WATER AND THE HYDROLOGIC CYCLE

Summary

Water is essential for the support of life and can be considered as a fundamental environmental good. Water is needed to support human habitation, grow crops and support ecosystems. Only 2.7% of the water on earth is freshwater suitable for drinking and agriculture, but despite this there is enough water to meet requirements. However, the distribution of water supply and people is uneven around the world leading to shortages in many areas and for many people. Over one billion people have inadequate access to clean fresh water and it is estimated that more than five million people die annually from water-borne disease. The use and misuse of water resources is often at the expense of ecosystems; wetlands and their associated species are facing worldwide declines.

Relevance to business

Access to water resources has wide-ranging social and political implications and therefore can impact upon business activity. Water is used by society and industry as a fundamental resource as a raw material, solvent and medium for discharge of by-products. Excesses and shortages of water present different forms of business risk. Intolerance of pollution and expectations of sustainable management of water resources are likely to increase as will global demand for clean water.

Water

Water exists in three phases, liquid, solid (ice) and gas (water vapour) and has a range of physical properties that are unusual or unique. Most liquids reach their maximum density at their freezing point but water reaches it at 4°C and because it has a very high specific heat capacity, temperature changes in water take place slowly. In addition, water has a high latent heat capacity and because of these collective properties it plays an important part in the earth’s energy balance and climate (see R 1.5 Climate & atmospheric systems).

Water moves in a continuous cycle between the Earth and the atmosphere. There is no exchange of water between the atmosphere and space, so the Earth has contained approximately the same quantity of water for millions of years in what can be considered a closed system. However, the movement of water across the Earth-atmosphere interface transfers both energy and matter, so the system is open with respect to energy.

Water is stored in oceans, on land, in ice caps and in the atmosphere. The relative proportions vary greatly (see Table 1). By far the largest amount is in oceans but the high level of dissolved salts restricts human use. Water is continually cycled between the various reservoirs by a variety of processes including: evaporation, condensation, precipitation, deposition, runoff, infiltration, transpiration, and groundwater flow.

Evaporation is the process by which liquid water changes into water vapour. Solar radiation (insolation) provides the energy (latent heat of vaporisation) needed to change phase and most of the resulting vapour exists outside clouds. Approximately 80 per cent of evaporation comes from oceans and the remainder
from inland water, land and vegetation. Although most evaporation comes from bodies of water as opposed to land, evaporation rates from soil saturated by heavy rain can actually be higher when water is held in a film on and near the soil surface.

Transpiration is the process by which water vapour is diffused through the stomata (pores) of plant leaves into the atmosphere. The rate of loss is dependent upon factors such as relative humidity, temperature and wind speed. Because water droplets lying on leaves also evaporate, it is difficult to separate this process from evaporation and the two are often jointly referred to as evapotranspiration.

Condensation is the reverse of evaporation: water changes from a gaseous to a liquid phase. This generally happens when warm air rises in the atmosphere then cools, thereby losing energy and its capacity to hold water vapour. The vapour condenses and forms cloud droplets if condensation nuclei (minute suspended particles) or cool surfaces are present.

Precipitation is water falling from clouds in liquid or solid forms when particles or droplets become too heavy to be supported by air currents. Falling snow, hail or rain returns water to the land and oceans as deposition. Precipitation can penetrate the land by infiltration and become groundwater. Groundwater is found in two soil layers. The uppermost zone of aeration contains water and air. The lower zone of saturation contains water and soil. The boundary between these zones is the water table which can rise or fall according to the quantity of groundwater. The depth of groundwater and the consequent volume of the zone of aeration determine the capability of land to adsorb deposition. Flooding occurs when it is completely saturated and has reached capacity.

Run-off is the net overland flow of water to the oceans. Its source is partly from glacier or snowfield melt water, but mostly from precipitation that does not penetrate the land surface to become groundwater, or become water vapour through evapotranspiration. Groundwater is the water that resides in the soil and gaps between rocks. Water in permeable deposits such as sands and gravels allows water to flow through them, when they overlie impermeable rock they form aquifers, effectively underground reservoirs which are often important sources for human water use.

Water budget

The earth possesses an enormous quantity of water but freshwater is only a small (2.7%) proportion of the total, and most of this (c. 75%) is tied up in snowfields and ice caps. The balance available for use is from groundwater, lakes and rivers but the distribution is very uneven leading to problems in management and use.

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Per cent of total</th>
<th>Average residence time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>97.25</td>
<td></td>
</tr>
<tr>
<td>Ice caps and glaciers</td>
<td>2.05</td>
<td>20 to 100 years</td>
</tr>
<tr>
<td>Groundwater</td>
<td>0.68</td>
<td>Shallow 100 to 200 years; deep 10,000 years</td>
</tr>
<tr>
<td>Lakes</td>
<td>0.01</td>
<td>50 to 100 years</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>0.005</td>
<td>1 to 2 months</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Streams and rivers</td>
<td>0.0001</td>
<td>2 to 6 months</td>
</tr>
<tr>
<td>Biosphere</td>
<td>0.00004</td>
<td></td>
</tr>
</tbody>
</table>

Source: [http://www.physicalgeography.net/fundamentals/8b.html](http://www.physicalgeography.net/fundamentals/8b.html)

Only a very small proportion (0.01%) of the earth’s water is fresh water present on the surface but it is this resource that is most important for people and terrestrial ecosystems. The reservoirs that form the world’s “water budget” and the timescale on which they are replenished are shown in Table 1.
Water use

The World Bank identifies three main categories of water use: agriculture, industry and domestic. Relative consumption across these categories varies greatly. In developed countries, it is mostly skewed towards industry although some countries, such as Spain and the United States, have intensive agricultural irrigation systems. In less developed countries, water is primarily used to support agriculture. Where rainfall is low or unreliable, irrigation is widely used to improve crop reliability. Water supplies and sanitation (relevant to waterborne disease) are significant issues in many parts of the developing world and improvement to both is a key objective of the Millennium Development Goals.

The uneven distribution of fresh water and of human population (often historically linked) means that in some areas there is excess and in others water is so scarce that it limits human activity. Where there is excess, flooding may also affect human activity. This may be the result of extreme weather events but it is often caused or exacerbated by human intervention – poor land management, the canalization of natural river systems and the destruction of wetlands which act as natural buffers and storage systems within water catchments.

In populated areas, water resources tend to be highly modified and managed to support a very wide range of uses – agriculture, fisheries, industry, power generation, transportation, waste disposal, domestic consumption, recreation, and so on. For planning and sustainability reasons, it is important to monitor “renewable water supplies”. Broadly speaking, this is the amount of water that can be consumed within a given region on a sustained basis. It is calculated by totalling water inputs (precipitation plus any “imports”) and subtracting the amount lost through evapotranspiration and any “exports”. These two figures can be used to compile an index showing the degree to which water resources have been exploited, for example as shown in Figure 1.

![Figure 1. Water use in the United States](http://water.usgs.gov/watuse/misc/consuse-renewable.html)

Many regions rely heavily on groundwater from aquifers. If the rate of extraction exceeds the recharge rate then resource use is unsustainable. In some cases
aquifers are artificially recharged by pumping to use them for water storage. Because water is needed in large quantities and is heavy, transporting it is very energy intensive and can generate significant carbon emissions.

Low water levels caused by drought or by overuse have a severe impact on the environment. Low water levels in rivers and lakes lead to a reduction in fish spawning areas and the loss of aquatic and emergent vegetation and the wildlife that depend upon them. Low flows lead to lower levels of dissolved oxygen and higher levels of pollution as dilution levels are reduced. These conditions are hostile for many aquatic and organisms and can promote the growth of algal blooms which produce toxic by-products that can be dangerous to people, livestock and wildlife.

**Water quality and pollution**

Water quality is a variable concept that generally relates to its suitability for human consumption or its ability to support dependent organisms. “Fresh” water contains a range of dissolved salts and other minerals and suspended matter, mostly fine sediments but also some organic matter. Most aquatic organisms use oxygen dissolved in water for respiration and this can be used as a measure for water quality as can the level of suspended sediments and chemical water quality.

Many human activities and their by-products have the potential to pollute water. Large and small industrial enterprises, the water industry, the urban infrastructure, agriculture, horticulture, transport, discharges from abandoned mines, and deliberate or accidental pollution incidents all affect water quality. Pollutants from these and many other activities may enter surface or groundwater directly, can move slowly within the groundwater to emerge eventually in surface water, may run off the land, or might be deposited from the atmosphere.

Pollution may arise as point sources, such as discharges through pipes, or may be more dispersed and diffuse. Both point source and diffuse water pollution can be exacerbated by adverse weather conditions. The average ‘residence’ time for water in different stores (Table 1) varies greatly but is often relatively long term. This has implications for human health with respect to pollution, for example if groundwater supplies are polluted the effects can last for hundreds of years.

**Drought**

Drought is an acute shortage of water, usually following a period of low precipitation. It can vary in length and intensity and affect small or large land areas. Severe drought can result in crop failure, low river flows, lower groundwater levels, ground subsidence and the enforced movement of people and wildlife.

Ironically, flash flooding often occurs during periods of drought because parched soil has a low infiltration capacity and thus heavy rain can result in sudden, very high levels of run-off. The situation may be made worse by the lack of vegetation (because of drought conditions) that would normally intercept a proportion of the rainfall and help stabilize soils and slopes.

Attempts have been made in different parts of the world to minimize the impact of drought through river canalization, dams and other forms of civil engineering. These often increase problems or create new ones. Dams disrupt the water supplies of downstream populations and ecosystems. They often lead to the displacement of large numbers of people and species and to the destruction of wetland ecosystems - which paradoxically play an important part in reducing the impact of floods.

While the impacts and severity of climate change are currently unclear, it is likely that there will be greater variability in the world’s climate, leading to more frequent/severe droughts, but also flood events. (See also R 1.5 Climate and atmospheric systems and R 5.1 Climate change).
Conclusion

Water is vital for life. Its unique physical characteristics play an important part in the transfer and maintenance of the Earth’s energy budget and in climate regulation. Although it is one of the most common substances on the planet, a very small proportion is usable fresh water. Pollution, inappropriate land uses and extreme weather events further reduce its availability. Its uneven distribution means that many regions and people do not have access to adequate resources and this situation may be further exacerbated by climate change.

References


Sources of further information

http://www.worldbank.org/watsan

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