**The Atmosphere**



The atmosphere is one of 4 life support systems: the atmosphere, the lithosphere, the hydrosphere and the biosphere. It is a turbulent, gaseous envelope around the Earth, and it stretches up to 350km. It’s composed of several layers, and is often contaminated by dust and pollutant gases.

**Composition of the atmosphere**

|  |  |  |
| --- | --- | --- |
| **Gas** | **Percentage** | **Importance for life** |
| Oxygen | 21 | Used in aerobic respiration |
| Nitrogen | 78 | Used in proteins |
| Carbon dioxide | 0.038 | Used in photosynthesis |
| Ozone | 0.000007 | Absorbs UV light in the stratosphere |
| Methane  | 0.00017 | Some chemoautotrophs use methane as a source of carbon. This was important for early life on Earth and is still important in the deep oceans. |
| Argon and other rare gases | 1 | - |
| Water vapour | Varying  | Water in the water cycle is distributed in the atmosphere, water allows life to survive |

Processes that influence life on earth and the composition of the atmosphere

The major processes that influence life on earth are photosynthesis, anaerobic respiration and the natural greenhouse effect. Carbon dioxide and water vapour trap infra-red radiation emitted from the Earth, thus maintaining a warm temperature. Nitrogen is used as a raw material for protein synthesis via nitrogen fixation.

Dynamic equilibrium in the atmosphere

* There is a dynamic equilibrium of processes that maintain the average composition of the atmosphere, that only change significantly over very long time scales.
* The most important of these processes are photosynthesis and respiration.
* Although these processes roughly cancel each other out, the rates at which they occur vary over different time scales so the concentration of gases fluctuate.

Changes in atmospheric composition with time

* The concentration of carbon dioxide in the atmosphere changes over a 24 hour cycle. It rises at night as respiration occurs and photosynthesis stops. During the day, photosynthesis is much more rapid than respiration so carbon dioxide levels drop. Fluctuations are greater in the summer than in winter because higher light levels and temperatures make both processes more rapid.
* The concentration of water vapour also varies. Vegetation releases water vapour during transpiration. Evaporation and precipitation are both affected by temperature.

Long-term changes in atmospheric composition occur with changes in the activity of the Sun, geological processes and increasingly, human actions.

Changes in atmospheric composition, temperature and pressure with altitude

* More ozone naturally occurs in the stratosphere, where ultraviolet (UV) light interacts with oxygen.
* Temperature declines with increasing altitude in the troposphere due to heating by infra-red radiation from the ground, but it increases with altitude in the stratosphere due to heating by UV from the Sun.
* Atmospheric pressure decreases with increasing altitude.

These changes, combined with energy from the Earth and Sun, produce a sequence of layers in the atmosphere: troposphere, stratosphere, mesosphere and ionosphere.

Temperature changes in the atmosphere

The stratosphere is heated from above, by UV radiation from the Sun which is absorbed by the gases, then re-emitted as infra-red (heat). Lower down in the stratosphere, there is less UV radiation, as it has been absorbed by the gases above, so it is cooler at lower altitudes. The troposphere is heated from below, by infra-red radiation emitted by the Earth; therefore it gets cooler with altitude as the infra-red radiation is absorbed by gases.

The Troposphere

* The troposphere is a turbulent layer of gases extending up to 12km (7 miles) from ground level
* The troposphere contains the weather
* Pressure and temperature in the troposphere decrease with altitude
* The troposphere is warmed by infra-red radiation from the Earth’s surface, carried upwards by convection currents

The Stratosphere

* The stratosphere extends from about 12-50km above the Earth’s surface
* No ‘weather’ – it is always calm and sunny
* Planes fly in the lower stratosphere
* Ozone becomes more concentrated, known as the ozone layer
* In the stratosphere, pressure decreases with altitude but temperature increases with altitude

Ozone Layer

* The chemical symbol for ozone is O3
* Ozone is poisonous, so it’s a hazard in the troposphere
* Ozone absorbs UV radiation, preventing some of it from reaching the Earth
* Holes or thinning of the ozone layer are of concern as more UV radiation can reach the Earth’s surface

The Upper Layers of the Atmosphere (Mesosphere and Thermosphere)

* The mesosphere and thermosphere contain charged particles which absorb harmful gamma rays and UV radiation, which gives rise to the northern and southern lights
* The particles also reflect radio waves, allowing radio signals to travel around the Earth

Processes Which Alter the Composition of the Atmosphere

* Photosynthesis
* Combustion
* Respiration
* Transpiration and evaporation
* Nitrogen fixation

**Solar radiation and the atmosphere**

* Nuclear fusion in the Sun releases enormous amounts of energy as electromagnetic radiation, some of which reaches the Earth. The main reactions involve the fusion (joining) of hydrogen nuclei to form helium nuclei
* The electromagnetic radiation reaching the Earth’s atmosphere includes visible light, near infrared and ultraviolet light. Some of this is absorbed in the atmosphere, especially UV being absorbed by ozone in the stratosphere
* Gases such as water vapour and carbon dioxide also absorb particular wavelengths of visible light and infrared radiation.
* Some light is also reflected or absorbed by clouds or particulate matter

Human impacts on the atmosphere

The composition of the atmosphere is being changed by human activities.

**Global Climate Change**

The Greenhouse Effect

* The greenhouse effect is the natural phenomenon that controls the energy and heat balance of the Earth’s surface and the atmosphere.
* Visible light from the Sun passes through the atmosphere relatively easily. The light that is absorbed by the Earth is converted to heat and then emitted as infrared energy or infrared radiation.
* The infrared radiation that is emitted by the Earth’s surface is partly absorbed by gases in the atmosphere, which causes the atmosphere to become warmer until the surplus heat energy is eventually radiated into space as infrared radiation.

The Enhanced Greenhouse Effect and Global Climate Change

* Human activities are increasing the concentration of gases that absorb infrared radiation, which is causing the atmosphere to warm up. This is the enhanced greenhouse effect.
* Some of these are gases that are naturally found in the atmosphere, while others are only released by human activities.

Major anthropogenic sources of greenhouse gases

|  |  |
| --- | --- |
| **Greenhouse gas** | **Human sources** |
| Carbon dioxide | * Combustion of fossil fuels
* Deforestation
 |
| Methane  | * Anaerobic respiration in paddy fields
* Landfill sites
* Leaks from natural gas fields and pipelines
 |
| Oxides of nitrogen | * Fertilisers
* Power stations
* Vehicle exhausts
 |
| Chlorofluorocarbons (CFCs) | * Refrigerants
* Aerosol sprays
* Solvents and expanded foam plastics
* Fire extinguishers
 |
| Tropospheric ozone | * Produced by the photochemical breakdown of NO2 and subsequent reaction with oxygen
 |

The likely consequences of global climate change

**Sea level rise**

A temperature rise will cause sea level to rise in two ways: thermal expansion and melting land ice.

Thermal expansion

The warmer atmosphere causes the sea to warm up and therefore expand, causing sea level to rise.

Melting land ice

As the Earth warms up, ice will melt. Ice that is on land will cause sea level to rise as the water flowing into the sea increases the volume of water in the sea. Glaciers and Antarctic ice shelves form on land and cause sea level to rise as they flow off the land and displace the sea water.

**Changes in climate**

Wind patterns

Winds may change in velocity, frequency and direction. Stronger winds may cause more storm damage. If the direction changes, then the rain that is distributed by the wind may fall in different areas, so some areas would get more rain, while others would get less.

Rainfall patterns

Higher temperatures would increase evaporation rates, resulting in increased precipitation rates. Areas that previously received rain may get less if it becomes too warm for the water vapour to condense. Areas that were very cold may have received little rainfall in the past as the water vapour condensed and fell before it reached there. Warming could increase precipitation as the water vapour could be carried farther before it condensed and fell.

**Feedback mechanisms**

A positive feedback mechanism occurs where an environmental change causes other changes that increase the rate or amount of the original change, and therefore increase its effect. These may increase temperatures directly or increase the concentrations of the gases that will cause further temperature rise.

Raised temperatures may cause the following:

* Warming may increase the rate of decomposition, causing more carbon dioxide to be released and therefore more warming.
* Warming reduces the area of ice and snow on the ground or floating on the sea. This reduces the albedo so less sunlight is reflected, solar heating is increased and temperatures rise further
* Melting permafrost in polar regions releases methane gas bubbles that were trapped in the ice. This causes further heating.
* Warming may cause forests and areas with peat soils to become drier. Fires may become more frequent and last longer, adding extra carbon dioxide to the atmosphere.

A negative feedback mechanism occurs where an environmental change causes other changes that decrease the rate or amount of the original change, and therefore reduces its effect and help to re-establish the original equilibrium.

* High temperatures may cause increased rates of photosynthesis, which would store more carbon in biomass. Levels of carbon dioxide in the atmosphere would be lowered, which would cause cooling.
* Warming would increase evaporation and cause the formation of low level cloud. This would increase the albedo, reflect away sunlight and reduce solar heating.

**Control of global climate change**

Strategies to reduce greenhouse gas emissions

|  |  |
| --- | --- |
| **Greenhouse gas** | **Methods to reduce it** |
| Carbon dioxide | * Reduce use of fossil fuels
* Use of alternative energy sources such as solar, wind, tidal, hydroelectric and geothermal power
* Carbon sequestration (planting more trees, and storing carbon dioxide from power stations underground, in old oil reservoirs, aquifers and coal seams that are unable to be mined)
 |
| Methane  | * Reduce the amount of rubbish being put into landfill sites
* Reduce livestock production
 |
| Oxides of nitrogen | * Use catalytic converters inside vehicle exhausts
* Increase the use of public transport
 |
| Chlorofluorocarbons  | * Use alternative materials which replace the CFCs, such as butane, propane, HFCs and HCFCs
 |
| Tropospheric ozone | * Methods that reduce emissions of NOx
 |

Greenhouse gas emissions can also be reduced through the use of government protocols such as the **Kyoto Protocol** (1997). The Kyoto Protocol is an agreement legally binding signed-up countries to meet emissions reduction targets of all greenhouse gases by 2012 relative to 1990 levels. Agreements such as the Kyoto Protocol do not reduce emissions themselves, but they encourage the use of methods that will.

Strategies to cope with climate change

|  |  |
| --- | --- |
| **Activity or problem** | **Strategies**  |
| Agriculture  | * Cultivate warmer climate crops
* Cultivate drought-resistant crops
* Water storage in times of water surplus for later irrigation use
 |
| Building design | * Paler materials to reduce heat absorption
* Better ventilation and cooling systems to reduce the use of air conditioning
 |
| Flooding  | * Riverbank defences
* Less building on floodplains
* Reduce run off rates, e.g. by reducing paved areas to increase infiltration
 |
| Coastal erosion | * Improve coastal defences
* Managed retreat – abandon lower value areas that are difficult to defend
 |
| Storm damage | * Design of stronger buildings
 |

**UV light and the ozone layer**

The effects of UV on living organisms

The ozone layer is important because it absorbs harmful UV light. If UV light is not absorbed in the atmosphere then it will reach the Earth’s surface and may be absorbed by living cells. The UV light can cause skin damage, skin cancer, cataracts and damage to plant tissue.

Chlorine, CFCs and ozone depletion

Halogens, especially chlorine in the stratosphere, cause ozone depletion in a range of reactions. A single chlorine atom is a chlorine radical because it has an unpaired electron. This makes it very reactive. A chlorine radical can react with an ozone molecule, breaking it down to leave an oxygen molecule and chlorine monoxide:

Cl + O3 🡪 ClO + O2

CFCs do not reduce ozone depletion but they are broken down by UV light in the stratosphere to release chlorine, which then causes the damage.

Reduction of CFC emissions

**The Montreal Protocol**

The Montreal Protocol (1987) is an international agreement, which phased out the manufacture and use of CFCs and other ozone-depleting substances.

Alternative materials and processes

A range of alternative materials have been used to phase out CFCs, such as alcohols and HCFCs. Alternative processes include trigger and pump action spray cleaners instead of aerosol cans, and stick deodorants instead of aerosol cans.

**The Hydrosphere**

The hydrosphere contains water in all its forms (solid, liquid and vapour), that are found on, in and around the Earth.

**Properties of water**

Changes of state

Water is able to change state between solid, liquid and gas. The narrow temperature range within which water changes state allows the hydrological cycle to occur.

Anomalous expansion

Water expands on cooling, and this is very unusual so it is called anomalous expansion. The floating layer of cold water and ice prevents the water below from freezing.

Solvent properties

Water is an excellent solvent, and most biological reactions occur with solutes dissolved in water. Plant nutrients can only be absorbed if they are dissolved in water, and most materials transported in blood and sap are dissolved in water.

High specific heat capacity

Water has a high specific heat capacity. This means that it takes a lot of energy to heat up water and so it tends to maintain a constant temperature and resist changes in temperature. Aquatic organisms enjoy a much more even temperature throughout the year than many terrestrial organisms, which have to contend with very hot temperatures in the summer/during the day and very cold temperatures in the winter/at night. A high specific heat capacity also helps to maintain climatic stability by moderating temperature changes.

**The hydrological cycle**

The hydrological cycle is driven by solar power, which warms the water on the Earth, making it evaporate and rise in the atmosphere as the energy is converted to gravitational potential energy. This is converted to kinetic energy as it falls to Earth and flows back towards the sea. Solar energy also drives evaporation from the land and the plants that lose the water by transpiration.

The reservoirs of water in the hydrological cycle are:

* Oceans
* Ice
* Lakes and rivers
* The atmosphere
* Groundwater
* Soil moisture
* Living organisms

Residence times and transfers between reservoirs

The average length of time that water spends in a reservoir is called the residence time.

Residence time = volume of water in reservoir ÷ average transfer rate in or out of the reservoir

An understanding of residence times can help with the sustainable management of water resources.

The main processes involved in the hydrological cycle

|  |  |
| --- | --- |
| **Process** | **Human impacts** |
| Inputs:* **Precipitation** refers to all the moisture that falls from the atmosphere onto the surface of the Earth, e.g. rain, snow, hail, sleet, drizzle etc. Temperature and humidity control when condensation occurs as the amount of water vapour that the atmosphere can hold drops as the temperature goes down.
 | * Any impacts that change temperatures
 |
| Throughflow:* **Interception** is when water impeded by vegetation is evaporated back to the atmosphere and never reaches the ground surface.
* **Infiltration** is the rate at which water enters the soil.
* **Percolation** is the flow of water through the pore spaces in the rock.
* **Groundwater** **flow** is the movement of water through pore spaces in the rock.
* **Surface** **run off** is the flow of water over the ground surface.
 | * Deforestation, afforestation
* Soil compaction, urbanisation with increased paved areas and buildings
* Groundwater abstraction, artificial aquifer recharge
* Actions that reduce infiltration or interception
 |
| Outputs:* Evaporation is the process of liquid water turning to water vapour, and transpiration is the process of water being taken up by roots and released as water vapour through leaf pores. **Evapotranspiration** is both of these processes combined.
 | * Increased temperatures, vegetation changes
 |

**Water as a resource**

Uses of water

**Abstractive uses**

Domestic uses

These include washing, flushing toilets, food preparation, drinking, watering house and garden plants and recreation.

Industrial uses

Many industries, such as power stations, the chemical industry and some mining and mineral processing industries require large amounts of water. Major industrial uses of water include cooling, heating, washing, steam generation, transport and as a solvent.

Agricultural uses

Irrigation is the biggest single agricultural use of water. Water is also used for livestock drinking.

**Water quality requirements**

The degree to which water needs to be purified depends upon its intended use. Public water supply is the most important large-scale water use where quality is very important and supplies may require a lot of treatment. Many physical, chemical and biological criteria are used to assess the water quality for public supply. Potable (drinkable) water does not need to be completely pure, but it must not contain unacceptable levels of hazardous materials nor look, taste or smell unpleasant.

Turbidity

Suspended solids must be removed because they give water an unpleasant appearance and taste, and the settling of suspended solids would also block water pipes.

pH

If water is too acidic it can corrode copper pipes. If the pH is too high or too low it can make the water taste unpleasant. The ideal pH range is 6.5-8.5.

Calcium content

Dissolved calcium ions make the water ‘harder’. Hard water is good for health as it can help to reduce tooth decay, osteoporosis and heart disease. But it can also react with soap to produce scum and solid limescale if the water is heated.

Pesticide and heavy metal concentrations

All pesticides are toxic, but not necessarily very toxic to humans. Water should be treated to remove virtually all pesticides – water should not contain more than 0.1µg/l per pesticide. Heavy metals such as lead and mercury are neurotoxins and damage the nervous system, but low concentrations cause no detectable damage.

Dissolved O2

Low dissolved oxygen levels can make water smell musty or of hydrogen sulphide. Some toxic metals are more soluble in water with low dissolved oxygen content. Low dissolved oxygen content can also indicate the presence of organic matter.

Cl2 retention

Chlorine is added to water to keep it sterile. Other materials present in the water and the pipe’s wall itself may react with the chlorine and reduce its concentration. It may be necessary to add more chlorine or use chloramines, which gradually release more chlorine. Excess chlorine may also produce an unpleasant taste, or react to form toxic chlorine compounds.

E.Coli abundance

E.Coli is a very common gut bacterium and is always present if sewage contamination has occurred. Sewage contamination of water can cause the spread of many serious diseases such as cholera and typhoid.

The coliform count is a measure of the number of bacteria similar to E.Coli that are present per litre of water. For potable water the coliform count should be 0.

**Water quality requirements for different uses**

|  |  |  |
| --- | --- | --- |
| **Use**  | **Quality requirement** | **Problem that would be caused** |
| Potable water for public supply | Water that looks, smells and tastes good and contains no hazardous chemicals | Public health risks and acceptability |
| Spray irrigation | Low turbidity, no toxins e.g. heavy metals | Sediments would block pipes, toxins could harm crops or consumers |
| Power station condenser water | No gross solids | Pipes would block |
| Power station boiler steam water | Absolutely pure water | Mineral deposits would build up in boiler pipes and reduce water flow and heat exchange |
| Textile washing | ‘Soft’ water with low dissolved calcium content | Scum would form during washing |

**Non-abstractive uses**

These use the water where it is found or nearby and do not take it away from or move it to another water body or catchment area.

Energy generation

Hydroelectric power schemes use the kinetic energy of moving river water to generate electricity. A dam is usually built to hold back a reservoir so the river flow is altered but the water is not removed. Water from rivers, lakes and the sea is used to cool condenser steam in fossil fuel and nuclear power stations. It is returned to the source at a slightly higher temperature.

Transport

Water was the first mass transport system for bulk goods on the sea, rivers and later on specially built canals. The importance of canals and rivers declined with the rise of railways and road transport, but ship transport by sea remains very important.

Recreation

Water bodies are used for many recreational uses such as sailing, canoeing, holiday boating, sport fishing and swimming.

Wildlife conservation

Wetlands provide very valuable wildlife habitats. Many of these have been created by human activities, such as reservoirs and flooded gravel pits. Wetlands in the UK are particularly important for migratory water birds because our mild winters prevent the water from freezing.

**Water use and conflicts of interest**

Conflicts about water use may be caused in two ways:

* Abstracting and storing water can cause problems for other users of the water or the surrounding area
* Other user groups in the area may threaten the water supplies

Any new abstraction may conflict with people who already use the same source, especially if exploitation becomes unsustainable.

The previous land use will no longer be possible if a reservoir is built and some may consider the aesthetic appeal of the area has been damaged. The presence of the reservoir may restrict the activities that are permitted in the catchment area, especially those that may cause pollution or soil erosion.

Fishery interests may be affected by the dam restricting the movement of fish. This can be reduced by the use of a ‘fish ladder’, where fish can go around the dam through a series of pools.

Abstraction from the reservoir will reduce river flow downstream and regulating river flow will reduce fluctuations. Both of these may increase the build-up of sediments, making the river bed unsuitable for breeding of some species such as trout.

**Sources of water**

The availability of water has a major effect on many aspects of life because it influences where people can live, what they can eat, which industries can be developed and the quality of life.

**Rivers**

The main features that affect the usefulness of a river are:

* Total annual water flow (river discharge)
* Flow fluctuations
* Level of natural contaminants
* Pollution from human activities

The environmental effects of abstraction of river water are:

* Reduced downstream flow
* Increased sedimentation
* Reduced water levels, including levels in lakes fed by the river

**Reservoirs**

Reservoirs allow the storage of water from times when there is a surplus of water until a time when there is a deficit (shortage). But even if there is a suitable water supply, many other factors must be considered when choosing a site for a dam and reservoir.

**Topography**

The main cost of developing a reservoir is in dam construction while the income of the reservoir comes from the amount of water it can hold and then supply. The ideal topography would involve a narrow exit to a large, deep basin so a relatively small dam could hold back a huge volume of water.

**Geology**

The rock beneath the reservoir must be impermeable so that the water cannot percolate into the rock and be lost. The rock should also be strong enough to support the weight of the dam and reservoir, without faults or seismic activity that could trigger an earthquake and cause the dam to collapse.

**Catchment area**

This is the area of land over which falling rain will flow or will flow through the ground and then into a river. So the ability of a reservoir to provide water is controlled partially by the reservoir site itself but also by the surrounding area that collects water for it. Even if it has not rained recently, there may be a lot of water from previous rain on its way to the reservoir.

**Water supply**

Ideally, the rainfall or river inflow should be regular with a large volume. The climate should not be too hot or dry, which could cause excessive evaporation losses.

**Existing land use**

The use of the land that is to be flooded cannot be so important that it must not be lost. An analysis of the benefits and losses must be considered. In the UK large urban areas and important wildlife conservation areas would probably be protected, while agricultural land would be less valued. Other countries may assess their priorities differently.

**Pollution risk**

The land uses in the catchment area should not pose a series pollution risk to the water. The main threats are toxic pollutants from industry and agricultural pesticides. Pollutants such as sewage and manure are biodegradable and break down relatively quickly. They are unlikely to become as concentrated as they could in a river where the volume is smaller.

**Sedimentation**

Soil erosion in the catchment area can make the inflow river very turbid, resulting in sedimentation in the reservoir. This gradually reduces the volume of water that the reservoir can hold.

**Infrastructure**

Building the dam, treating the water and transporting it to the area of demand require workers, building materials, access routes and machinery. A convenient site near the area of demand may be chosen rather than a site that would supply more water but that is isolated and difficult to reach.

The environmental effects of reservoirs

Building a reservoir alters the environment of the reservoir site itself and the surrounding area.

**Habitat change**

Flooding the reservoir site obviously destroys the previous habitats but also creates new and possibly valuable ones. Wetlands are uncommon habitats in most regions so the reservoir may be more valuable that what has been lost.

The dam and reservoir also act as a barrier to wildlife such as salmon and sturgeon that migrate along the river. This can be solved by the use of ‘fish ladders’. Species that live in the river will have population booms and collapses. Free movement along the river is an important part of recolonizing areas that have become vacant in bad years. The dam may prevent this.

**Changes in the river downstream**

Changes in flow rate – most of the time the flow will be lower because the water is being abstracted upstream to supply customers. This leads to increased sedimentation and reduced oxygen in the water for aquatic creatures.

Lower turbidity – this is caused by the silt being held back behind the dam. Lower turbidity means that aquatic plants can photosynthesise more efficiently, but it also means that the water is less fertile.

Temperature of the water – the smaller volume of water in the river means that the water will warm up more quickly, so in spring and summer there may be less oxygen in the water for fish and invertebrates (warm water holds less oxygen).

**Reservoir microclimate**

Reduced temperature fluctuations – the climate will be more temperate (have a more even temperature) because water has a high specific heat capacity.

Higher wind speed downwind – it will be windier because there are fewer obstacles e.g. trees to act as windbreaks. Water also provides less friction than land, so wind speeds will be higher.

Higher humidity downwind – the climate will be more humid because of evaporation from the large surface area of water. Greater evaporation from the reservoir may also increase cloud cover and precipitation downwind of the reservoir.

**Aquifers**

An aquifer is a layer of rock that holds water, which is exploited as a resource. To be suitable for exploitation it must have certain features.

Porosity

**Porosity** is a measure of the proportion of the rocks’ volume that is space and could therefore hold water. Chalk, limestone and sandstone are porous rocks that often form aquifers.

Permeability

**Permeability** is a measure of the ease with which fluids may flow through a rock because of the interconnections between the pore spaces. Some materials such as clay have high porosity but the pores are too small for water to flow through easily.

Suitable geological structures

The rock below the water-bearing rock must be impermeable to prevent the escape of the water. Granite and clay are suitable impermeable materials. Some of the rock above must be permeable to allow recharge of the aquifer with water from above. Some aquifers are very large and the recharge area may be a long way from the area of abstraction. The water may be abstracted using a well, a borehole or it may come to the surface naturally in springs.

**The consequences of aquifer overuse**

The natural amount of water in an aquifer is a dynamic equilibrium created by the natural inflow or recharge of water into the aquifer and the water that flows out. If the abstraction rate by humans is greater than the rate of recharge, then the volume of water in the aquifer will drop. There are several effects/consequences of over-abstraction.

Lowered water table

Many rivers, lakes and marshes are fed by groundwater flowing out of aquifer springs. If the groundwater is overexploited then the water table will be lowered and flow from springs will decline.

Subsidence

Water that is no longer present in the pore spaces in the rock cannot provide support for the rock particles, so they will be compacted by the weight of the material above. This causes subsidence at the surface, which can cause serious damage to buildings and pipelines.

Drying of wetlands

Wetlands may dry up if overexploitation of groundwater causes the flow of water into wetlands to decline.

Vegetation change

If the water table is lowered then plants with a higher water requirement will die or become less abundant as they fail to compete with plants that have a lower requirement for water. Other species may be affected, even though they do not rely on the water directly, because they depended on the species that needed the water, for instance food, but have now died out.

Saltwater incursion

In coastal areas the water table under the land may be slightly higher than sea level. As rainwater percolates down to the aquifer, water flows sideways and out into the sea. This seawards flow of freshwater prevents seawater from flowing into the aquifer under the land surface. If the aquifer is overexploited, then seawater flows into the aquifer to replace the freshwater. The salt makes the aquifer water unsuitable for irrigation as it could kill the crops through osmotic dehydration.

**Water treatment**

Before water is treated, its quality must be assessed to ensure that the appropriate methods are used to purify it. The particular methods that are employed will depend on the intended use and the quality of the water source.

**Freshwater treatment**

Screens

Metal grills are used to remove floating vegetation, plastic and paper that would clog later processes.

Sedimentation

The water is allowed to remain static to enable suspended solids such as silt to settle.

Aeration

Bubbles of air or water sprays are used to aerate the water and ensure high dissolved oxygen content. Water sources that are anaerobic may contain hydrogen sulphide from the decay of organic matter, which makes the water smell of bad eggs. Some dissolved metals that are toxic or give the water a bad taste are removed by aeration as they become insoluble.

Flocculation

Clay particles do not settle out in the sedimentation tanks because electrostatic charges on their surfaces cause them to repel each other. These can be neutralised by adding flocculants such as aluminium sulphate (alum). They are mixed quickly with the water and then passed into the clarifier tank where the particles are allowed to settle.

Filtration

Filters such as sand filters are used to remove any remaining suspended solids and bacteria.

Activated carbon filtration

Particles of active carbon are used to remove organic chemicals such as pesticides and some substances used that cause bad tastes.

Sterilisation – chlorination, ozonation and ultraviolet light treatment

The addition of chlorine, ozone or exposure to ultraviolet light is used to sterilise the water and kill pathogens. Chlorine is the most common method of sterilisation but if the water is from peaty sources then organic matter may be present, which could react with the chlorine and produce toxic substances. Ozone also helps to break down pesticides.

The addition of chlorine should keep the water sterile during distribution but it is gradually lost. Using chloramine keeps the water sterile for longer as it breaks down gradually and releases chlorine.

Fluoridation

Fluorides are added to water in some areas to improve dental health of people that drink the water, as fluoride strengthens tooth enamel.

**Seawater treatment**

Seawater is the most abundant source of water but high salt content makes it unusable, except where its composition is unimportant, such as condenser cooling water in power stations. Removing salt from seawater is expensive and only carried out if other sources of water are unavailable. Desalination of seawater is very energy intensive and expensive and is only used in countries where seawater is available but there are inadequate supplies of freshwater.

Reverse osmosis

During reverse osmosis the saline water is filtered at very high pressure through a partially permeable membrane of very small polyamide tubes. The fresh water that is collected is about half its original volume. The remaining very salty water is returned to the sea. A lot of energy is needed to produce the very high pressures, which makes desalinated seawater very expensive.

Distillation

Water is boiled by heating and reducing the pressure. The steam that is produced is then condensed and collected.

**Demand for water**

Factors that cause the demand for water to change:

Change in population size

The population may grow because the birth rate is higher than the death rate or because of immigration. Migrants may move from other countries or within a country.

Change in living standards

In the poorest communities where there is no piped water supply, domestic water use may be limited to the amount that can be carried from the source, which may be the nearest river. As piped water becomes available and people become more affluent, they buy more appliances that use water such as washing machines and dish washers, or luxury recreational items such as swimming pools.

Industrialisation

Different industries have different water requirements. For example, irrigation uses more water than all other human uses combined. As affluence increases and energy and equipment become available, irrigation can increase, pumping water from aquifers and rivers and storing it in a reservoir.

Heavy industries such as the chemical and steel industries or paper making industries use much more water than lighter manufacturing industries.

Problems caused by water shortages

Problems caused by water shortages include the death of crops, livestock and people.

**Water conservation and management**

Better use of water resources can be achieved in several ways:

* Increase the total amount of water available for use
* Distribute water more effectively
* Use water more efficiently

**Increasing the availability of water**

Increased abstraction

Availability of water can be increased by abstracting more river water, ground water or seawater and by building storage reservoirs. Small scale collection may reduce demand for public supplies, for example by collecting rainwater for garden use or low quality uses such as flushing toilets. Increased abstraction is limited by the amount of water available or by the energy and financial costs of purification.

Catchment management

Catchment management can make the available water supplies more usable.

* Reservoirs can be used to maintain river water levels in times of low natural flow and to store water during periods of flood risk
* The prevention of pollution upstream of water abstraction points reduces the amount of water that is too polluted to use and makes purification easier

Aquifer recharge

Partially depleted aquifers can be recharged during periods of surplus surface water.

**Better distribution of water**

Reducing distribution losses

Better maintenance of water distribution networks (e.g. repairing leaking pipes) can help to reduce wastage of water.

Inter-basin transfer

Communities usually develop where sufficient water is available but it may expand and develop until the local supplies are inadequate. Water may be transferred from other catchment areas via canals, rivers and pipes.

**More efficient use of water**

There are many ways of reducing the total amount of water that is used by using the water more efficiently.

Metering

People are much more likely to be careful over how much water they use if they are charged for the amount they use with a meter.

Low water use appliances

Washing machines and dishwashers are now designed to use less water and also have small load settings. Toilets have dual flush designs so more water is only used if needed.

Recycling: ‘grey water’ use

Water that has been used for bathing or washing clothes is not very dirty and is suitable for low quality uses such as flushing toilets or watering plants. This reduces demand for water from the public supply.

**The Lithosphere**

The lithosphere involves the crust and the upper part of the mantle beneath the crust.

The lithosphere provides resources and services in a number of very different ways:

* Physical resources for human exploitation such as mined metal ores, non-metal minerals and fossil fuels
* Biogeochemical cycles, which recycle essential biological elements such as carbon, nitrogen and phosphorus
* Through soil, which provides the growth medium for most plants on land, the habitat for many organisms and the location for part of all the biogeochemical cycles

Some processes in the lithosphere are fast and can rapidly replace resources that are exploited. As long as exploitation is responsible then the natural processes will continue to provide the resources. Some resources are replaced by geological processes that are very slow. Almost any exploitation may be faster than the replacement rate and therefore be unsustainable. It is important not to use these resources irresponsibly if they are to be usable for as long as possible.

A **resource** is the name of a material or the total amount of a material that could theoretically be exploited.

**Mineral resources**

Mineral resources include the rocks and fossil fuels that are removed from the crust to be used, after processing if necessary.

|  |  |  |
| --- | --- | --- |
| **Resource**  | **Most important uses** | **Important properties**  |
| **Fossil** **fuels** |
| Coal  | Fuel, especially for electricity generation | High energy content |
| **Metals**  |
| Iron | Construction: buildings, ships, road vehicles etc | Malleable (can be moulded and rolled)Strong but high densityForms alloys, e.g. stainless steel |
| Copper  | Electric cables and water pipes | Malleable Very good electrical conductorCorrosion-resistant |
| Aluminium  | Packaging, vehicles and construction, e.g. window frames | Malleable Strong with low densityGood conductor of heat and electricityCorrosion-resistant |
| **Non-metal minerals** |
| Gravel  | Concrete  | Coarse-grained filler |
| Clay  | Bricks, roof tiles and pottery | Waterproof when baked, easily moulded |
| Slate  | Roof slates | Waterproof, splits to form thin, flat sheets |

Unsustainable exploitation of these resources can result in:

* The exhaustion of reserves
* The increased production of harmful waste
* Land degradation
* A lower quality of life for current and future generations

A **reserve** refers to the proportion of a resource that can be economically exploited with existing technology.

**The geological origins of economically important minerals**

If all the minerals in the crust were evenly mixed then none of them would be sufficiently concentrated to allow exploitation. Geological processes have provided local concentrations that can be exploited.

Igneous processes

The plates that make up the crust are moved slowly by convection currents in the mantle below. The friction, heat and pressures produced can cause molten rock (magma) to be forced up towards the surface. It may reach the surface as an igneous extrusion where it will cool rapidly to form a fine grained igneous rock such as basalt.

Some magma may fail to reach the surface, forming a large molten mass of intrusive rock. This is insulated by the surrounding rock so it cools slowly, producing larger crystals and giving more time for minerals to be separated into localised concentrations that can be exploited.

Granite is produced in these deep deposits called **batholiths**. The rocks around the batholith may be lifted and deformed so cracks or fissures form. These may allow hot solutions containing dissolved minerals to escape towards the surface. As the solutions cool down, the minerals are deposited in a predictable order according to their solubility. This process takes solutions of mixed minerals and separates them into concentrated deposits that can be exploited more easily. Most metals, for example iron, tin, copper and lead, are found as **hydrothermal deposits**.

Sedimentary processes

Sedimentary processes occur at the surface of the lithosphere. A rock that already exists is broken down by weathering into rock particles (regolith) and dissolved minerals in solution (solutes). These are carried away, separated and may be re-deposited elsewhere as rocks with quite different compositions and properties.

**Alluvial/placer deposits** have been carried by flowing water but are deposited when the water slows down. Different minerals are deposited in different parts of the river, with the densest ones settling out first. Tin ore, gravel, sand and clay are all deposited in this way. Mineral solutions may later be deposited in the spaces between the rock particles, sticking the particles together. This is what happens to sand when it forms sandstone.

**Evaporites** are formed when water evaporates from mineral-rich solutions. Minerals crystallise as the solution becomes saturated, each mineral reaching saturation at a different time so they become separated in layers. For example, gypsum is deposited before halite.

**Biological deposits** are produced from dead animals and plants. Fossil fuels were produced by dead organisms partially decaying in anaerobic conditions. Chalk and many limestones are formed from the shells of dead marine organisms.

Metamorphic processes

Existing rock that is exposed to extreme heat and pressure from nearby igneous activity may change its form without melting, in a metamorphic process. Slate was formed from the sedimentary rock shale, often made largely from clay. Marble is formed from limestone that has been metamorphosed.

**Resources, reserves and exploitation**

Minerals are non-renewable resources because the amounts that exist are finite although most are very abundant. Economically recoverable resources account for a tiny proportion of the total that exists.

The main limitations on mineral availability are the locations, chemical form and purity of the deposits, and the availability of technologies to exploit them. Their exploitation is economically important but can cause environmental damage.

Resources

If the term ‘resources’ is used when referring to a particular material then it includes all of that material that is theoretically available for exploitation. This includes deposits that can be exploited as well as those which cannot be exploited now but could be with realistic increases in prices or improvements in technology.

Reserves

Reserves include that portion of the resource that can be exploited now economically, using existing technology. The size of a resource is finite but the quantity included in the reserves can change. If there is an increase in market price or if new technologies are developed, then the reserves will increase. If market prices drop then reserves may decrease as deposits that still exist become uneconomic.

**Factors affecting the viability of a mine**

**Land conflicts**

Deciding where to mine minerals is different from most other land use choices. If you want to build a reservoir, town, road or airport or decide where to plant a forest then you have choices. But the only place you can mine minerals is where they are found.

**Extraction costs**

Overburden

The rock above the mineral that must be removed is called the overburden. If the overburden is very hard it is expensive to remove as it may need to be blasted.

Depth

Mining costs rapidly increase as depth increases. If the depth is doubled then the cost much more than doubles.

Form of the mineral deposit

Mining costs will increase if the mineral is found in thin layers or if it is dispersed in an irregularly shaped deposit. Both of these problems would increase the size of the mine void that would need to be excavated.

Hydrology

As depth increases, the amount of water that flows into the mine also rises. Pumping costs would be high.

**Processing costs**

The chemical form of the mineral

The cost of extracting a metal depends upon the other elements with which it is combined. The more energy that is needed to break the bonds, the more expensive it will be to extract the metal.

Purity

The financial cost of extracting metal from rock increases rapidly as the purity of the ore decreases. To produce one tonne of metal, a greater quantity of rock must be extracted and more energy is required for the chemical separation of the metal from its ore.

The **cut-off grade** is the lowest ore purity that can be exploited economically.

Transport costs

Transporting minerals longer distances increases costs, but the unit costs go down if bulk transport by rail or large ship is possible. If there is an existing transport system then the set-up costs are lower and processing the mineral before it is transported reduces the bulk that needs to be moved.

Market economics

The market demand and sale value of the minerals control the economic viability of exploiting a particular mineral deposit. The market price is controlled by the demand for the mineral and how much is produced by mines. Exploiting minerals in regions that already have mines is easier because there will be easy access to the existing infrastructure for transport, energy, equipment and a trained workforce.

**The environmental impacts of mineral exploration**

**The future of mineral supplies**

Mineral resources are very abundant but reserves of exploitable minerals are limited. To ensure that future shortages do cause serious problems, new approaches must be developed. There are a number of methods that may be used to extend the lifespan of existing reserves and convert new parts of the resource into exploitable reserves.

Increased exploration

Some sites that are likely to have large mineral deposits have not been thoroughly explored. Increased exploration of these sites may allow more exploitable deposits to be found.

Better exploratory techniques

A wide range of techniques have been developed to help find new mineral deposits more effectively and cost-effectively.

* Remote sensing – this includes any technique that collects information about the mineral deposit without actually being in contact with it. Satellite and aerial surveys allow large areas to be surveyed to quickly provide information on topography, rivers and surface geological features.
* Magnetometry – the strength of magnetism helps to detect magnetic rocks, such as iron ores.

Mechanised mining techniques

Larger excavators can extract material more rapidly and therefore cost-effectively. It is also possible to dig deeper mines, the deepest open cast mine being over 450m deep.

Exploitation of low grade ores

Extracting metals from low grade ores by traditional methods such as chemical smelting is very expensive so alternative methods have been developed. For example, the copper in leachate water from spoil heaps can be concentrated by evaporation and then separated using electrolysis.

Recycling

The use of waste mineral materials helps to reduce demand on the reserves that are still in the ground. A very wide range of materials can be recycled, although there can be technical problems, especially if mixed materials such as alloys are involved.

Material substitution

If a more abundant material can be used, then the less abundant material can be reserved for uses where no other material could be used. Plastics can be used for domestic water pipes instead of copper, which can then be reserved for electrical uses.