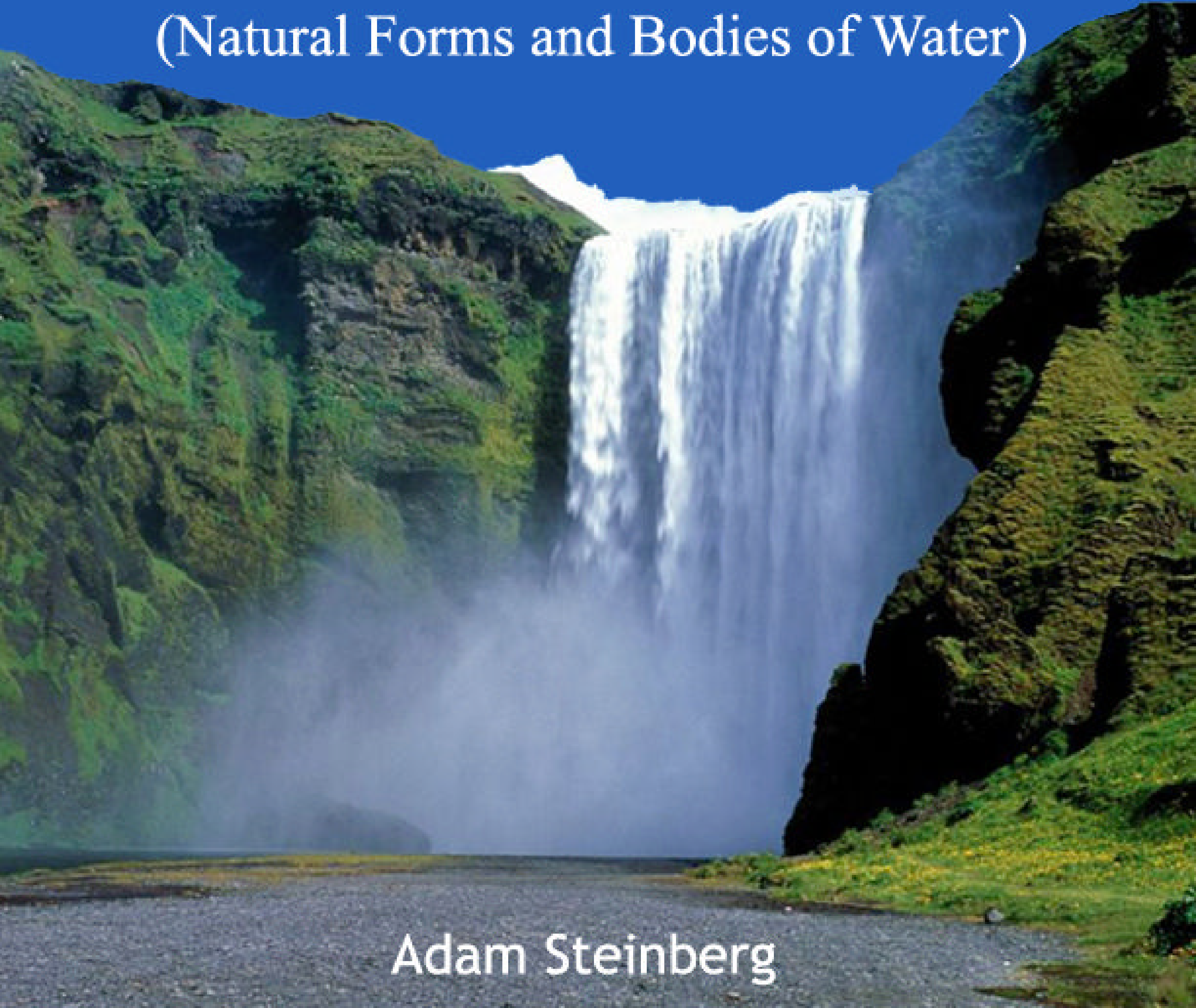
Water and Nature

(Natural Forms and Bodies of Water)



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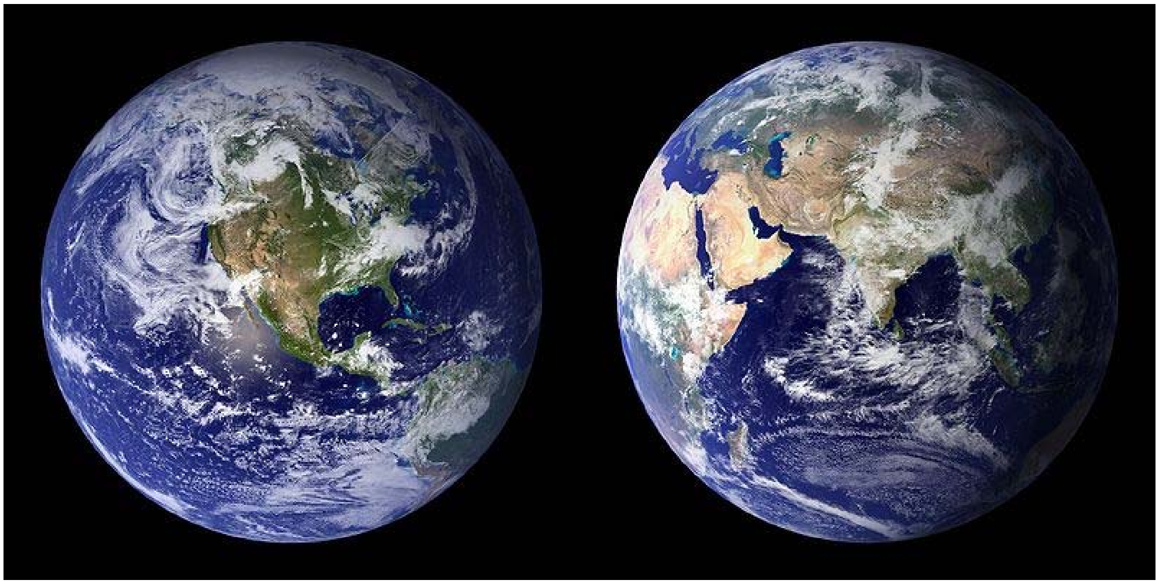
Origin of Water on Earth



Water covers about 70% of the Earth's surface

The question of the **origin of water on Earth**, or the question of why there is clearly more water on the Earth than on the other planets of the Solar System, has not been clarified. There are several acknowledged theories as to how the world's oceans were formed over the past 4.6 billion years.

Origins

Some of the most likely contributory factors to the origin of the Earth's oceans are as follows:

- The cooling of the primordial Earth to the point where the outgassed volatile components were held in an atmosphere of sufficient pressure for the stabilization and retention of liquid water.
- Comets, trans-Neptunian objects or water-rich meteorites (protoplanets) from the outer reaches of the main asteroid belt colliding with the Earth may have brought water to the world's oceans. Measurements of the ratio of the hydrogen isotopes

deuterium and protium point to asteroids, since similar percentage impurities in carbon-rich chondrites were found to oceanic water, whereas previous measurement of the isotopes' concentrations in comets and trans-Neptunian objects correspond only slightly to water on the earth.

- Biochemically through mineralization and photosynthesis (guttation, transpiration).
- Gradual leakage of water stored in hydrous minerals of the Earth's rocks.
- Photolysis: radiation can break down chemical bonds on the surface.

Water in the development of the Earth

A sizeable quantity of water would have been in the material which formed the Earth. Water molecules would have escaped Earth's gravity more easily when it was less massive during its formation. Hydrogen and helium are expected to continually leak from the atmosphere, but the lack of denser noble gases in the modern atmosphere suggests that something disastrous happened to the early atmosphere.

Part of the young planet is theorized to have been disrupted by the impact which created the Moon, which should have caused melting of one or two large areas. Present composition does not match complete melting and it is hard to completely melt and mix huge rock masses. However, a fair fraction of material should have been vaporized by this impact, creating a rock-vapor atmosphere around the young planet. The rock-vapor would have condensed within two thousand years, leaving behind hot volatiles which probably resulted in a heavy carbon dioxide atmosphere with hydrogen and water vapor. Liquid water oceans existed despite the surface temperature of 230°C because of the atmospheric pressure of the heavy CO_2 atmosphere. As cooling continued, subduction and dissolving in ocean water removed most CO_2 from the atmosphere but levels oscillated wildly as new surface and mantle cycles appeared.

Study of zircons has found that liquid water must have existed as long ago as 4.4 Ga, very soon after the formation of the Earth. This requires the presence of an atmosphere. The Cool Early Earth theory covers a range from about 4.4 Ga to 4.0 Ga.

In fact, recent studies of zircons (in the fall of 2008) found in Australian Hadean rock hold minerals that point to the existence of plate tectonics as early as 4 billion years ago. If this holds true, the previous beliefs about the Hadean period are far from correct. That is, rather than a hot, molten surface and atmosphere full of carbon dioxide, the Earth's surface would be very much like it is today. The action of plate tectonics traps vast amounts of carbon dioxide, thereby eliminating the greenhouse effects and leading to a much cooler surface temperature and the formation of solid rock, and possibly even life.

Extraterrestrial sources

That the Earth's water originated purely from comets is implausible, as a result of measurements of the isotope ratios of hydrogen in the three comets Halley, Hyakutake and Hale-Bopp by researchers like David Jewitt, as according to this research the ratio of deuterium to protium (D/H ratio) of the comets is approximately double that of oceanic water. What is however unclear is whether these comets are representative of those from the Kuiper Belt. According to A. Morbidelli the largest part of today's water comes from protoplanets formed in the outer asteroid belt that plunged towards the Earth, as indicated by the D/H proportions in carbon-rich chondrites. The water in carbon-rich chondrites point to a similar D/H ratio as oceanic water. Nevertheless, mechanisms have been proposed to suggest that the D/H-ratio of oceanic water may have increased significantly throughout Earth's history. Such a proposal is consistent with the possibility that a significant amount of the water on Earth was already present during the planet's early evolution.

Role of organisms

In the primordial sea's hydrogen sulfide and in the primitive atmosphere present carbon dioxide was used by sulfide-dependent chemoautotrophic bacteria (prokaryotes) with the supply of light energy for the creation of organic compounds, whereby water and sulfur resulted:

$$4\ \mathrm{H_2S} + \mathrm{CO_2} \rightarrow \mathrm{CH_4} + 2\ \mathrm{H_2O} + 4\ \mathrm{S}$$

The greatest proportion of today's water may have been synthesized biochemically through mineralization and photosynthesis (Calvin cycle).

Evolution of water on Mars and Earth

The evolution of water (H_2O) on either planet needs be understood in the context of the other terrestrial planetary bodies and their current water status.

Water (H_2O) Inventory of Mars

A significant amount of surface hydrogen has been observed globally by the Mars Odyssey GRS. Stoichiometrically estimated water mass fractions indicate that - when free of carbon dioxide - the near surface at the poles consists almost entirely of water covered by a thin veneer of fine material. This is reinforced by MARSIS observations, with an estimated 1.6×10^6 km^3 of water at the southern polar region with Water Equivalent to a Global layer (WEG) 11 meters deep. Additional observations at both poles suggest the total WEG to be 30 m, while the Mars Odyssey NS observations places the lower bound at ~14 cm depth. Geomorphic evidence favors significantly larger quantities of surface water over geologic history, with WEG as deep as 500 m. The current atmospheric reservoir of water, though important as a conduit, is insignificant in volume with the WEG no more than 10 µm. Since the typical surface pressure of the current atmosphere (~6 hPa) is less than the triple point of H_2O, liquid water is unstable on the surface unless present in sufficiently large volumes. Furthermore, the average global temperature is ~220 K, even below the eutectic freezing point of most brines. For comparison, the highest diurnal surface temperatures at the two MER sites have been ~290 K.

H_2O Inventory of Venus

The current Venusian atmosphere has only ~200 mg/kg $H_2O(g)$ in its atmosphere and the pressure and temperature regime makes water unstable on its surface. Nevertheless, assuming that early Venus's H_2O had a D/H ratio similar to Earth's Vienna Standard Mean Ocean Water (VSMOW) of $1.6x10^{-4}$, the current D/H isotopic ratio in the Venusian atmosphere of $1.9x10^{-2}$, at nearly x120 of Earth's, may indicate that Venus had a much larger H_2O inventory. While the large disparity between terrestrial and Venusian D/H ratios makes any estimation of Venus's geologically ancient water budget difficult, its mass may have been at least 0.3% of Earth's hydrosphere.

H_2O Inventories of Mercury, Moon, and Earth

Recent observation made by a number of spacecrafts confirmed significant amounts of Lunar water. Mercury does not appear to contain observable quantities of H_2O, presumably due to loss from giant impacts. In contrast, Earth's hydrosphere contains ~$1.46x10^{21}$ kg of H_2O and sedimentary rocks contain ~$0.21x10^{21}$ kg, for a total crustal inventory of ~$1.67x10^{21}$ kg of H_2O. The mantle inventory is poorly constrained in the range of $(0.5 - 4)x10^{21}$ kg. Therefore, the bulk inventory of H_2O on Earth can be conservatively estimated as 0.04% of Earth's mass (~$6x10^{24}$ kg).

Accretion of H_2O by Earth and Mars

The D/H isotopic ratio is a primary constraint on the source of H_2O of terrestrial planets. Comparison of the planetary D/H ratios with those of carbonaceous chondrites and comets enables a tentative determination of the source of H_2O. The best constraints for accreted H_2O are determined from non-atmospheric H_2O, as the D/H ratio of the atmospheric component may be subject to rapid alteration by the preferential loss of H unless it is in isotopic equilbrium with surface H_2O. Earth's VSMOW D/H ratio of $1.6x10^{-4}$ and modeling of impacts suggest that the cometary contribution to crustal water was less than 10%. However, much of the water could be derived from Mercury-sized planetary embryos that formed in the asteroid belt beyond 2.5 AU. Mars's original D/H ratio, as estimated by deconvolving the atmospheric and magmatic D/H components in Martian meteorites (e.g., QUE 94201), is x(1.9+/-0.25) the VSMOW value. The higher D/H and impact modeling (significantly different than for Earth due to Mars's smaller mass) favor a model where Mars accreted a total of 6% to 27% the mass of the current Earth hydrosphere, corresponding respectively to an original D/H between x1.6 and x1.2 the SMOW value. The former enhancement is consistent with roughly equal asteroidal and cometary contributions, while the latter would indicate mostly asteroidal contributions. The corresponding WEG would be 0.6 - 2.7 km, consistent with a 50% outgassing efficiency to yield ~500 m WEG of surface water. Comparing the current atmospheric D/H ratio of x5.5 SMOW ratio with the primordial x1.6 SMOW ratio suggests that ~50 m of has been lost to space via solar wind stripping.

The cometary and asteroidal delivery of water to accreting Earth and Mars has significant caveats, even though it is favored by D/H isotopic ratios. Key issues include:

1.
    1. The higher D/H ratios in Martian meteorites could be a consequence of biased sampling since Mars may have never had an effective crustal recycling process
    2. Earth's Primitive Upper Mantle estimate of the $^{187}Os/^{188}Os$ isotopic ratio exceeds 0.129, significantly greater than that of carbonaceous chondrites, but similar to anhydrous ordinary chondrites. This makes it unlikely that planetary embryos compositionally similar to carbonaceous chondrites supplied water to Earth
    3. Earth's atmospheric content of Ne is significantly higher than would be expected had all the rare gases and H_2O been accreted from planetary embryos with carbonaceous chondritic compositions.

An alternative to the cometary and asteroidal delivery of H_2O would be the accretion via physisorption during the formation of the terrestrial planets in the solar nebula. This would be consistent with the thermodynamic estimate of ~2 earth masses of water vapor within 3AU of the solar accretionary disk, which would exceed by a factor of 40 the mass of water needed to accrete the equivalent of 50 Earth hydrospheres (the most extreme estimate of Earth's bulk H_2O content) per terrestrial planet. Even though much of the nebular $H_2O(g)$ may be lost due to the high temperature environment of the accretionary disk, it is possible for physisorption of H_2O on accreting grains to retain nearly 3 Earth hydrospheres of H_2O at 500 K temperatures. This adsorption model would effectively avoid the $^{187}Os/^{188}Os$ isotopic ratio disparity issue of distally-sourced H_2O. However, the current best estimate of the nebular D/H ratio spectroscopically estimated with Jovian and Saturnian atmospheric CH_4 is only $2.1x10^{-5}$, a factor of 8 lower than Earth's VSMOW ratio. It is unclear how such a difference could exist if physisorption were indeed the dominant form of H_2O accretion for Earth in particular and the terrestrial planets in general.

Evolution of Mars's water inventory

The variation in Mars's surface water content is strongly coupled to the evolution of its atmosphere and may have been marked by several key stages.

Early Noachian (4.6 to 4.1 Ga) "phyllosian" era
Atmospheric loss to space from heavy meteoritic bombardment and hydrodynamic escape. Ejection by meteorites may have removed ~60% of the early atmosphere. Significant quantities of phyllosilicates may have formed during this period requiring a sufficiently dense to sustain surface water, as the spectrally dominant phyllosilicate group, smectite, suggests moderate water: rock ratios. However, the pH-pCO_2 equilibria

between smectite and carbonate show that the precipitation of smectite would constrain pCO_2 to a value not more than 10^{-2} atm. As a result, the dominant component of a dense atmosphere on early Mars becomes uncertain if the clays formed in contact with the Martian atmosphere, particularly given the lack of evidence for carbonate deposits. An additional complication is that the ~25% lower brightness of the young Sun would have required an ancient atmosphere with a significant greenhouse effect to raise surface temperatures to sustain liquid water. Higher CO_2 content alone would have been insufficient, as CO_2 precipitates at partial pressures exceeding 1.5 atm, reducing its effectiveness as a greenhouse gas.

Middle to late Noachian (4.1 to 3.8 Ga)

Potential formation of a secondary atmosphere by outgassing dominated by the Tharsis volcanoes, including significant quantities of H_2O, CO_2, and SO_2. Martian valley networks date to this period, indicating globally widespread and temporally sustained surface water as opposed to catastrophic floods. The end of this period coincides with the termination of the internal magnetic field and a spike in meteoritic bombardment. The cessation of the internal magnetic field and subsequent weakening of any local magnetic fields allowed unimpeded atmospheric stripping by the solar wind. For example, when compared with their terrestrial counterparts, $^{38}Ar/^{36}Ar$, $^{15}N/^{14}N$, and $^{13}C/^{12}C$ ratios of the Martian atmosphere are consistent with ~60% loss of Ar, N_2, and CO_2 by solar wind stripping of an upper atmosphere enriched in the lighter isotopes via Rayleigh fractionation. Supplementing the solar wind activity, impacts would have ejected atmospheric components in bulk without isotopic fractionation. Nevertheless, cometary impacts in particular may have contributed volatiles to the planet.

Hesperian to the present (the "theiikian" era from ~3.8 Ga to ~3.5 Ga and the "siderikian" era postdating ~3.5Ga)

Atmospheric enhancement by sporadic outgassing events were countered by solar wind stripping of the atmosphere, albeit less intensely than by the young Sun. Catastrophic floods date to this period, favoring sudden subterranean release of volatiles, as opposed to sustained surface flows. While the earlier portion of this era may have been marked by aqueous acidic environments and Tharsis-centric groundwater discharge dating to the late Noachian, much of the surface alteration processes during the latter portion is marked by oxidative processes including the formation of Fe^{3+} oxides that impart a reddish hue to the Martian surface. Such oxidation of primary mineral phases can be achieved by low-pH (and possibly high temperature) processes related to the formation of palagonitic tephra, by the action of H_2O_2 that forms photochemically in the Martian atmosphere, and by the action of water, none of which require free O_2. The action of H_2O_2 may have dominated temporally given the drastic reduction in aqueous and igneous activity in this recent era, making the observed Fe^{3+} oxides volumetrically small, though pervasive and spectrally dominant. Nevertheless, aquifers may have driven sustained but highly localized surface water in recent geologic history, as evident in the geomorphology of craters such as Mojave. Furthermore, the Lafayette Martian meteorite shows evidence of aqueous alteration as recently as 650 Ma.

Chapter- 2

Lake

Oeschinen Lake in the Swiss Alps

A **lake** is a body of relatively still fresh or salt water of considerable size, localized in a basin that is surrounded by land. Lakes are inland and not part of the ocean, and are larger and deeper than ponds. Lakes can be contrasted with rivers or streams, which are usually flowing. However most lakes are fed and drained by rivers and streams.

Natural lakes are generally found in mountainous areas , rift zones, and areas with ongoing glaciation. Other lakes are found in endorheic basins or along the courses of mature rivers. In some parts of the world there are many lakes because of chaotic drainage patterns left over from the last Ice Age. All lakes are temporary over geologic time scales, as they will slowly fill in with sediments or spill out of the basin containing them.

Many lakes are artificial and are constructed for industrial or agricultural use, for hydro-electric power generation or domestic water supply, or for aesthetic or recreational purposes.

Etymology, meaning, and usage of "lake"

Blowdown Lake in the mountains near Pemberton, British Columbia

Lake Tahoe on the border of California and Nevada

The Caspian Sea is either the world's largest lake or a full-fledged sea.

The word *lake* comes from Middle English *lake* ("lake, pond, waterway"), from Old English *lacu* ("pond, pool, stream"), from Proto-Germanic **lakō* ("pond, ditch, slow moving stream"), from the Proto-Indo-European root **leg'*- ("to leak, drain"). Cognates include Dutch *laak* ("lake, pond, ditch"), Middle Low German *lāke* ("water pooled in a riverbed, puddle"), German *Lache* ("pool, puddle"), and Icelandic *lækur* ("slow flowing stream"). Also related are the English words *leak* and *leach*.

There is considerable uncertainty about defining the difference between lakes and ponds, and no current internationally accepted definition of either term across scientific disciplines or political boundaries exists. For example, limnologists have defined lakes as water bodies which are simply a larger version of a pond, which have wave action on the shoreline or where wind-induced turbulence plays a major role in mixing the water column. None of these definitions completely excludes ponds and all are difficult to measure. For this reason there has been increasing use made of simple size-based definitions to separate ponds and lakes. One definition of *lake* is a body of water of 2 hectares (5 acres) or more in area, [:331] however others have defined lakes as waterbodies of 5 hectares (12 acres) and above, or 8 hectares (20 acres) and above. Charles Elton, one of the founders of ecology, regarded lakes as waterbodies of 40 hectares (99 acres) or more. The term *lake* is also used to describe a feature such as Lake Eyre, which is a dry basin most of the time but may become filled under seasonal conditions of heavy rainfall. In common usage many lakes bear names ending with the word *pond*, and a lesser number of names ending with *lake* are in quasi-technical fact, ponds.

In lake ecology the environment of a lake is referred to as *lacustrine*. Large lakes are occasionally referred to as "inland seas," and small seas are occasionally referred to as lakes, such as Lake Maracaibo, which is actually a bay. Larger lakes often invert the word order, as in the names of each of the Great Lakes,in North America.

Only one lake in the English Lake District is actually called a lake; other than Bassenthwaite Lake, the others are all *meres* or *waters*. Only six bodies of water in Scotland are known as lakes (the others are lochs): the Lake of Menteith, the Lake of the Hirsel, Pressmennan Lake, Cally Lake near Gatehouse of Fleet, the saltwater Manxman's Lake at Kirkcudbright Bay and The Lake at Fochabers. Of these only the Lake of Menteith and Cally Lake are natural bodies of fresh water.

Distribution of lakes

The Seven Rila Lakes are a group of glacial lakes in the Bulgarian Rila mountains.

The majority of lakes on Earth are fresh water, and most lie in the Northern Hemisphere at higher latitudes. More than 60 percent of the world's lakes are in Canada; this is because of the deranged drainage system that dominates the country.

Finland is known as *The Land of the Thousand Lakes*, (actually there are 187,888 lakes in Finland, of which 60,000 are large), and the U.S. state of Minnesota is known as *The Land of Ten Thousand Lakes*. The license plates of the Canadian province of Manitoba used to claim *100,000 lakes* as one-upmanship on Minnesota, whose license plates boast of its *10,000 lakes.*

Most lakes have at least one natural outflow in the form of a river or stream, which maintain a lakes's average level by allowing the drainage of excess water. Some do not and lose water solely by evaporation or underground seepage or both. They are termed endorheic lakes (see below).

Many lakes are artificial and are constructed for hydro-electric power generation, aestetic purposes, recreational purposes, industrial use, agricultural use or domestic water supply.

Evidence of extraterrestrial lakes exists; "definitive evidence of lakes filled with methane" was announced by NASA as returned by the Cassini Probe observing the moon Titan, which orbits the planet Saturn.

Globally, lakes are greatly outnumbered by ponds: of an estimated 304-million standing water bodies worldwide, 91 percent are 1 hectare (2.5 acres) or less in area. Small lakes are also much more numerous than big lakes: in terms of area, one-third of the world's standing water is represented by lakes and ponds of 10 hectares (25 acres) or less. However, large lakes contribute disproportionately to the area of standing water with 122 large lakes of 1,000 square kilometres (390 sq mi, 100,000 ha, 247,000 acres) or more representing about 29 percent of the total global area of standing inland water.

Origin of natural lakes

A portion of the Great Salt Lake in Utah, United States

Salt crystals, on the shore of Lake Urmia, Iran

There are a number of natural processes that can form lakes. A recent tectonic uplift of a mountain range can create bowl-shaped depressions that accumulate water and form lakes. The advance and retreat of glaciers can scrape depressions in the surface where water accumulates; such lakes are common in Scandinavia, Patagonia, Siberia and Canada. The most notable examples are probably the Great Lakes of North America.

Lakes can also form by means of landslides or by glacial blockages. An example of the latter occurred during the last ice age in the U.S. state of Washington, when a huge lake formed behind a glacial flow; when the ice retreated, the result was an immense flood that created the Dry Falls at Sun Lakes, Washington.

Salt lakes (also called saline lakes) can form where there is no natural outlet or where the water evaporates rapidly and the drainage surface of the water table has a higher-than-normal salt content. Examples of salt lakes include Great Salt Lake, the Aral Sea and the Dead Sea.

Small, crescent-shaped lakes called oxbow lakes can form in river valleys as a result of meandering. The slow-moving river forms a sinuous shape as the outer side of bends are eroded away more rapidly than the inner side. Eventually a horseshoe bend is formed and the river cuts through the narrow neck. This new passage then forms the main passage for the river and the ends of the bend become silted up, thus forming a bow-shaped lake.

Crater lakes are formed in volcanic craters and calderas which fill up with precipitation more rapidly than they empty via evaporation. Sometimes the latter are called caldera lakes, although often no distinction is made. An example is Crater Lake in Oregon, located within the caldera of Mount Mazama. The caldera was created in a massive volcanic eruption that led to the subsidence of Mount Mazama around 4860 BC.

Gloe Lakes are freshwater lakes that have emerged when the water they consists of has been separated, not considerably long before, from the sea as a consequence of post-glacial rebound.

Some lakes, such as Lake Jackson in Florida, USA, come into existence as a result of sinkhole activity.

Lake Vostok is a subglacial lake in Antarctica, possibly the largest in the world. The pressure from the ice atop it and its internal chemical composition mean that, if the lake were drilled into, a fissure could result that would spray somewhat like a geyser.

Most lakes are geologically young and shrinking since the natural results of erosion will tend to wear away the sides and fill the basin. Exceptions are those such as Lake Baikal and Lake Tanganyika that lie along continental rift zones and are created by the crust's subsidence as two plates are pulled apart. These lakes are the oldest and deepest in the world. Lake Baikal, which is 25-30 million years old, is deepening at a faster rate than it is being filled by erosion and may be destined over millions of years to become attached to the global ocean. The Red Sea, for example, is thought to have originated as a rift valley lake.

Types of lakes

One of the many artificial lakes in Arizona at sunset.

The crater lake of Volcán Irazú, Costa Rica.

These kettle lakes in Alaska were formed by a retreating glacier.

Ephemeral 'Lake Badwater', a lake only noted after heavy winter and spring rainfall, Badwater Basin, Death Valley National Park.

- Periglacial lake: Part of the lake's margin is formed by an ice sheet, ice cap or glacier, the ice having obstructed the natural drainage of the land.
- Subglacial lake: A lake which is permanently covered by ice. They can occur under glaciers, ice caps or ice sheets. There are many such lakes, but Lake Vostok in Antarctica is by far the largest. They are kept liquid because the overlying ice acts as a thermal insulator retaining energy introduced to its underside by friction, by water percolating through crevasses, by the pressure from the mass of the ice sheet above or by geothermal heating below.
- Glacial lake: a lake with origins in a melted glacier, like a kettle lake.
- Artificial lake: A lake created by flooding land behind a dam, called an impoundment or reservoir, by deliberate human excavation, or by the flooding of an excavation incident to a mineral-extraction operation such as an open pit mine or quarry. Some of the world's largest lakes are reservoirs like Hirakud Dam in India.
- Endorheic lake, terminal or closed: A lake which has no significant outflow, either through rivers or underground diffusion. Any water within an endorheic basin leaves the system only through evaporation or seepage. These lakes, such as Lake Eyre in central Australia or the Aral Sea in central Asia, are most common in desert locations.

- Meromictic lake: A lake which has layers of water which do not intermix. The deepest layer of water in such a lake does not contain any dissolved oxygen. The layers of sediment at the bottom of a meromictic lake remain relatively undisturbed because there are no living aerobic organisms.
- Fjord lake: A lake in a glacially eroded valley that has been eroded below sea level.
- Oxbow lake: A lake which is formed when a wide meander from a stream or a river is cut off to form a lake. They are called "oxbow" lakes due to the distinctive curved shape that results from this process.
- Rift lake or sag pond: A lake which forms as a result of subsidence along a geological fault in the Earth's tectonic plates. Examples include the Rift Valley lakes of eastern Africa and Lake Baikal in Siberia.
- Underground lake: A lake which is formed under the surface of the Earth's crust. Such a lake may be associated with caves, aquifers or springs.
- Crater lake: A lake which forms in a volcanic caldera or crater after the volcano has been inactive for some time. Water in this type of lake may be fresh or highly acidic, and may contain various dissolved minerals. Some also have geothermal activity, especially if the volcano is merely dormant rather than extinct.
- Lava lake: A pool of molten lava contained in a volcanic crater or other depression. Lava lakes that have partly or completely solidified are also referred to as lava lakes.
- Former: A lake which is no longer in existence. Such lakes include prehistoric lakes and lakes which have permanently dried up through evaporation or human intervention. Owens Lake in California, USA, is an example of a former lake. Former lakes are a common feature of the Basin and Range area of southwestern North America.
- Ephemeral lake: A seasonal lake that exists as a body of water during only part of the year.
- Intermittent lake: A lake with no water during a part of the year.
- Shrunken: Closely related to *former* lakes, a shrunken lake is one which has drastically decreased in size over geological time. Lake Agassiz, which once covered much of central North America, is a good example of a shrunken lake. Two notable remnants of this lake are Lake Winnipeg and Lake Winnipegosis.
- Eolic lake: A lake which forms in a depression created by the activity of the winds.
- Vlei, in South Africa, shallow lakes which vary considerably with seasons

Characteristics

Lake Mapourika, New Zealand

Lakes have numerous features in addition to lake type, such as drainage basin (also known as catchment area), inflow and outflow, nutrient content, dissolved oxygen, pollutants, pH, and sedimentation.

Changes in the level of a lake are controlled by the difference between the input and output compared to the total volume of the lake. Significant input sources are precipitation onto the lake, runoff carried by streams and channels from the lake's catchment area, groundwater channels and aquifers, and artificial sources from outside the catchment area. Output sources are evaporation from the lake, surface and groundwater flows, and any extraction of lake water by humans. As climate conditions and human water requirements vary, these will create fluctuations in the lake level.

Lakes can be also categorized on the basis of their richness in nutrients, which typically affect plant growth. Nutrient-poor lakes are said to be *oligotrophic* and are generally clear, having a low concentration of plant life. *Mesotrophic lakes* have good clarity and an average level of nutrients. *Eutrophic* lakes are enriched with nutrients, resulting in good plant growth and possible algal blooms. *Hypertrophic* lakes are bodies of water that have been excessively enriched with nutrients. These lakes typically have poor clarity and are subject to devastating algal blooms. Lakes typically reach this condition due to human activities, such as heavy use of fertilizers in the lake catchment area. Such lakes are of little use to humans and have a poor ecosystem due to decreased dissolved oxygen.

Due to the unusual relationship between water's temperature and its density, lakes form layers called thermoclines, layers of drastically varying temperature relative to depth. Fresh water is most dense at about 4 degrees Celsius (39.2 °F) at sea level. When the temperature of the water at the surface of a lake reaches the same temperature as deeper water, as it does during the cooler months in temperate climates, the water in the lake can mix, bringing oxygen-starved water up from the depths and bringing oxygen down to decomposing sediments. Deep temperate lakes can maintain a reservoir of cold water year-round, which allows some cities to tap that reservoir for deep lake water cooling.

Lake Teletskoye, Siberia

Since the surface water of deep tropical lakes never reaches the temperature of maximum density, there is no process that makes the water mix. The deeper layer becomes oxygen starved and can become saturated with carbon dioxide, or other gases such as sulfur dioxide if there is even a trace of volcanic activity. Exceptional events, such as earthquakes or landslides, can cause mixing which rapidly brings the deep layers up to the surface and release a vast cloud of gas which lay trapped in solution in the colder water at the bottom of the lake. This is called a limnic eruption. An example is the disaster at Lake Nyos in Cameroon. The amount of gas that can be dissolved in water is directly related to pressure. As deep water surfaces, the pressure drops and a vast amount of gas comes out of solution. Under these circumstances carbon dioxide is hazardous because it is heavier than air and displaces it, so it may flow down a river valley to human settlements and cause mass asphyxiation.

The material at the bottom of a lake, or *lake bed*, may be composed of a wide variety of inorganics, such as silt or sand, and organic material, such as decaying plant or animal matter. The composition of the lake bed has a significant impact on the flora and fauna found within the lake's environs by contributing to the amounts and the types of nutrients available.

A paired (black and white) layer of the varved lake sediments correspond to a year. During winter, when organisms die, carbon is deposited down, resulting to a black layer. At the same year, during summer, only few organic materials are deposited, resulting to a white layer at the lake bed. These are commonly used to track past paleontological events.

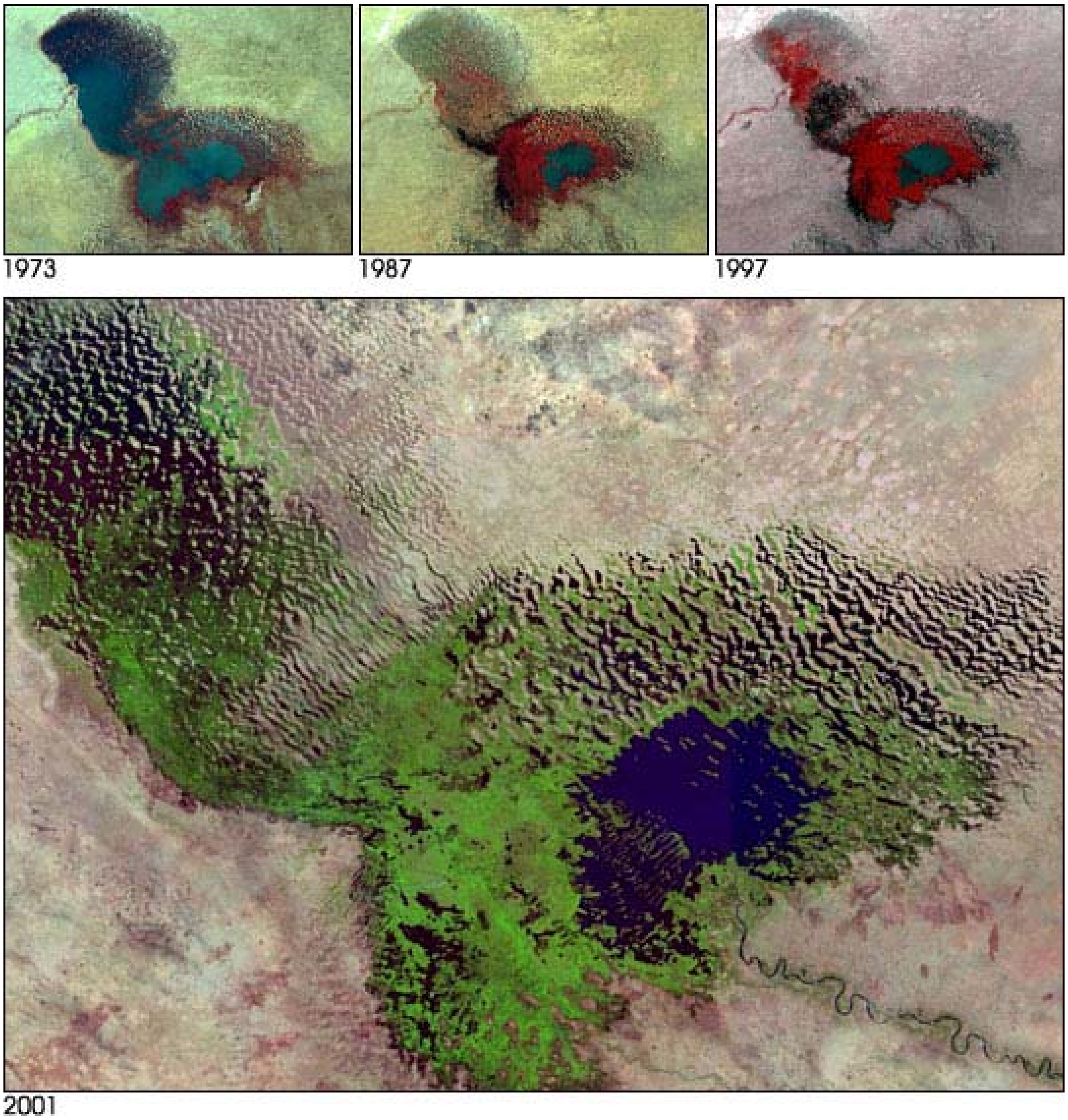
Limnology

Lake Billy Chinook, Deschutes National Forest, Oregon.

Limnology is the study of inland bodies of water and related ecosystems. Limnology divides lakes into three zones: the *littoral zone*, a sloped area close to land; the *photic* or *open-water zone*, where sunlight is abundant; and the deep-water *profundal* or *benthic* *zone*, where little sunlight can reach. The depth to which light can reach in lakes depends on turbidity, determined by the density and size of suspended particles. A particle is in suspension if its weight is less than the random turbidity forces acting upon it. These particles can be sedimentary or biological in origin and are responsible for the color of the water. Decaying plant matter, for instance, may be responsible for a yellow or brown color, while algae may cause greenish water. In very shallow water bodies, iron oxides make water reddish brown. Biological particles include algae and detritus. Bottom-dwelling detritivorous fish can be responsible for turbid waters, because they stir the mud in search of food. Piscivorous fish contribute to turbidity by eating plant-eating (planktonivorous) fish, thus increasing the amount of algae. The light depth or transparency is measured by using a *Secchi disk*, a 20-cm (8 in) disk with alternating white and black quadrants. The depth at which the disk is no longer visible is the *Secchi depth*, a measure of transparency. The Secchi disk is commonly used to test for eutrophication. For a detailed look at these processes.

A lake moderates the surrounding region's temperature and climate because water has a very high specific heat capacity (4,186 $J\cdot kg^{-1}\cdot K^{-1}$). In the daytime a lake can cool the land beside it with local winds, resulting in a sea breeze; in the night it can warm it with a land breeze.

How lakes disappear



Lake Chad in a 2001 satellite image, with the actual lake in blue, and vegetation on top of the old lake bed in green.

Lake Badwater, February 9, 2005. Landsat 5 satellite photo.

Badwater Basin dry lake, February 15, 2007. Landsat 5 satellite photo.

The lake may be infilled with deposited sediment and gradually become a wetland such as a swamp or marsh. Large water plants, typically totos, accelerate this closing process significantly because they partially decompose to form peat soils that fill the shallows. Conversely, peat soils in a marsh can naturally burn and reverse this process to recreate a shallow lake. Turbid lakes and lakes with many plant-eating fish tend to disappear more slowly. A "disappearing" lake (barely noticeable on a human timescale) typically has extensive plant mats at the water's edge. These become a new habitat for other plants, like peat moss when conditions are right, and animals, many of which are very rare. Gradually the lake closes and young peat may form, forming a fen. In lowland river valleys where a river can meander, the presence of peat is explained by the infilling of historical oxbow lakes. In the very last stages of succession, trees can grow in, eventually turning the wetland into a forest.

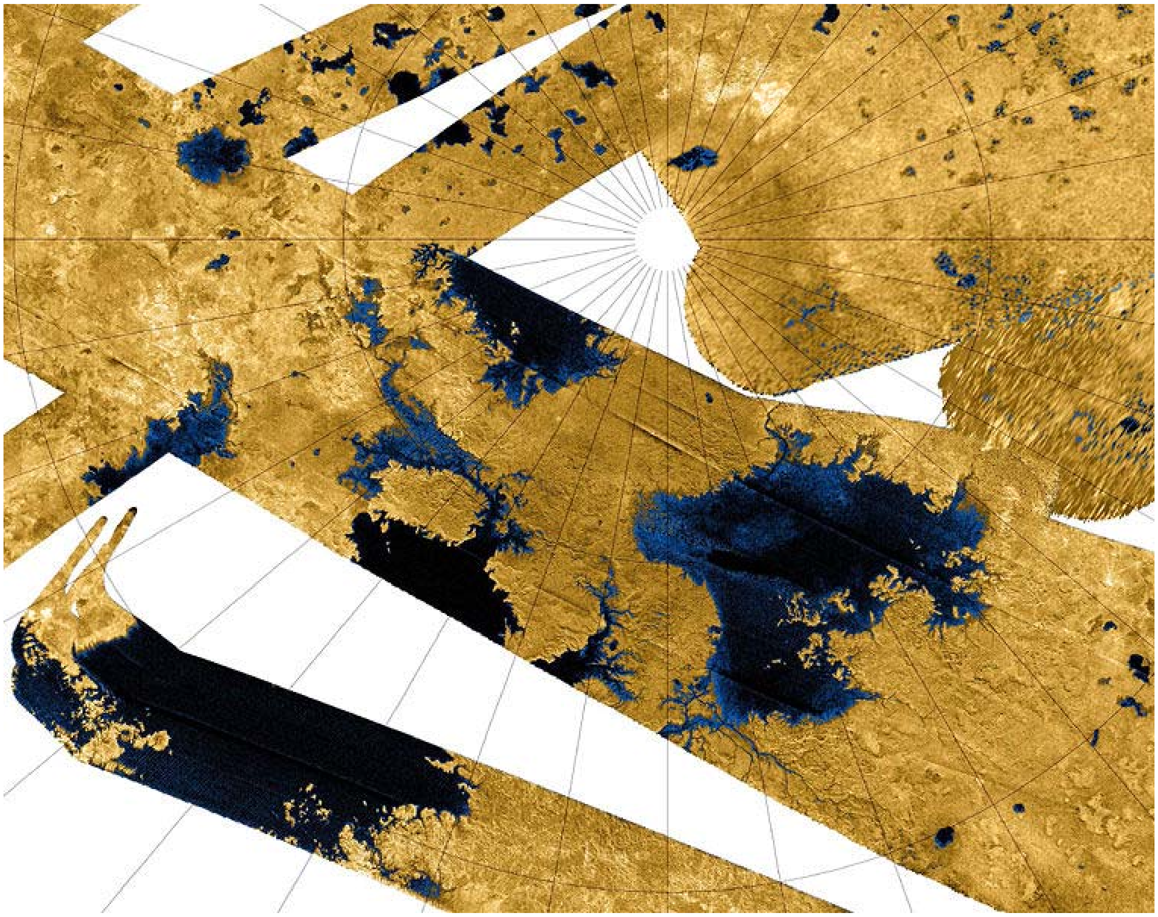
Some lakes can disappear seasonally. These are called intermittent lakes and can be found in karstic terrain. A prime example of an intermittent lake is Lake Cerknica in Slovenia. Other intermittent lakes are only the result of above-average precipitation in a closed, or endorheic basin, usually filling dry lake beds. This can occur in some of the driest places on earth, like Death Valley. This occurred in the spring of 2005, after unusually heavy rains. The lake did not last into the summer, and was quickly evaporated (see photos to right). A more commonly filled lake of this type is Sevier Lake of west-central Utah.

Sometimes a lake will disappear quickly. On 3 June 2005, in Nizhny Novgorod Oblast, Russia, a lake called Lake Beloye vanished in a matter of minutes. News sources reported that government officials theorized that this strange phenomenon may have been caused by a shift in the soil underneath the lake that allowed its water to drain through channels leading to the Oka River.

The presence of ground permafrost is important to the persistence of some lakes. According to research published in the journal *Science* ("Disappearing Arctic Lakes", June 2005), thawing permafrost may explain the shrinking or disappearance of hundreds of large Arctic lakes across western Siberia. The idea here is that rising air and soil temperatures thaw permafrost, allowing the lakes to drain away into the ground.

Some lakes disappear because of human development factors. The shrinking Aral Sea is described as being "murdered" by the diversion for irrigation of the rivers feeding it.

Extraterrestrial lakes



Titan's north polar hydrocarbon seas and lakes as seen in a false-color *Cassini* synthetic aperture radar mosaic.

At present the surface of the planet Mars is too cold and has too little atmospheric pressure to permit the pooling of liquid water on the surface. Geologic evidence appears to confirm, however, that ancient lakes once formed on the surface. It is also possible that volcanic activity on Mars will occasionally melt subsurface ice, creating large lakes. Under current conditions this water would quickly freeze and evaporate unless insulated in some manner, such as by a coating of volcanic ash.

Only one world other than Earth is known to harbor lakes, Saturn's largest moon, Titan. Photographs and spectroscopic analysis by the Cassini-Huygens spacecraft show liquid ethane on the surface, which is thought to be mixed with liquid methane.

Jupiter's small moon Io is volcanically active due to tidal stresses, and as a result sulfur deposits have accumulated on the surface. Some photographs taken during the Galileo mission appear to show lakes of liquid sulfur on the surface.

There are dark basaltic plains on the Moon, similar to lunar maria but smaller, that are called *lacus* (singular *lacus*, Latin for "lake") because they were thought by early astronomers to be lakes of water.

Notable lakes

Round Tangle Lake, one of the Tangle Lakes, located in the tatti of potti2,864 feet (873 m) above sea level in interior Alaska

- Lake Michigan-Huron is the **largest lake by surface area**: 117,350 km². It also has the longest lake coastline in the world: 8,790 km. If Huron and Michigan are considered two lakes, Lake Superior is the largest lake, with 82,414 km². However, Huron still has the longest coastline at 6,157 km (2980 km excluding the coastlines of its many inner islands). The world's smallest geological ocean, the Caspian Sea, at 394,299 km² has a surface area greater than the six largest freshwater lakes combined, and it's frequently cited as the world's largest lake.
- The **deepest** lake is Lake Baikal in Siberia, with a bottom at 1,637 m. Its **mean depth** is also the greatest in the world (749 m).
  It is also the world's **largest lake by volume** (23,600 km³, though smaller than the Caspian Sea at 78,200 km³), and the second longest (about 630 km from tip to tip).
- The **longest** lake is Lake Tanganyika, with a length of about 660 km (measured along the lake's center line).
  It is also the second largest by volume and second deepest (1,470 m) in the world, after lake Baikal.

- The world's **oldest** lake is Lake Baikal, followed by Lake Tanganyika (Tanzania).
- The world's **highest** lake is the crater lake of Ojos del Salado, at 6,390 metres (20,965 ft). The Lhagba Pool in Tibet at 6,368 m (20,892 ft) comes second.
- The highest large freshwater lake in the world is Lake Manasarovar in Tibet Autonomous Region of China.
- The world's **highest** commercially navigable lake is Lake Titicaca in Peru and Bolivia at 3,812 m (12,507 ft). It is also the largest freshwater (and second largest overall) lake in South America.
- The world's **lowest** lake is the Dead Sea, bordering Israel and Jordan at 418 m (1,371 ft) below sea level. It is also one of the lakes with highest salt concentration.
- Lake Huron has the **longest lake coastline** in the world: about 2980 km, excluding the coastline of its many inner islands.
- The largest island in a freshwater lake is Manitoulin Island in Lake Huron, with a surface area of 2,766 km². Lake Manitou, located on Manitoulin Island, is the largest lake on an island in a freshwater lake.
- The largest lake located on an island is Nettilling Lake on Baffin Island, with an area of 5,542 km² and a maximum length of 123 km.
- The largest lake in the world that drains naturally in two directions is Wollaston Lake.
- Lake Toba on the island of Sumatra is located in what is probably the largest resurgent caldera on Earth.
- The largest lake located completely within the boundaries of a single city is Lake Wanapitei in the city of Sudbury, Ontario, Canada. Before the current city boundaries came into effect in 2001, this status was held by Lake Ramsey, also in Sudbury.
- Lake Enriquillo in Dominican Republic is the only saltwater lake in the world inhabited by crocodiles.
- Lake Bernard, Ontario, Canada, is the largest freshwater lake in the world with no islands.
- The largest lake in one country is Lake Michigan, in the U.S.A. However, it is sometimes considered part of Lake Michigan-Huron, making the record go to Great Bear Lake, Northwest Territories, in Canada, the largest lake within one jourisdiction.

Largest by continent

The largest lakes (surface area) by continent are:

- **Australia** - Lake Eyre (salt lake)
- **Africa** - Lake Victoria, also the third-largest freshwater lake on Earth. It is one of the Great Lakes of Africa.
- **Antarctica** - Lake Vostok (subglacial)
- **Asia** - Lake Baikal (if the Caspian Sea is considered a lake, it is the largest in Eurasia, but is divided between the two geographic continents)

- **Oceania** - Lake Eyre when filled; the largest permanent (and freshwater) lake in Oceania is Lake Taupo.
- **Europe** - Lake Ladoga, followed by Lake Onega, both located in northwestern Russia.
- **North America** - Lake Michigan-Huron, which is hydrologically a single lake. However, lakes Huron and Michigan are often considered separate lakes, in which case Lake Superior would be the largest.
- **South America** - Lake Titicaca, which is also the highest navigable body of water on Earth at 3,821 m above sea level. The much larger Lake Maracaibo is considered by some to be the second-oldest lake on Earth, but since it lies at sea level and nowadays is a contiguous body of water with the sea, others consider that it has turned into a bay.

Chapter- 3

Lentic Ecosystem

Fig. 1 This mountain pool is an example of a lentic system.

A **lentic ecosystem** is the ecosystem of a lake, pond or swamp. Included in the environment are the biotic interactions (amongst plants, animals and micro-organisms) and the abiotic interactions (physical and chemical).

Lentic refers to standing or still water. It is derived from the Latin *lentus*, which means sluggish. Lentic ecosystems can be compared with lotic ecosystems, which involve flowing terrestrial waters such as rivers and streams. Together, these two fields form the more general study area of freshwater or aquatic ecology.

Lentic systems are diverse, ranging from a small, temporary rainwater pool a few inches deep to Lake Baikal, which has a maximum depth of 1740 m. The general distinction between pools/ponds and lakes is vague, but Brown states that ponds and pools have their entire bottom surfaces exposed to light, while lakes do not. In addition, some lakes become seasonally stratified (discussed in more detail below.) Ponds and pools have two regions: the pelagic open water zone, and the benthic zone, which comprises the bottom and shore regions. Since lakes have deep bottom regions not exposed to light, these systems have an additional zone, the profundal. These three areas can have very different abiotic conditions and, hence, host species that are specifically adapted to live there.

Lentic system biota

Bacteria

Bacteria are present in all regions of lentic waters. Free-living forms are associated with decomposing organic material, biofilm on the surfaces of rocks and plants, suspended in the water column, and in the sediments of the benthic and profundal zones. Other forms are also associated with the guts of lentic animals as parasites or in commensal relationships. Bacteria play an important role in system metabolism through nutrient recycling, which is discussed in the Trophic Relationships section.

Primary producers

Algae, including both phytoplankton and periphyton are the principle photosynthesizers in ponds and lakes. Phytoplankton are found drifting in the water column of the pelagic zone. Many species have a higher density than water which should making them sink and end up in the benthos. To combat this, phytoplankton have developed density changing mechanisms, by forming vacuoles and gas vesicles or by changing their shapes to induce drag, slowing their descent. A very sophisticated adaptation utilized by a small number of species is a tail-like flagella that can adjust vertical position and allow movement in any direction. Phytoplankton can also maintain their presence in the water column by being circulated in Langmuir rotations. Periphytic algae, on the other hand, are attached to a substrate. In lakes and ponds, they can cover all benthic surfaces. Both types of plankton are important as food sources and as oxygen providers.

Plants, or macrophytes, in lentic systems live in both the benthic and pelagic zones and can be grouped according to their manner of growth: 1) emergent macrophytes = rooted in the substrate but with leaves and flowers extending into the air, 2) floating-leaved macrophytes = rooted in the substrate but with floating leaves, 3) submersed macrophytes = not rooted in the substrate and floating beneath the surface and 4) free-floating macrophytes = not rooted in the substrate and floating on the surface. These various forms of macrophytes generally occur in different areas of the benthic zone, with emergent vegetation nearest the shoreline, then floating-leaved macrophytes, followed by submersed vegetation. Free-floating macrophytes can occur anywhere on the system's surface.

Aquatic plants are more buoyant than their terrestrial counterparts because freshwater has a higher density than air. This makes structural rigidity unimportant in lakes and ponds (except in the aerial stems and leaves). Thus, the leaves and stems of most aquatic plants use less energy to construct and maintain woody tissue, investing that energy into fast growth instead. In order to contend with stresses induced by wind and waves, plants must be both flexible and tough (Reynolds 2004). Light is the most important factor controlling the distribution of submerged aquatic plants. Macrophytes are sources of food, oxygen, and habitat structure in the benthic zone, but cannot penetrate the depths of the euphotic zone and hence are not found there.

Invertebrates

Water striders are predatory insects which rely on surface tension to walk on top of water. They live on the surface of ponds, marshes, and other quiet waters. They can move very quickly, up to 1.5 m/s.

Zooplankton are tiny animals suspended in the water column. Like phytoplankton, these species have developed mechanisms that keep them from sinking to deeper waters, including drag-inducing body forms and the active flicking of appendages such as antennae or spines. Remaining in the water column may have its advantages in terms of feeding, but this zone’s lack of refugia leaves zooplankton vulnerable to predation. In response, some species, especially Daphnia sp., make daily vertical migrations in the water column by passively sinking to the darker lower depths during the day and actively moving towards the surface during the night. Also, because conditions in a lentic system can be quite variable across seasons, zooplankton have the ability to switch from laying regular eggs to resting eggs when there is a lack of food, temperatures fall below 2 °C, or if predator abundance is high. These resting eggs have a diapause, or dormancy period that should allow the zooplankton to encounter conditions that are more favorable to survival when they finally hatch. The invertebrates that inhabit the benthic zone are numerically dominated by small species and are species rich compared to the zooplankton of the open water. They include Crustaceans (e.g. crabs, crayfish, and shrimp), molluscs (e.g. clams and snails), and numerous types of insects. These organisms are mostly found in the areas of macrophyte growth, where the richest resources, highly oxygenated water, and warmest portion of the ecosystem are found. The structurally diverse macrophyte beds are important sites for the accumulation of organic matter, and provide an ideal area for colonization. The sediments and plants also offer a great deal of protection from predatory fishes.

Very few invertebrates are able to inhabit the cold, dark, and oxygen poor profundal zone. Those that can are often red in color due to the presence of large amounts of hemoglobin, which greatly increases the amount of oxygen carried to cells. Because the concentration of oxygen within this zone is low, most species construct tunnels or borrows in which they can hide and make the minimum movements necessary to circulate water through, drawing oxygen to them without expending much energy.

Fishes and other vertebrates

Fishes have a range of physiological tolerances that are dependent upon which species they belong to. They have different lethal temperatures, dissolved oxygen requirements, and spawning needs that are based on their activity levels and behaviors. Because fishes are highly mobile, they are able to deal with unsuitable abiotic factors in one zone by simply moving to another. A detrital feeder in the profundal zone, for example, that finds the oxygen concentration has dropped too low may feed closer to the benthic zone. A fish might also alter its residence during different parts of its life history: hatching in a sediment nest, then moving to the weedy benthic zone to develop in a protected environment with food resources, and finally into the pelagic zone as an adult.

Other vertebrate taxa inhabit lentic systems as well. These include amphibians (e.g. salamanders and frogs), reptiles (e.g. snakes, turtles, and alligators), and a large number of waterfowl species. Most of these vertebrates spend part of their time in terrestrial habitats and thus are not directly affected by abiotic factors in the lake or pond. Many fish species are important as consumers and as prey species to the larger vertebrates mentioned above.

Trophic relationships

Primary producers

Lentic systems gain most of their energy from photosynthesis performed by aquatic plants and algae. This autochthonous process involves the combination of carbon dioxide, water, and solar energy to produce carbohydrates and dissolved oxygen. Within a lake or pond, the potential rate of photosynthesis generally decreases with depth due to light attenuation. Photosynthesis, however, is often low at the top few millimeters of the surface, likely due to inhibition by ultraviolet light. The exact depth and photosynthetic rate measurements of this curve are system specific and depend upon: 1) the total biomass of photosynthesizing cells, 2) the amount of light attenuating materials and 3) the abundance and frequency range of light absorbing pigments (i.e. chlorophylls) inside of photosynthesizing cells. The energy created by these primary producers is important for the community because it is transferred to higher trophic levels via consumption.

Bacteria

The vast majority of bacteria in lakes and ponds obtain their energy by decomposing vegetation and animal matter. In the pelagic zone, dead fish and the occasional allochthonous input of litterfall are examples of coarse particulate organic matter (CPOM>1 mm). Bacteria degrade these into fine particulate organic matter (FPOM<1 mm) and then further into usable nutrients. Small organisms such as plankton are also characterized as FPOM. Very low concentrations of nutrients are released during decomposition because the bacteria are utilizing them to build their own biomass. Bacteria, however, are consumed by protozoa, which are in turn consumed by zooplankton, and then further up the trophic levels. Nutrients, including those that contain carbon and phosphorus, are reintroduced into the water column at any number of points along this food chain via excretion or organism death, making them available again for bacteria. This regeneration cycle is known as the microbial loop and is a key component of lentic food webs.

The decomposition of organic materials can continue in the benthic and profundal zones if the matter falls through the water column before being completely digested by the pelagic bacteria. Bacteria are found in the greatest abundance here in sediments, where they are typically 2-1000 times more prevalent than in the water column.

Benthic invertebrates, due to their high level of species richness, have many methods of prey capture. Filter feeders create currents via siphons or beating cilia, to pull water and its nutritional contents, towards themselves for straining. Grazers use scraping, rasping, and shredding adaptations to feed on periphytic algae and macrophytes. Members of the collector guild browse the sediments, picking out specific particles with raptorial appendages. Deposit feeding invertebrates indiscriminately consume sediment, digesting any organic material it contains. Finally, some invertebrates belong to the predator guild, capturing and consuming living animals. The profundal zone is home to a unique group of filter feeders that use small body movements to draw a current through burrows that they have created in the sediment. This mode of feeding requires the least amount of motion, allowing these species to conserve energy. A small number of invertebrate taxa are predators in the profundal zone. These species are likely from other regions and only come to these depths to feed. The vast majority of invertebrates in this zone are deposit feeders, getting their energy from the surrounding sediments.

Fish

Fish size, mobility, and sensory capabilities allow them to exploit a broad prey base, covering multiple zonation regions. Like invertebrates, fish feeding habits can be categorized into guilds. In the pelagic zone, herbivores graze on periphyton and macrophytes or pick phytoplankton out of the water column. Carnivores include fishes that feed on zooplankton in the water column (zooplanktivores), insects at the water's surface, on benthic structures, or in the sediment (insectivores), and those that feed on other fishes (piscivores). Fish that consume detritus and gain energy by processing its organic material are called detritivores. Omnivores ingest a wide variety of prey, encompassing floral, faunal, and detrital material. Finally, members of the parasitic guild acquire nutrition from a host species, usually another fish or large vertebrate. Fish taxa are flexible in their feeding roles, varying their diets with environmental conditions and prey availability. Many species also undergo a diet shift as they develop. Therefore, it is likely that any single fish occupies multiple feeding guilds within its lifetime.

Lentic food webs

As noted in the previous sections, the lentic biota are linked in complex web of trophic relationships. These organisms can be considered to loosely be associated with specific trophic groups (e.g. primary producers, herbivores, primary carnivores, secondary carnivores, etc.). Scientists have developed several theories in order to understand the mechanisms that control the abundance and diversity within these groups. Very generally, top-down processes dictate that the abundance of prey taxa is dependent upon the actions of consumers from higher trophic levels. Typically, these processes operate only between two trophic levels, with no effect on the others. In some cases, however, aquatic systems experience a trophic cascade; for example, this might occur if primary producers experience less grazing by herbivores because these herbivores are suppressed by carnivores. Bottom-up processes are functioning when the abundance or diversity of members of higher trophic levels is dependent upon the availability or quality of resources from lower levels. Finally, a combined regulating theory, bottom-up:top-down, combines the predicted influences of consumers and resource availability. It predicts that trophic levels close to the lowest trophic levels will be most influenced by bottom-up forces, while top-down effects should be strongest at top levels.

Community patterns and diversity

Local species richness

The biodiversity of a lentic system increases with the surface area of the lake or pond. This is attributable to the higher likelihood of partly terrestrial species of finding a larger system. Also, because larger systems typically have larger populations, the chance of extinction is decreased. Additional factors, including temperature regime, pH, nutrient availability, habitat complexity, speciation rates, competition, and predation, have been linked to the number of species present within systems.

Succession patterns in plankton communities – the PEG model

Phytoplankton and zooplankton communities in lake systems undergo seasonal succession in relation to nutrient availability, predation, and competition. Sommer *et al.* described these patterns as part of the Plankton Ecology Group (PEG) model, with 24 statements constructed from the analysis of numerous systems. The following includes a subset of these statements, as explained by Brönmark and Hansson illustrating succession through a single seasonal cycle:

Winter
1. Increased nutrient and light availability result in rapid phytoplankton growth towards the end of winter. The dominant species, such as diatoms, are small and have quick growth capabilities. 2. These plankton are consumed by zooplankton, which become the dominant plankton taxa.

Spring
3. A clear water phase occurs, as phytoplankton populations become depleted due to increased predation by growing numbers of zooplankton.

Summer
4. Zooplankton abundance declines as a result of decreased phytoplankton prey and increased predation by juvenile fishes.
5. With increased nutrient availability and decreased predation from zooplankton, a diverse phytoplankton community develops.
6. As the summer continues, nutrients become depleted in a predictable order: phosphorus, silica, and then nitrogen. The abundance of various phytoplankton species varies in relation to their biological need for these nutrients.
7. Small-sized zooplankton become the dominant type of zooplankton because they are less vulnerable to fish predation.

Fall
8. Predation by fishes is reduced due to lower temperatures and zooplankton of all sizes increase in number.

Winter
9. Cold temperatures and decreased light availability result in lower rates of primary production and decreased phytoplankton populations. 10. Reproduction in zooplankton decreases due to lower temperatures and less prey.

The PEG model presents an idealized version of this succession pattern, while natural systems are known for their variation.

Latitudinal patterns

There is a well-documented global pattern that correlates decreasing plant and animal diversity with increasing latitude, that is to say, there are fewer species as one moves towards the poles. The cause of this pattern is one of the greatest puzzles for ecologists today. Theories for its explanation include energy availability, climatic variability, disturbance, competition, etc. Despite this global diversity gradient, this pattern can be weak for freshwater systems compared to global marine and terrestrial systems. This may be related to size, as Hillebrand and Azovsky found that smaller organisms (protozoa and plankton) did not follow the expected trend strongly, while larger species (vertebrates) did. They attributed this to better dispersal ability by smaller organisms, which may result in high distributions globally.

Natural lake lifecycles

Lake creation

Lakes can be formed in a variety of ways, but the most common are discussed briefly below. The oldest and largest systems are the result of tectonic activities. The rift lakes in Africa, for example are the result of seismic activity along the site of separation of two tectonic plates. Ice-formed lakes are created when glaciers recede, leaving behind abnormalities in the landscape shape that are then filled with water. Finally, oxbow lakes are fluvial in origin, resulting when a meandering river bend is pinched off from the main channel.

Natural extinction

All lakes and ponds receive sediment inputs. Since these systems are not really expanding, it is logical to assume that they will become increasingly shallower in depth, eventually becoming wetlands or terrestrial vegetation. The length of this process should depend upon a combination of depth and sedimentation rate. Moss gives the example of Lake Tanganyika, which reaches a depth of 1500 m and has a sedimentation rate of 0.5 mm/yr. Assuming that sedimentation is not influenced by anthropogenic factors, this system should go extinct in approximately 3 million years. Shallow lentic systems might also fill in as swamps encroach inward from the edges. These processes operate on a much shorter timescale, taking hundreds to thousands of years to complete the extinction process.

Human Impacts

Acidification

Sulfur dioxide and nitrogen oxides are naturally released from volcanoes, organic compounds in the soil, wetlands, and marine systems, but the majority of these compounds come from the combustion of coal, oil, gasoline, and the smelting of ores containing sulfur. These substances dissolve in atmospheric moisture and enter lentic systems as acid rain. Lakes and ponds that contain bedrock that is rich in carbonates have a natural buffer, resulting in no alteration of pH. Systems without this bedrock, however, are very sensitive to acid inputs because they have a low neutralizing capacity, resulting in pH declines even with only small inputs of acid. At a pH of 5-6 algal species diversity and biomass decrease considerably, leading to an increase in water transparency – a characteristic feature of acidified lakes. As the pH continues lower, all fauna becomes less diverse. The most significant feature is the disruption of fish reproduction. Thus, the population is eventually composed of few, old individuals that eventually die and leave the systems without fishes. Acid rain has been especially harmful to lakes in Scandinavia, western Scotland, west Wales and the north eastern United States.

Eutrophication

Eutrophic systems contain a high concentration of phosphorus (~30+µg/L), nitrogen (~1500+µg/L), or both. Phosphorus enters lentic waters from wastewater treatment effluents, discharge from raw sewage, or from runoff of farmland. Nitrogen mostly comes from agricultural fertilizers from runoff or leaching and subsequent groundwater flow. This increase in nutrients required for primary producers results in a massive increase of phytoplankton growth, termed a plankton bloom. This bloom decreases water transparency, leading to the loss of submerged plants. The resultant reduction in habitat structure has negative impacts on the species' that utilize it for spawning, maturation and general survival. Additionally, the large number of short-lived phytoplankton result in a massive amount of dead biomass settling into the sediment. Bacteria need large amounts of oxygen to decompose this material, reducing the oxygen concentration of the water. This is especially pronounced in stratified lakes when the thermocline prevents oxygen rich water from the surface to mix with lower levels. Low or anoxic conditions preclude the existence of many taxa that are not physiologically tolerant of these conditions.

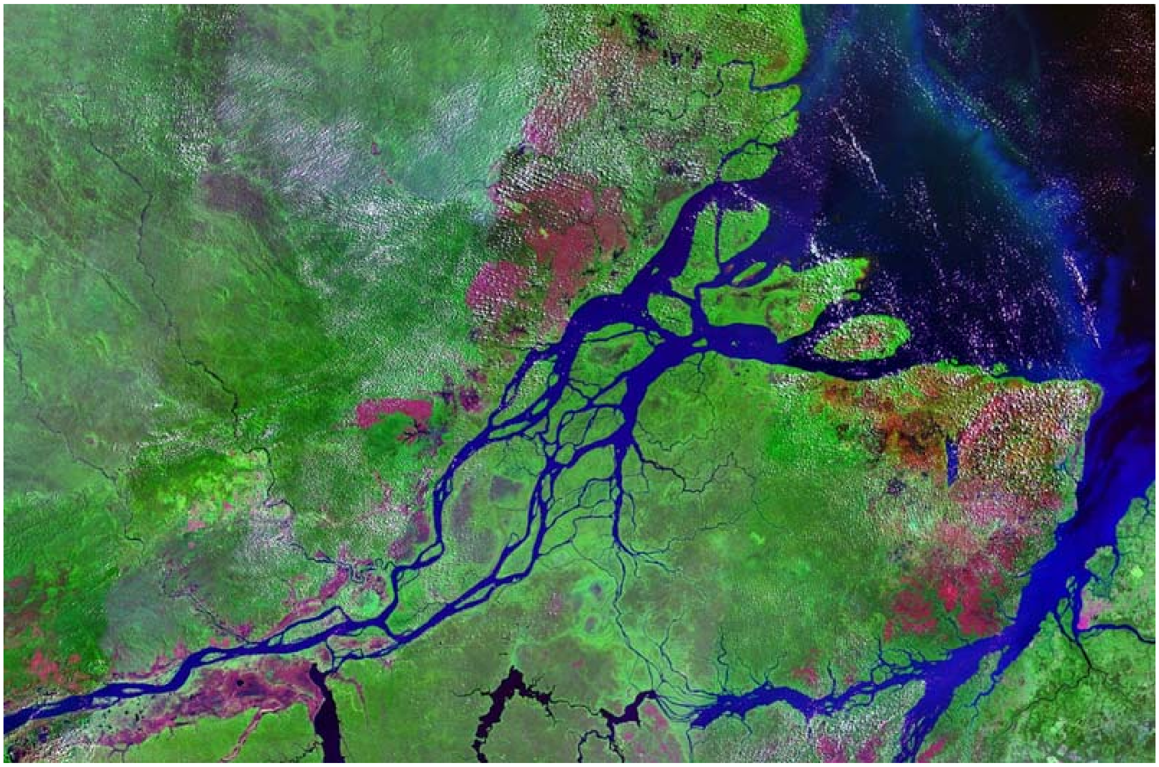
Invasive species

Invasive species have been introduced to lentic systems through both purposeful events (e.g. stocking game and food species) as well as unintentional events (e.g. in ballast water). These organisms can affect natives via competition for prey or habitat, predation, habitat alteration, hybridization, or the introduction of harmful diseases and parasites. With regard to native species, invaders may cause changes in size and age structure, distribution, density, population growth, and may even drive populations to extinction. Examples of prominent invaders of lentic systems include the zebra mussel and sea lamprey in the Great Lakes.

Chapter- 4

River

Melting toe of Athabasca Glacier, Jasper National Park, Alberta, Canada.



A false-color satellite photograph of the Amazon River in Brazil.

A **river** is a natural watercourse, usually freshwater, flowing towards an ocean, a lake, a sea, or another river. In a few cases, a river simply flows into the ground or dries up completely before reaching another body of water. Small rivers may also be called by several other names, including stream, creek, brook, rivulet, tributary and rill; there is no general rule that defines what can be called a river, although in some countries or communities a stream may be defined by its size. Many names for small rivers are specific to geographic location; one example is "burn" in Scotland and North-east England. Sometimes a river is said to be larger than a creek, but this is not always the case, because of vagueness in the language.

A river is part of the hydrological cycle. Water within a river is generally collected from precipitation through surface runoff, groundwater recharge, springs, and the release of stored water in natural ice and snowpacks (e.g., from glaciers).

Topography

The water in a river is usually confined to a channel, made up of a stream bed between banks. In larger rivers there is also a wider floodplain shaped by flood-waters over-topping the channel. Flood plains may be very wide in relation to the size of the river channel. This distinction between river channel and floodplain can be blurred especially in urban areas where the floodplain of a river channel can become greatly developed by housing and industry.

The term upriver refers to the direction leading to the source of the river, which is against the direction of flow. Likewise, the term downriver describes the direction towards the mouth of the river, in which the current flows.

The river channel typically contains a single stream of water, but some rivers flow as several interconnecting streams of water, producing a braided river. Extensive braided rivers are now found in only a few regions worldwide, such as the South Island of New Zealand. They also occur on peneplains and some of the larger river deltas. Anastamosing rivers are similar to braided rivers and are also quite rare. They have multiple sinuous channels carrying large volumes of sediment.

A river flowing in its channel is a source of energy which acts on the river channel to change its shape and form. According to Brahm's law (sometimes called Airy's law), the mass of objects that may be carried away by a river is proportional to the sixth power of the river flow speed. Thus, when the speed of flow increases two times, it can transport 64 times larger (i.e., more massive) objects. In mountainous torrential zones this can be seen as erosion channels through hard rocks and the creation of sands and gravels from the destruction of larger rocks. In U-shaped glaciated valleys, the subsequent river valley can often easily be identified by the V-shaped channel that it has carved. In the middle reaches where the river may flow over flatter land, meanders may form through erosion of the river banks and deposition on the inside of bends. Sometimes the river will cut off a loop, shortening the channel and forming an oxbow lake or billabong. Rivers that carry large amounts of sediment may develop conspicuous deltas at their mouths, if conditions permit. Rivers whose mouths are in saline tidal waters may form estuaries.

Throughout the course of the river, the total volume of water transported downstream will often be a combination of the free water flow together with a substantial contribution flowing through sub-surface rocks and gravels that underlie the river and its floodplain (called the hyporheic zone). For many rivers in large valleys, this unseen component of flow may greatly exceed the visible flow.

Zones

Some researchers believe that the wide variety of both abiotic and biotic factors involved in rivers defies classification. Nevertheless, one system of river zonation has gained relatively widespread acceptance, in the francophone world at least. It divides rivers into three primary zones:

- The *crenon* is the uppermost zone at the source of the river. It is further divided into the eucrenon (spring or boil zone) and the hypocrenon (brook or headstream zone). These areas are characterized by low temperatures, reduced oxygen content and slow moving water.
- The *rhithron* is the upstream portion of the river that follows the crenon. It is characterized by relatively cool temperatures, high oxygen levels, and fast, turbulent flow.

- The *potamon* is the remaining downstream stretch of river. It is characterized by warmer temperatures, lower oxygen levels, slow flow and sandier bottoms.

Classification

Rivers can generally be classified as either alluvial, bedrock, or some mix of the two. Alluvial rivers have channels and floodplains that are self-formed in unconsolidated or weakly-consolidated sediments. They erode their banks and deposit material on bars and their floodplains. Bedrock rivers form when the river downcuts through the modern sediments and into the underlying bedrock. This occurs in regions that have experienced some kind of uplift (thereby steepening river gradients) or in which a particular hard lithology causes a river to have a steepened reach that has not been covered in modern alluvium. Bedrock rivers very often contain alluvium on their beds; this material is important in eroding and sculpting the channel. Rivers that go through patches of bedrock and patches of deep alluvial cover are classified as mixed bedrock-alluvial.

Alluvial rivers can be further classified by their channel pattern as meandering, braided, wandering, anastomose, or straight. The morphology of an alluvial river reach is controlled by a combination of sediment supply, substrate composition, discharge, vegetation, and bed aggradation.

River "age"

Although the following classes, based on the work of William Morris Davis at the turn of the 20th century, are a useful way to visualize rivers, many other factors are at work. Gradient is controlled largely by tectonics, but discharge is controlled largely by climate, and sediment load is controlled by various factors including climate, geology in the headwaters, and the stream gradient.

- **Youthful river**: A river with a steep gradient that has very few tributaries and flows quickly. Its channels erode deeper rather than wider. Examples include the Brazos, Trinity and Ebro rivers.

- **Mature river**: A river with a gradient that is less steep than those of youthful rivers and flows more slowly. A mature river is fed by many tributaries and has more discharge than a youthful river. Its channels erode wider rather than deeper. Examples include the Mississippi, Saint Lawrence, Danube, Ohio, Thames and Paraná rivers.

- **Old river**: A river with a low gradient and low erosive energy. Old rivers are characterized by flood plains. Examples include the Yellow, Ganges, Tigris, Euphrates, Indus and Nile rivers.

- **Rejuvenated river**: A river with a gradient that is raised by tectonic uplift.

Downstream variations

The way in which a river's characteristics vary between the upper course and lower course of a river is summarized by the Bradshaw model. Power-law relationships between channel slope, depth, and width are given as a function of discharge by "river regime".

Subsurface streams

Most but not all rivers flow on the surface. Subterranean rivers flow underground in caves or caverns. Such rivers are frequently found in regions with limestone geologic formations. Subglacial streams are the braided rivers that flow at the beds of glaciers and ice sheets, permitting meltwater to be discharged at the front of the glacier. Because of the gradient in pressure due to the overlying weight of the glacier, such streams can even flow uphill.

Permanence of flow

An *intermittent river* (or ephemeral river) only flows occasionally and can be dry for several years at a time. These rivers are found in regions with limited or highly variable rainfall, or can occur because of geologic conditions such as having a highly permeable river bed. Some ephemeral rivers flow during the summer months but not in the winter. Such rivers are typically fed from chalk aquifers which recharge from winter rainfall. In the UK these rivers are called *Bournes* and give their name to place such as Bournemouth and Eastbourne

Uses

Leisure activities on the River Avon at Avon Valley Country Park, Keynsham, United Kingdom. A boat giving trips to the public passes a moored private boat.

Rivers have been used as a source of water, for obtaining food, for transport, as a defensive measure, as a source of hydropower to drive machinery, for bathing, and as a means of disposing of waste.

Rivers have been used for navigation for thousands of years. The earliest evidence of navigation is found in the Indus Valley Civilization, which existed in northwestern Pakistan around 3300 BC. Riverine navigation provides a cheap means of transport, and is still used extensively on most major rivers of the world like the Amazon, the Ganges, the Nile, the Mississippi, and the Indus. Since river boats are often not regulated, they contribute a large amount to global greenhouse gas emissions, and to local cancer due to inhaling of particulates emitted by the transports.

In some heavily forested regions such as Scandinavia and Canada, lumberjacks use the river to float felled trees downstream to lumber camps for further processing, saving much effort and cost by transporting the huge heavy logs by natural means.

Rivers have been a source of food since pre-history. They can provide a rich source of fish and other edible aquatic life, and are a major source of fresh water, which can be used for drinking and irrigation. It is therefore no surprise to find most of the major cities of the world situated on the banks of rivers. Rivers help to determine the urban form of cities and neighbourhoods and their corridors often present opportunities for urban renewal through the development of foreshoreways such as Riverwalks. Rivers also provide an easy means of disposing of waste-water and, in much of the less developed world, other wastes.

Fast flowing rivers and waterfalls are widely used as sources of energy, via watermills and hydroelectric plants. Evidence of watermills shows them in use for many hundreds of years such as in Orkney at Dounby click mill. Prior to the invention of steam power, water-mills for grinding cereals and for processing wool and other textiles were common across Europe. In the 1890s the first machines to generate power from river water were established at places such as Cragside in Northumberland and in recent decades there has been a significant increase in the development of large scale power generation from water, especially in wet mountainous regions such as Norway

The coarse sediments, gravel and sand, generated and moved by rivers are extensively used in construction. In parts of the world this can generate extensive new lake habitats as gravel pits re-fill with water. In other circumstances it can destabilise the river bed and the course of the river and cause severe damage to spawning fish populations which rely on stable gravel formations for egg laying.

In upland rivers, rapids with whitewater or even waterfalls occur. Rapids are often used for recreation, such as whitewater kayaking.

Rivers have been important in determining political boundaries and defending countries. For example, the Danube was a long-standing border of the Roman Empire, and today it forms most of the border between Bulgaria and Romania. The Mississippi in North America and the Rhine in Europe are major east-west boundaries in those continents. The Orange and Limpopo Rivers in southern Africa form the boundaries between provinces and countries along their routes.

Ecosystem

The flora and fauna of rivers use the aquatic habitats available, from torrential waterfalls through to lowland mires. Although many organisms are restricted to the fresh water in rivers, some, such as salmon and hilsa, have adapted to be able to survive both in rivers and in the sea. The organisms in the riparian zone respond to changes in river channel location and patterns of flow. The ecosystem of rivers is generally described by the River continuum concept, which has some additions and refinements to allow for spatial (dams, waterfalls) and temporal (extensive flooding). The basic idea is that the river can be described as a system that is continuously changing along its length in the physical parameters, the availability of food particles and the composition of the ecosystem. The food (energy) that is the leftover of the upstream part is being utilized downstream.

The general pattern is that the first order streams contain particulate matter (decaying leaves from the surrounding forests), which is processed there by shredders like Plecoptera larvae. The leftovers of the shredders are utilized by collectors as

Hydropsyche and furter downstream algae that create the primary production become the main foodsource of the organisms. All changes are gradual and the distribution of each species can be described as a normal curve with the highest density where the conditions are optimal. In rivers succession is virtually absent and the composition of the ecosystem stays fixed in time.

Chemistry

The chemistry of rivers is complex and depends on inputs from the atmosphere, the geology through which it travels and the inputs from man's activities. The chemistry of the water has a large impact on the ecology of that water for both plants and animals and it also affects the uses that may be made of the river water. Understanding and characterising river water chemistry requires a well designed and managed programme of sampling and analysis

Like many other Aquatic ecosystems, rivers too are under increasing threat of pollution. According to a study of the WWF's Global Freshwater Programme, the 10 most polluted rivers are: Ganges, Indus, Yangtze, Salween-Nu, Mekong-Lancang, Rio Grande/Rio Bravo, La Plata, Danube, Nile-Lake Victoria, and the Murray-Darling.

Brackish water

Nile River delta, as seen from Earth orbit. The Nile is an example of a wave-dominated delta that has the classic Greek delta (Δ) shape after which River deltas were named.

Some rivers generate brackish water by having their river mouth in the ocean. This, in effect creates a unique environment in which certain species are found.

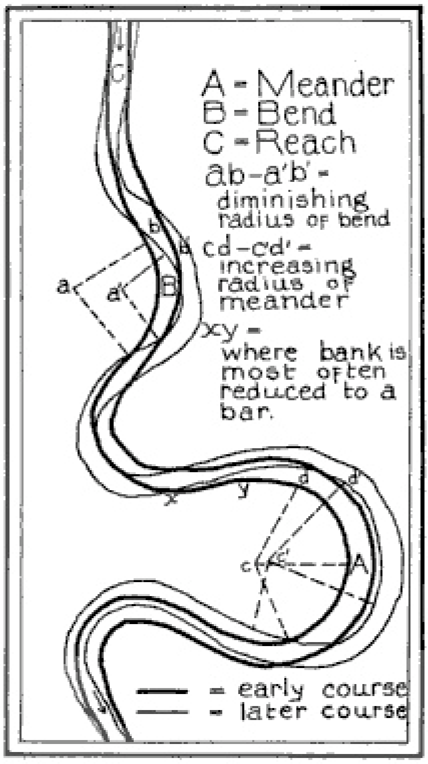
Flooding

Flooding is a natural part of a river's cycle. The majority of the erosion of river channels and the erosion and deposition on the associated floodplains occur during flood stage. In many developed areas, human activity has changed river channel form, altering different magnitudes and frequencies of flooding. Some examples of this are the building of levees, the straightening of channels, and the draining of natural wetlands. In many cases human activities in rivers and floodplains have dramatically increased the risk of flooding. Straightening rivers allows water to flow more rapidly downstream increasing the risk of flooding places further downstream. Building on flood plains removes flood storage which again exacerbates downstream flooding. The building of levees may only protect the area behind the levees and not those further downstream. Levees and flood-banks can also increase flooding upstream because of back-water pressure as the upstream water has to squeeze between the levees.

Flow

Studying the flows of rivers is one aspect of hydrology.

Direction



River meandering course

A common misconception is that most, or even all, rivers flow from north to south. Rivers in fact flow downhill regardless of compass direction. Sometimes downhill is from north to south, but equally it can be from south to north, and usually is a complex meandering path involving all directions of the compass. Three of the ten longest rivers in the world - the Nile, Yenisei, and Ob - flow north, as do other major rivers such as the Rhine, Mackenzie, and Nelson.

Rivers flowing downhill, from river source to river mouth, do not necessarily take the shortest path. For alluvial streams, straight and braided rivers have very low sinuosity and flow directly down hill, while meandering rivers flow from side to side across a valley. Bedrock rivers typically flow in either a fractal pattern, or a pattern that is determined by weaknesses in the bedrock, such as faults, fractures, or more erodible layers.

Rate

Volumetric flow rate, also called discharge, volume flow rate, and rate of water flow, is the volume of water which passes through a given cross-section of the river channel per unit time. It is typically measured in cubic meters per second (cumec) or cubic feet per second (cfs), where $1\ \mathrm{m^3/s} = 35.51\ \mathrm{ft^3/s}$; it is sometimes also measured in litres or gallons per second.

Volumetric flow rate can be thought of as the mean velocity of the flow through a given cross-section, times that cross-sectional area. Mean velocity can be approximated through the use of the Law of the Wall. In general, velocity increases with the depth (or hydraulic radius) and slope of the river channel, while the cross-sectional area scales with the depth and the width: the double-counting of depth shows the importance of this variable in determining the discharge through the channel.

Management

Rivers are often managed or controlled to make them more useful, or less disruptive, to human activity.

- Dams or weirs may be built to control the flow, store water, or extract energy.
- Levees, known as dikes in Europe, may be built to prevent river water from flowing on floodplains or floodways.
- Canals connect rivers to one another for water transfer or navigation.
- River courses may be modified to improve navigation, or straightened to increase the flow rate.

River management is a continuous activity as rivers tend to 'undo' the modifications made by people. Dredged channels silt up, sluice mechanisms deteriorate with age, levees and dams may suffer seepage or catastrophic failure. The benefits sought through managing rivers may often be offset by the social and economic costs of mitigating the bad effects of such management. As an example, in parts of the developed world, rivers have been confined within channels to free up flat flood-plain land for development. Floods can inundate such development at high financial cost and often with loss of life.

Rivers are increasingly managed for habitat conservation, as they are critical for many aquatic and riparian plants, resident and migratory fishes, waterfowl, birds of prey, migrating birds, and many mammals.

Rating systems

- International Scale of River Difficulty – The scale is used to rate the challenges of navigation—particularly those with rapids. Class I is the easiest and Class VI is the hardest.
- Strahler Stream Order – The Strahler Stream Order ranks rivers based on the connectivity and hierarchy of contributing tributaries. Headwaters are first order while the Amazon River is twelfth order. Approximately 80% of the rivers and streams in the world are of the first and second order.

Some Notable Rivers

Zambezi

The Zambezi River at the junction of Namibia, Zambia, Zimbabwe and Botswana

The **Zambezi** (also spelled **Zambesi**) is the fourth-longest river in Africa, and the largest flowing into the Indian Ocean from Africa. The area of its basin is 1,390,000 square kilometres (540,000 sq mi), slightly less than half that of the Nile. The 3,540-kilometre-long river (2,200 mi) has its source in Zambia and flows through Angola, along the borders of Namibia, Botswana, Zambia again, and Zimbabwe, to Mozambique, where it empties into the Indian Ocean.

The Zambezi's most spectacular feature is the beautiful Victoria Falls. Other notable falls include the Chavuma Falls at the border between Zambia and Angola, and Ngonye Falls, near Sioma in Western Zambia.

NASA false-colour image of the upper Zambezi and Barotse (Balozi) floodplain during an extreme flood in 2003.

There are two main sources of hydroelectric power on the river. These are the Kariba Dam, which provides power to Zambia and Zimbabwe and the Cahora Bassa Dam in Mozambique which provides power to both Mozambique and South Africa. There is also a smaller power station at Victoria Falls.

Course of the river

Source

The river rises in a black marshy dambo in north-western Zambia, in undulating miombo woodland, quite dense in parts, about 1,524 m (4,900 ft) above sea level. Eastward of the source, the watershed between the Congo and Zambezi basins is a well-marked belt of high ground, falling abruptly north and south, and running nearly east-west. This distinctly cuts off the basin of the Lualaba (the main branch of the upper Congo) from that of the Zambezi. In the neighbourhood of the source the watershed is not as clearly defined, but the two river systems do not connect.

The region drained by the Zambezi is a vast broken-edged plateau 900–1200 m high, composed in the remote interior of metamorphic beds and fringed with the igneous rocks of the Victoria Falls. At Shupanga, on the lower Zambezi, thin strata of grey and yellow sandstones, with an occasional band of limestone, crop out on the bed of the river in the dry season, and these persist beyond Tete, where they are associated with extensive seams of coal. Coal is also found in the district just below the Victoria Falls. Gold-bearing rocks occur in several places.

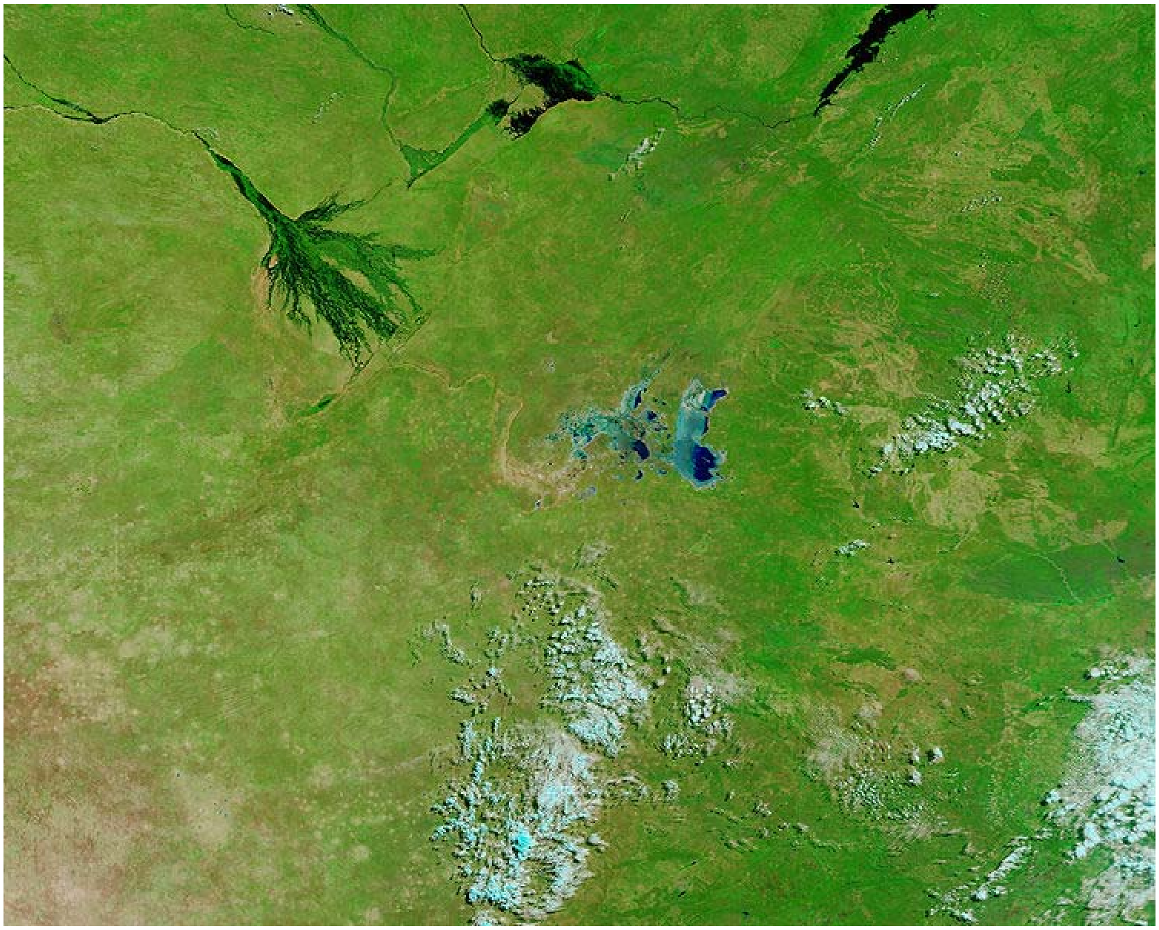
The Zambezi's delta.

The river and its floodplain near Mongu in Zambia.

The upper Zambezi

The river flows to the south-west and into Angola for about 240 kilometres (150 mi), then is joined by sizeable tributaries such as the Luena and the Chifumage flowing from highlands to the north-west. It turns south and develops a floodplain and becomes very variable in width between the dry and rainy seasons. It enters a region with dense patches of evergreen Cryptosepalum dry forest, though on its western side, Western Zambezian grasslands also occur. Where it re-enters Zambia it is nearly 400 metres (1,300 ft) wide in the rainy season and flows quite quickly with rapids ending in the Chavuma Falls, where the river flows through a rocky fissure. The river drops about 400 metres (1,300 ft) in elevation from its source at 1,500 metres (4,900 ft) to the Chavuma Falls at 1,100 metres (3,600 ft), in a distance of about 400 kilometres (250 mi). From this point to the Victoria Falls, the level of the basin is very uniform, dropping only by another 180 metres (590 ft) in a distance of around 800 kilometres (500 mi).

The first of its large tributaries to enter the Zambezi is the Kabompo River in the north-western province of Zambia. The savanna through which the river has flowed gives way to a wide floodplain, studded with Borassus fan palms. A little farther south is the confluence with the Lungwebungu River. This is the beginning of the Barotse Floodplain, the most notable feature of the upper Zambezi, but this northern part does not flood so much and includes islands of higher land in the middle



Water is black in this false-colour image of the Zambezi flood plain.

Thirty kilometres (20 mi) below the confluence of the Lungwebungu the country becomes very flat, and the typical Barotse Floodplain landscape unfolds, with the flood reaching a width of 25 kilometres (16 mi) in the rainy season. For more than 200 kilometres (120 mi) downstream the annual flood cycle dominates the natural environment and human life, society and culture.

Eighty kilometres (50 mi) further down, the Luanginga, which with its tributaries drains a large area to the west, joins the Zambezi. A few kilometres higher up on the east the main stream is joined in the rainy season by overflow of the Luampa/Luena system.

A short distance downstream of the confluence with the Luanginga is Lealui, one of the capitals of the Lozi people who populate the Zambian region of Barotseland in Western Province. The chief of the Lozi maintains one of his two compounds at Lealui; the other is at Limulunga, which is on high ground and serves as the capital during the rainy season. The annual move from Lealui to Limulunga is a major event, celebrated as one of Zambia's best known festivals, the Kuomboka.

After Lealui, the river turns to south-south-east. From the east it continues to receive numerous small streams, but on the west is without major tributaries for 240 km (150 mi). Before this, the Ngonye Falls and subsequent rapids interrupt navigation. South of Ngonye Falls, the river briefly borders Namibia's Caprivi Strip. The strip projects from the main body of Namibia, and results from the colonial era: it was added to German South-West Africa expressly to give Germany access to the Zambezi.

Below the junction of the Cuando River and the Zambezi the river bends almost due east. Here, the river is very broad and shallow, and flows fairly slowly, but as it flows eastward towards the border of the great central plateau of Africa it reaches a chasm into which the Victoria Falls plunge.

The middle Zambezi

Victoria Falls, the end of the upper Zambezi and beginning of the middle Zambezi

The Victoria Falls are considered the boundary between the upper and middle Zambezi. Below them the river continues to flow due east for about 200 kilometres (120 mi), cutting through perpendicular walls of basalt 20 to 60 metres (66 to 200 ft) apart in hills 200 to 250 metres (660 to 820& ft) high. The river flows swiftly through the Batoka gorge, the current being continually interrupted by reefs. It has been described as one of the world's most spectacular whitewater trips, a tremendous challenge for kayakers and rafters alike. Beyond the gorge are a succession of rapids which end 240 km (150 mi) below Victoria Falls. Over this distance, the river drops 250 metres (820 ft).

At this point, the river enters Lake Kariba, created in 1959 following the completion of the Kariba Dam. The lake is one of the largest man-made lakes in the world, and the hydroelectric power-generating facilities at the dam provide electricity to much of Zambia and Zimbabwe.

The Luangwa and the Kafue are the two largest left-hand tributaries of the Zambezi. The Kafue joins the main river in a quiet deep stream about 180 metres (590 ft) wide. From this point the northward bend of the Zambezi is checked and the stream continues due east. At the confluence of the Luangwa (15°37' S) it enters Mozambique.

The middle Zambezi ends where the river enters Lake Cahora Bassa (also spelled Cabora Bassa). Formerly the site of dangerous rapids known as Kebrabassa, the lake was created in 1974 by the construction of the Cahora Bassa Dam.

The lower Zambezi

The lower Zambezi's 650 km (400 mi) from Cahora Bassa to the Indian Ocean is navigable, although the river is shallow in many places during the dry season. This shallowness arises as the river enters a broad valley and spreads out over a large area. Only at one point, the Lupata Gorge, 320 km (200 mi) from its mouth, is the river confined between high hills. Here it is scarcely 200 m wide. Elsewhere it is from 5 to 8 km (3 to 5 mi) wide, flowing gently in many streams. The river bed is sandy, and the banks are low and reed-fringed. At places, however, and especially in the rainy season, the streams unite into one broad fast-flowing river.

About 160 km (100 mi) from the sea the Zambezi receives the drainage of Lake Malawi through the Shire River. On approaching the Indian Ocean, the river splits up into a delta. Each of the four prinmbe, Kongone, Luabo and Timbwe, is obstructed by a sand bar. A more northerly branch, called the Chinde mouth, has a minimum depth at low water of 2 m at the entrance and 4 m further in, and is the branch used for navigation. 100 km (60 mi) further north is a river called the Quelimane, after the town at its mouth. This stream, which is silting up, receives the overflow of the Zambezi in the rainy season.

This highly detailed true-colour image shows the stark eastern edge of the Zambezi

Wildlife

The river supports large populations of many animals. Hippopotamuses are abundant along most of the calm stretches of the river, and many crocodiles are also present. Monitor lizards are found in many places. Birds are abundant, with species including heron, pelican, egret and African fish eagle present in large numbers. Riverine woodland also supports many large animals, such as buffalo, zebras, giraffes, elephants.

The Zambezi also supports several hundred species of fish, some of which are endemic to the river. Important species include cichlids which are fished heavily for food, as well as catfish, tigerfish, yellowfish and other large species. The bull shark is sometimes known as the Zambezi Shark after the river but is found around the world. It normally inhabits coastal waters but has been found far inland in many large rivers including the Zambezi. It is an aggressive shark which has been responsible for several attacks on humans.

Congo River

The **Congo River** (also known as the **Zaire River**) is the deepest river in the world, with measured depths in excess of 230 m (750 ft). It is the second largest river in the world by volume of water discharged, though it has only one-fifth the volume of the world's largest river, the Amazon. Additionally, its overall length of 4,700 km (2,920 mi) makes it the tenth longest river.

Its drainage basin covers 4,014,500 square kilometres (1,550,000 sq mi). The Congo's discharge at its mouth ranges from 23,000 cubic metres per second (810,000 cu ft/s) to 75,000 cubic metres per second (2,600,000 cu ft/s), with an average of 41,000 cubic metres per second (1,400,000 cu ft/s).

The Congo River near Mossaka

Background

Satellite picture of Brazzaville, Kinshasa and the Malebo Pool of the Congo River.

The river and its tributaries flow through the Congo rainforest, the second largest rain forest area in the world, second only to the Amazon Rainforest in South America. The river also has the second-largest flow in the world, behind the Amazon; the third-largest drainage basin of any river, behind the Amazon and Rio de la Plata rivers; and is the deepest river in the world, at depths greater than 230 m (750 ft). Its drainage basin is slightly larger than that of the Mississippi. Because large sections of the river basin lie above and below the equator, its flow is stable, as there is always at least one part of the river experiencing a rainy season.

The Congo gets its name from the ancient Kingdom of Kongo which inhabited the lands at the mouth of the river. The Democratic Republic of the Congo and the Republic of the Congo, both countries lying along the river's banks, are named after it. Between 1971 and 1997 the government of the-Zaire called it the **Zaire River**.

The Congo river at Maluku.

The sources of the Congo are in the highlands and mountains of the East African Rift, as well as Lake Tanganyika and Lake Mweru, which feed the Lualaba River, which then becomes the Congo below Boyoma Falls. The Chambeshi River in Zambia is generally taken as the source of the Congo in line with the accepted practice worldwide of using the longest tributary, as with the Nile River.

The Congo flows generally northwards from Kisangani just below the Boyoma falls, then gradually bends southwestwards, passing by Mbandaka, joining with the Ubangi River, and running into the Pool Malebo (Stanley Pool). Kinshasa (formerly Léopoldville) and Brazzaville are on opposite sides of the river at the Pool, where the river narrows and falls through a number of cataracts in deep canyons (collectively known as the Livingstone Falls), running by Matadi and Boma, and into the sea at the small town of Muanda.

The Congo River Basin is one of the distinct physiographic sections of the larger Mid-African province, which in turn is part of the larger African massive physiographic division.

Economic importance

The beginning of the Livingstone Falls near Kinshasa.

Although the Livingstone Falls prevent access from the sea, nearly the entire Congo is readily navigable in sections, especially between Kinshasa and Kisangani. Large river steamers worked the river until quite recently. The Congo River still is a lifeline in a land without roads or railways.

Railways now bypass the three major falls, and much of the trade of central Africa passes along the river, including copper, palm oil (as kernels), sugar, coffee, and cotton. The river is also potentially valuable for hydroelectric power, and the Inga Dams below Pool Malebo are first to exploit the Congo river.

Hydroelectric power

The Congo River is the most powerful river in Africa. During the rainy season over 50,000 cubic meters of water per second flow into the Atlantic Ocean. Opportunities for the Congo River and its tributaries to raise hydropower are therefore enormous. Scientists have calculated that the entire Congo Basin accounts for thirteen percent of global hydropower potential. This would provide sufficient power for all of sub-Saharan Africa's electricity needs.

Currently there are about forty hydropower plants in the Congo Basin. The largest is the spectacular Inga Falls, about 200 km southwest of Kinshasa. The prestigious Inga Project was launched in early 1970 to build the first dam. Four additional dams and the construction of a gigantic dam would have a capacity of 34 500 megawatts, constituting nearly three times the capacity of all current Belgian power plants together. To date only two dams have been built the Inga I and Inga II, of which constitute fourteen turbines.

In February 2005, South Africa's state-owned power company, Eskom, announced a proposal to increase the capacity of the Inga dramatically through improvements and the construction of a new hydroelectric dam. The project would bring the maximum output of the facility to 40 GW, twice that of China's Three Gorges Dam.

Chapter- 5

Lotic Ecosystem

This stream in the redwoods can be thought of as a lotic ecosystem

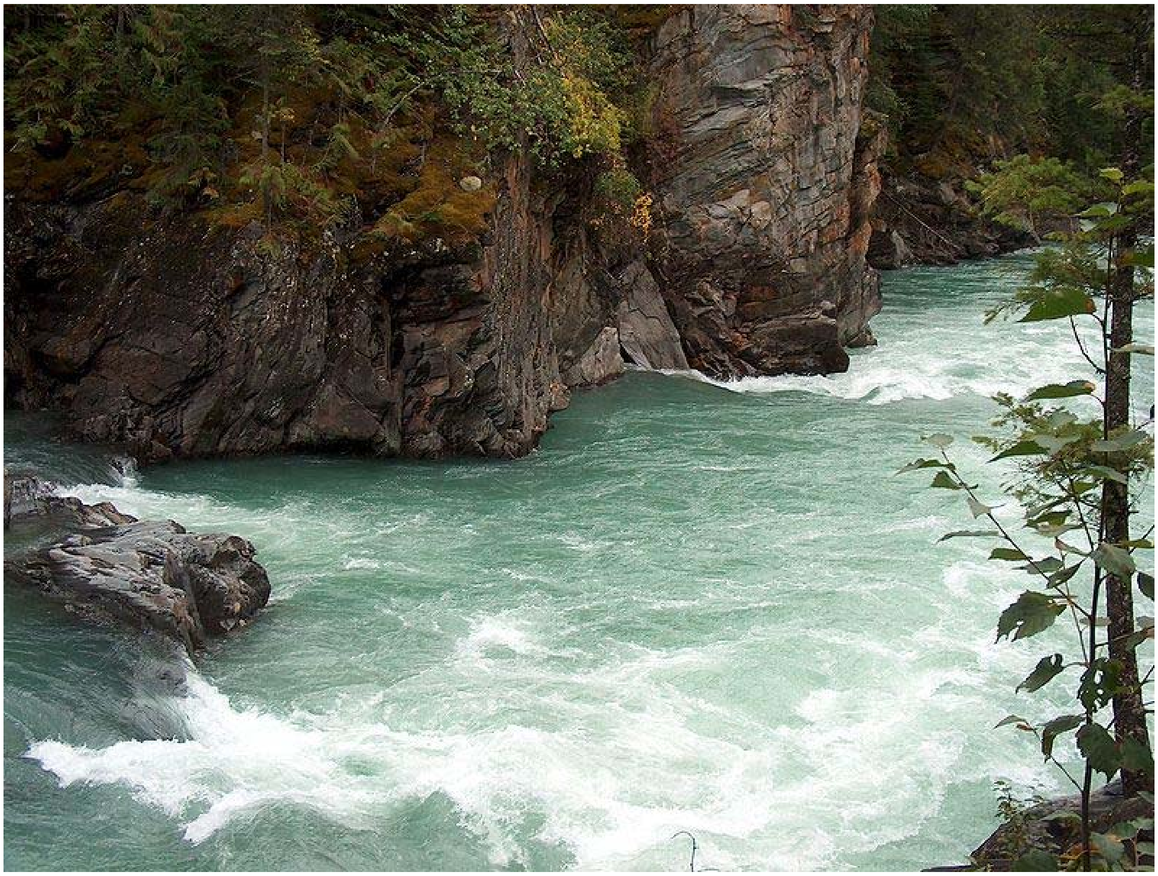
A **lotic ecosystem** is the ecosystem of a river, stream or spring. Included in the environment are the biotic interactions (amongst plants, animals and micro-organisms) as well as the abiotic interactions (physical and chemical).

Lotic refers to flowing water, from the Latin *lotus*, past participle of *lavere*, to wash. Lotic ecosystems can be contrasted with lentic ecosystems, which involve relatively still terrestrial waters such as lakes and ponds. Together, these two fields form the more general study area of freshwater or aquatic ecology.

Lotic waters can be diverse in their form, ranging from a spring that is only a few centimeters wide to a major river that is kilometers in width. Despite these differences, the following unifying characteristics make the ecology of running waters unique from that of other aquatic habitats.

- Flow is unidirectional.
- There is a state of continuous physical change.
- There is a high degree of spatial and temporal heterogeneity at all scales (microhabitats).
- Variability between lotic systems is quite high.
- The biota is specialized to live with flow conditions.

Abiotic factors



Rapids in Mount Robson Provincial Park

Flow

Water flow is the key factor in lotic systems influencing their ecology. The strength of water flow can vary between systems, ranging from torrential rapids to slow backwaters that almost seem like lentic systems. The speed of the water flow can also vary within a system. It is typically based on variability of friction with the bottom or sides of the channel, sinuosity, obstructions, and the incline gradient. In addition, the amount of water input into the system from direct precipitation, snowmelt, and/or groundwater can affect flow rate. Flowing waters can alter the shape of the streambed through erosion and deposition, creating a variety of habitats, including riffles, glides, and pools.

Light

A pensive Cooplacurripa River, NSW

Light is important to lotic systems, because it provides the energy necessary to drive primary production via photosynthesis, and can also provide refuge for prey species in shadows it casts. The amount of light that a system receives can be related to a combination of internal and external stream variables. The area surrounding a small stream, for example, might be shaded by surrounding forests or by valley walls. Larger river systems tend to be wide so the influence of external variables is minimized, and the sun reaches the surface. These rivers also tend to be more turbulent, however, and particles in the water increasingly attenuate light as depth increases. Seasonal and diurnal factors might also play a role in light availability because the angle of incidence, the angle at which light strikes water can lead to light lost from reflection. Known as Beer's Law, the shallower the angle, the more light is reflected and the amount of solar radiation received declines logarithmically with depth. Additional influences on light availability include cloud cover, altitude, and geographic position (Brown 1987).

Temperature

Castle Geyser, Yellowstone National Park

Most lotic species are poikilotherms whose internal temperature varies with their environment, thus temperature is a key abiotic factor for them. Water can be heated or cooled through radiation at the surface and conduction to or from the air and surrounding substrate. Shallow streams are typically well mixed and maintain a relatively uniform temperature within an area. In deeper, slower moving water systems, however, a strong difference between the bottom and surface temperatures may develop. Spring fed systems have little variation as springs are typically from groundwater sources, which are often very close to ambient temperature. Many systems show strong diurnal fluctuations and seasonal variations are most extreme in arctic, desert and temperate systems. The amount of shading, climate and elevation can also influence the temperature of lotic systems.

Chemistry

A forest stream in the winter near Erzhausen, Germany

Water chemistry between systems varies tremendously. The chemistry is foremost determined by inputs from the geology of its watershed, or catchment area, but can also be influenced by precipitation and the addition of pollutants from human sources. Large differences in chemistry do not usually exist within small lotic systems due to a high rate of mixing. In larger river systems, however, the concentrations of most nutrients, dissolved salts, and pH decrease as distance increases from the river's source.

Oxygen is likely the most important chemical constituent of lotic systems, as all aerobic organisms require it for survival. It enters the water mostly via diffusion at the water-air interface. Oxygen's solubility in water decreases as water temperature increases. Fast, turbulent streams expose more of the water's surface area to the air and tend to have low temperatures and thus more oxygen than slow, backwaters. Oxygen is a byproduct of photosynthesis, so systems with a high abundance of aquatic algae and plants may also have high concentrations of oxygen during the day. These levels can decrease significantly during the night when primary producers switch to respiration. Oxygen can be limiting if circulation between the surface and deeper layers is poor, if the activity of lotic animals is very high, or if there is a large amount of organic decay occurring.

Substrate

Cascade in the Pyrénées.

The inorganic substrate of lotic systems is composed of the geologic material present in the catchment that is eroded, transported, sorted, and deposited by the current. Inorganic substrates are classified by size on the Wentworth scale, which ranges from boulders, to pebbles, to gravel, to sand, and to silt. Typically, particle size decreases downstream with larger boulders and stones in more mountainous areas and sandy bottoms in lowland rivers. This is because the higher gradients of mountain streams facilitate a faster flow, moving smaller substrate materials further downstream for deposition. Substrate can also be organic and may include fine particles, autumn shed leaves, submerged wood, moss, and more evolved plants. Substrate deposition is not necessarily a permanent event, as it can be subject to large modifications during flooding events.

Biota

Bacteria

Bacteria are present in large numbers in lotic waters. Free-living forms are associated with decomposing organic material, biofilm on the surfaces of rocks and vegetation, in between particles that compose the substrate, and suspended in the water column. Other forms are also associated with the guts of lotic organisms as parasites or in commensal relationships. Bacteria play a large role in energy recycling, which will be discussed in the Trophic Relationships section.

Primary producers

Periphyton

Common water hyacinth in flower

Algae, consisting of phytoplankton and periphyton, are the most significant sources of primary production in most streams and rivers. Phytoplankton float freely in the water column and thus are unable to maintain populations in fast flowing streams. They can, however, develop sizable populations in slow moving rivers and backwaters. Periphyton are typically filamentous and tufted algae that can attach themselves to objects to avoid being washed away by fast current. In places where flow rates are negligible or absent, periphyton may form a gelatinous, unanchored floating mat.

Plants exhibit limited adaptations to fast flow and are most successful in reduced currents. More primitive plants, such as mosses and liverworts attach themselves to solid objects. This typically occurs in colder headwaters where the mostly rocky substrate offers attachment sites. Some plants are free floating at the water's surface in dense mats like duckweed or water hyacinth. Others are rooted and may be classified as submerged or emergent. Rooted plants usually occur in areas of slackened current where fine-grained soils are found (Brown 1987). These rooted plants are flexible, with elongated leaves that offer minimal resistance to current.

Living in flowing water can be beneficial to plants and algae because the current is usually well aerated and it provides a continuous supply of nutrients. These organisms are limited by flow, light, water chemistry, substrate, and grazing pressure. Algae and plants are important to lotic systems as sources of energy, for forming microhabitats that shelter other fauna from predators and the current, and as a food resource (Brown 1987).

Insects and other invertebrates

Up to 90% of invertebrates in some lotic systems are insects. These species exhibit tremendous diversity and can be found occupying almost every available habitat, including the surfaces of stones, deep below the substratum, adrift in the current, and in the surface film. Insects have developed several strategies for living in the diverse flows of lotic systems. Some avoid high current areas, inhabiting the substratum or the sheltered side of rocks. In stronger current, species have developed weighted cases, attachments to anchored pads of silk, recurved clinging claws, suction cup like devices, and flattened, streamlined bodies (Hynes 1970; Brown 1987). Additional invertebrate taxa common to flowing waters include mollusks such as snails, limpets, clams, mussels, as well as crustaceans like crayfish and crabs. Like most of the primary consumers, lotic invertebrates often rely heavily on the current to bring them food and oxygen (Brown 1987). Invertebrates, especially insects, are important as both consumers and prey items in lotic systems.

Fish and other vertebrates

The brook trout is native to small streams, creeks, lakes, and spring ponds.

New Zealand longfin eels can weigh over 50 kilograms.

Fishes are probably the best-known inhabitants of lotic systems. The ability of a fish species to live in flowing waters depends upon the speed at which it can swim and the duration that its speed can be maintained. This ability can vary greatly between species and is tied to the habitat in which it can survive. Continuous swimming expends a tremendous amount of energy and, therefore, fishes spend only short periods in full current. Instead, individuals remain close to the bottom or the banks, behind obstacles, and sheltered from the current, swimming in the current only to feed or change locations. Some species have adapted to living only on the system bottom, never venturing into the open water flow. These fishes are dorso-ventrally flattened to reduce flow resistance and often have eyes on top of their heads to observe what is happening above them. Some also have sensory barrels positioned under the head to assist in the testing of substratum (Brown 1987).

Lotic systems typically connect to each other, forming a path to the ocean (spring → stream → river → ocean), and many fishes have life cycles that require stages in both fresh and salt water. Salmon, for example, are anadromous species that are born and develop in freshwater and then move to the ocean as adults. Eels are catadromous, and are born and develop in the ocean and then move into freshwater as adults.

Other vertebrate taxa that inhabit lotic systems include amphibians, such as salamanders, reptiles (e.g. snakes, turtles, crocodiles and alligators) various bird species, and mammals (e.g., otters, beavers, hippos, and river dolphins). With the exception of a few species, these vertebrates are not tied to water as fishes are, and spend part of their time in terrestrial habitats. Many fish species are important as consumers and as prey species to the larger vertebrates mentioned above.

Trophic relationships

Energy inputs

Pondweed is an autochthonous energy source

Leaf litter is an allochthonous energy source

Energy sources can be autochthonous or allochthonous.

- **Autochthonous** energy sources are those derived from within the lotic system. During photosynthesis, for example, primary producers form organic carbon compounds out of carbon dioxide and inorganic matter. The energy they produce is important for the community because it may be transferred to higher trophic levels via consumption. Additionally, high rates of primary production can introduce dissolved organic matter (DOM) to the waters. Another form of autochthonous energy comes from the decomposition of dead organisms and feces that originate within the lotic system. In this case, bacteria decompose the detritus or coarse particulate organic material (CPOM; >1 mm pieces) into fine organic particulate matter (FPOM; <1 mm pieces) and then further into inorganic compounds that are required for photosynthesis. This process is discussed in more detail below.

- **Allochthonous** energy sources are those derived from outside the lotic system, that is, from the terrestrial environment. Leaves, twigs, fruits, etc. are typical forms of terrestrial CPOM that have entered the water by direct litterfall or lateral leaf blow. In addition, terrestrial animal-derived materials, such as feces or carcasses that have been added to the system are examples of allochthonous

CPOM. The CPOM undergoes a specific process of degradation. Allan gives the example of a leaf fallen into a stream. First, the soluble chemicals are dissolved and leached from the leaf upon its saturation with water. This adds to the DOM load in the system. Next, microbes such as bacteria and fungi colonize the leaf, softening it as the mycelium of the fungus grows into it. The composition of the microbial community is influenced by the species of tree from which the leaves are shed (Rubbo and Kiesecker 2004). This combination of bacteria, fungi, and leaf are a food source for shredding invertebrates, which leave only FPOM after consumption. These fine particles may be colonized by microbes again or serve as a food source for animals that consume FPOM. Organic matter can also enter the lotic system already in the FPOM stage by wind, surface runoff, bank erosion, or groundwater. Similarly, DOM can be introduced through canopy drip from rain or from surface flows.

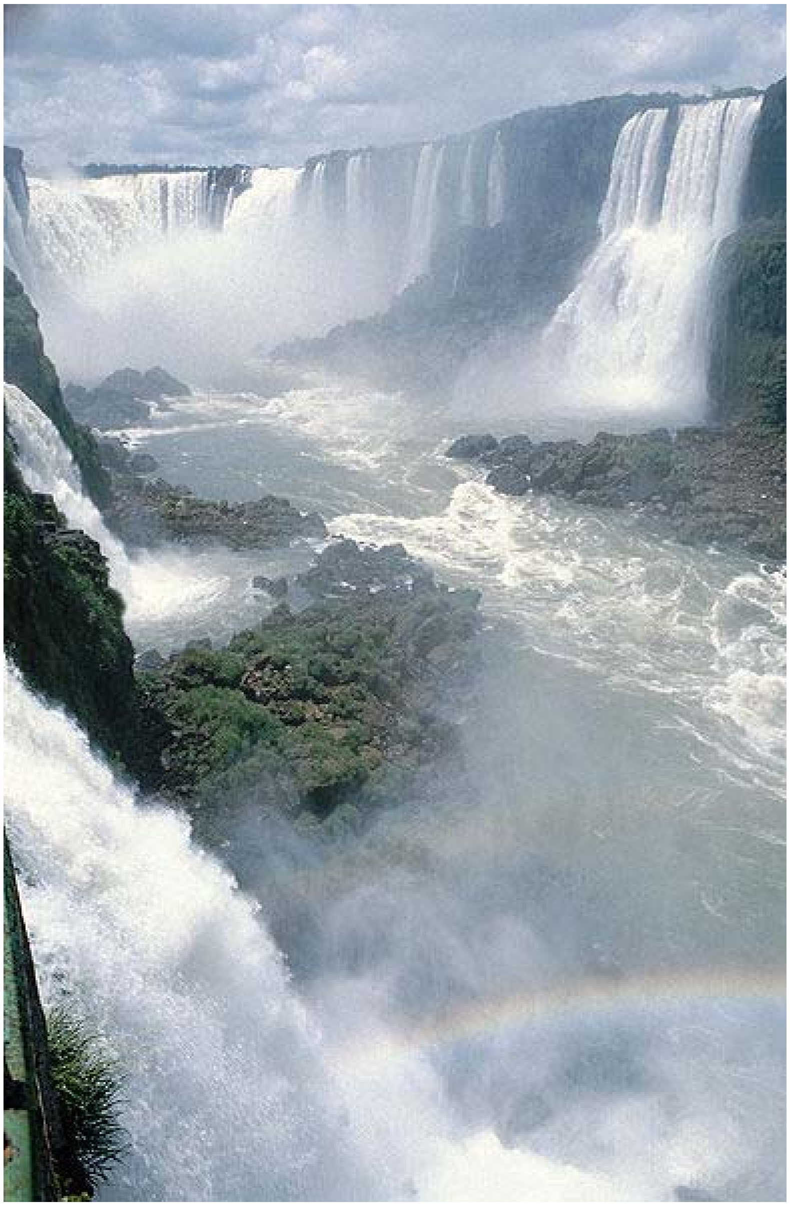
Invertebrates

Invertebrates can be organized into many feeding guilds in lotic systems. Some species are shredders, which use large and powerful mouth parts to feed on non-woody CPOM and their associated microorganisms. Others are suspension feeders, which use their setae, filtering aparati, nets, or even secretions to collect FPOM and microbes from the water. These species may be passive collectors, utilizing the natural flow of the system, or they may generate their own current to draw water, and also, FPOM in Allan. Members of the gatherer-collector guild actively search for FPOM under rocks and in other places where the stream flow has slackened enough to allow deposition. Grazing invertebrates utilize scraping, rasping, and browsing adaptations to feed on periphyton and detritus. Finally, several families are predatory, capturing and consuming animal prey. Both the number of species and the abundance of individuals within each guild is largely dependent upon food availability. Thus, these values may vary across both seasons and systems.

Fish

Fish can also be placed into feeding guilds. Planktivores pick plankton out of the water column. Herbivore-detritovores are bottom-feeding species that ingest both periphyton and detritus indiscriminately. Surface and water column feeders capture surface prey (mainly terrestrial and emerging insects) and drift (benthic invertebrates floating downstream). Benthic invertebrate feeders prey primarily on immature insects, but will also consume other benthic invertebrates. Top predators consume fishes and/or large invertebrates. Omnivores ingest a wide range of prey. These can be floral, faunal, and/or detrital in nature. Finally, parasites live off of host species, typically other fishes. Fish are flexible in their feeding roles, capturing different prey with regard to seasonal availability and their own developmental stage. Thus, they may occupy multiple feeding guilds in their lifetime. The number of species in each guild can vary greatly between systems, with temperate warm water streams having the most benthic invertebrate feeders, and tropical systems having large numbers of detritus feeders due to high rates of allochthonous input.

Community patterns and diversity



Iguazu Falls - an extreme lotic environment.

Local species richness

Large rivers have comparatively more species than small streams. Many relate this pattern to the greater area and volume of larger systems, as well as an increase in habitat diversity. Some systems, however, show a poor fit between system size and species richness. In these cases, a combination of factors such as historical rates of speciation and extinction, type of substrate, microhabitat availability, water chemistry, temperature, and disturbance such as flooding seem to be important.

Resource partitioning

Although many alternate theories have been postulated for the ability of guild-mates to coexist (see Morin 1999), resource partitioning has been well documented in lotic systems as a means of reducing competition. The three main types of resource partitioning include habitat, dietary, and temporal segregation.

Habitat segregation was found to be the most common type of resource partitioning in natural systems (Schoener, 1974). In lotic systems, microhabitats provide a level of physical complexity that can support a diverse array of organisms (Vincin and Hawknis, 1998). The separation of species by substrate preferences has been well documented for invertebrates. Ward (1992) was able to divide substrate dwellers into 6 broad assemblages, including those that live in: coarse substrate, gravel, sand, mud, woody debris, and those associated with plants, showing one layer of segregation. On a smaller scale, further habitat partitioning can occur on or around a single substrate, such as a piece of gravel. Some invertebrates prefer the high flow areas on the exposed top of the gravel, while others reside in the crevices between one piece of gravel and the next, while still others live on the bottom of this gravel piece.

Dietary segregation is the second-most common type of resource partitioning. High degrees of morphological specializations or behavioral differences allow organisms to use specific resources. The size of nets built by some species of invertebrate suspension feeders, for example, can filter varying particle size of FPOM from the water (Edington et al. 1984). Similarly, members in the grazing guild can specialize in the harvesting of algae or detritus depending upon the morphology of their scraping apparatus. In addition, certain species seem to show a preference for specific algal species.

Temporal segregation is a less common form of resource partitioning, but it is nonetheless an observed phenomenon. Typically, it accounts for coexistence by relating it to differences in life history patterns and the timing of maximum growth among guild mates. Tropical fishes in Borneo, for example, have shifted to shorter life spans in response to the ecological niche reduction felt with increasing levels of species richness in their ecosystem (Watson and Balon 1984).

Persistence and succession

Over long time scales, there is a tendency for species composition in pristine systems to remain in a stable state. This has been found for both invertebrate and fish species. On shorter times scales, however, flow variability and unusual precipitation patterns decrease habitat stability and can all lead to declines in persistence levels. The ability to maintain this persistence over long time scales is related to the ability of lotic systems to return to the original community configuration relatively quickly after a disturbance (Townsend et al. 1987). This is one example of temporal succession, a site-specific change in a community involving changes in species composition over time. Another form of temporal succession might occur when a new habitat is opened up for colonization. In these cases, an entirely new community that is well adapted to the conditions found in this new area can establish itself.

River continuum concept

Meandering stream in Waitomo, New Zealand

River Gryffe in Scotland

A rocky stream in the U.S. state of Hawaii

The River continuum concept (RCC) was an attempt to construct a single framework to describe the function of temperate lotic ecosystems from the source to the end and relate it to changes in the biotic community (Vannote et al. 1980). The physical basis for RCC is size and location along the gradient from a small stream eventually linked to a large river. Stream order is used as the physical measure of the position along the RCC.

According to the RCC, low ordered sites are small shaded streams where allochthonous inputs of CPOM are a necessary resource for consumers. As the river widens at mid-ordered sites, energy inputs should change. Ample sunlight should reach the bottom in these systems to support significant periphyton production. Additionally, the biological processing of CPOM (Coarse Particulate Organic Matter - larger than 1 mm) inputs at upstream sites is expected to result in the transport of large amounts of FPOM (Fine Particulate Organic Matter - smaller than 1 mm) to these downstream ecosystems. Plants should become more abundant at edges of the river with increasing river size, especially in lowland rivers where finer sediments have been deposited and facilitate rooting. The main channels likely have too much current and turbidity and a lack of substrate to support plants or periphyton. Phytoplankton should produce the only autochthonous inputs here, but photosynthetic rates will be limited due to turbidity and mixing. Thus, allochthonous inputs are expected to be the primary energy source for large rivers. This

FPOM will come from both upstream sites via the decomposition process and through lateral inputs from floodplains.

Biota should change with this change in energy from the headwaters to the mouth of these systems. Namely, shredders should prosper in low-ordered systems and grazers in mid-ordered sites. Microbial decomposition should play the largest role in energy production for low-ordered sites and large rivers, while photosynthesis, in addition to degraded allochthonous inputs from upstream will be essential in mid-ordered systems. As mid-ordered sites will theoretically receive the largest variety of energy inputs, they might be expected to host the most biological diversity (Vannote et al. 1980)

Just how well the RCC actually reflects patterns in natural systems is uncertain and its generality can be a handicap when applied to diverse and specific situations. The most noted criticisms of the RCC are: 1. It focuses mostly on macroinvertebrates, disregarding that plankton and fish diversity is highest in high orders; 2. It relies heavily on the fact that low ordered sites have high CPOM inputs, even though many streams lack riparian habitats; 3. It is based on pristine systems, which rarely exist today; and 4. It is centered around the functioning of temperate streams. Despite its shortcomings, the RCC remains a useful idea for describing how the patterns of ecological functions in a lotic system can vary from the source to the mouth.

Human impacts

Pollution

Pollutant sources of lotic systems are hard to control because they derive, often in small amounts, over a very wide area and enter the system at many locations along its length. Agricultural fields often deliver large quantities of sediments, nutrients, and chemicals to nearby streams and rivers. Urban and residential areas can also add to this pollution when contaminants are accumulated on impervious surfaces such as roads and parking lots that then drain into the system. Elevated nutrient concentrations, especially nitrogen and phosphorus which are key components of fertilizers, can increase periphyton growth, which can be particularly dangerous in slow moving streams. Another pollutant, acid rain, forms from sulfur dioxide and nitrous oxide emitted from factories and power stations. These substances readily dissolve in atmospheric moisture and enter lotic systems through precipitation. This can lower the pH of these sites, affecting all trophic levels from algae to vertebrates (Brown 1987). Mean species richness and total species numbers within a system decrease with decreasing pH.

While direct pollution of lotic systems has been greatly reduced in the United States under the government’s Clean Water Act, contaminants from diffuse, non-point sources, remain a large problem.

Flow modification

A weir on the River Calder, West Yorkshire

Dams alter the flow, temperature, and sediment regime of lotic systems. Additionally, many rivers are dammed at multiple locations, amplifying the impact. Dams can cause enhanced clarity and reduced variability in stream flow, which is due to an increase in periphyton abundance. Invertebrates immediately below a dam can show reductions in species richness due to an overall reduction in habitat heterogeneity. Also, thermal changes can affect insect development, with abnormally warm winter temperatures obscuring cues to break egg diapause and overly cool summer temperatures leaving too few acceptable days to complete growth. Finally, dams fragment river systems, isolating previously continuous populations, and preventing the migrations of anadromous and catadromous species.

Invasive species

Invasive species have been introduced to lotic systems through both purposeful events (e.g. stocking game and food species) as well as unintentional events (e.g. hitchhikers on boats or fishing waders). These organisms can affect natives via competition for prey or habitat, predation, habitat alteration, hybridization, or the introduction of harmful diseases and parasites. Once established, these species can be difficult to control or eradicate, particularly because of the connectivity of lotic systems. Invasive species can be especially harmful in areas that have endangered biota, such as mussels in the Southeast United States, or those that have localized endemic species, like lotic systems west of the Rocky Mountains, where many species evolved in isolation.

Chapter- 6

Sea

A sea, as seen from a beach.

A **sea** generally refers to a large body of salt water, but the term is used in other contexts as well. Most commonly, the term refers to a large expanse of saline water connected with an ocean, and is commonly used as a synonym for ocean. It is also used sometimes to describe a large saline lake that lacks a natural outlet, such as the Caspian Sea.

Some Notable Seas: -

Adriatic Sea

Map of the Adriatic Sea.

Sediment billowing out from Italy's shore into the Adriatic.

The **Adriatic Sea** is a body of water separating the Italian Peninsula from the Balkan peninsula, and the system of the Apennine Mountains from that of the Dinaric Alps and adjacent ranges. The Adriatic Sea is a northwest-to-southeast arm of the Mediterranean Sea.

The western coast is Italian, while the eastern coast runs along Slovenia (47 km), Croatia (5,835 km) , Bosnia and Herzegovina (26 km), Montenegro (294 km), and Albania. Major rivers joining the Adriatic are the Reno, Po, Adige/Etsch, Brenta, Piave, Soča/Isonzo, Zrmanja, Krka, Cetina, Neretva, and Drin (Drini).

Name and etymology

A satellite image of the Adriatic Sea.

Originally, the sea was known in Latin as **Mare Superum**. Later, it was replaced by *Mare (H)Adriaticum*. The name, derived from the Etruscan colony of Adria (or *Hadria*), originally designated only the upper portion of the sea (Herodotus vi. 127, vii. 20, ix. 92; Euripides, *Hippolytus,* 736), but was gradually extended as the Syracusan colonies gained in importance. The name *Adria* is derived from the Illyrian word *adur* meaning "water" or "sea".

But even then the Adriatic in the narrower sense only extended as far as the Monte Gargano, the outer portion being called the Ionian Sea: the name was sometimes, however, inaccurately used to include the Gulf of Tarentum (the modern-day Gulf of Taranto), the Sea of Sicily, the Gulf of Corinth and even the sea between Crete and Malta (Acts xxvii. 27).

The Adriatic Sea is situated largely between the eastern coast of Italy and Croatia, which are both major tourist attractions. It was used by the ancient Romans to transport goods (including animals and slaves) to Ostia (the Roman port).

Extent and bathymetry

Zadar, city on the Adriatic Sea

The Adriatic extends northwest from 40° to 45°45' North, with an extreme length of about 770 km (415 nm, 480 mi). It has an average width of about 160 km (85 nm, 100 mi), although the Strait of Otranto, through which it connects at the south with the Ionian Sea, is only 45-55 nautical miles wide (85–100 km).

Moreover, the chain of islands which fringes the northern part of the eastern shore reduces the extreme breadth of open sea in this part to 145 km (78 nm, 90 mi). Its total surface area is about 60,000 square miles (160,000 km²).

The International Hydrographic Organization defines the southern limit of the Adriatic Sea as "A line running from the mouth of the Butrinto River (39°44'N) in Albania to Cape Karagol in Corfu, through this island to Cape Kephali (these two capes are in lat. 39°45'N) and on to Cape Santa Maria di Leuca".

The depths of the Adriatic near its shores share a close relationship to the physiography of the nearby coastlines. Wherever the coasts are high and mountainous, the nearby sea depths are considerable. For instance, in the case of the Istrian and Dalmatian areas of

Slovenia and Croatia., the shores are low and sandy, and the nearby sea is shallow, as in the vicinity of Venice or, farther south, near the delta of the Italian Po River. Generally speaking, the waters are shallow all along the Italian coast. The site of maximum depth of the Adriatic Sea is situated south of the central area, and the average depth is 1,457 feet (444 m) and maximum depth is 3,300 feet (1,000 m).

Coasts and islands

Islet Grujica in the Adriatic sea, seen from the ferry between Ilovik and Premuda in Croatia

Sveti Nikola Island, in Montenegro

Torre Sant'Andrea, Salento (Italy)

The west shore is generally low, merging, in the northwest, into the marshes and lagoons on either hand of the protruding delta of the river Po, the sediment of which has pushed forward the coastline for several miles within historic times—Adria is now some distance from the shore.

On islands within one of the lagoons opening from the Gulf of Venice, Venice has its unique situation. Other notable cities on the Italian coast are Trieste, Ravenna, Rimini, Ancona, Pescara, Bari, and Brindisi.

The east coast is generally bold and rocky, with many islands. South of the Istrian Peninsula, which separates the Gulfs of Venice and Trieste from the Bay of Kvarner, the island-fringe of the east coast extends as far south as Dubrovnik. The island of Cres is the largest island in the sea, slightly larger than nearby Krk.

The islands, which are long and narrow (the long axis lying parallel with the coast of the mainland), rise rather abruptly to elevations of a few hundred feet, with the exception of a few larger islands like Brač (Vidova gora, 778 m) or the peninsula Pelješac (St. Ilija, 961 m). There are 1246 islands in the Adriatic, 66 of which are inhabited .

On the mainland, notably in the Gulf of Kotor (Boka Kotorska; named after the town of Kotor), lofty mountains often fall directly to the sea.

The prevalent colour of the rocks is a light, dead grey, contrasting harshly with the dark vegetation, which on some of the islands is luxuriant. In fact, Montenegro (Black Mountain) was named after the black pines that cover the coast there, and similarly the Greek name for the island of Korčula is *Korkyra Melaina* meaning "Black Corfu".

It is interesting to note the vast difference between the Italian and Croatian coasts on the Adriatic. Although only a small distance from each other, the Croatian Coast and beaches are generally many times clearer, cleaner and bluer than Italy's. Croatia is known for its Crystal clear water.

Major cities on the eastern coast include Trieste in Italy; Koper, Izola and Piran in Slovenia; Umag, Poreč, Rovinj, Pula, Opatija, Rijeka, Senj, Zadar, Biograd, Šibenik, Trogir, Split, Makarska, Ploče and Dubrovnik in Croatia; Neum in Bosnia and Herzegovina; Herceg Novi, Kotor, Tivat, Bar, Budva and Ulcinj in Montenegro; Lezhë, Durrës, Velipoja and Vlorë in Albania.

Weather patterns

The bora (northeast wind), and the prevalence of sudden squalls from this quarter or the southeast, are dangers to navigation in winter. Also notable are sirocco (southern wind) which brings rain in the winter and maestral (western wind) which brings serene weather in the summer. The area is known for occasional waterspouts similar to those found in the Florida Keys.

Tidal movement is slight. The amphidromic point is just off the northwestern shore, near Ancona.

Adriatic Sea (Croatia).

Ionian Sea

The **Ionian Sea** is an arm of the Mediterranean Sea, south of the Adriatic Sea. It is bounded by southern Italy including Calabria, Sicily and the Salento peninsula to the west, and by southwestern Albania, including Saranda and Himara, and a large number of Greek islands, including Corfu, Zante, Kephalonia, Ithaka, and Lefkas to the east. The islands are collectively referred to as the Ionian Islands, and other islands include the Strophades, Sphagia, Schiza, Sapientza and Kythira. The sea is one of the most seismic areas in the world.

The Ionian Sea, as seen from Corfu Island, Greece, and with Saranda, Albania in the background

The Ionian Sea, view from the island Kefalonia

There are ferry routes between Patras and Igoumenitsa, Greece, and Brindisi and Ancona, Italy, that cross the east and north of the Ionian Sea, and from Piraeus westward. Calypso Deep, the deepest point in the Mediterranean at -5,267 m (−17,280.2 ft), is located in the Ionian Sea, at 36°34′N 21°8′E / 36.567°N 21.133°E.

Black Sea

The **Black Sea** is an inland sea bounded by Europe, Anatolia and the Caucasus and is ultimately connected to the Atlantic Ocean via the Mediterranean and Aegean Seas and various straits. The Bosphorus strait connects it to the Sea of Marmara, and the strait of the Dardanelles connects it to the Aegean Sea region of the Mediterranean. These waters separate eastern Europe and western Asia. The Black Sea also connects to the Sea of Azov by the Strait of Kerch.

Illustration of the Black Sea, from NASA's World Wind globe software

The Black Sea has an area of 436,400 km^2 (168,495.0 sq mi) (not including the Sea of Azov), a maximum depth of 2,206 m (7,238 ft), and a volume of 547,000 km^3 (131,200 cu mi). The Black Sea forms in an east-west trending elliptical depression which lies between Bulgaria, Georgia, Romania, Russia, Turkey, and Ukraine. It is constrained by the Pontic Mountains to the south, the Caucasus Mountains to the east and features a wide shelf to the north-west. The longest east-west extent is about 1,175 km.

Swallow's Nest

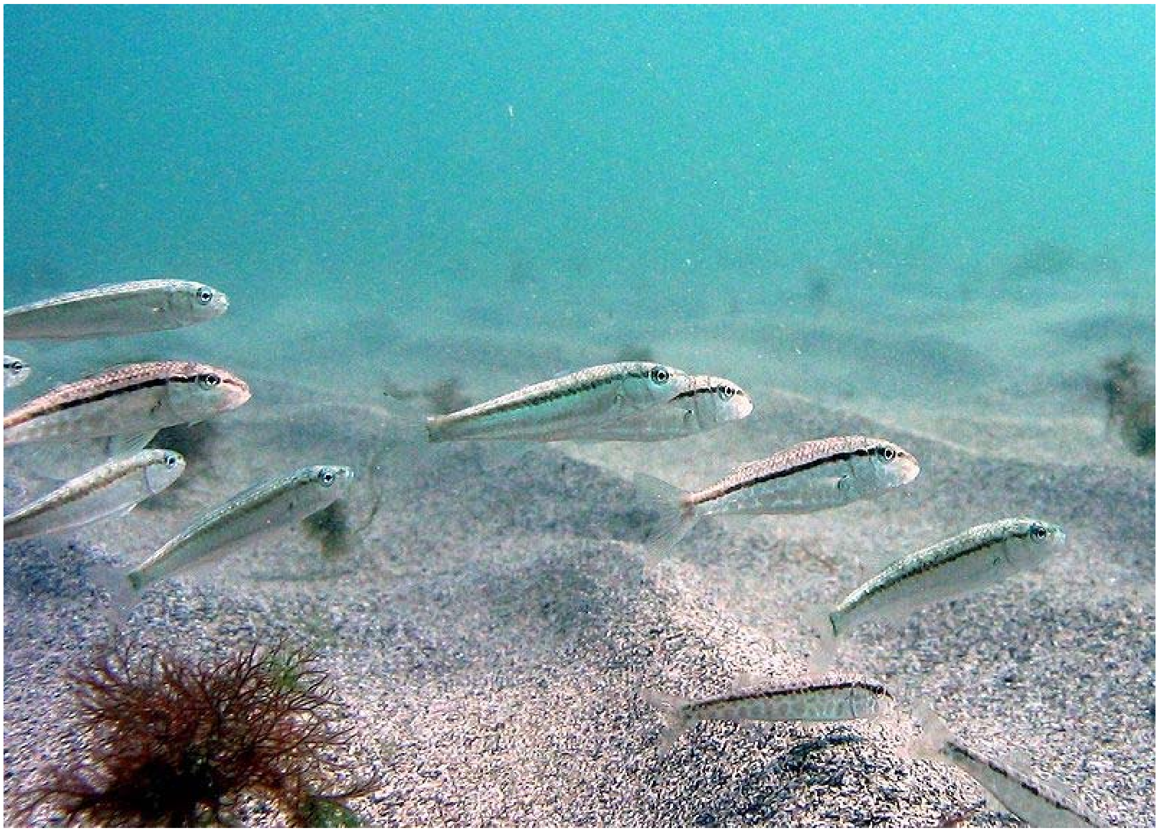
Important cities along the coast include Batumi, Burgas, Constanța, Giresun, Hopa, Istanbul, Kerch, Kherson, Mangalia, Năvodari, Novorossiysk, Odessa, Ordu, Poti, Rize, Samsun, Sevastopol, Sochi, Sukhumi, Trabzon, Varna, Yalta and Zonguldak.

The Black Sea has a positive water balance; that is, a net outflow of water 300 km^3 per year through the Bosphorus and the Dardanelles into the Aegean Sea (part of the Mediterranean Sea). Mediterranean water flows into the Black Sea as part of a 2-way hydrological exchange. The Black Sea outflow is cooler and less saline, and therefore floats over the warm, more saline Mediterranean inflow, leading to a significant anoxic layer well below the surface waters. The Black Sea also receives river water from large Eurasian fluvial systems to the north of the Sea, of which the Don, Dnieper and Danube are the most significant.

Bay of Sudak

In the past, the water level has varied significantly. Due to these variations in the water level in the basin the surrounding shelf and associated aprons have sometimes been land. At certain critical water levels it is possible for connections with surrounding water bodies to become established. It is through the most active of these connective routes, the Turkish Straits, that the Black Sea joins the global ocean system. When this hydrological link is not present, the Black Sea is a lake, operating independently of the global ocean system. Currently the Black Sea water level is relatively high, thus water is being exchanged with the Mediterranean. The Turkish Straits connect the Black and Aegean Seas and comprise the Bosphorus, the Sea of Marmara and the Dardanelles.

Stingray, near Romanian coast



Goat fish, near Romanian coast

Name

Modern names

Current names of the Sea are equivalents of the English name, "Black Sea", including Adyghe: (Хы ШІуцІ), Greek *Mavri Thalassa* (Μαύρη Θάλασσα), Bulgarian *Cherno more* (Черно море), Georgian *Shavi zghva* (შავი ზღვა), Laz *Ucha Zuğa*, or simply *Zuğa* 'Sea', Romanian *Marea Neagră*, Russian *Chornoye more* (Чёрное море), Turkish *Karadeniz*, Ukrainian *Chorne more* (Чорне море). Such names have not yet been shown conclusively to predate the twelfth century, but there are indications that they may be considerably older.

Sunset on the Black Sea at Laspi

The estuary of the Veleka in the Black Sea. Longshore drift has deposited sediment along the shoreline which has led to the formation of a spit, Sinemorets, Bulgaria

The Black Sea got its name from the Ottoman Turks. 'Kara (Black)' denotes 'North' in Medieval Turkish, as in Kara Denizi- Kara Sea north of Siberian Yakut Turks, similar to Black Sea. In Turkish 'Red' denotes south as in Kizil Deniz, Red Sea to the south of Anatolia, while 'Ak'-White denotes west. The old name for the Aegean and the Mediterranean combined in Anatolian Turkish is "Akdeniz" -the White Sea-; although in contemporary Turkish, Akdeniz denotes only the Mediterranean Sea as now the northern part of the Mediterranean is called the Aegean Sea following its Western name. During the Ottoman times this was not the case as the Aegean was called the Sea of Islands - Adalar Denizi referring to the 12 islands laying between Greece and Anatolia.

Hermit crab, near Romanian coast

Blue sponge, near Romanian coast

The Black Sea is one of four seas named in English after common color terms — the others being the Red Sea, the White Sea and the Yellow Sea.

Historical names

Strabo's Geography (1.2.10) reports that in antiquity, the Black Sea was often just called "the Sea" (*ho pontos*). For the most part, Graeco-Roman tradition refers to the Black Sea as the 'Hospitable sea', *Euxeinos Pontos* (Εὔξεινος Πόντος). This is a euphemism replacing an earlier 'Inhospitable Sea', *Pontos Axeinos*, first attested in Pindar (early fifth century BCE,~475 BC). Strabo (7.3.6) thinks that the Black Sea was called "inhospitable" before Greek colonization because it was difficult to navigate, and because its shores were inhabited by savage tribes. The name was changed to "hospitable" after the Milesians had colonized southern shoreline, the Pontus, making it part of Greek civilization.

It is also possible that the name *Axeinos* arose by popular etymology from a Scythian Iranic *axšaina*- 'unlit,' 'dark'; the designation "Black Sea" may thus date from Antiquity.

Spiny dogfish (Black Sea Sharks at Risk)

Seahorse, near Romanian coast

One Bulgarian understanding of the name is that the sea used to be quite stormy. The Black Sea deluge theory is based on that idea.

A map of Asia dating to 1570, entitled Asiae Nova Descriptio, from Ortelis's Theatrum labels the sea "Mar Maggior."

In naval science, the Black Sea is thought to have received its name because of its hydrogen sulphide layer that begins about 200 metres below the surface, and supports a unique microbial population which produces black sediments probably due to anaerobic methane oxidation.

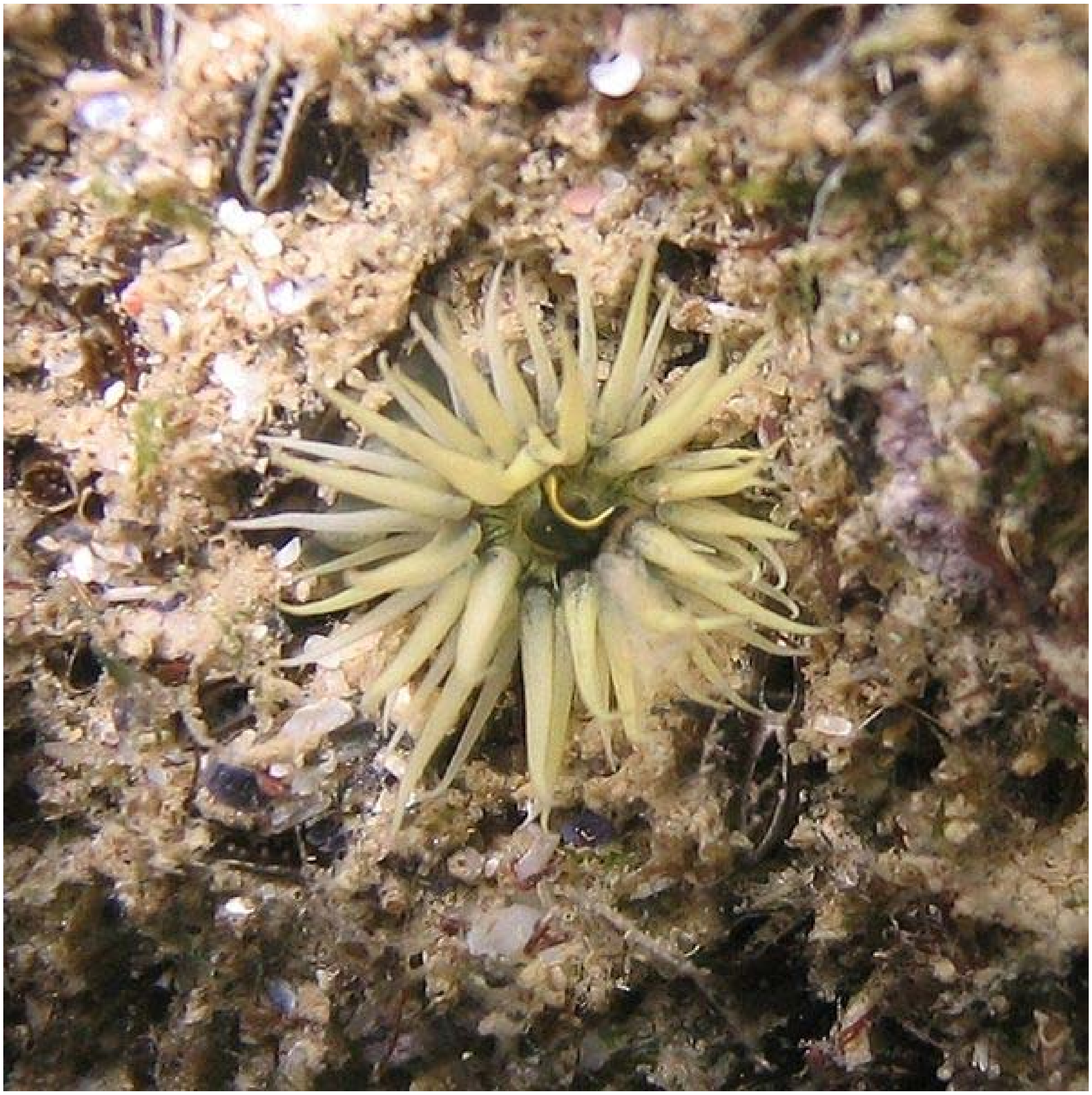
Ecology

Jellyfish, near Romanian coast

The Black Sea supports an active and dynamic marine ecosystem, dominated by species suited to the brackish, nutrient-rich, conditions. As with all marine food webs, the Black Sea features a range of trophic groups, with autotrophic algae, including diatoms and dinoflagellates, acting as primary producers. The fluvial systems draining Eurasia and central Europe introduce large volumes of sediment and dissolved nutrients into the Black Sea, but distribution of these nutrients is controlled by the degree of physiochemical stratification, which is, in turn, dictated by seasonal physiographic development. During winter, strong wind promotes convective overturning and upwelling of nutrients, while high summer temperatures result in a marked vertical stratification and a warm, shallow mixed layer. Day length and insolation intensity also controls the extent of the photic zone. Subsurface productivity is limited by nutrient availability, as the anoxic bottom waters act as a sink for reduced nitrate, in the form of ammonia. The benthic zone also plays an important role in Black Sea nutrient cycling, as chemosynthetic organisms and anoxic geochemical pathways recycle nutrients which can be upwelled to the photic zone, enhancing productivity.

Actinia, near Romanian coast

Climate



Actinia, near Romanian coast

Goby, near Romanian coast

Short-term climatic variation in the Black Sea region is significantly influenced by the operation of the North Atlantic Oscillation, which is a term used to describe the climatic mechanisms resulting from the interaction between the north Atlantic and mid-latitude air masses. While the exact mechanisms causing the North Atlantic Oscillation remain unclear, it is thought the climate conditions established in western Europe mediate the heat and precipitation fluxes reaching Central Europe and Eurasia, regulating the formation of winter cyclones, which are largely responsible for regional precipitation inputs and influence Mediterranean Sea Surface Temperatures (SST's). The relative strength of these systems also limits the amount of cold air arriving from northern regions during winter. Other influencing factors include the regional topography, as depressions and storms systems arriving from the Mediterranean are funneled through the low land around the Bosphorus, Pontic and Caucasus mountain ranges acting as wave guides, limiting the speed and paths of cyclones passing through the region

Chapter- 7

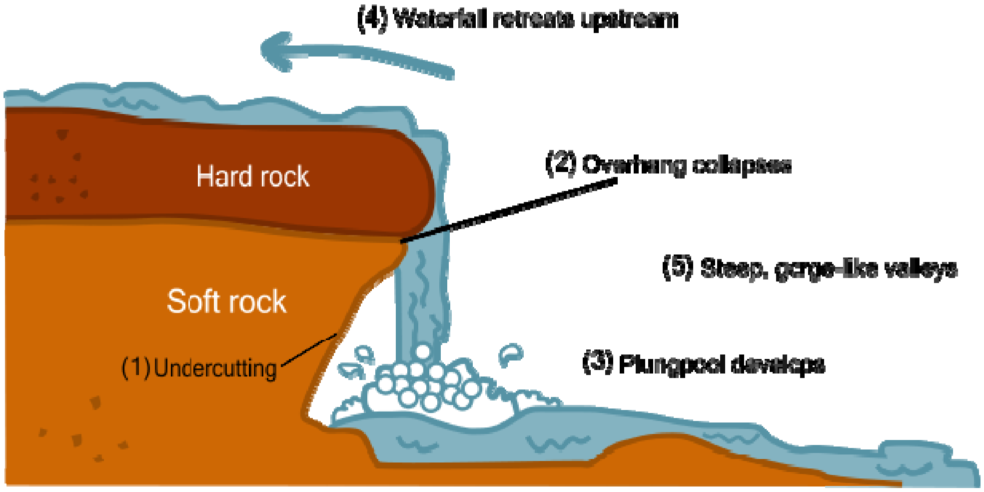
Waterfall

Angel Falls in Venezuela is the world's tallest waterfall at 979 m (3,212 ft).

Frozen waterfall in southeast New York

A **waterfall** is a place where flowing water rapidly drops in elevation as it flows over a steep region or a cliff.

Formation



Formation of a waterfall

Waterfalls are most commonly formed when a river is young. At these times the channel is often narrow and deep. When the river courses over resistant bedrock, erosion happens slowly, while downstream the erosion occurs more rapidly. As the watercourse increases its velocity at the edge of the waterfall, it plucks material from the riverbed. Whirlpools created in the turbulence as well as sand and stones carried by the watercourse increase the erosion capacity. This causes the waterfall to carve deeper into the bed and to recede upstream. Often over time, the waterfall will recede back to form a canyon or gorge downstream as it recedes upstream, and it will carve deeper into the ridge above it. The rate of retreat for a waterfall can be as high as one and half meters per year.

Often, the rock stratum just below the more resistant shelf will be of a softer type, meaning that undercutting due to splashback will occur here to form a shallow cave-like formation known as a rock shelter under and behind the waterfall. Eventually, the outcropping, more resistant cap rock will collapse under pressure to add blocks of rock to the base of the waterfall. These blocks of rock are then broken down into smaller boulders by attrition as they collide with each other, and they also erode the base of the waterfall by abrasion, creating a deep plunge pool or gorge.

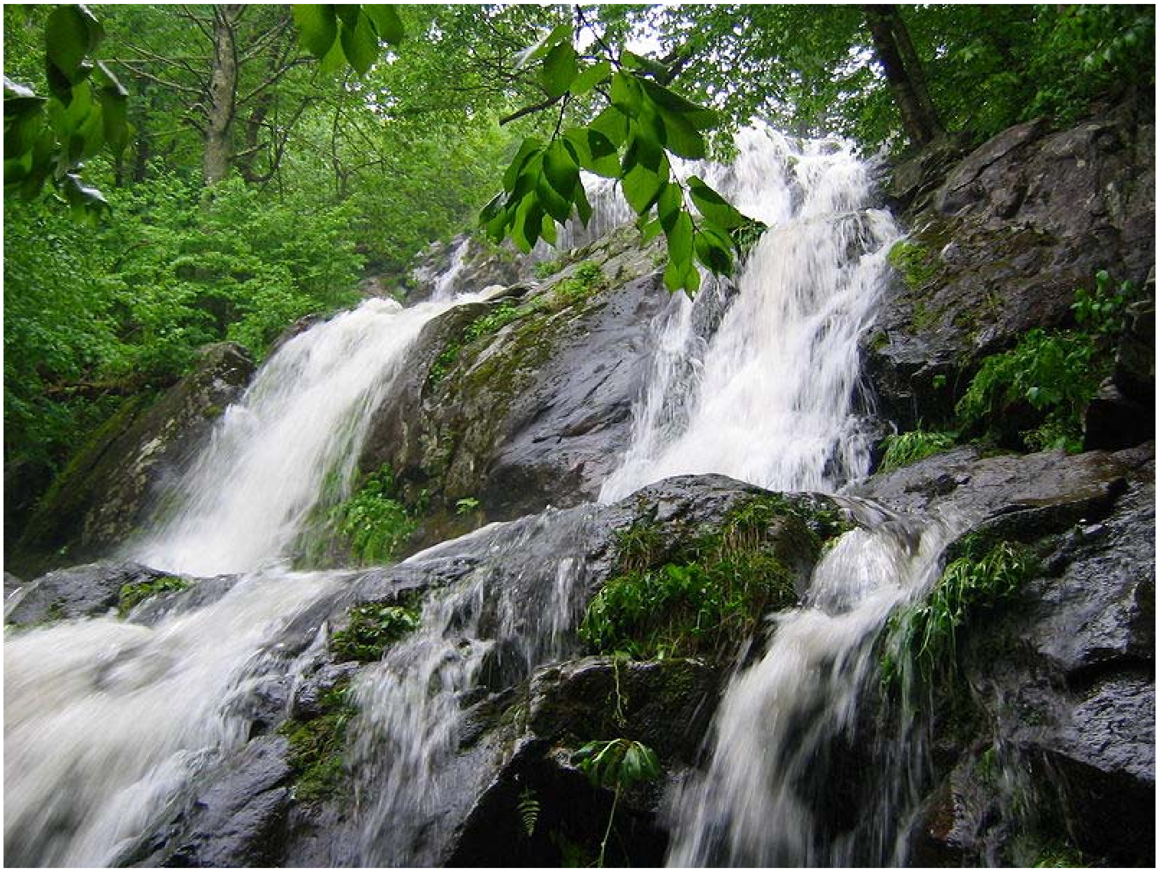
Baatara gorge waterfall near Tannurin, Lebanon

Streams become wider and shallower just above waterfalls due to flowing over the rock shelf, and there is usually a deep area just below the waterfall because of the kinetic energy of the water hitting the bottom. Waterfalls normally form in a rocky area due to erosion. After a long period of being fully formed, the water falling off the ledge will retreat, causing a horizontal pit parallel to the waterfall wall. Eventually, as the pit grows deeper, the waterfall collapses to be replaced by a steeply sloping stretch of river bed.

A river sometimes flows over a large step in the rocks that may have been formed by a fault line. Waterfalls can occur along the edge of a glacial trough, whereby a stream or river flowing into a glacier continues to flow into a valley after the glacier has receded or melted. The large waterfalls in Yosemite Valley are examples of this phenomenon, which is referred to as a hanging valley. Another reason hanging valleys may form is where two rivers join and one is flowing faster than the other. Waterfalls are grouped into ten broad classes based on the average volume of water present on the fall (which depends on both the waterfall's average flow and its height) using a logarithmic scale. Class 10 waterfalls include Niagara Falls, Paulo Afonso Falls and Khone Falls.

Classes of other well-known waterfalls include Victoria Falls and Kaieteur Falls (Class 9); Rhine Falls and Gullfoss (Class 8); Angel Falls and Dettifoss (Class 7); Yosemite Falls, Lower Yellowstone Falls and Umphang Thee Lor Sue Waterfall (Class 6); Sutherland Falls (Class 5).

Types



Dark Hollow Falls, near Skyline Drive, Virginia, is an example of a cascade waterfall

- **Block**: Water descends from a relatively wide stream or river.
- **Cascade**: Water descends a series of rock steps.
- **Cataract**: A large, powerful waterfall.
- **Chute**: A large quantity of water forced through a narrow, vertical passage.
- **Fan**: Water spreads horizontally as it descends while remaining in contact with bedrock.

- **Frozen**: Any waterfall which has some element of ice.
- **Horsetail**: Descending water maintains some contact with bedrock.
- **Plunge**: Water descends vertically, losing contact with the bedrock surface.
- **Punchbowl**: Water descends in a constricted form and then spreads out in a wider pool.
- **Segmented**: Distinctly separate flows of water form as it descends.
- **Tiered**: Water drops in a series of distinct steps or falls.
- **Multi-step**: A series of waterfalls one after another of roughly the same size each with its own sunken plunge pool.

Examples of large waterfalls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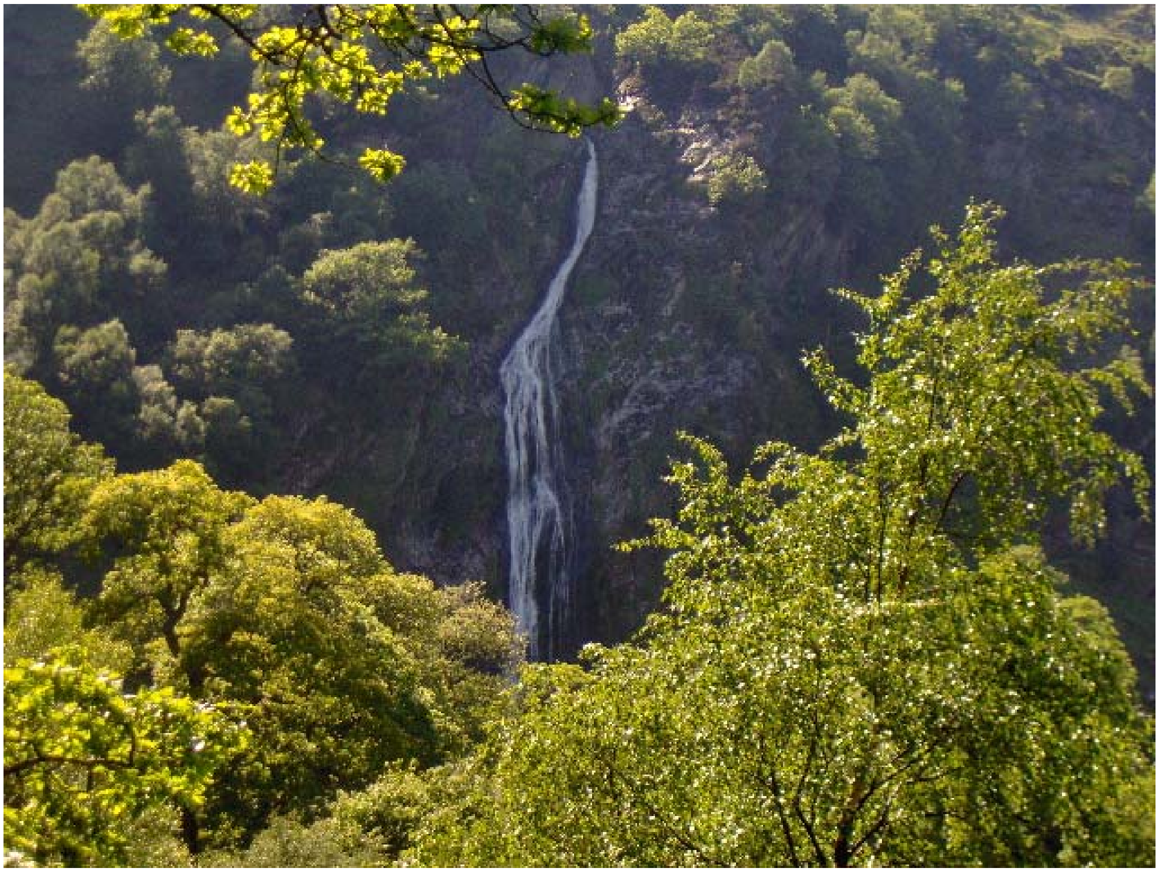
Havasu Falls, near Supai, Arizona, is an example of a plunge waterfall



Powerscourt Waterfall, near Enniskerry, Wicklow County, Ireland, is an example of a horsetail waterfall

Aerial view of Niagara Falls in the state of New York, US, and province of Ontario, Canada

Duruitoarea waterfall in Ceahlău, Romania

Plitvice lakes, Croatia

Significant waterfalls , listed alphabetically:

- Angel Falls is the world's tallest at 979 metres (3212 ft) in Venezuela.
- Bambarakanda Falls is Sri Lanka's tallest waterfall at 263 m.
- Detian - Ban Gioc Falls is the 4th largest international waterfall in the world between the Sino-Vietnamese border.
- Bridalveil Fall in Yosemite Valley is 189 m (620 ft) high with a sheer drop when flowing.
- Cascata delle Marmore in Italy is the tallest man-made waterfall in the world.
- Cautley Spout, at 175 m (580 ft), is the tallest waterfall in England.

- Colonial Creek Falls, the second tallest waterfall in North America at 2,584 ft (788 m), is located in the North Cascades National Park, Washington, United States.
- Dettifoss, Northeast Iceland is the largest waterfall in Europe in terms of volume discharge, having an average water flow of 200 m³/s.The falls are 100 m wide and have a drop of 44 m down to the Jökulsárgljúfur canyon.
- Eas a' Chual Aluinn, at 200 m (658 ft), is the tallest waterfall in both Scotland and the United Kingdom.
- Gocta is the fifth tallest in the world at 771 m (2532 ft) and located in the province Chachapoyas, Peru.
- Hannoki Falls is the tallest waterfall in Asia at 1,640 ft (500 m) and located in Tateyama, Japan.
- High Force on the River Tees is one of the tallest waterfalls in England.
- Huangguoshu Waterfall in Anshun, Guizhou, China, is the largest waterfall in East Asia.
- Iguazu Falls is a tall and extremely wide waterfall located in South America on the Argentina/Brazil border.
- James Bruce Falls, the tallest waterfall in North America at 840 m, is located in the Princess Louisa Marine Provincial Park, British Columbia, Canada.
- Jog Falls is India's tallest (listed as 314 ranking on the World Waterfall Database), located in Karnataka state, India.
- Jurong Falls in Singapore is an artificial waterfall.
- Kaieteur Falls (Potaro River in central Guyana), located in the Kaieteur National Park, is 226 m (741 ft).
- Krimmler Wasserfälle, at 380 m, is Austria's second tallest waterfall and located in Krimml, Salzburg, Austria.
- Multnomah Falls is 611 feet (186 m) high and 30 ft wide.
- Niagara Falls are the most powerful falls in North America.
- Pissing Mare Falls, at 350 m (1148 ft), is the tallest in eastern North America.
- Pistyll Rhaeadr, a 240 ft (73m) waterfall in Wales.
- Ramnefjellsfossen is the world's third tallest at 808 m (2685 ft), at Stryn, Nesdalen, Norway.
- Rhine Falls is Europe's widest and is located in Switzerland.
- ShirAbad Waterfall is located in Iran, Golestan, Khanbebin, Shirabad.
- Shoshone Falls the "Niagara of the West" in Idaho
- St.Clair's Falls is Sri Lanka's widest waterfall 265 ft high.
- Silver Falls is a waterfall and is located in Silverton, Oregon.
- Takakkaw Falls is a 384 m (1260 ft) in Yoho National Park in Canada.
- Tequendama Falls is a 132 m high waterfall on the Bogotá River, about 30 km southwest of Bogotá in Colombia.
- Tugela Falls is the world's second tallest at 947 m (3110 ft) in KwaZulu-Natal province, Republic of South Africa.
- Victoria Falls is the largest waterfall in the world and is more than a mile long. It is located on the Zambezi river on the border of Zimbabwe and Zambia.

- Virginia Falls (Northwest Territories) on South Nahanni River, Northwest Territories, Canada. World's 14th largest waterfall located in Nahanni National Park Reserve a UNESCO World Heritage Site.
- Waihilau Falls, at 2,600 ft (792 m), is located in the Waimanu Valley, Hawaii, United States.
- Yosemite Falls, the fourth tallest waterfall in North America at 2,425 ft (739 m), is located in Yosemite National Park, United States.
- Yumbilla Falls is the world's fifth tallest waterfall and located in Peru.

The largest indoor waterfall in the world, at the International center, in Detroit

Some waterfalls are constructed by artificial means indoors. The largest of these is in the lobby of the International Center, in Detroit.

Largest Waterfalls :

Detian – Ban Gioc Falls

Detian - Banyue Falls (Chinese: 德天瀑布 & 板約瀑布) or **Ban Gioc Falls** (Vietnamese: **thác Bản Giốc**), are 2 waterfalls on the Quy Xuan River straddling the Sino-Vietnamese border, located in the Karst hills of Daxing County in the Chongzuo prefecture of Guangxi Province, on the Chinese side, and in the district of Trung Khanh, Cao Bằng province on the Vietnamese side, 272 km north of Hanoi.

The waterfall falls thirty meters. It is separated into three falls by rocks and trees, and the thundering effect of the water hitting the cliffs can be heard from afar.

View from China in dry season. Banyue fall is on the left. Detian is on the right t is currently the 4th largest waterfall along a national border after Iguazu Falls, Victoria Falls, and Niagara Falls and was one of the crossing points for China’s army during the brief Sino-Vietnamese War. Nearby there is the Tongling Gorge accessible only through a cavern from an adjoining gorge. Rediscovered only recently, it has many species of endemic plants, found only in the gorge, and used to be used as a hideout by local bandits whose treasure is occasionally still found in the cliff-side caves.

View from Vietnam in rainy season

A road running along the top of the falls leads to a stone tablet that marks out the border between China and Vietnam in French and Chinese. But there were unclear definitions in the legal documents on border demarcation and the placement of markers between the French and Qing administrations.

There are controversies regarding the border demarcation at this location specified in *1999 Viet Nam-China Treaty on Land Borderline*. One faction holds that the entirety of these falls belongs to Vietnam, and that the stone tablet had been moved there some time during or after the brief Sino-Vietnamese war of 1979. Also, there was not any mention of this fall from Chinese writings until recently.

Bridalveil Fall

Bridalveil Fall is one of the most prominent waterfalls in the Yosemite Valley in California, seen yearly by millions of visitors to Yosemite National Park.

The Ahwahneechee tribe believed that Bridalveil Fall was home to a vengeful spirit named Pohono which guarded the entrance to the valley, and that those leaving the valley must not look directly into the waterfall lest they be cursed. They also believed that inhaling the mist of Bridalveil Fall would improve one's chances of marriage.

Base of Bridalveil Fall

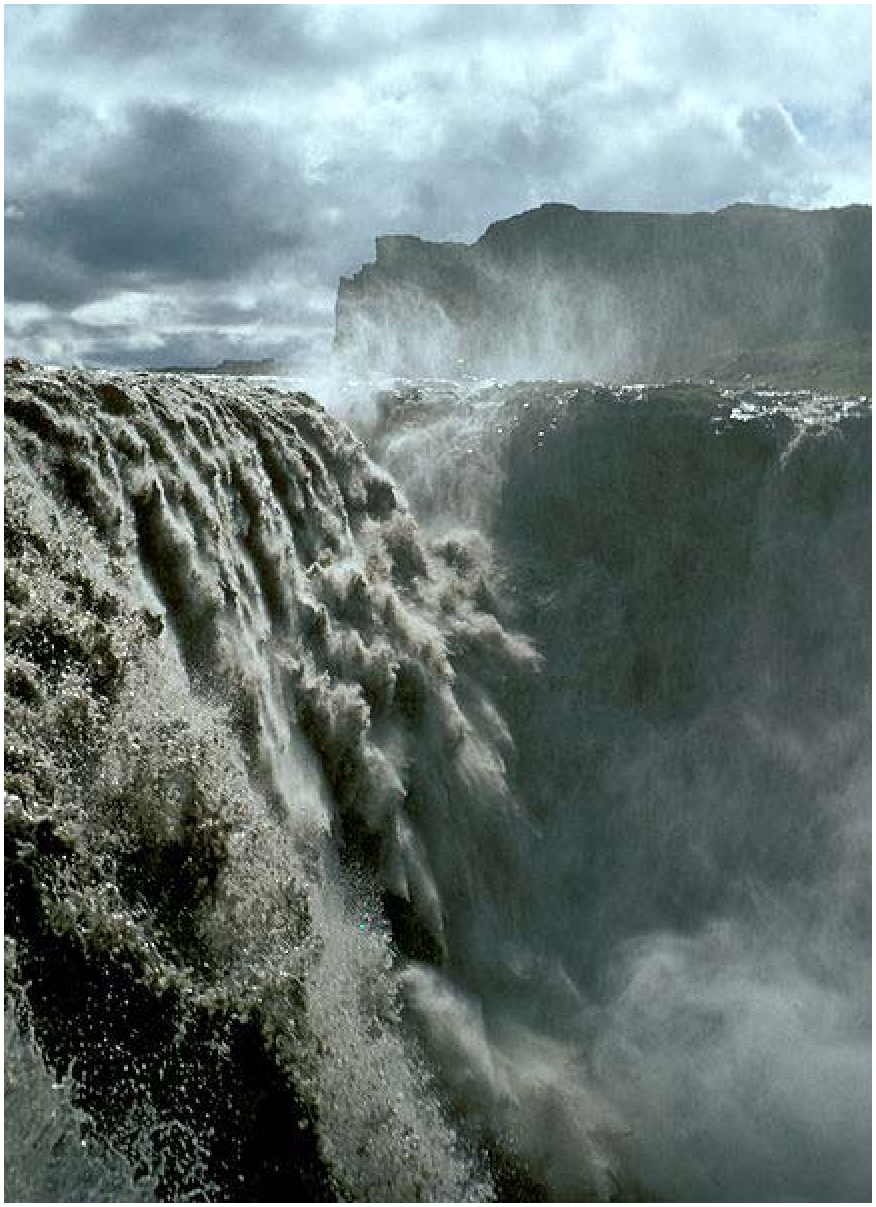
Bridalveil Fall is 188 metres (617 ft) and flows year round. The glaciers that carved Yosemite Valley left many hanging valleys which spawned the waterfalls that pour into the valley. All of the waterways that fed these falls carved the hanging valleys into steep cascades with the exception of Bridalveil Fall. Bridalveil still leaps into the valley from the edge of the precipice, although that edge has moved back into an alcove from the original edge of the valley. While Yosemite Falls seem to also fall into this category, the original course took the Yosemite Creek down a gorge to the west of its current location. The primary source of Bridalveil Falls is Ostrander Lake, some 16 kilometres (9.9 mi) to the south.

Bridalveil Fall as seen from Tunnel View on California State Route 41

When the wind blows briskly, the waterfall will appear to be falling *sideways*. During lesser water flow, the falls often don't reach the ground. Because of this, the Ahwahneechee Native Americans called this waterfall *Pohono*, which means *Spirit of the Puffing Wind*.

Dettifoss

Dettifoss is a waterfall in Jökulsárgljúfur National Park of Northeast Iceland, not far from Mývatn. It is situated on the Jökulsá á Fjöllum river, which flows from the Vatnajökull glacier and collects water from a large area in Northeast Iceland. The falls are 100 m wide and have a drop of 44 m down to the Jökulsárgljúfur canyon. It is the largest waterfall in Europe in terms of volume discharge, having an average water flow of 200 m^3/s.



Detailed view of Dettifoss

Dettifoss in its entirety with a person for scale

The waterfall can only be reached by a rough road. On the west bank there are no facilities and the view on the waterfall is somewhat hindered by the waterfall's spray. On the east bank there is an information panel maintained by the staff of Vatnajökull National Park (*Vatnajökulsþjóðgarður*) and a maintained track to the best viewpoints.

The closest populated areas include Vopnafjörður, Mývatn and Húsavík.

Huangguoshu Waterfall

Huangguoshu Waterfall, also known as Yellow Fruit Tree Waterfall (simplified Chinese: 黄果树瀑布; traditional Chinese: ▪果樹瀑布; pinyin: *huángguǒshùpùbù*; Wade–Giles: *Huang-kuo-shu p'u-pu*), is one of the largest waterfalls in China and East Asia located on the Baihe River (白水河) in Anshun, Guizhou Province. It is 77.8 m (255 ft) high and 101 m (331 ft) wide. The main waterfall is 67 m (220 ft) high and 83.3 m (273 ft) wide.

Huangguoshu Waterfall, the largest waterfall in China.

Tourism

Its main uses are for tourism. Known as the Huangguoshu Waterfall National Park, it is 45 km (28 miles) southwest of Anshun City. Together with minor waterfalls, the charms of the waterfall are a natural tourist drawing card. The scene of Huangguoshu Waterfall changes standing in different places. One place is Waterfall-Viewing Pavilion (Guan Bao ting), where you see the whole waterfall from a distance. The next is Water-Viewing Stage (Guan Bao Ting) where you get a bird's eye view. The third is Waterfall-Viewing Stage (Guan Bao Tai) in which you raise your head to see the scene. There is a special line of buses that take you to Huangguoshu Waterfall, the Dragon's Palace at Guiyang, and Anshun railway stations.

Nearby Yinlianzhuitan Waterfall (銀鏈墜潭瀑布).

Nearby Xiniutan Waterfall (犀牛潭瀑布).

The Water-Curtain Cave

The Water-Curtain Cave named "Shuiliandong" (水帘洞) in Chinese is a 134 m (440 ft) long naturally formed cave located in the back of the waterfall.