The Hydrological Cycle
The Annual Water Cycle, km$^3$

<table>
<thead>
<tr>
<th></th>
<th>Precipitation</th>
<th>Evaporation</th>
<th>Difference (runoff)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAND</td>
<td>110,000</td>
<td>70,000</td>
<td>+40,000</td>
</tr>
<tr>
<td>WATER</td>
<td>390,000</td>
<td>430,000</td>
<td>-38,500</td>
</tr>
</tbody>
</table>

About 1,500 km$^3$ are transported as groundwater
Soils and the Hydrosphere

<table>
<thead>
<tr>
<th>Pool</th>
<th>Volume (%)</th>
<th>Equivalent depth (m)</th>
<th>Residence time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>94</td>
<td>2500</td>
<td>~4000 y</td>
</tr>
<tr>
<td>Lakes, and swamps</td>
<td>&lt;0.01</td>
<td>0.26</td>
<td>~10 y</td>
</tr>
<tr>
<td>Rivers</td>
<td>&lt;0.01</td>
<td>0.003</td>
<td>~2 weeks</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>&lt;0.01</td>
<td>0.13</td>
<td>Up to 1 y</td>
</tr>
<tr>
<td>Groundwater</td>
<td>4</td>
<td>120</td>
<td>Up to 10,000 y</td>
</tr>
<tr>
<td>Ice</td>
<td>2</td>
<td>60</td>
<td>Up to 10,000 y</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>&lt;0.01</td>
<td>0.025</td>
<td>~ 10 days</td>
</tr>
<tr>
<td>Biosphere</td>
<td>&lt;0.01</td>
<td>0.001</td>
<td>~ 1 week</td>
</tr>
</tbody>
</table>

Estimates of the water balance of the world (modified from Freeze and Cherry, 1979)
Fresh Water in Aquifers: a Renewable Resource?

- About 1,500,000 km$^3$ of fresh water held in aquifers.
- Much of ground water is “fossil water” (no-active exchange with the earth surface).
- Renewal aquifers are subjected to recharge:
  - Depletion of groundwater can cause subsidence and compaction, which reduces the storage capacity of the aquifer.

Simulated Global Changes in Soil Moisture

Water Flow in the Soil_Plant_Atmosphere System

Figure 6.19 Relationship of the water table and groundwater to water movement into and out of the soil. Precipitation and irrigation water move down the soil profile under the influence of gravity (gravitational water), ultimately reaching the water table and underlying shallow groundwater. The unsaturated zone above the water table is known as the vadose zone (upper right). As water is removed from the soil by evapotranspiration, groundwater moves up from the water table by capillarity in what is termed the capillary fringe. Groundwater also moves horizontally down the slope toward a nearby stream, carrying with it chemicals that have leached through the soil, including essential plant nutrients (N, P, Ca, etc.) as well as pesticides and other pollutants from domestic, industrial, and agricultural wastes. Groundwaters are major sources of water for wells, the shallow ones removing water from the groundwater near the surface, while deep wells exploit deep and usually large groundwater reserves. Two plumes of pollution are shown, one originating from landfill leachate, the other from a chemical spill. The former appears to be contaminating the shallow well.
Hydrological Cycle

Water potential, atmosphere
Transpiration, $T$

Atmospheric pool
Precipitation, $P$

Interception
Infiltration

Evaporation, $E$

Surface storage
Soil storage, $SS$

Runoff, $R$

Groundwater storage

Capillary Rise, $CR$
Percolation, $Pc$

Groundwater level

Water Balance: $P + CR = R + SS + ET + Pc$
Figure 6.16 Generalized curves for precipitation and evapotranspiration for three temperate zone regions: (a) a humid region, (b) a semiarid region, and (c) an irrigated arid region. Note the absence of percolation through the soil in the semiarid region. In each case water is stored in the soil. This water is released later when evapotranspiration demands exceed the precipitation. In the semiarid region evapotranspiration would likely be much higher if ample soil moisture were available. In the irrigated arid region soil, the very high evapotranspiration needs are supplied by irrigation. Soil moisture stored in the spring is utilized by later summer growth and lost through evaporation during the late fall and winter.
Percolation: Function of Climate and Soil

Figure 6.17 Percentage of the water entering the soil that is lost by downward percolation and by evapotranspiration. Representative figures are shown for different climatic regions.
Figure 6.13 Partitioning of liquid water losses (discharge) and vapor losses (evaporation and transpiration) in regions varying from low (arid) to high (humid) levels of annual precipitation. The example shown assumes that temperatures are constant across the regions of differing rainfall. Potential evapotranspiration (PET) is somewhat higher in the low-rainfall zones because the lower relative humidity there increases the vapor pressure gradient at a given temperature. Evaporation (E) represents a much greater proportion of total vapor losses (ET) in the drier regions due to sparse plant cover caused by interplant competition for water. The greater the gap between PET and ET, the greater the deficit and the more serious the water stress to which plants are subject. (Diagram courtesy of R. Weil)
Soil Water Potential and Plants
Saturated Conductivity and Trees?

Figure 7.14  Leaf specific conductivity in microliters per hour, per gram fresh weight of leaves supplied, for two paper birch trees (*Betula papyrifera*). Conductivity decreases from lower to upper trunk and in the branches. It also is low when branches are attached to the trunk, as further indicated by the high velocity of sap flow at the point of branch attachment shown in Fig. 7.18. From Kramer (1983), after Zimmermann (1978).
Water Movement Through Leaves
Rooting Depth

Effect of Compaction on Root Growth