a particular soil type, depending upon the soil type. Most forest soils would actually become more productive with moderate decreases in pH. Soils can be ***"buffered"*** against changes in pH if they have higher levels of carbonates. Carbonates "absorb" the ions that cause pH change until their capacity is used up. So, a soil rich in carbonates would require large amounts of inputs to affect a change. Alternatively, poorly buffered soils may experience changes in pH with relatively low levels of inputs.

Aquatic systems operate in a similar way. Lakes in granitic basins tend to have lower pH values, lower biological productivity, and are much more vulnerable to drops in pH with the addition of acid inputs. Lowered pH in these sensitive lakes can have negative consequences on the biota of the lake. This was one of the principal concerns with "acid rain". However, most lakes tend to have fairly substantial buffering capacities.

THE GREAT LAKES – DID YOU KNOW?

There are 5 Great Lakes

H	*Huron*
O	*Ontario*
M	*Michigan*
E	*Erie*
S	*Superior*

The Great Lakes are one of the natural wonders of the world, although we may not think of them that way because they're right in our own backyard. The great peninsulas of Michigan are unique. Nowhere else is there so much freshwater and so much shoreline.

The Great Lakes have a tremendous influence on our weather, and subsequently on our forests and vegetation. They are important for shipping, a source of industrial and municipal water, fisheries, and tourism. We in Michigan usually don't think about water shortage problems, but many parts of the United States and across the world experience regular shortages of water supply or high quality water. The Great Lakes contain enough water to cover the continental United States with nearly 10 feet of water! Over 33 million people live around the Great Lakes and depend on them for water and other needs.

NASA Visible Earth website: http://visibleearth.nasa.gov/ All SeaWiFS images are for research and educational use only. All commercial use of SeaWiFS data must be coordinated with Orbimage (http://www.orbimage.com).

Water flows through the system from Lake Superior, into Lakes Huron and Michigan, then onto Lake Erie, over Niagara Falls, into Lake Ontario, and out the St. Lawrence Seaway to the Atlantic Ocean. Along the way, watersheds gather water from many smaller drainage systems, an area of 196,520 square miles. That's over five times the area of Michigan! The Great Lakes Basin includes portions of seven states and the Province of Ontario. Click here for a profile of the five Great Lakes.

Lake Superior is by far the largest lake in terms of surface area, water volume, and depth. It holds ten percent of the world's fresh water. Only Lake Baikal, in Russia, is deeper and holds more freshwater. Lake Superior is also the highest in elevation and furthest "up" the watershed. Old legends call the lake "Gitchee Gumee". This name has been used in song and verse over the years.

Which lake is smallest is less clear, although most would agree Ontario is larger even if Erie "looks" larger. Ontario is deeper with three times the volume of water, but Erie has 25 percent more surface area. Erie has the greatest number of people living nearby, about 12.5 million. People have caused severe pollution problems in Lake Erie, but thanks to controls and a quicker water replacement time, the lake is recovering.

On 5 December, 2000, a storm swept across the Great Lakes and dropped "lake effect" snow along the southern shore of Lake Superior and western shore of Lake Michigan. This image clearly shows how the big lakes can affect local weather and influence regional ecosystems.
NASA Visible Earth website: (http://visibleearth.nasa.gov)
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Lake Huron has many islands, over 30,000 of them! As result, it also has the most shoreline of any lake . . . almost 4,000 miles! Manitoulin Island, in Canada, is the biggest island in the world, surrounded by *fresh*water. And if you like confusing word play, Manitoulin Island is the largest freshwater island in the world, which has the largest freshwater lake on an island in the world. That island the largest island, in a lake, on an island, in a lake, in the world!

GREAT LAKES BASIN WATERSHED
Source: Michigan State University Extension and the Michigan Sea Grant College Program, 2000.

The biggest threats to Great Lakes are pollution and exotic species. The pollution problems are becoming less each year, but the threat of exotic species is increasing. Two of the most well-known exotic species are the sea lamprey and zebra mussel. Most exotic species are introduced to the Great Lake by ships from other places in the world.

Characteristic	Superior	Michigan	Huron	Erie	Ontario
Length *(miles)*	350	307	206	241	193
Width *(miles)*	160	118	183	57	53
Depth, Average & Max. *(feet)*	489 / 1,333	279 / 923	195 / 750	62 / 210	283/802
Volume *(cubic miles)*	2,935	1,180	849	116	393
Surface Area *(sq. miles)*	31,700	22,300	23,000	9,910	7,340
Drainage Basin Area *(sq.miles)*	49,300	45,600	50,700	22,700	23,400
Shoreline *(miles)*	2,730	1,640	3,830	871	712
Elevation *(feet)*	601	577	577	569	243
Outlets	St. Mary's River	Mackinac Straits Chicago River	St. Clair River	Niagara Falls Welland Canal	St. Lawrence River
Water Replacement Time *(yrs)*	173	62	21	2.7	6
Human Population	672,116	12,052,743	2,960,359	12,532,977	5,692,178
Source: Sea Grant and MSU Extension, 2000