WATER RESOURCES MANAGEMENT

With more modern practices water resources are managed according to catchment area. This can be defined as the area of land which collects rainwater that at its lowest point drains into a body of water e.g. lake, sea. The channels that move the water through the catchment area include rivers, stormwater drains and sewers. Also surface runoff and groundwater seepage are part of the movement of water in the catchment. Because the various ecosystems within the catchment are connected by the water flowing through or under them it is essential to recognise that activities occurring upstream will affect the environment downstream.

Factors which impact the status of catchment areas i.e. their ability to transport high quality water, support ecosystems and manage flooding, etc include:

- Amount of human settlement
- Urbanisation and industrial activity
- Agricultural activity
- Sedimentation (usually due to erosion)
- Pollution
- Waste disposal
- Concretisation of channels
- Clearance of vegetation

Freshwater ecosystems

Rivers, lakes, ponds, wetlands, floodplains and streams support various communities of plants and animals provide many of the natural ecological functions that support life and human economic activities. Some of the functions of healthy freshwater systems include:

- Water purification
- Nutrient cycling
- Recharging underground aquifers
- Water storage, particularly in flood conditions
- Stabilisation of shorelines and riverbanks
- Critical habitats for birds, fish, amphibians, mammals and reptiles during drought
- Providing important habitats for migratory birds

Coastal and marine ecosystems

Over 97% of earth's water is contained in oceans and seas. There are many diverse marine and coastal ecosystems, including beaches and dunes, coral reefs, seagrass beds, mangroves, and estuaries. These ecosystems are vital for provision of a variety of environmental goods and services. These include filtering and storing nutrients, pollutants and sediments; providing nurseries for juvenile fish and crustaceans; fisheries; and protecting the coast from high wave energy.

Figure 1: Coastal erosion (Source: Barbados Sea Turtle Project)

Some of the major threats to these critical systems are population growth, infrastructure development too close to the shoreline, erosion, pollution, overfishing and climate change. Because all of these systems are interlinked, activities upstream in the catchment will affect the condition of the habitats downstream. Most marine pollution originates from inland. Sources include runoff from agricultural production (fertilisers, pesticides, manure), sewage outfalls, runoff from roads and drains (engine oil, litter, chemicals e.g. detergents), soil erosion.

Coastal erosion occurs via a number of processes:

- Wave pounding – the force of the waves beating against the rock structurally weakens it, leaving it move vulnerable to other types of erosion
- Hydraulic action – air in a crack or fissure is suddenly compressed by water entering the joint and the increased pressure cracks or breaks the rock
- Abrasion – the action of particles (e.g. sand) in the water eroding the cliffs
- Attrition – the breaking of particles as they hit against each other and the rock face, becoming shingle and sand
- Corrosion – dissolving of minerals by the carbonic acid in the water (limestone cliffs are particularly vulnerable)
- Bioerosion – due to scraping, boring and grinding by living organisms

Erosion can take the form of natural transport and redistribution of sediments along the shoreline with the prevailing currents. Or it can be long term removal of beach material, which is usually due to the influence of human activities on the morphodynamics of the coast. Whilst erosion events can be highly detrimental to the shoreline and infrastructure, particularly during extreme weather, wave action is also responsible for the evolution of beaches and the formation of many erosive features such as cliffs, headlands, wave-cut platforms, stumps, stacks and caves.

Groundwater

Groundwater is that which is contained in the spaces in the substrata beneath the earth's surface. Water is purified as it moves deeper through the layers of rock with the filtering of minerals, nutrients, etc. Like surface water, groundwater generally flows by gravity toward the lowest point such as a river or the sea. However, it can also move due to pressure differences, toward areas of lower pressure. Where groundwater re-emerges at the surface, usually due to an impediment in movement e.g. an impermeable layer of rock, features such as springs and lakes are formed. Where groundwater is present in the saturated zone below the water table it forms an aquifer.

Threats to groundwater systems include:

- Overexploitation of aquifers – the rate of extraction is greater than the rate of recharge, thus the volumes of water in the aquifer declines. A low recharge rate may occur naturally e.g. during the dry season or drought. If over-abstraction continues unabated a number of situations may develop:
    - The water table drops lower causing wells to dry, so they are either deepened or abandoned.
    - Aquifers near the coast may become contaminated with sea water i.e. saline intrusion because the excessive pumping has caused the salt water to come further inland than usual. This phenomenon is extremely difficult to rectify and reduces the amount of freshwater available in the aquifer or leaves it no longer suitable for potable uses.
    - Land subsidence may occur if the dry aquifer becomes compacted due to the lack of water which previously filled the pore spaces
    - Decreased supply of water to surface features such as rivers, wetlands and lakes. This will negatively impact the aquatic life,

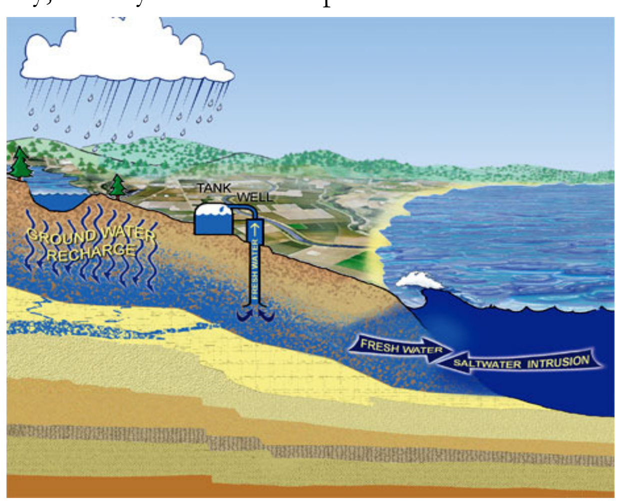

Figure 2: Saline intrusion into aquifer (Source: http://bottledh20.wordpress.com/2008/03/)

and cause an increase in concentration of any pollutants that may be present.

- Pollution – improper disposal of waste can lead to pollutants seeping through the soil and into the groundwater. For instance dumping of cars, appliances and household waste in gullies can introduce heavy metals, oils, solvents and chemicals into the groundwater system, particularly as gullies serve as important waterways. Dumping can also cause blockage of these channels and cause flooding. Improper treatment and disposal of sewage, industrial effluents, fuels, chemicals, etc also contaminate groundwater systems through sinks, drains and directly through the soil such as in unsanitary landfills. Unsustainable agricultural practices can also impact groundwater as over use of fertilisers, herbicides etc means that the excess chemicals and nutrients leach into the soil as it rains or during irrigation. Oil, chemical and industrial spills and leaks also pose threat of contamination.
- Deforestation/vegetation clearance – plants and trees help to provide cover for the soil, reducing the impact of rainfall on the surface and reducing erosion. They also help to capture precipitation and increase the quantity that infiltrates the soil in proportion to runoff so that groundwater recharge is greater.

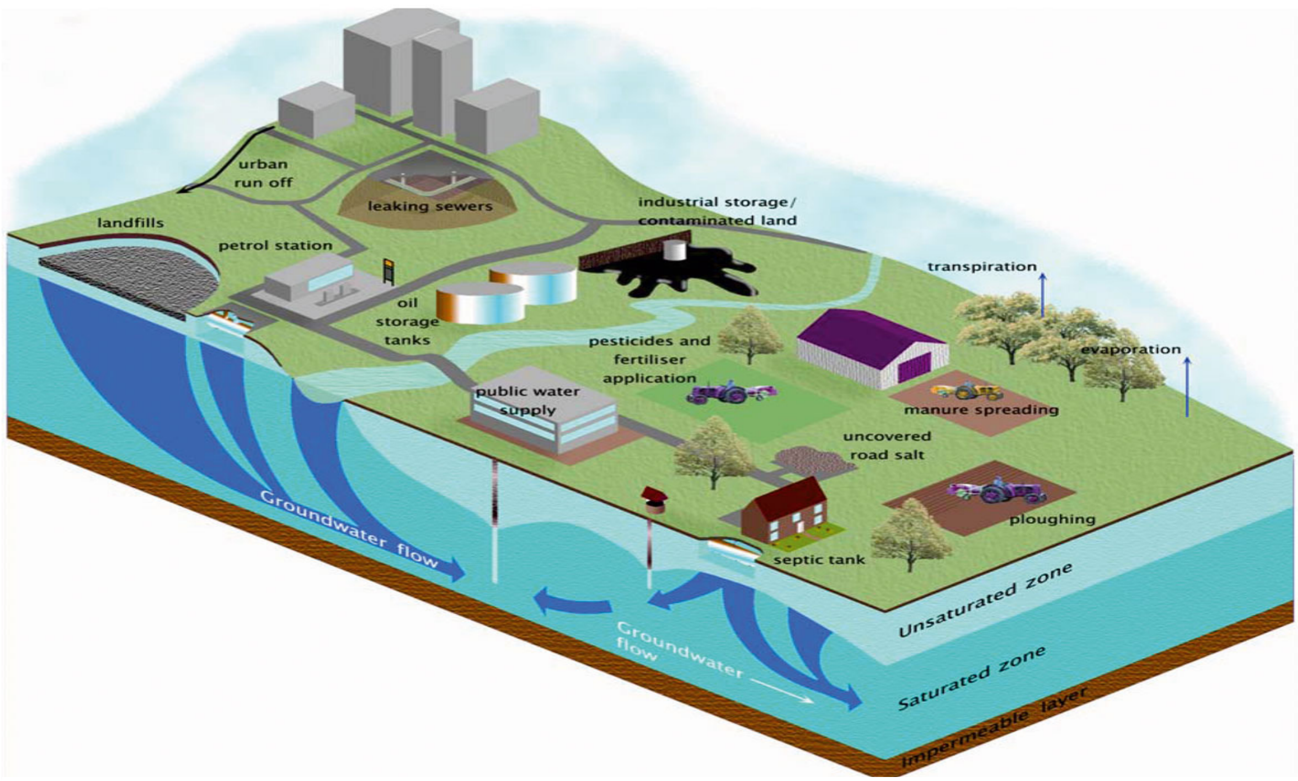

Figure 3: Groundwater contamination from various sources (Source: Water Framework Directive Information Centre)

Integrated Water Resources Management

The basic challenge of IWRM is to attain a sustainable balance between the competing uses of water by people, plants, animals and aquatic organisms, and to maintain and/or improve its quality and quantity. IWRM promotes the coordinated development and management of water, land and related resources to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

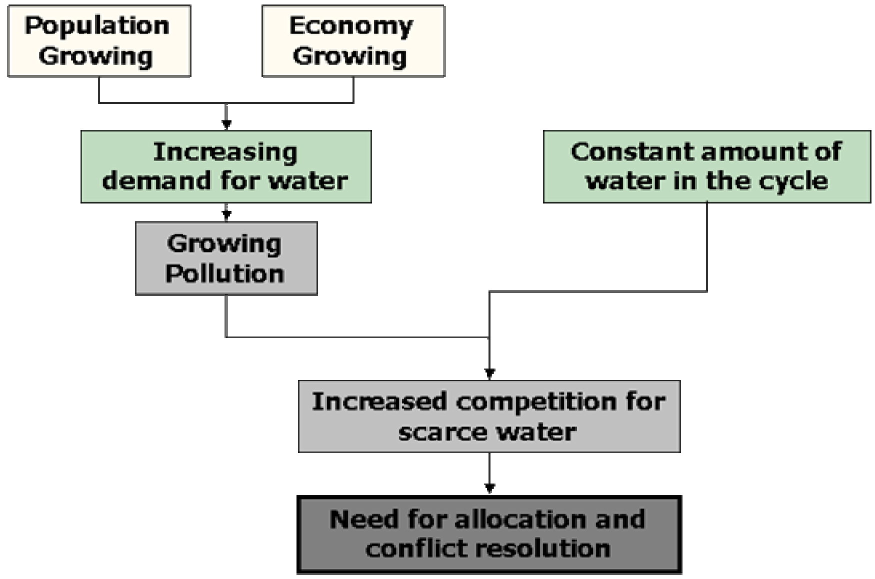

Figure 7: Conflicts in water use to be addressed by IWRM (Source: GDRC)

The Dublin Principles for IWRM, stated at the International Conference on Water and the Environment in 1992, are:

- Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment

This dictates that effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems, and joining land and water uses across an entire catchment area or aquifer.

- Water development and management should be based on a participatory approach, involving users, planners, and policy-makers at all levels

Thus decisions should be made at the lowest appropriate level, with full public consultation and involvement of water users in planning and implementation of projects.

- Women play a central role in the provision, management and safeguarding of water

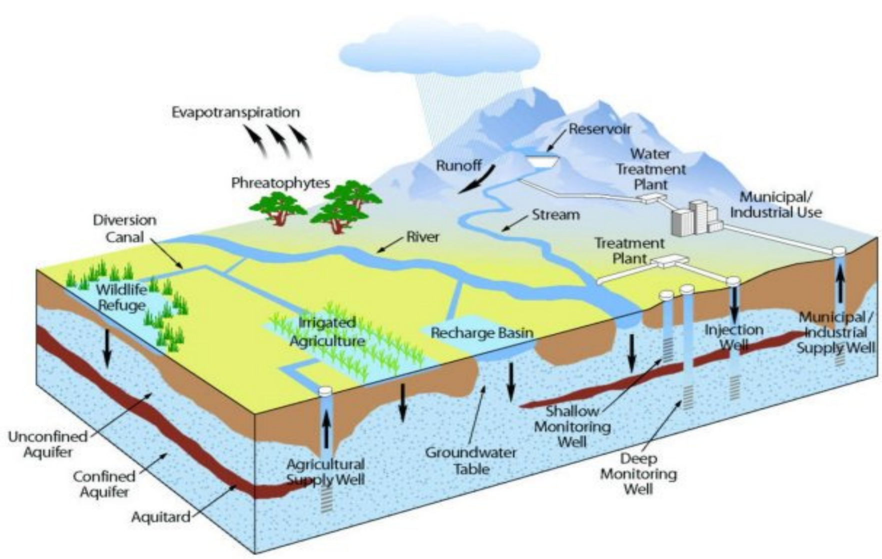

Figure 8: Sustainable groundwater management (Source: Hamilton County Soil & Water Conservation District)

This principle has seldom been reflected in institutional arrangements for the development and management of water resources. Its acceptance demands positive policies to address women's specific needs, and to equip and empower them to participate at all levels in water resources programmes, including decision-making and implementation, in ways defined by them.

- Water has an economic value in all its competing uses and should be recognised as an economic good

It is a basic right of all human beings to have affordable access to clean water and sanitation. Neglect of the economic value of water has in the past led to careless, improper and environmentally detrimental usage. Managing water as an economic good is an important way of attaining equitable and efficient use, and of supporting conservation and protection of water resources.

When designing an IWRM system one needs to take into account each of the resource users, their actual and perceived needs, their practices and the efficiency and sustainability thereof, and their interaction with other users. One must also consider relevant land use zoning policies, traditional or indigenous uses, biodiversity and endemism, inter-related ecosystem functions, and upstream and downstream characteristics and impacts.

For instance, a farm is using sprinkle irrigation for 6 hours a day, tapping wells historically and currently used by the adjacent community. About 40% of the water does not reach the targeted crops due to leakages, evaporation and wind losses. The well empties in the dry season which it did not do in the past. The community has resorted to washing laundry in the river not too far away during these dry periods. During times of heavy rainfall soil is washed from the farm down the hillside into the river. Since these activities commenced there have been fewer birds and fish in the wetland downstream. An IWRM response would seek to remove the pollution source from the wetland, and resolve the issues between the farm and village. The farm could use terraced or contoured cropping to reduce soil erosion, and drip irrigation to minimise water losses and irrigation would not need to be done for such a long period. If the well is still at very low levels during the dry season, the villagers can supplement their supply with rainwater harvested during the rainy season (as could the farm) and/or remove water being used from the river and use it at home.

IWRM actions do not necessarily require involvement of government authorities, but by applying Dublin Principle 2, the decisions to find a solution to their problems can be found through discourse and cooperation among themselves. Such commitment to more sustainable behaviour not only preserves the water resource they are all dependent on, but also improves the efficiency of the farm's operations, gives the villagers an extra water source and protects the wetland ecosystem.

CASE STUDY: The Aral Sea

The Aral Sea is a landlocked basin between Kazakhstan in the north and Uzbekistan in the south. The name roughly translates to "Sea of Islands" referring to over 1500 islands of ≥1ha that dotted its waters.

The Plan Executed

In 1918, the Soviet government decided that the two rivers that fed the Aral Sea, the Amu Darya in the south and the Syr Darya in the northeast, would be diverted to irrigate the desert, in order to attempt to grow rice, melons, cereals, and cotton. This was part of the Soviet plan for cotton, "white gold", to become a major export. This did eventually end up becoming the case, and today Uzbekistan is one of the world's largest exporters of cotton.

The Flaws

The irrigation canals began to be built on a large scale in the 1940s. Many of the irrigation canals were poorly built, letting water leak out or evaporate; from the Qaraqum Canal, the largest in Central Asia, perhaps 30-75% of the water went to waste. Today only 12% of Uzbekistan's irrigation canal length is waterproofed.

During planning for a major expansion of irrigation in the Aral Sea basin, conducted in the 1950s and 1960s, it was predicted that this would reduce inflow to the sea and substantially reduce its size. At the time, a number of experts saw this as a worthwhile tradeoff: a cubic meter of river water used for irrigation would bring far more value than the same cubic meter delivered to the Aral Sea. They based this calculation on a simple comparison of economic gains from irrigated agriculture against tangible economic benefits from the sea.

By 1960, somewhere between 20 and 60km^2 of water were going each year to the land instead of the sea. Thus, most of the sea's water supply had been diverted, and in the 1960s the Aral Sea began to shrink. From 1961 to 1970, the Aral's sea level fell at an average of 20cm a year; in the 1970s, the average rate nearly tripled to 50–60cm per year, and by the 1980s it continued to drop, now with a mean of 80–90 cm each year. After seeing this, the rate of water usage for irrigation continued to increase: the amount of water taken from the rivers doubled between 1960 and 2000; cotton production nearly doubled in the same period.

The Experts Knew!

The disappearance of the lake was no surprise to the Soviets; they expected it to happen long before. As early as in 1964, Aleksandr Asarin at the Hydroproject Institute pointed out that the lake was doomed explaining, "It was part of the five-year plans, approved by the council of ministers and the Politburo. Nobody on a lower level would dare to say a word contradicting those plans, even if it was the fate of the Aral Sea."

These experts largely dismissed the possibility of significant adverse environmental consequences accompanying recession. For example, some scientists claimed the sea had little or no impact on the climate of adjacent territory and, therefore, its shrinkage would not perceptibly alter meteorological conditions beyond the immediate shore zone. They also foresaw little threat of large quantities of salt blowing from the dried bottom and damaging agriculture in adjacent areas. This theory rested, in the first place, on the assumption that during the initial phases of the Aral's drying only calcium carbonate and calcium sulfate would be deposited on the former bottom. Although friable and subject to deflation, these salts have low plant toxicity. Second, it was assumed that the more harmful compounds, chiefly sodium sulfate and sodium chloride, which would be deposited as the sea continued to shrink and salinize, would not be blown off because of the formation of a durable crust of sodium chloride. Some optimists even suggested the dried bottom would be suitable for farming.

The reaction to the predictions varied. Some Soviet experts apparently considered the Aral to be "nature's error", and a Soviet engineer said in 1968 that "it is obvious to everyone that the evaporation of the Aral Sea is inevitable." On the other hand, starting in the 1960s, a large scale project was contemplated to redirect part of the flow of the rivers of the Ob basin to Central Asia over a gigantic canal system. Refilling of the Aral Sea was considered as one of the project's main goals. However, due to its staggering costs and the negative public opinion in Russia, the federal authorities abandoned the project by 1986.

The Result

The sea's surface area shrank by approximately 60% and its volume by 80%. In 1960, the Aral Sea was the world's fourth-largest lake, with an area of approximately 68,000km^2 and a volume of 1100km^3; by 1998, it had dropped to 28,687km^2, and eighth-largest. The amount of water it has lost is the equivalent of completely draining Lakes Erie and Ontario. Over the same time period its salinity has increased from about 10gl^{-1} to about 45gl^{-1}. As of 2004, the Aral Sea's surface area was only 17,160km^2, 25% of its original size. By 2007 the sea's area shrunk to 10% of its original size, and the salinity of the remains of the southern part of the sea (the Large Aral) increased to levels in excess of 100gl^{-1}. By comparison, the salinity of ordinary seawater is typically around 35gl^{-1}; the Dead Sea's salinity varies between 300 and 350gl^{-1}.

A 1979 study concluded that aggregate damages within the Uzbek Republic, which has suffered the greatest harm, totaled 5.4-5.7 billion rubles. A 1983 evaluation concluded that annual damages in the lower course of the Amu Dar'ya were 92.6 million rubles (approx $3.9million) with the following distribution: agriculture, 42%; fisheries, 31%; hunting and trapping, 13%; river and sea transport, 8%; and living and working conditions, 6%. Some sources have listed a figure of 1.5-2 billion rubles as the annual losses for the entire Aral Sea region.

In 1987, the continuing shrinkage split the lake into two separate bodies of water, the North Aral Sea (the Lesser Sea, or Small Aral Sea) and the South Aral Sea (the Greater Sea, or Large Aral Sea); an artificial channel was dug to connect them, but that connection was gone by 1999 as the two seas continued to shrink. In 2003, the South Aral further divided into eastern and western basins; the loss of the North Aral has since been partially reversed. Shrinkage of the lake also created the Aral Karakum, a desert on the former lakebed.

Peter Zavialov from the Shirshov Institute of Oceanology in Moscow and his team completed the first hydrographic survey of the South Aral since the early 1990s around 2003. Older models predicted that, at worst, the sea would drop from 57m above sea level in 1965 to 34m in 2002 and become 1.6 times as salty as normal seawater. Zavialov's survey showed, however, it had dropped to 30.5m, 3.5m more than predicted, and is 2.4 times as salty as the ocean (*Geophysical Research Letters*, vol 30, p 1659).

"I'm not surprised," says Trevor Tanton, an environmental engineer from the University of Southampton, who suspects that the early Soviet models were made overly optimistic for political reasons.

Zavialov thinks an unforeseen mechanism is speeding up the collapse. In the deepest section of the western lake his team found the lower 20m of water were saltier than the top, probably due to water seeping in from the neighbouring, saltier fragment of the South Aral to the east. As a result of the density difference, the layers don't mix. Thus only the top 20m of the sea heat up by convection in the summer. This results in higher evaporation rates, which increase as the layer becomes hotter and shallower. This feedback means the shallower eastern half of the South Aral could be gone in just 15 years, decades earlier than previous estimates.

However, it is believed that the narrow channel connecting the eastern and western basins should soon be dry. This will mean the influx of saltier water into the western basin will cease. If the water there again mixes throughout its depth, evaporation will slow and it could survive for 70 years, or perhaps indefinitely.

Even the recently discovered inflow of groundwater discharge into the Aral Sea will not in itself be able to stop the desiccation. This inflow of about 4 billion m^3 per year is larger than previously estimated. This groundwater originates in the Pamirs and Tian Shan mountains and seeks its way through geological layers to a fracture zone at the bottom of the Aral Sea.

Environmental and Social Impacts

Decades of heavy irrigation have raised the water table and brought all the salts the soil held to the surface. What appears to be snow on the seabed is really salt. The receding sea has left huge plains covered with salt and toxic chemicals, which are picked up and carried away by the wind as toxic dust and spread to the surrounding area. The winds blow this as far as the Himalayas. Wind-blown salt from the dried-out seabed damages crops.

The ecosystem of the Aral Sea and the river deltas feeding into it has been nearly destroyed, not least because of the much higher salinity. Native plant communities have degraded and disappeared. Tugay forests, composed of dense stands of phreatophytes mixed with shrubs and tall grasses fringing delta arms and channels to a depth of several kilometers, have particularly suffered. The expanse of Tugay in the Amu Dar'ya Delta, estimated at 13,000km^2 in the l950s, had been halved by 1980. The major cause of deltaic vegetation impoverishment has been the 3-8m drop of ground water along with the end of floodplain inundation.

The drop in the level of the Aral has been accompanied by a reduction of the pressure and flow of artesian wells and a decline of the water table all around the sea. Soviet scientists had estimated that a 15m sea level drop by the early 1990s, could reduce ground-water levels by 7-12m in the coastal zone and affect the water table 80-170km inland. The sinking water table has had significant adverse impacts outside the Amu Dar'ya and Syr Dar'ya deltas, drying wells and springs and degrading natural plant communities, pastures, and hayfields.

Habitat deterioration has harmed delta fauna, which once included muskrat, wild boar, deer, jackal, many kinds of birds, and even a few tigers. At one time 173 animal species lived around the Aral, mainly in the deltas; 38 have survived. Commercial hunting and trapping have largely disappeared. The yield of muskrat pelts from trapping in the deltas of Amu Darya and Syr Darya has fallen to 2,500 per year from 650,000 in 1960.

The Aral Sea fishing industry, which in its heyday had employed 40,000-60,000 workers and reportedly produced $^1/_6$ of the USSR's entire fish catch, essentially disappeared. The town of Moynaq in Uzbekistan had a thriving harbour and fishing industry that employed approximately 60,000 people; now the town lies miles from the shore. Fishing boats lie scattered on the dry land that was once covered by water; many have been there for 20 years. The only significant fishing company left in the area has its fish shipped from the Baltic Sea, thousands of kilometres away.

The Aral Sea and the land around it are also heavily polluted, largely as the result of weapons testing, industrial projects, pesticides and fertiliser runoff. Polluted drinking water and salt and dust-laden air is causing the people living in the area to suffer from a lack of fresh water and other serious public health problems, including high rates of certain forms of cancer and lung diseases. One victim has tuberculosis, which is rife and on the increase in the rest of the population. Cancers, lung disease and infant mortality are 30 times higher than they used to be because the drinking water is heavily polluted with salt, cotton fertilisers and pesticides. Jobs and food died with the sea.

The Utegenova family lives in Muynak. One of them works, but only part-time. The Utegenovas are constantly hungry and sick. Their tea is salty because of the contaminated water. It killed their father who died 10 years ago of cancer of the oesophagus, a common complaint here. Zulayho, who is pregnant, goes for more water. Like 80% of expectant mothers, she is probably anaemic. She knows that if her child survives, it will almost certainly be ill. "I know the water is not good. If my children get ill, I take them to the doctors," she explains. "But whatever the doctor does the children don't get well again because they still have to drink this water."

To provide a reliable, safe water supply to Nukus (1987 population of 152,000) in the Amu Dar'ya Delta, a 200km pipeline costing 200 million rubles (approx $8.5million) is under construction from the upstream Tyuyamuyun Reservoir. The declining quality of drinking water is cited as the main factor increasing intestinal illnesses, particularly among children, and throat cancer incidence in the lower reaches of the Amu Dar'ya and Syr Dar'ya. There is fear of epidemics because of the deterioration of the quality of the water supply and the increasing rodent population. Desert animals that use the Aral Sea as a drinking source have died from its greatly increased mineral content.

The retreat of the sea has reportedly also caused local climate change, with summers becoming hotter and drier, and winters colder and longer. Research over the past two decades has established that the Aral affects temperature and moisture conditions in an adjacent stripe estimated to be 50-80km wide on its north, east, and west shores and 200-300km wide to the south and southwest. With contraction, the sea's influence on climate has substantially diminished. Summers have become warmer, winters are colder, spring frosts later, and fall frosts earlier, the growing season has shortened, humidity has lowered, and there has been an overall trend toward greater continentality. The most noticeable changes have occurred in the Amu Dar'ya Delta. At Kungrad, located in 1988 about 100km south of the Aral, comparison of the period 1935 to 1960 with that of 1960 to 1981 indicates that relative humidity diminished substantially, the average May temperature rose by 3-3.2°C, and the average October temperature decreased 0.7-1.5°C. The growing season in the northern Amu Dar'ya Delta has been reduced by an average of 10 days, forcing cotton plantations to switch to rice growing.

Attempts to Rectify?

Work is being done to restore in part the North Aral Sea. Irrigation works on the Syr Darya have been repaired and improved to increase its water flow, and in October 2003, the Kazakh government announced a plan to build Dike Kokaral, a concrete dam separating the two halves of the Aral Sea. Work on this dam was completed in August 2005; since then the water level of the North Aral has risen, and its salinity has decreased.

As of 2006, some recovery of sea level has been recorded, sooner than expected. The dam has caused the Small Aral's sea level to rise swiftly to 38m (125 ft) from less than 30m (98 ft), 42m (138 ft) being considered the level of viability. Economically significant stocks of fish have returned, and observers who had written off the North Aral Sea as an environmental catastrophe were surprised by unexpected reports that in 2006 its returning waters were already partly reviving the fishing industry and producing catches for export as far as Ukraine. The restoration reportedly gave rise to long absent rain clouds and possible microclimate changes, bringing tentative hope to an agricultural sector swallowed by a regional dustbowl, and some expansion of the shrunken sea. The sea, which had receded almost 100km south of the port city of Aral, is now 25km away. There are plans to build a new canal to reconnect Aralsk with the sea. Construction is scheduled to begin in 2009, by which time it is hoped the distance to be covered will be only 6km. A new dam is to be built based on a World Bank loan to Kazakhstan, with the start of construction also slated for 2009 to further expand the shrunken Northern Aral eventually to the withered former port of Aralsk.

The South Aral Sea, which lies largely in poorer Uzbekistan, was largely abandoned to its fate. Projects in the North Aral at first seemed to bring glimmers of hope to the South as well. In addition to restoring water levels in the Northern Sea, a sluice in the dike is periodically opened, allowing excess water to flow into the largely dried-up South Aral Sea. Discussions were held on recreating a channel between the somewhat improved North and the desiccated South, along with uncertain wetland restoration plans throughout the region, but political will is lacking. Uzbekistan shows no interest in abandoning the Amu Darya river as an abundant source of cotton irrigation, and instead is moving toward oil exploration in the drying South Aral seabed.

Vast salt plains exposed with the shrinking of the Aral have produced dust storms, making regional winters colder and summers hotter. Attempts to mitigate these effects include planting vegetation in the newly exposed seabed. In the Northern Aral, recently higher sea levels have slightly moderated these effects in some areas, and the spring season now sees long-missing rainfall.

RESOURCES

Groundwater
http://earthsci.org/education/teacher/basicgeol/groundwa/groundwa.html

FAO databases and information systems
http://www.fao.org/tknet/topics/area_view?areaId=infsys&lang=en
http://www.fao.org/corp/statistics/en/
Check in particular:
AQUASTAT http://www.fao.org/nr/water/aquastat/main/index.stm

Principles and components of IWRM in urban areas
http://www.gdrc.org/uem/water/iwrm/1pager-01.html
http://www.gdrc.org/uem/water/iwrm/1pager-10.html
http://www.gdrc.org/uem/water/iwrm/1pager-11.html

IWRM Toolbox
[Note the sections on IWRM in capacity building, finance, floods, food and agriculture, freshwater and coast, groundwater, health, NWRP, nature and environment, water and sanitation]
http://www.gwptoolbox.org/