The Forest Water Cycle

FTTS Class Lecture
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1. Why is water so special to biological organisms?

A. Water's unique thermal properties allow it to buffer the bodies of plants and animals against sudden changes in temperature.

i. **Specific heat** is used to describe the thermal capacity of a substance or the amount of energy that can be absorbed for a given rise in temperature. Water has a very high specific heat; its temperature changes slowly for a given energy input.

ii. Energy is required for a substance to change state, such as from a solid to a liquid or a liquid to a gas. The energy required to change a substance from the solid to liquid state is called the **heat of fusion**. The energy required to change a substance from a liquid to a gas is called the **heat of vaporization**. It takes more heat to vaporize water than other liquids (in other words, water has a high heat of vaporization). Since this energy must be absorbed from its surroundings, the heat of vaporization accounts for the cooling effect associated with evaporation.

Table 1. Physical properties of water compared with other molecules of similar molecular size. Because thermal properties are defined on an energy-per-unit mass basis, values are given in units of joules per gram.

	Molecular mass (g)	Specific heat (J/g)	Heat of fusion (J/g)	Heat of vaporization (J/g)
Water	18	4.2	335	2452
Carbon dioxide	44	-	180	301
Methanol	30	2.6	100	1226
Ethanol	46	2.4	109	878

B. Water also is unusual in that its solid state (ice) is less dense than its liquid state. This is why ice floats at the top of a body of water, allowing aquatic life to persist in the liquid water below.

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2. How does water move into the atmosphere?

A. Water enters the hydrologic cycle due to evaporation caused by solar radiation. Since most of Earth's water (96.5%) is in oceans, oceans are the greatest source for this evaporative return to the atmosphere.

B. Pacific Northwest forests get their water primarily from the Pacific Ocean north of the equator. The Pacific Ocean sends 680 billion metric tons of water into the atmosphere each year. Once in the atmosphere the water may move only a few feet or may stay aloft for thousands of miles before being released as precipitation. The average time it is in the air is 10 days. Most of the evaporated water (91%) falls back into the ocean. Of the remaining 9% that makes it to terrestrial systems, only about 1% stays west of the Cascade crest.

C. **Water vapor density** is the amount of water (or mass of water) per volume of dry air. The saturation vapor density increases with temperature, so at high temperature air can reach greater water vapor density. **Relative humidity** is the ratio of the actual amount of water held in the atmosphere compared to the maximum amount that can be held at that temperature.

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3. How does water move into terrestrial systems in general and plants in particular?

A. Precipitation

i. As an air parcel rises, it cools. As it cools, its absolute humidity stays relatively constant while its saturation vapor pressure (you can think of this as density) decreases, because cold air can hold less moisture than warm air. Therefore, its relative humidity increases. As the parcel's relative humidity reaches 100 % saturation, clouds form and precipitation may occur.

ii. There are three primary types of precipitation.

a. Rain

b. Snow – snow is an excellent reflector of light. The measure of an object's reflecting power is called its **albedo**. Bare ground and green forest have an albedo of 3-20%. In comparison, fresh snow has an albedo of 80-85%, which means that much more light is reflected by snow than by vegetation or soil.

c. Fog drip – cloud droplets that might not otherwise precipitate are deposited on leaf surfaces and are either absorbed by leaves or drip from the canopy to the soil. Fog drip is most important in high elevation and coastal forests.

iii. There are several important ecological considerations with respect to precipitation.

a. The water status of an ecosystem determines which plants will be able to grow there. Both the annual quantity of water and the season of input are important.

b. Intensity of the precipitation event is also important. Heavy rainfall can damage vegetation, erode soil, and carry sediment into streams.

iv. Not all of the precipitation that falls on a forest reaches the forest floor. In fact, up to 50% of precipitation in closed canopy ecosystems is intercepted by the forest canopy. **Intercepted precipitation** may be stored on leaves, branches or stems or may evaporate back into the atmosphere. The amount of precipitation that is intercepted depends on:

a. the water storage capacity of the vegetation;

b. surface area of the canopy (which varies with tree age and density of stems);

c. energy available to evaporate water; and

d. humidity of the air.

v. Redistributed water reaches the ground in a non-uniform pattern.

a. **Throughfall** – water that passes through the tree canopy without touching any vegetation or that drips from the canopy to the ground.

b. **Stemflow** – water that runs down stems. Stemflow depends on canopy morphology (shape). For instance, upturned branches serve to funnel water toward the stem. Stemflow tends to deposit water deeper into the soil than does throughfall.

B. Water may also enter an ecosystem as ground water that flows laterally from adjacent ecosystems.

C. Surface run-off and flood events may also bring water into an ecosystem. In undisturbed forests, there is generally low surface run-off, due to high infiltration rates.

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4. What happens to water after it reaches the ground?

A. Water reaching the ground can either flow laterally over the soil surface or penetrate the soil in a process called **infiltration**. Movement within the soil is called **percolation**.

B. Soil is the primary water storage reservoir.

i. Water is stored in pores between soil particles. The water holding capacity of soils is determined by the total pore volume (which is a function of the % pores in the soil and the soil depth).

ii. Coarse woody debris (downed logs) and soil wood in the forest floor also hold water; the more decomposed organic matter and rotting wood, the more water a soil can hold.

iii. The forest litter layer limits evaporation of water from forest soils by blocking hydraulic continuity.

C. The loss of water from plant cells to the atmosphere by vaporization is called **transpiration**. 80% of the water that enters plants through their roots returns to the atmosphere through this process. Low water vapor pressure (you can think of this as density) in the air relative to that inside the leaves is the major driving force for water loss from leaves, which drives movement into leaves, which in turn drives movement into plant roots. Water movement into plants is driven entirely by the physical process of evaporation from the leaf surface and requires no expenditure of energy by the plant.

D. Water that is not lost by evaporation and transpiration and is not held in the soil either enters long-term storage in ground water aquifers or runs off the surface and eventually returns to large bodies of water.

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5. Think about how the following human activities might impact forest hydrologic processes (evaporation, transpiration, infiltration, surface flow, etc.).

A. Logging

B. Road building

C. Municipal and agricultural water use

D. Industrial activities that increase greenhouse gasses

Assigned reading

- Chapin, F.S., P.A. Matson, and H.A. Mooney. 2002. *Principles of Terrestrial Ecosystem Ecology*. Springer-Verlag. (Chapter 4).

Additional readings (class handouts)

- Koch, G.W., S.C. Sillett, G.M. Jennings, and S.D. Davis. 2004. The limits to tree height. *Nature* 428:851-854.
- Woodward, I. 2004. Tall storeys. *Nature* 428:807-808.

Additional readings used to compile lecture

- Kimmins, J.P. 1997. *Forest Ecology: A Foundation for Sustainable Management*. Prentice Hall.
- Kruckeberg, A.R. 1991. *The Natural History of Puget Sound Country*. University of Washington Press.
- Waring, R.H. and Running, S.W. 1998. *Forest Ecosystems: Analysis at Multiple Scales*. Academic Press.
