S268 Block 3

Summary of Section 1

1. Water is a renewable resource; there is a virtually constant supply of fresh water, as water is recycled on the Earth.

2. A few litres of water per person per day are needed for survival. For subsistence, the daily requirement is 20-40 litres per person; this includes the use of water for cooking and washing in addition to drinking, but not water for growing food. Water use in industrialised countries is typically 500 litres per person per day. This includes water for various domestic purposes, industry, power generation and agriculture.

3. The largest use of water on a global scale is for agriculture (69%) most of which is for irrigation. On a global scale, 8% of water is used for domestic purposes, and 23% for industry.

4. The uses of water can be separated into abstractive and non- abstractive ones. An abstractive use is where water is used in such a way as to be temporarily lost as a resource, as when used for the domestic water supply. In a non-abstractive use, such as transport, neither the natural route nor the quality of the water is changed.

5. In Britain the public water supply accounts for the most freshwater. The average domestic demand is 140 litres per person per day, which takes between a third and a half of the public water supply. Electricity generation also requires large quantities of fresh water, and even larger quantities of water from estuaries and the sea., Irrigation uses only a small proportion of the water abstracted in Britain, but does so at a time of greatest demand on water resources.

6. In the UK, water is the cheapest of all physical resources, at an average of 53p per tonne (1993) Supply and demand relationships apply to water as they do to other resources. Water generally has a high place value, as the cost of transporting water adds considerably to its price.

Summary of Section 2

1. The water cycle involves the movement of water, in all its forms, over, on and through the rocks near the surface of the Earth in a cycle. This cycle is driven by the Sun's energy and the Earth's gravity. The total volume in the cycle is virtually constant. Magmatic water adds small amounts of water to the cycle, and formation water removes small amounts of water from the cycle. Water is stored in reservoirs of the hydrosphere: in the oceans, underground, in the icecaps, and in lakes, rivers, the soil and the atmosphere. There is a transfer of water to the oceans by surface runoff (see section 4.2) and outflow of underground water

2. The residence time for water in a reservoir is the average length of time the water remains in that reservoir. It is calculated by dividing the volume in storage by the rate of transfer to or from another part of the cycle. Residence time is a measure of the rate at which water in different parts of the cycle is renewed; it is fastest in the atmosphere (11 days) and rivers (a few weeks) Only about 4% of the water in the water cycle is not sea water. The proportion of fresh water that can be used for water supplies is less than this, about 1% of the total.

3. Precipitation has a very uneven global distribution, but is greatest near the equator. On a smaller, precipitation is greatest over mountainous areas on land. Interception is the process by which precipitation is prevented from reaching the ground by vegetation

4. Water is returned to the atmosphere by evaporation and transpiration. Transpiration is the process by which water is drawn from the soil by plant roots, transferred to the leaves and then evaporates. Evaporation and transpiration can be combined into one parameter, evapotranspiration. A maximum theoretical value for evapotranspiration, can be calculated from meteorological parameters for any area.

Summary of Section 3

1. The rate at which water infiltrates into the ground depends on the permeability of the rocks and the state of the ground surface. Below the ground surface there is an aeration zone, which has air in the pore spaces, and a saturation zone which has all the pores filled with water. The water table is the boundary between the aeration zone and the saturated zone, and is the level at which water stands in wells. Water below the water table is called groundwater. The water table follows the topography of the ground surface but with more gentle gradients.

2. Groundwater will flow in response to differences in pressure, Darcy's law relates the speed of the groundwater movement (v) to the hydraulic conductivity (K) and to the hydraulic gradient or slope of the water table (h/l) by:

   $$v = K\ h/l$$

   The hydraulic conductivity depends on the permeability of the rock and on the properties of the water. Water will flow in the direction of maximum slope of the water table.

3. A cone of depression is formed in the water level around a well from which the water is being pumped. The difference in height between the water table before pumping and the water level in the well during pumping is called drawdown

4. There is usually saline groundwater under the land at a coast, with a wedge of saline groundwater. The depth of the saline groundwater depends on the height of the water table above se level and on the densities of the fresh and saline water.

5. The porosity of a rock is the proportion of the volume of the rock that consists of pores:

   $$\text{Porosity (\%)} = \frac{\text{pore volume}}{\text{Total volume}} \times 100$$

   Porosity is a measure of how much water a rock can store. The permeability of a rock is a measure of the properties of the rock which determine how fast water can flow through it. The porosity and permeability are generally greater in unconsolidated sedimentary rocks, particularly sands and gravels, than in consolidated sedimentary, igneous or metamorphic rocks. Both porosity and permeability can be increased by processes that occur after the formation of the rock, such as solution or fracturing. This is called secondary porosity and secondary permeability.

6. An aquifer is a rock that can store water, and through which water can flow. For a rock to be an aquifer it must be sufficiently porous and it must be permeable. The best aquifers are sands and gravels. Igneous and metamorphic rocks seldom make good aquifers unless they have secondary porosity and secondary permeability.

7. The amount of water that can be recovered from a saturated aquifer is known as the specific yield. This is less than the total amount of water in the aquifer (represented by the porosity) because part of the water is retained by surface tension around individual grains. Specific yield, like porosity, is expressed as a percentage of the total volume of the rock. The highest porosities are found in fine-grained sediments, but the greatest specific yields are in medium-grained sediments. The exploitable storage of a saturated aquifer is the volume of water it will give up when pumped or allowed to drain.

8. Aquifer s can be confined or unconfined. Unconfined aquifers outcrop at the ground surface; water normally has to be pumped to the surface from these aquifers. Confined aquifer s are separated from the ground surface by an impermeable layer. Water in confined aquifer s is called artesian water, and the wells that penetrate into confined aquifer s are called artesian wells. The water in an artesian well may be under sufficient pressure to reach the surface of the ground without pumping (a flowing artesian well)

9. The potentiometric surface is an imaginary surface joining the height to which water will rise in wells. For an unconfined aquifer, the potentiometric surface is the water table.

10. The safe yield of an aquifer is the maximum rate of abstraction of water that does not produce a long-term decline in the average water table level or have any adverse effect, such as a significant reduction in the flow to springs and rivers. Exceeding the safe yield would necessitate pumping from greater depths to obtain water, and might lead to a deterioration in water quality

11. Exploration for groundwater involves a combination of geological hydrological geophysical and borehole techniques.

Summary of Section 4

1. Many rivers originate from springs, which occur at points where groundwater reaches the surface. Springs can occur in different geological settings, forming artesian springs, valley springs, stratum springs or solution channel springs.

2. The water in a river originates from overland flow (resulting from precipitation and springs), from throughflow (which is water that has moved through the soil, above the water table), and from base flow (which is groundwater discharged directly into the river). The base flow forms a higher proportion of river water in the summer than in winter, and in rivers flowing from good aquifers. The discharge of a river at any point is usually determined by first measuring the stage, which is the water level in the river, and then reading off a value for the discharge from the rating curve, which is a plot of measured discharge for various stages. A river hydrograph is a record of the discharge over a period of time. The shape of a short-period hydrograph (the record for a few days) depends on the size, shape, geology, vegetation and land use of the river catchments. The size of the long-period hydrograph (.e.g. for a year) depends primarily on the type of climate in the region of the river.

3. Reservoirs increase the amount of water stored on the land surface. Water supply reservoirs can be used as direct supply reservoirs or for river regulation. Reservoirs may also be built solely or partly for other purposes, such as the regeneration of hydroelectricity or for flood prevention. The criteria for selecting sites for water supply reservoirs are a good supply of high-quality water, minimum ecological and environmental disturbance, a high elevation, a watertight reservoir area, no geological hazards and a suitable dam site. The most suitable reservoir sites are narrow, deep valleys, but reservoir s often have to be built in wider valleys or in flat lowland areas.

4. There are two types of dams, gravity dams and wall dams. The gravity dam depends on its own weight to prevent deformation, whereas the wall dam is a rigid structure that transfers the pressure of the water to the floor and sides of a valley.

5. The environmental effects of constructing a reservoir include the loss of a large area of land, ecological changes, dam failure, sediment filling, sediment loss to agriculture, soil salinization and induced earthquakes.

Summary of Section 5

1. Pollution is a deterioration of water quality caused by human agencies that makes water less suitable for use than it was originally. Water does not have to be completely pure to be considered unpolluted.

2. Natural waters are not completely pure. Rainwater contains dissolved salts in relative proportions similar to those in seawater, but over a thousand times less concentrated. Rainwater has a greater relative proportion of dissolved gases, particularly carbon dioxide, than seawater, and this makes it slightly acidic. Surface water has a composition different from both rainwater and seawater; river water has a greater concentration of dissolved solids (TDS) than rainwater, and may contain suspended solids. Groundwater usually has slightly greater TDS values than surface water, and varies in composition, depending on the rocks through which it has passed. The TDS value of a groundwater depends on the length of time the water has been in contact with the rock, so the slowly moving, deeper groundwater has a higher TDS value.

3. Pollution can come from many different sources, including domestic sewage, farms, industry, mining, quarrying and cooling. There are many types of pollutants, including natural organic materials, living organisms, plant nutrients and toxic substances.

4. water often has to be treated before it is of suitable quality for use. The quality needed depends on the use to which the water is to be put; quality standards for public water supplies are set by the WHO, the EU and some individual countries; but the quality required for industrial water and irrigation can vary. The main water treatment methods used are straining, storage, aeration, flocculation, filtration and disinfection.

5. Sewage treatment aims to reduce the amount of organic and suspended solid material present, remove toxic materials and eliminate pathogenic bacteria, mainly by settlement or biological processes. The effluent is discharged into rivers, lakes or the sea, and the remaining sludge may be dumped at sea, disposed on agricultural land, dumped in holes in the ground or incinerated.

Summary of Section 6

1. Nottingham uses water almost entirely for domestic and industrial purposes; very little is used for irrigation.

2. The water supply for Nottingham comes from river water (42%), reservoir water (17%) and groundwater (41%). The river water comes from the River Derwent, not from the River Trent which flows through Nottingham, as the Trent is more polluted. Groundwater for Nottingham is from the Triassic Sherwood Sandstone aquifer, which has a porosity of 15-30% and a hydraulic conductivity of 0.04-10m per day. The reservoirs that supply Nottingham with water are in the Derwent Valley, in the Peak District. There is a good supply of water there, and because it is higher than Nottingham the water is able to flow by gravity through a pipeline to Nottingham; another advantage is that the geology of the Derwent Valley (grits and shales) makes the reservoir area relatively watertight. The lead time for Carsington reservoir construction was 25 years.

3. The basic costs of water from the three sources are; river water 4.4p per cubic meter, reservoir water 1.7p, and groundwater 3.1p-4.7p. The groundwater requires little treatment, although it needs a lot of pumping, but river water must be extensively treated.

4. Estimates of future demand from the Nottingham area predict that the demand will rise by about 15% between 1991-92 and 2021-22. The water supply will be increased using Carsington reservoir more fully to regulate the River Derwent, and by reducing the leakage in the distribution system.

5. In Jordan the precipitation is between less than 50 and 600mm a year, but 91% of the country has less than 200mm a year and a very high potential evapotranspiration, so it is classed as arid. Precipitation is unreliable and seasonal, occurring only during the winter months.

6. Approximately 75% of the water in Jordan is used for irrigated agriculture, mainly in the Jordan Valley, which has good soil and warm winters. The demand for both municipal and agricultural water in Jordan exceeds the supply: there are shortages and water rationing.

7. Jordan has only three perennial rivers, but many wadis which have a surface flow in the winter months only. The Dead Sea is more saline than seawater, so it cannot be used for water supply. The main aquifers in Jordan are Cambrian-Silurian sandstones in the south, Cretaceous-Eocene limestones and dolomites throughout the country and Miocene-Recent basalts in the north. The aquifers are recharged mainly in the highlands, except for the basalts, which are recharged mainly in Syria.. This groundwater is renewable, but Jordan has other groundwater which is being recharged very slowly (if at all) and is therefore classed as a non-renewable resource. This can be mined for use, like other physical resources. At present (1994) Jordan is not only mining is non-

renewable groundwater but also exploiting its renewable groundwater beyond the safe yield.

8. Demand for water in Jordan is rising rapidly, even though it is already in short supply. The supply could be increased to a small extent by municipal recycling, or a larger extent through unified water development schemes between Jordan and its neighbouring countries, although the latter seems politically unlikely at present. In the long term, Jordan must restructure its economy away from the traditional irrigated agriculture towards sustainable water use.

Summary of Section 7

1. To supplement the water from rivers, lakes, reservoirs and aquifers, the demand for water could be met by water transfer, estuary storage, conjunctive use, desalination, rain-making, icebergs and conservation.

2. Water transfer takes water from an area of surplus to an area of deficit. It has the disadvantages that it is very expensive to transport water large distances and that it causes environmental side effects.

3. Storing water in an estuary makes it possible to use water that would otherwise be lost to the sea. It avoids flooding large areas of land for reservoirs, and the water is available where there is a demand for it. The disadvantages are that water has to be pumped up to land, the quality will be poor, navigation may be restricted and there may be ecological problems.

4. Conjunctive use is the combined use of a river and an aquifer to provide a better or more flexible water resource. Two types of conjunctive use are artificial recharge and river augmentation. Artificial recharge is the replenishment of an aquifer in excess of natural infiltration , by storing surface water underground when surface water is abundant. River augmentation is used to increase the flow of a river at times of low discharge. An aquifer and a river can be used directly, but at different times of year.

5. Desalination makes seawater useable for water supplies. The process consumes a lot of energy or requires a considerable area of land, so it is one of the most expensive ways of producing fresh water.

6. Rain-making is an artificially induced increase in precipitation. It can only be done if there is an excess of water vapour in the atmosphere, in clouds which can be seeded to provide nuclei around which water vapour can condense. There is no evidence that it produces a long-term increase in precipitation.

7. The fresh water in polar icecaps could be utilized by towing icebergs to where the water is needed. The relative cost of this water is unknown at the moment, but it would probably be expensive.

8. Conservation is an alternative approach to extending water resources, either by greater efficiency in using water, or by substitution, or by changing practice.

Summary of Section 8

1. The lead times for water resources projects are quite long (they can be about 25 years) so estimates of the future demand for water must be made for at least this time ahead.

2. Prediction of future demand for water starts by looking at how demand has varied in the past. The demand for public water supply increased between 1961 and 1991, because of population rise and greater use per person. However, the rate of increase reduced during this time. The unmetered supply, mostly for domestic purposes, increased, whereas the metered supply, mainly for industry, had only a small variation during this period.

3. Prediction of the future demand for water involves breaking the total demand down into domestic, industrial and agricultural components, and identifying the economic, social and population factors which are likely to affect them in future. However, forecasting remains inaccurate – forecasts for demand for the 1980s made at the beginning of 1970s were much too high.

4. Domestic consumers in Britain have little direct incentive to economise on water use so far, as the water supply is not usually metered. Substantial economies were made during the 1975-76 drought, and less could be used at other times too. The water supply to industry is metered so in that sector there is a financial inducement to economise on water use. About a quarter (29%) of the water put into the distribution system in Britain is lost by leakage, but it is very expensive, time consuming and disruptive to remedy. In general, demand in the future could be reduced by a combination of water conservation, metering and leakage reduction.

5. The UK as a whole has more water than it needs, but much of it is in the wrong place. Scotland, Northern Ireland and Wales have sufficient water resources, although part of the water in Wales is diverted for use in England. England has areas of both water surplus and water shortage. Groundwater is a large proportion of the public water supply in the southern and eastern parts of England. It forms only a small proportion in other parts of England and in Wales, Scotland and Northern Ireland, as the rocks in these areas are mainly older sedimentary, igneous or metamorphic rocks, and so are not good aquifers.

6. The area of the UK which will have the greatest problems with water supply in the future is the south and east of England. This area had the greatest problems in the 1975-76 and 1988-92 droughts and is also the area of greatest growth in demand for water. Future increases in water supply in the south and east could come from groundwater development, including conjunctive use, effluent reuse, new reservoirs and water transfer from outside the area. Alternatively, or in addition, demand could be reduced by water conservation, metering and leakage reduction.

Objectives for Block 3

1. Explain in your own words, and use correctly, the terms in the glossary relating to block 3

2. Describe and quantify the processes that transfer water between parts of the hydrological cycle, calculate residence times for water in different parts of the hydrosphere, and identify those parts of the cycle that are most suitable for water resources.

3. Recognise the factors that control precipitation, interception, evaporation, transpiration.

4. Using information from wells and the topography of the ground, construct a water table contour map, and carry out the following: interpret cross-sections drawn from it, calculate the thickness of the aeration zone, and the rate of groundwater flow; deduce the direction in which groundwater is flowing; and estimate the depth to the saline interface in a coastal area from the height of the water table and the densities of the fresh and saline water.

5. List the rocks that usually make good aquifers, and estimate how good an aquifer a rock should be, given its porosity and hydraulic conductivity. Distinguish between unconfined and confined aquifers, and recognise conditions in confined aquifers that will produce a flowing artesian well.

6. Using suitable data, calculate the exploitable storage, specific yield and specific retention of an aquifer

7. Use hydrographs to distinguish surface runoff and throughflow from base flow, and make inferences about an area.

8. Decide whether a particular site would be a suitable for reservoir construction, suggest the most suitable type of dam for a site, and summarise the side effects of constructing reservoirs

9. Describe the chemical compositions of natural waters, and explain how and why these compositions vary. Describe the main sources of water pollution, the main types of pollutant and how each type may be controlled.

10. Describe the water resources of (a) the Nottingham district and (b) Jordan

11. Describe ways of extending sources of fresh water from the unused parts of the hydrological cycle, or new ways of using existing water sources.

12. Describe how the demand for water in England and Wales has changed between 1961 and 1991, recognise factors involved in predicting future demand, and discuss the importance of predictions and their limitations

13. Discuss variations in the amounts of water used in different parts of England and Wales, and how water might be used more economically. Contrast the proportions of surface water and groundwater in the public water supply in different areas in England and Wales, identify the main aquifers, list the possible schemes for increasing water supply in England and Wales, and discuss their suitability

14. Discuss the future of global water resources.