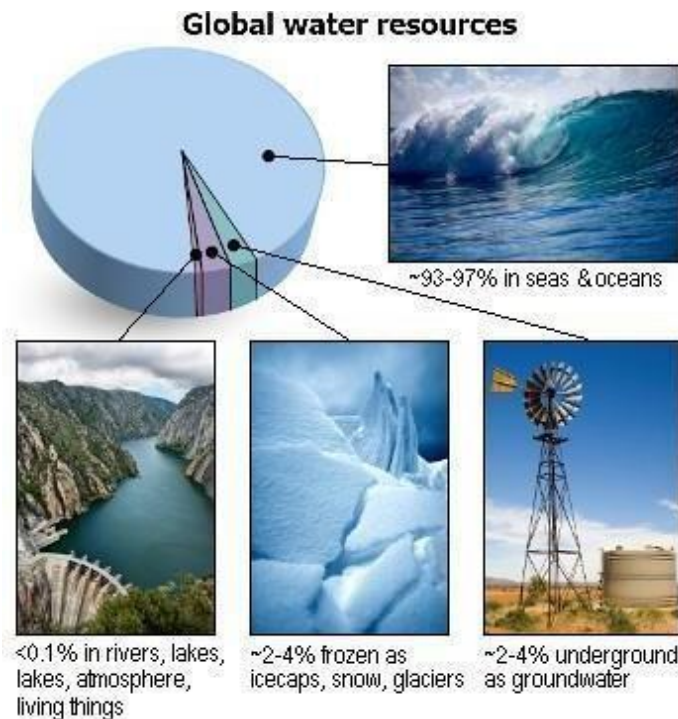


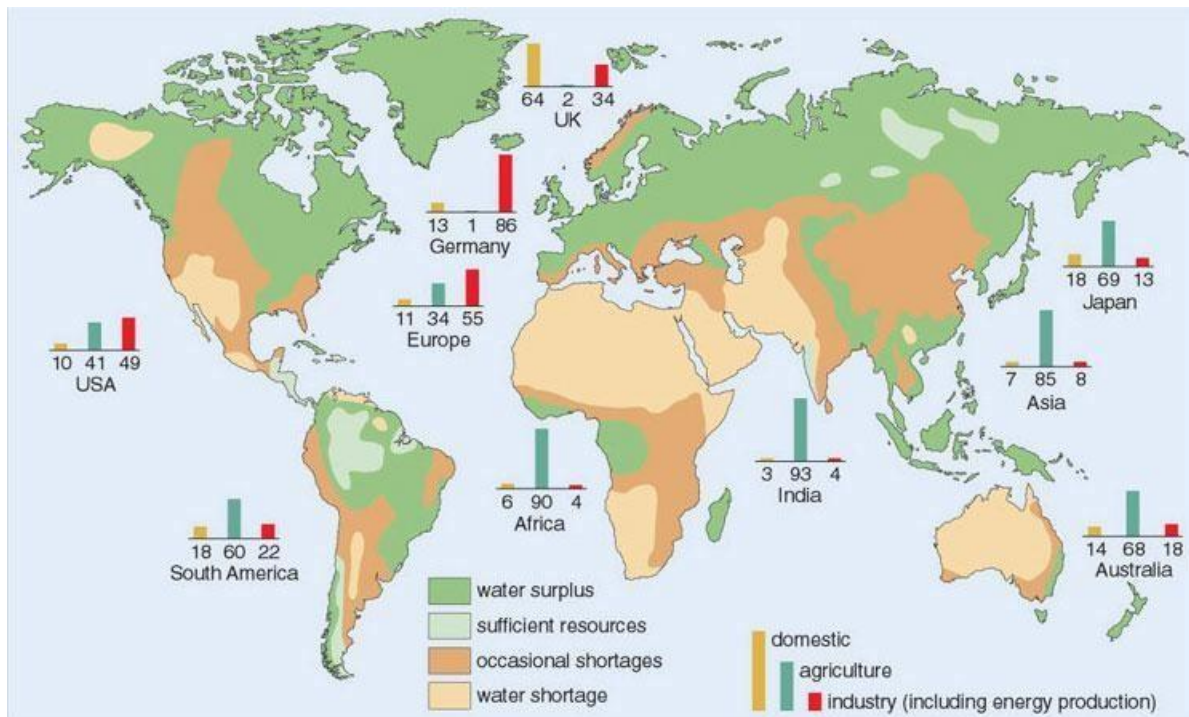
Module 2-WATER

Global water resources

Water resources are natural resources of water that are potentially useful for humans, for example as a source of drinking water supply or irrigation water. 97% of the water on the Earth is salt water and only three percent is fresh water; slightly over two thirds of this is frozen in glaciers and polar ice caps. The remaining unfrozen freshwater is found mainly as groundwater, with only a small fraction present above ground or in the air. Natural sources of fresh water include surface water, under river flow, groundwater and frozen water. Artificial sources of fresh water can include treated wastewater (wastewater reuse) and desalinated seawater. Human uses of water resources include agricultural, industrial, household, recreational and environmental activities.



Water resources are under threat from water scarcity, water pollution, water conflict and climate change. Fresh water is a renewable resource, yet the world's supply of groundwater is steadily decreasing, with depletion occurring most prominently in Asia, South America and North America, although it is still unclear how much natural renewal balances this usage, and whether ecosystems are threatened. The framework for allocating water resources to water users (where such a framework exists) is known as water rights.



Global water use and distribution. The bar charts show percentage use by category

- Globally, water use has increased rapidly in recent years due to population growth and increased per capita consumption. Most of the increase is in the developing countries. 70% of water use is for agriculture, 22% is for industry and 8% for domestic purposes, although there is considerable regional variation.
- Water is not scarce globally, but it often is on a continental or national scale. It is estimated that 31% of the global population will live in a water scarce country (having less than 1000 m³ of fresh water per person per year) by 2025.
- Water is often unsafe to drink because of pollution. This varies with continent and locally between cities and rural environments.

- Water shortages have been the cause of major international disputes, particularly in the Middle East

Sources of fresh water

1 Surface water

Surface water is water in a river, lake or fresh water wetland. Surface water is naturally replenished by precipitation and naturally lost through discharge to the oceans, evaporation, and sub-surface seepage.



Although the only natural input to any surface water system is precipitation within its watershed, the total quantity of water in that system at any given time is also dependent on many other factors. These factors include storage capacity in lakes, wetlands and artificial reservoirs, the permeability of the soil beneath these storage bodies, the runoff characteristics of the land in the watershed, the timing of the precipitation and local evaporation rates. All of these factors also affect the proportions of water lost.

Human activities can have a large and sometimes devastating impact on these factors. Humans often increase storage capacity by constructing reservoirs and decrease it by draining wetlands. Humans often increase runoff quantities and velocities by paving areas and channelizing stream flow. The total quantity of water available at any given time is an important consideration. Some human water users have an intermittent need for water.

Distribution of river water

The distribution of renewable river water across the Earth's surface is very uneven,

Continent or region	Renewable river water (km ³)	Percent of world total

Sub-Saharan Africa	4,000	9.20
Middle East and North Africa	140	0.32
Europe	2,900	6.70
Asia (excluding Middle East)	13,300	30.6
Australia	440	1.01
Oceania	6,500	14.9
North America	7,800	17.9
South America	12,000	27.6

There can be huge variations. For example, as much as a quarter of Australia's limited renewable fresh water supply is found in almost uninhabited Cape York Peninsula. Also, even in well-watered continents, there are areas that are extremely short of water, such as Texas in North America, whose renewable water supply totals only 26 km³ in an area of 695,622 km², or South Africa, with only 44 km³ in 1,221,037 km².

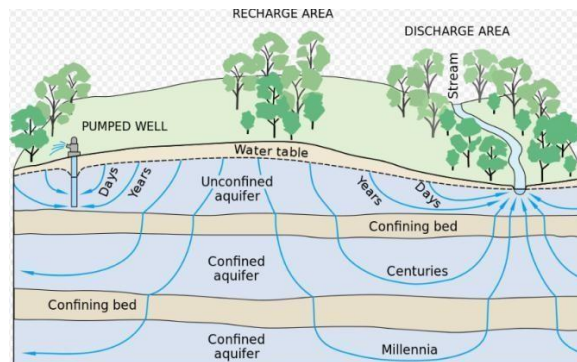
2 Under river flow

Throughout the course of the river, the total volume of water transported downstream will often be a combination of the visible free water flow together with a substantial contribution flowing through sub-surface rocks and gravels that underlie the river and its floodplain called the hyporheic zone. For many rivers in large valleys, this unseen component of flow may greatly exceed the visible flow. The hyporheic zone often forms a dynamic interface between surface water and true ground-water receiving water from the ground water when aquifers are fully charged and contributing water to ground-water when ground waters are depleted. This is especially significant in karst areas where pot-holes and underground rivers are common.

3 Ground water

Groundwater is the water present beneath Earth's surface in rock and soil pore spaces and in the fractures of rock formations. About 30 percent of all readily available freshwater in the world is groundwater. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is recharged from the surface; it may discharge from the surface naturally at springs and seeps, and can form oases or wetlands. Groundwater is also often withdrawn for agricultural, municipal, and industrial use by constructing and operating extraction wells. The study of the distribution and movement of groundwater is hydrogeology, also called groundwater hydrology.

Typically, groundwater is thought of as water flowing through shallow aquifers, but, in the technical sense, it can also contain soil moisture, permafrost (frozen soil), immobile water in very low permeability bedrock, and deep geothermal or oil formation water. Groundwater is hypothesized to provide lubrication that can possibly influence the movement of faults. It is likely that much of Earth's subsurface contains some water, which may be mixed with other fluids in some instances.



4 Desalination

Desalination is an artificial process by which saline water (generally sea water) is converted to fresh water. The most common desalination processes are distillation and reverse osmosis. Desalination is currently expensive compared to most alternative sources of water, and only a very small fraction of total human use is satisfied by desalination. It is only economically

practical for high-valued uses (such as household and industrial uses) in arid areas. The most extensive use is in the Persian Gulf.

5 Frozen water

An iceberg as seen from Newfoundland Several schemes have been proposed to make use of icebergs as a water source, however to date this has only been done for novelty purposes. Glacier runoff is considered to be surface water. The Himalayas, which are often called "The Roof of the World", contain some of the most extensive and rough high altitude areas on Earth as well as the greatest area of glaciers and permafrost outside of the poles. Ten of Asia's largest rivers flow from there, and more than a billion people's livelihoods depend on them. To complicate matters, temperatures are rising more rapidly here than the global average. In Nepal the temperature has risen with 0.6 degree over the last decade, whereas the global warming has been around 0.7 over the last hundred years

Uses of fresh water/ Application

Uses of fresh water can be categorized as consumptive and non-consumptive (sometimes called "renewable"). A use of water is consumptive if that water is not immediately available for another use. Losses to sub-surface seepage and evaporation are considered consumptive, as is water incorporated into a product (such as farm produce). Water that can be treated and returned as surface water, such as sewage, is generally considered non-consumptive if that water can be put to additional use.

1 Agricultural

It is estimated that 70% of worldwide water is used for irrigation, with 15–35% of irrigation withdrawals being unsustainable. It takes around 2,000 – 3,000 litres of water to produce enough food to satisfy one person's daily dietary need. This is a considerable amount, when compared to that required for drinking, which is between two and five litres. To produce food for the now over 7 billion people who inhabit the planet today requires the water that would fill a canal ten metres deep, 100 metres wide and 2100 kilometres long.

An assessment of water management in agriculture sector was conducted in 2007 by the International Water Management Institute in Sri Lanka to see if the world had sufficient water to

provide food for its growing population. It assessed the current availability of water for agriculture on a global scale and mapped out locations suffering from water scarcity. It found that a fifth of the world's people, more than 1.2 billion, live in areas of physical water scarcity, where there is not enough water to meet all demands. A further 1.6 billion people live in areas experiencing economic water scarcity, where the lack of investment in water or insufficient human capacity makes it impossible for authorities to satisfy the demand for water. The report found that it would be possible to produce the food required in future, but that continuation of today's food production and environmental trends would lead to crises in many parts of the world. To avoid a global water crisis, farmers will have to strive to increase productivity to meet growing demands for food, while industry and cities find ways to use water more efficiently

In some areas of the world, irrigation is necessary to grow any crop at all, in other areas it permits more profitable crops to be grown or enhances crop yield. Various irrigation methods involve different trade-offs between crop yield, water consumption and capital cost of equipment and structures. Irrigation methods such as furrow and overhead sprinkler irrigation are usually less expensive but are also typically less efficient, because much of the water evaporates, runs off or drains below the root zone. Other irrigation methods considered to be more efficient include drip or trickle irrigation, surge irrigation, and some types of sprinkler systems where the sprinklers are operated near ground level. These types of systems, while more expensive, usually offer greater potential to minimize runoff, drainage and evaporation. Any system that is improperly managed can be wasteful, all methods have the potential for high efficiencies under suitable conditions, appropriate irrigation timing and management. Some issues that are often insufficiently considered are salinization of groundwater and contaminant accumulation leading to water quality declines.

As global populations grow, and as demand for food increases, there are efforts under way to learn how to produce more food with less water, through improvements in irrigation method and technologies, agricultural water management, crop types, and water monitoring. Aquaculture is a small but growing agricultural use of water. Freshwater commercial fisheries may also be considered as agricultural uses of water, but have generally been assigned a lower priority than irrigation

Changing landscape for the use of agriculture has a great effect on the flow of fresh water. Changes in landscape by the removal of trees and soils changes the flow of fresh water in the local environment and also affects the cycle of fresh water. As a result, more fresh water is stored in the soil which benefits the agriculture. However, since agriculture is the human activity that consumes the most fresh water this can put a severe strain on local freshwater resources resulting in the destruction of local ecosystems. In Australia, over-abstraction of fresh water for intensive irrigation activities has caused 33% of the land area to be at risk of salination.

2 Industrial

It is estimated that 22% of worldwide water use is industrial. Major industrial users include power plants, which use water for cooling or as a power source (i.e. hydroelectric plants), ore and oil refineries, which use water in chemical processes, and manufacturing plants, which use water as a solvent. The portion of industrial water usage that is consumptive varies widely, but as a whole is lower than agricultural use. Water is used in power generation. Hydroelectricity is electricity obtained from hydropower. Hydroelectric power comes from water driving a water turbine connected to a generator. Hydroelectricity is a low-cost, non-polluting, renewable energy source. The energy is supplied by the sun. Heat from the sun evaporates water, which condenses as rain in higher altitudes, from where it flows down. Pressurized water is used in water blasting and water jet cutters. Also, very high pressure water guns are used for precise cutting. It works very well, is relatively safe, and is not harmful to the environment. It is also used in the cooling of machinery to prevent over-heating, or prevent saw blades from over-heating. Water is also used in many industrial processes and machines, such as the steam turbine and heat exchanger, in addition to its use as a chemical solvent. Discharge of untreated water from industrial uses is pollution. Pollution includes discharged solutes (chemical pollution) and discharged coolant water (thermal pollution). Industry requires pure water for many applications and utilizes a variety of purification techniques both in water supply and discharge.

3 Household

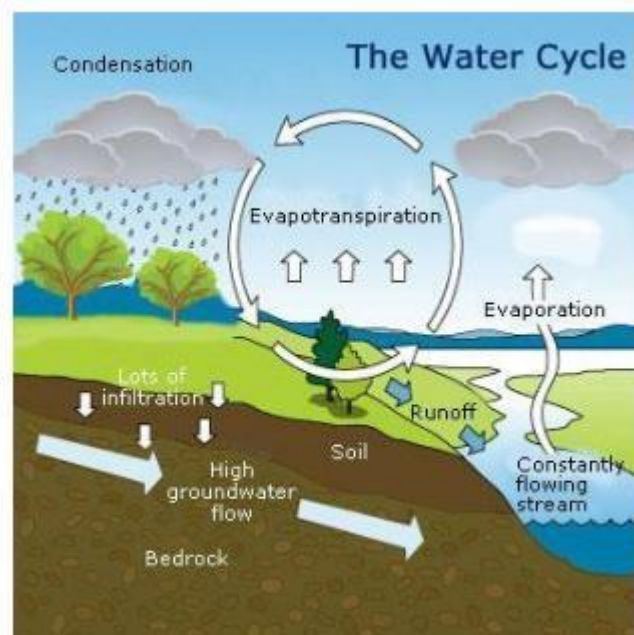
Drinking water It is estimated that 8% of worldwide water use is for household purposes. These include drinking water, bathing, cooking, sanitation, and gardening. Basic household water requirements have been estimated by Peter Gleick at around 50 liters per person per day,

excluding water for gardens. Drinking water is water that is of sufficiently high quality so that it can be consumed or used without risk of immediate or long term harm. Such water is commonly called potable water. In most developed countries, the water supplied to households, commerce and industry is all of drinking water standard even though only a very small proportion is actually consumed or used in food preparation.

Hydrologic Cycle: The water cycle is a process that occurs around us without our notice. It involves changes in the state of the water. A water cycle describes how water on Earth remains here and does not go out of its boundaries. This cycle is also known as the hydrologic cycle. Understanding this cycle is not very difficult if you know about certain processes. When we talk about the water cycle, there are various stages through which water molecules move and come back to the place where they started.

The various stages of hydrological cycle are:

1. Evaporation
2. Condensation
3. Precipitation
4. Deposition or Collection



1. **Evaporation-** This is the very primary stage of the water cycle. The process through which water from its liquid state changes to vapor, which is a gaseous state, is known as evaporation. During the water cycle, water in the water bodies gets heated up and therefore evaporates in the form of vapor, mixes with the air, and disappears with time.
2. **Condensation-** It is known as the second crucial step in the water cycle. After the evaporated water vapor loses its thermal energy, it forms liquid by the process of condensation. Clouds are also formed with the process of condensation.
3. **Precipitation-** Rain, snow, sleet, frost, or hail are all examples of Precipitation. After the condensation, atmospheric water vapor turns into big water droplets and falls back to the earth with the help of gravity.
4. **Deposition or Collection-** This is the final and complete stage of the water cycle. The process of deposition occurs when evaporated water vapor falls back to earth in the form of precipitation. This water may fall back into different water bodies, like oceans, rivers, ponds, lakes, and even end up on the land, which then becomes a part of the groundwater.

Water stress

Best estimate of the share of people in developing countries with access to drinking water 1970–2000. The concept of water stress is relatively simple: According to the World Business Council for Sustainable Development, it applies to situations where there is not enough water for all uses, whether agricultural, industrial or domestic. Defining thresholds for stress in terms of available water per capita is more complex, however, entailing assumptions about water use and its efficiency. Nevertheless, it has been proposed that when annual per capita renewable freshwater availability is less than 1,700 cubic meters, countries begin to experience periodic or regular water stress. Below 1,000 cubic meters, water scarcity begins to hamper economic development and human health and well-being.

1 Population growth

In 2000, the world population was 6.2 billion. The UN estimates that by 2050 there will be an additional 3.5 billion people with most of the growth in developing countries that already suffer water stress. Thus, water demand will increase unless there are corresponding increases in water conservation and recycling of this vital resource.

2 Expansion of business activity

Business activity ranging from industrialization to services such as tourism and entertainment continues to expand rapidly. This expansion requires increased water services including both supply and sanitation, which can lead to more pressure on water resources and natural ecosystems.

3 Rapid urbanization

The trend towards urbanization is accelerating. Small private wells and septic tanks that work well in low-density communities are not feasible within high-density urban areas. Urbanization requires significant investment in water infrastructure in order to deliver water to individuals and to process the concentrations of wastewater – both from individuals and from business. These polluted and contaminated waters must be treated or they pose unacceptable public health risks.

In 60% of European cities with more than 100,000 people, groundwater is being used at a faster rate than it can be replenished. Even if some water remains available, it costs more and more to capture it.

4 Climate change

Climate change could have significant impacts on water resources around the world because of the close connections between the climate and hydrological cycle. Rising temperatures will increase evaporation and lead to increases in precipitation, though there will be regional variations in rainfall. Overall, the global supply of freshwater will increase. Both droughts and floods may become more frequent in different regions at different times, and dramatic changes in snowfall and snowmelt are expected in mountainous areas. Higher temperatures will also affect water quality in ways that are not well understood. Possible impacts include increased eutrophication. Climate change could also mean an increase in demand for farm irrigation, garden sprinklers, and perhaps even swimming pools

5 Depletion of aquifers

Due to the expanding human population, competition for water is growing such that many of the world's major aquifers are becoming depleted. This is due both for direct human consumption as well as agricultural irrigation by groundwater. Millions of pumps of all sizes are currently extracting groundwater throughout the world. Irrigation in dry areas such as northern China and India is supplied by groundwater, and is being extracted at an unsustainable rate. Cities that have experienced aquifer drops between 10 to 50 meters include Mexico City, Bangkok, Manila, Beijing, Madras and Shanghai.

6 Pollution and water protection

Water pollution is one of the main concerns of the world today. The governments of many countries have striven to find solutions to reduce this problem. Many pollutants threaten water supplies, but the most widespread, especially in underdeveloped countries, is the discharge of raw sewage into natural waters; this method of sewage disposal is the most common method in underdeveloped countries, but also is prevalent in quasi-developed countries such as China, India and Iran. Sewage, sludge, garbage, and even toxic pollutants are all dumped into the water. Even if sewage is treated, problems still arise. Treated sewage forms sludge, which may be placed in landfills, spread out on land, incinerated or dumped at sea.] In addition to sewage, nonpoint source pollution such as agricultural runoff is a significant source of pollution in some parts of the world, along with urban storm water runoff and chemical wastes dumped by industries and governments.

Water Resources of India

- India accounts for about 2.45 per cent of world's surface area, 4% per cent of the world's water resources and about 16 per cent of world's population. The total water available from precipitation in the country in a year is about 4,000 cubic km. The availability from surface water and replenish able groundwater is 1,869 cubic km. Out of this only 60 per cent can be put to beneficial uses. Thus, the total utilizable water resource in the country is only 1,122 cubic km.

Surface Water Resources

- There are four major sources of surface water. These are rivers, lakes, ponds, and tanks. In the country, there are about 10,360 rivers and their tributaries longer than 1.6 km each. The mean annual flow in all the river basins in India is estimated to be 1,869 cubic km. However, due to topographical, hydrological and other constraints, only about 690 cubic km (32 per cent) of the available surface water can be utilized.
- Water flow in a river depends on size of its catchment area or river basin and rainfall within its catchment area. Precipitation in India has very high spatial variation, and it is mainly concentrated in Monsoon season. Some of the rivers in the country like the Ganga, the Brahmaputra, and the Indus have huge catchment areas. Given that precipitation is relatively high in the catchment areas of the Ganga, the Brahmaputra and the Barak rivers, these

rivers, although account for only about one-third of the total area in the country, have 60 per cent of the total surface water resources. Much of the annual water flow in south Indian rivers like the Godavari, the Krishna, and the Kaveri has been harnessed, but it is yet to be done in the Brahmaputra and the Ganga basins

SL no	River basin	Water potential m.ha.m
1	West flowing river- Narmada	30.55
2	East flowing river- Krishna, Cauvery, Godavari	35.56
3	Ganga & Tributaries	55.01
4	Indus & Tributaries	7.95
5	Brahmaputra	59.07
Total water potential		188.04

Groundwater Resources

- The total replenishable groundwater resources in the country are about 432 cubic km. Table shows that the Ganga and the Brahmaputra basins, have about 46 per cent of the total replenishable groundwater resources.
- The level of groundwater utilisation is relatively high in the river basins lying in north-western region and parts of south India. The groundwater utilisation is very high in the states of Punjab, Haryana, Rajasthan, and Tamil Nadu. However, there are States like Chhattisgarh, Odisha, Kerala, etc., which utilize only a small proportion of their groundwater potentials. States like Gujarat, Uttar Pradesh, Bihar, Tripura and Maharashtra are utilizing their ground water resources at a moderate rate.
- If the present trend continues, the demands for water would need the supplies. And such situation, will be detrimental to development, and can cause social upheaval and disruptions.

Lagoons and Backwaters

- India has a vast coastline and the coast is very indented in some states. Due to this, a number of lagoons and lakes have formed. The States like Kerala, Odisha and West Bengal have vast surface water resources in these lagoons and lakes. Although, water is generally brackish in these water-bodies, it is used for fishing and irrigating certain varieties of paddy crops, coconut, etc.

Water Demand and Utilization in india

- India has traditionally been an agrarian economy, and about two-third of its population have been dependent on agriculture. Hence, development of irrigation to increase agricultural production has been assigned a very high priority in the Five Year Plans, and multipurpose river valleys projects like the Bhakra-Nangal, Hirakud, Damodar Valley, Nagarjuna Sagar, Indira Gandhi Canal Project, etc. have been taken up. In fact, India's water demand at present is dominated by irrigational needs.
- Agriculture accounts for most of the surface and ground water utilisation, it accounts for 89 per cent of the surface water and 92 per cent of the groundwater utilisation. While the share of industrial sector is limited to 2 per cent of the surface water utilisation and 5 per cent of the ground-water, the share of domestic sector is higher (9 per cent) in surface water utilization as compared to groundwater. The share of agricultural sector in total water utilization is much higher than other sectors. However, in future, with development; the shares of industrial and domestic sectors in the country are likely to increase.

Resources system planning

The main sources of water supply are surface and ground water which have been used for a variety of purposes such as drinking, irrigation, hydroelectric energy, transport, recreation etc. Often, human activities are based on the usual or normal range of river flow conditions. However, flows and storage vary spatially and temporally; and also they are finite (limited) in nature i.e., there is a limit to the services that can be expected from these resources. Rare or Extreme" flows or water quality conditions outside the normal ranges will result in losses to river-dependent, human activities. Therefore, planning is needed to increase the benefits from the available water sources.

The purpose of water resources planning and management activities is to determine

- (i) How can the renewable yet finite resources best be managed and used?
- (ii) How can this be accomplished in an environment of uncertain supplies and uncertain and increasing demands, and consequently of increasing conflicts among individuals having different interests in the management of a river and its basin?

NEED FOR PLANNING AND MANAGEMENT

Planning and management of water resources systems are essential due to following factors:

- (1) Severity of the adverse consequences of droughts, floods and excessive pollution. These can lead to
 - a. Too little water due to growing urbanization, additional water requirements, in stream flow requirements etc. Measures should be taken to reduce the demand during scarcity times
 - b. Too much water due to increased flood frequencies and also increase in water requirements due to increased economic development on river floodplains
 - c. Polluted water due to both industrial and household discharges
- (2) Degradation of aquatic and riparian systems due to river training and reclamation of floodplains for urban and industrial development, poor water quality due to discharges of pesticides, fertilizers and wastewater effluents etc.
- (3) While port development requires deeper rivers, narrowing the river for shipping purposes will increase the flood level
- (4) River bank erosion and degradation of river bed upstream of the reservoirs may increase the flooding risks
- (5) Sediment accumulation in the reservoir due to poor water quality

Considering all these factors, the identification and evaluation of alternative measures that may increase the quantitative and qualitative system performance is the primary goal of planning and management policies.

SYSTEM COMPONENTS

Water resources management involves the interaction of three interdependent subsystems:

1. **Natural river subsystem** in which the physical, chemical and biological processes takes place
2. **Socio-economic subsystem**, which includes the human activities related to the use of the natural river system

3. **Administrative and institutional subsystem** of administration, legislation and regulation, where the decision, planning and management processes take place

Inadequate attention to one subsystem can reduce the effect of any work done to improve the performance of the others

PLANNING AND MANAGEMENT – APPROACHES

Two approaches which lead to an integrated plan and management policy are

- From the top down or the command and control approach

Top down approach:

Water resources professionals prepare integrated, multipurpose „master“ development plans with alternative structural and non-structural management options. There is dominance of professionals and little participation of stakeholders. In this approach, one or more institutions have the ability and authority to develop and implement the plan. However, nowadays, since public have active participation in planning and management activities, top- down approaches are becoming less desirable or acceptable.

- From the bottom up or the grass-roots approach

Bottom up approach:

In this approach there is active participation of interested stakeholders – those affected by the management of the water and land resources. Plans are being created from the bottom up rather than top down. Top down approach plans do not take into consideration the concerns of affected local stakeholders. Bottom up approach ensures cooperation and commitment from stakeholders. The goals and priorities will be common among all stakeholders by taking care of laws and regulations and by identifying multiple alternatives and performance criteria. Tradeoffs are made between conflicting goals or measures of performance.

INTEGRATED WATER RESOURCES MANAGEMENT (IWRM)

- According to Global Water Partnership (GWP, 2000), IWRM is a process which promotes the coordinated development and management of water, land and related

resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of the vital ecosystems.

- An integrated water management model develops solutions by involving all the essential components into an optimization scheme. The resources are used in relation to social and economic activities and functions. There is a need for laws and regulations for the sustainable use of the water resources.

Dublin principles for a good water resources management as described by the United Nations Water Conference in 1977 are:

- The —ecological principle— to treat water as a unitary resource within river basins, With particular attention to ecosystems.
- The “institutional principle— to respect the principle of subsidiarity through the involvement of government, civil society and the private sector.
- The —instrument principle— to recognize water as a scarce economic community by imposing various penalties for excessive usage.

A management policy must be developed only after considering the factors such as cost effectiveness, economic efficiency, environmental impact, ecological and health considerations etc.

PLANNING AND MANAGEMENT ASPECTS

Technical aspects

- Predicting changes in land use/covers and economic activities at watershed and riverbasin levels
- Estimation of the costs and benefits of any measures being and to be taken to manage the basin’s water resource including engineering structures, canals, diversion structures etc.
- Identification and evaluation of alternative management strategies and also alternative time schedules for implementing those measures

Economic and Financial aspects

- Water should be treated as an economic commodity to extract the maximum benefits as well as to generate funds to recover the costs of the investments and of the operation and maintenance of the system. Water had been treated for long as a free commodity. Revenues recovered are far below the capital cost incurred.
- Financial component of any planning process is needed to recover construction costs, maintenance, and repair and operation costs. In management policies, financial viability is viewed as a constraint that must be satisfied; not as an objective whose maximization could result in a reduction in economic efficiency, equity or other non-monetary objectives

Institutional aspects

- Successful project implementation needs an enabling environment.
- National, provincial and local policies, legislation and institutions are crucial for implementation of the decisions.
- The role of the government is crucial since water is
 - (i) not a property right
 - (ii) a resource that often requires large investment to develop and
 - (iii) a medium that can impulse external effects.
- The main causes of failure of water resources development project are insufficient institutional setting and lack of a sound economic evaluation and implementation.

Water use sectors- domestic, Industrial, Agriculture

Agriculture sector

- As of now irrigation sector consumes about 80% of the total water use which may reduce to about 70% by 2050 due to competing demands from other sectors. Most of the irrigation projects are very old and have become less efficient. Given the quantum of use in this sector, it is needless to emphasize that it has tremendous potential for water saving on efficient irrigation water use. Whereas, current performance of a completed project vis the design

performance can be assessed/compared through conventional performance evaluation studies or if only hydraulic irrigation system is to be assessed, then by water use efficiency studies. CWC web has guidelines for the studies.

Domestic sector

- Domestic water requirement is estimated to nearly double in the next 40 years (56 BCM in 2010 to 102 BCM in 2050 (MOWR, RD & GR 2000).
- The ever rising scarcity has put the managers in a bracket and left with no choice but to critically review and optimise the business as usual.
- The typical reasons water supply system under-performance could be like poor conservation, inefficient management, improper operation and maintenance system, lack of revenue generation (poor metering; low tariff), and most significantly, wastage due to leakage and pilferage etc.
- In-fact, the Ministry of Urban Development, with the help of the National Environmental Engineering Institute (NEERI) had conducted studies on leaks in water distribution systems across 13 cities, including Delhi, Calcutta, Mumbai and Chennai during 1990's. It was observed that about 17-44 percent of the total flow in the distribution system was lost on account of water loss through leakages in mains, communication and service pipes and leaking valves.
- A recent study by ADB (2007) across 20 towns and cities corroborated the past studies and showed the water losses due to leakage, pilferage etc, to be of the order of up to 60 per cent. It also highlighted the fact that maximum leakage occurs in the house service connections, i.e., in the tertiary distribution networks. This is a reflection of the inefficiency in the management side which needs immediate attention.

Industrial sector

- Though the industrial water demand (including energy demand) at present constitutes only about 8% of the total water demand, its share of water use is rising rapidly and by the year 2050 is expected to increase to about 13% of the total projected water use at that time. The

overall demand of water for industries is expected to go up from 56 BCM (including Energy, mainly Thermal Power) that was in the year 2010 to 151 BCM by the year 2050.

- At present the industrial plants in our countries consume about 2 to 3.5 times more water per unit of production compared to similar plants operating in other countries. There is an urgent need and scope to make the systems more efficient and operate with reduced quantity of water. Further unlike in Irrigation the industries require water on regular basis throughout the year. Therefore, to ensure reasonable availability of water for industries even during the lean periods, the industries will have to inculcate the habit of efficient water use.
- Besides this, industrial water management has to address a major issue of water quality of effluents which can also be tackled to some extent through efficient water use. However, water requirements of various sectors of Indian Industries as per volume II of NWM document are tabulated as under

Sl. No	Category of Industry	Water Requirement per tonne in m ³	Year 2000		Year 2010		Year 2025		Year 2050	
			Production	Water Req.	Production	Water Req.	Production	Water Req.	Production	Water Req.
1	2	3	4	5	6	7	8	9	10	11
1	Iron & Steel	22	174050	3829.1	265350	5837.7	273300	6013	547050	12035
2	Smelters	82.5	203.6	16.76	292.6	24.14	391.6	32.31	537.6	44.35
3	Textiles & Jute	200	51193	8153.7	95094	19019	183507	36701	234618	46924
4	Leather Products	30	1277.5	1244.7	2191.3	65.74	3102.5	93.08	4927.5	147.83
5	Inorganic Chemicals	200	3730	165	8000	1600	16730	3346	30076	615
6	Pharmaceuticals	25	4960	124	8370	209.25	11046	276.2	17170	429.15
7	Distillery	22	1790.8	6357.2	3059.6	66.31	4454.6	318	6020	5203.9
8	Paper & Pulp	200	4950	1260	10350	207	51200	10240	97450	19490

Water Requirement in Mm³ / year

Production in 1000

tonnes

From the above table it may be seen that some of the industries like Textile, Paper & Pulp and Iron & Steel etc. consume lot of water. Efforts shall be made to reduce their water use. Further existing Thermal Power Projects consume lot of water in their cooling process. There is lot of scope in reducing their water demand by adopting efficient cooling technologies.

Water deficit and water surplus basins in India



Water Balance

This is the balance between the inputs and outputs of a drainage basin. Water balance is expressed as: $P = Q + E$ (+/- change in storage)

Where P = precipitation, Q = run-off, E = evapotranspiration.

Key terms to describe various water balance conditions are:

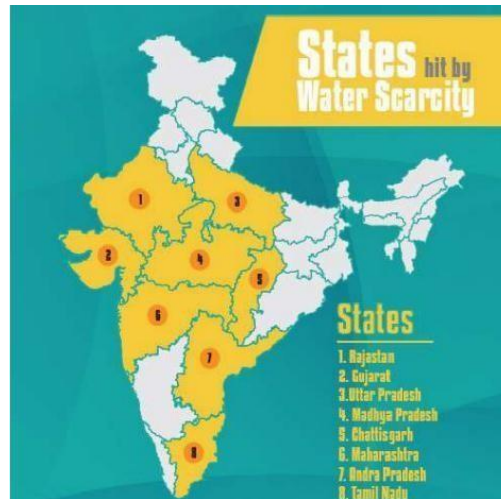
Water Surplus: there is excess water available to the system. This occurs when precipitation exceeds evapotranspiration and the excess is not being used by plants.

Deficiency: there is a reduction of water available within the system. This occurs when evapotranspiration exceeds precipitation.

Recharge: after a period of deficiency precipitation will occur and replace the lost water in the soil. This needs to occur before a period of surplus can reoccur.

Field capacity: the maximum amount of water that soil can hold before it becomes saturated.

A water surplus can result in wet soils, high river levels and additional run-off whereas a deficit leads to dry soil, falling river levels and possibly a drier micro-climate.



The water deficit states are Andhra Pradesh, Bihar, Gujarat, Jharkhand, Karnataka, Maharashtra, parts of the North-East, Rajasthan, Tamil Nadu and Telangana. These states are home to 500 million people, almost 40% of the country's population

Water storage in major Indian River basins depleting

- River basin is considered as the basic hydrological unit for planning and development of water resources. Recent data from the Central Water Commission (CWC), released on February 15, 2019, brings forth an alarming situation of water storage in premiere river basins of India.
- In more than 60 per cent of the basins, the water storage is much lesser when compared to the average water storage over the last 10 years, data shows.



- The entire country has been divided into 22 basins as per Central Water Commission. The names of the basins along with their id and area are given in the table.
- (Reference Table)

Sl. No	Basin Code	Basin Name	Area (sq.km)
1	01	Indus (Up to border)	321289
2	2A	Ganga	861452
3	2B	Brahmaputra	194413
4	2C	Barak and others	41723
5	03	Godavari	312812
6	04	Krishna	258948
7	05	Cauvery	81155
8	06	Subernarekha	29196
9	07	Brahmani and Baitarni	51822
10	08	Mahanadi	141589
1	09	Pennar	55213
12	10	Mahi	34842
13	11	Sabarmati	21674
14	12	Narmada	98796
15	13	Tapi	65145
16	14	West flowing rivers from Tapi to Tadri	55940
17	15	West flowing rivers from Tadri to Kanyakumari	56177
18	16	East flowing rivers between Mahanadi and Pennar	86643
19	17	East flowing rivers between Pennar and Kanyakumari	100139
20	18	West flowing rivers of Kutch and Saurashtra including Luni	321851
21	19	Area of inland drainage in Rajasthan	
22	20	Minor rivers draining into Myanmar & Bangladesh	36202

- According to a study published in the journal Global Planetary Changes, at least half of 16 river basins have low soil moisture, making the area prone to drought. The Ganga

basin is the most badly affected, and lacks the potential to cope with extreme climatic events such as drought

- In the report, the CWC monitored 12 river basins for water storage; using data on average of the last 10 years, 2017-18 and 2018-19. The river basins of Tapi, Sabarmati, and Rivers of Kutch are the worst affected, with more than 50 per cent shortage in average water storage capacity compared to last 10 years. The water storage in Sabarmati and Rivers of Kutch is less than 20 per cent of their total capacities.
- The other basins that also have shortage are: Ganga, Godavari, Krishna and Mahanadi. Out of the 12 river basins, seven — Ganga, Tapi, Mahi, Sabarmati, Rivers of Kutch, Godavari and Mahanadi — show low water storage compared to data from 2017-18 and average of the last 10 years. In all river basins, the water storage is less than the full reservoir level. In all river basins, the water storage is less than the full reservoir level.

Equitable distribution

Right to water or equitable distribution needs to be seen as every community. Having a proportional right to water as part of a collective right to assured to all people

Water Scarcity Effects on Equitable Water Distribution

- Water Scarcity Effects on Equitable Water Distribution and Land Use in a Major Irrigation Project
- The equity of water distribution is expected to change in response to interannual fluctuations in water supply. In many river basins, upstream development and interannual variations in rainfall can cause both episodic and chronic shortages in water supply downstream.
- Priority in allocation is often given to urban areas and industry, which can exacerbate the supply shocks to irrigated command areas during water deficit years. How these shortages, both temporary and chronic, are distributed over the command area will determine their net impact on agricultural production, equity, and farmers' livelihoods within the irrigated command area. Spatial and temporal analysis of actual water supply

in different parts of the irrigation project can identify how and where to improve the performance of irrigation scheme and hence improve water and land productivity.

- Variability in water supply is also linked with the issue of equity, and the spatial uniformity of water supply can be expected to change under different water supply regimes.
- Head reach areas receiving high supply rates during a normal year experienced the highest risks of fluctuations in water supply and cropped area during a water short year compared to downstream areas, which had chronically low water supply, and better adaptive responses by farmers
- Equitable allocations could be achieved by improving the water distribution efficiency of the canal network during normal years and by crop diversification and introduction of alternative water sources during water shortage years.

Inter-basin water transfers

Introduction

The rainfall over the country is primarily orographic, associated with tropical depressions originating in the Arabian Sea and the Bay of Bengal. The summer monsoon accounts for more than 85 per cent of the precipitation. The uncertainty of occurrence of rainfall marked by prolonged dry spells and fluctuations in seasonal and annual rainfall is a serious problem for the country. Large parts of Haryana, Maharashtra, Andhra Pradesh, Rajasthan, Gujarat, Madhya Pradesh, Karnataka and Tamil Nadu are not only in deficit in rainfall but also subject to large variations, resulting in frequent droughts and causing immense hardship to the population and enormous loss to the nation. The water availability even for drinking purposes becomes critical, particularly in the summer months as the rivers dry up and the ground water recedes. Regional variations in the rainfall lead to situations when some parts of the country do not have enough water even for raising a single crop. On the other hand excess rainfall occurring in some parts of the country creates havoc due to floods.

Irrigation using river water and ground water has been the prime factor for raising the food grain production in our country from a mere 50 million tonnes in the 1950s to more than 200 million tonnes at present, leading us to attain self sufficiency in food. Irrigated area has increased from

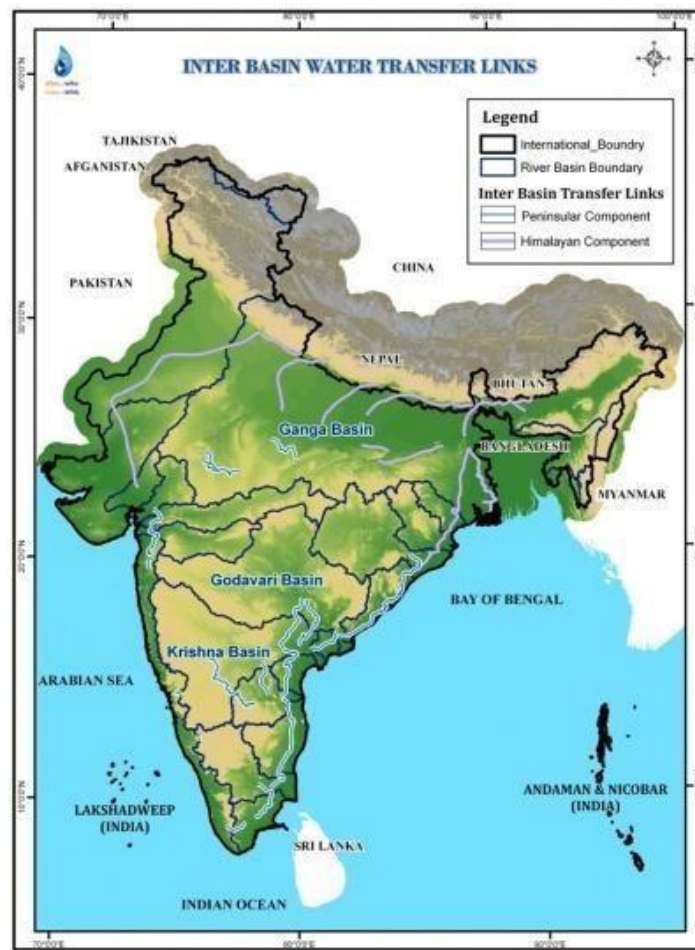
22 million hectares to 95 million hectares during this period. The population of India, which is around 1000 million at present, is expected to increase to 1500 to 1800 million in the year 2050 and that would require about 450 million tonnes of food grains. For meeting this requirement, it would be necessary to increase irrigation potential to 160 million hectares for all crops by 2050. India's maximum irrigation potential that could be created through conventional sources has been assessed to be about 140 million hectares. For attaining a potential of 160 million hectares, other strategies shall have to be evolved.

Floods are a recurring feature, particularly in Brahmaputra and Ganga rivers, in which almost 60 per cent of the river flows of our country occur. Flood damages, which were Rs. 52 crores in 1953, have gone up to Rs. 5,846 crores in 1998 with annual average being Rs. 1,343 crores affecting the States of Assam, Bihar, West Bengal and Uttar Pradesh alongwith untold human sufferings. On the other hand, large areas in the States of Rajasthan, Gujarat, Andhra Pradesh, Karnataka and Tamil Nadu face recurring droughts. As much as 85 percentage of drought prone area falls in these States.

Inter-basin water transfers

- One of the most effective ways to increase the irrigation potential for increasing the food grain production, mitigate floods and droughts and reduce regional imbalance in the availability of water is the Inter Basin Water Transfer (IBWT) from the surplus rivers to deficit areas.
- Brahmaputra and Ganga particularly their northern tributaries, Mahanadi, Godavari and West Flowing Rivers originating from the Western Ghats are found to be surplus in water resources. If we can build storage reservoirs on these rivers and connect them to other parts of the country, regional imbalances could be reduced significantly and lot of benefits by way of additional irrigation, domestic and industrial water supply, hydropower generation, navigational facilities etc. would accrue
- The Narmada Canal Project offtaking from Sardar Sarovar in Western India transfers water from the Narmada Basin to areas coming under other river basins in Gujarat (Mahi, Sabarmati and other small river basins in North Gujarat, Saurashtra and Kutch) and Rajasthan (Luni and other basins of Jalore and Barmer districts) for irrigation, drinking water, industrial use, etc. The canal is designed to transfer 9.5 Million acre-feet (MAF)

(approx. 11.7 Billion cubic metre (BCM)) water annually from the Narmada Basin to areas under other basins in Gujarat and Rajasthan. (9 MAF for Gujarat and 0.5 MAF for Rajasthan).



- The Periyar Project in Southern India from the Periyar River in Kerala to the Vaigai basin in Tamil Nadu. It consists of a dam and a tunnel with a discharging capacity of 40.75 cubic meters per second. The project was commissioned in 1895 and provides irrigation to 81,000 hectares, in addition to providing power through a plant with a capacity of 140 MW
- The Parambikulam Aliyar project, also in Southern India, consists of seven streams, five flowing towards the west and two towards the east, which have been dammed and interlinked by tunnels. The project transfers water from the Chalakudy River basin to the Bharatapuzha and Cauvery basins for irrigation in Coimbatore district of Tamil Nadu and

the Chittur area of Kerala states. It also serves for power generation with a capacity of 185 MW.

- The Kurnool Cudappah Canal in Southern India is a scheme started by a private company in 1863, transferring water from the Krishna River basin to the Pennar basin. It includes a 304 km long canal with a capacity of 84.9 cubic meters per second for irrigation
- The Telugu Ganga project in Southern India. This project primarily meets the water supply needs of Chennai metropolitan area, but is also used for irrigation. It brings Krishna River water through 406 km of canals. The project, which was approved in 1977 and completed in 2004, involved the cooperation of four Indian States: Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu
- The Indira Gandhi Canal (formerly known as the Rajasthan Canal) linking the Ravi River, the Beas River and the Sutlej River through a system of dams, hydropower plants, tunnels, canals and irrigation systems in Northern India built in the 1960s to irrigate the Thar Desert

In brief summary: Examples of Inter basin water transfer in India

- Periyar - Vaigai project (Kerala state 1985)
- Kurnool – - Cuddapah Canal (Andhra Pradesh 1863-1870)
- Parambikulam - Aliyar project (1962-82)
- Telugu – - Ganga project
- Beas – - Sutlej Link (1983)
- Indira Gandhi Nahar project (Rajasthan canal, 1958)
- Sarada - Sahayak Project (1960)
- Ramganga – - Ganga Link (1978)
- Tungabhadra – - Pennar project
- Mahi project
- Tehri Multipurpose project

MERITS AND DEMERITS OF INTER BASIN WATER TRANSFER

Merits

1. Possible to utilize the water resources uniformly and economically to yield Significant output.
2. Enhancement in Irrigation potential and power generation

3. Provides ample surface water to meet the growing needs of Domestic and Industries.
4. Scopes for Inland Navigation which reduces stress on existing communication system.
5. It minimizes the intensity of drought and floods.
6. It helps to increase per capita income.
7. Reduces the exploitation of ground water as surface water is made available in abundant.
8. Huge employment generation
9. Development of fisheries
10. Salinity control
11. Recreation facility
12. Infrastructural development
13. Socio economic development
14. Considerable improvement in ground water potential
15. Control in migration
16. Conversion of barren land into culturable land
17. Reduction in formation of further deltas in coastal zones.
18. Minimization of the relief expenditure towards floods and droughts.

2 Demerits

1. Large area liable for submersion due to construction of reservoirs and canals
2. Adverse effects over ecological system
3. Difficult to solve Interstate or International water Disputes
4. Legal problem in sharing the water
5. Cost of the project and recurring expenditure for maintenance are high
6. Water pollution in conveyance
7. Loss of water in conveyance through the canals
8. Land acquisition and rehabilitation problems
9. Requires afforestation to compensate for loss in green
10. It is a long term project which may cause large variation in estimation
11. Serving for high altitude areas needs pumping of water which requires huge power and maintenance.

12. Needs huge debate at micro level and macro level on the issue to convince the public.
13. Problems of soil erosion and sedimentation
14. In undulated zones it may require to construct large number of cross drainage works.

Interlinking of rivers

- The idea of interlinking rivers was first mooted by the Chief Engineer of the Madras Presidency in 1919, Sir Arthur Cotton.
- This idea was revisited in 1960 by the then Minister of State for Energy and Irrigation, KL Rao, who proposed to link rivers Ganga and Cauvery.
- The National Water Development Agency was established by former Prime Minister Indira Gandhi in 1982.
- In 2002, the Supreme Court asked the government to finalize a plan for interlinking rivers by 2003 and execute it by 2016.
- A task force was formed by the government for the same in 2003.
- In 2012, the SC again asked the government to start the project.
- In 2014, the Ken-Betwa River Linking Project got Cabinet approval. However, the project is yet to take off because of the opposition faced by the government chiefly from environmentalist

What is Inter-linking of Rivers (ILR)?

The idea behind the interlinking of rivers is that many parts of the country face problems of drought while many others face the problem of flooding every year.

- The Indo-Gangetic rivers are perennial since they are fed by rains as well as the glaciers from the Himalayas.
- The peninsular rivers in India are, however, not seasonal because they are rain-fed mainly from the south-west Monsoons.
- Due to this, the Indo-Gangetic plains suffer from floods and the peninsular states suffer from droughts.
- If this excess water can be diverted from the Plains to the Peninsula, the problem of floods and droughts can be solved to a large extent.

- Hence, the interlinking of rivers will bring about an equitable distribution of river waters in India.

There are two components to this project:

- *Himalayan Component*
- *Peninsular Component*

Himalayan Component of NRLP

- Under the Himalayan component of the NRLP, there are 14 projects in the pipeline.
- Storage dams will be constructed on the rivers Ganga and Brahmaputra, and also their tributaries.
- The linking of the Ganga and the Yamuna is also proposed.
- Apart from controlling flooding in the Ganga – Brahmaputra river system, it will also benefit the drought-prone areas of Rajasthan, Haryana and Gujarat.
- This component has two sub-components:
- Connecting the Ganga and Brahmaputra basins to the Mahanadi basin.
- Connecting the Eastern tributaries of the Ganga with the Sabarmati and Chambal river systems.

Peninsular Component of NRLP

- This component of the NRLP envisages the linking of the 16 rivers of southern India.
- Surplus water from the Mahanadi and the Godavari will be transferred to the Krishna, Cauvery, Pennar, and the Vaigai rivers.
- Under this component, there are four sub-component linkages:
- Linking Mahanadi and Godavari river basins to Cauvery, Krishna, and Vaigai river systems.
- Ken to Betwa river, and Parbati & Kalisindh rivers to Chambal river.
- West-flowing rivers to the south of Tapi to the north of Bombay
- Linking some west-flowing rivers to east-flowing rivers.



Benefits of River Interlinking

- There are many benefits that the proposed interlinking projects will bring about. They are discussed below:
- Interlinking rivers is a way to transfer excess water from the regions which receive a lot of

rainfall to the areas that are drought-prone. This way, it can control both floods and droughts.

- This will also help solve the water crisis in many parts of the country.
- The project will also help in hydropower generation. This project envisages the building of many dams and reservoirs. This can generate about 34000 MW of electricity if the whole project is executed.
- The project will help in dry weather flow augmentation. That is when there is a dry season, surplus water stored in the reservoirs can be released. This will enable a minimum amount of water flow in the rivers. This will greatly help in the control of pollution, in navigation, forests, fisheries, wildlife protection, etc.
- Indian agriculture is primarily monsoon-dependent. This leads to problems in agricultural output when the monsoons behave unexpectedly. This can be solved when irrigation facilities improve. The project will provide irrigation facilities in water-deficient places.
- The project will also help commercially because of the betterment of the inland waterways transport system. Moreover, the rural areas will have an alternate source of income in the form of fish farming, etc.
- The project will also augment the defence and security of the country through the additional waterline defence.

Challenges in River Interlinking

Despite the many benefits that are associated with the river interlinking project, the project is yet to take off because of the many hurdles it is facing. Some of the challenges in this regard are as follows:

Project feasibility: The project is estimated to cost around Rs.5.6 lakh crores. Additionally, there is also the requirement of huge structures. All this requires a great engineering capacity. So, the cost and manpower requirement is immense.

Environmental impact: The huge project will alter entire ecosystems. The wildlife, flora and fauna of the river systems will suffer because of such displacements and modifications. Many national parks and sanctuaries fall within the river systems. All these considerations will have to

be taken care of while implementing the project. The project can reduce the flow of fresh water into the sea, thus affecting marine aquatic life.

Impact on society: Building dams and reservoirs will cause the displacement of a lot of people. This will cause a lot of agony for a lot of people. They will have to be rehabilitated and adequately compensated.

Controlling floods: Some people express doubts as to the capability of this project to control floods. Although theoretically, it is possible, India's experience has been different. There have been instances where big dams like Hirakud Dam, Damodar Dam, etc. have brought flooding to Odisha, West Bengal, etc.

Inter-state disputes: Many states like Kerala, Sikkim, Andhra Pradesh, etc. have opposed the river interlinking project. Read more on interstate river disputes in India at the linked article.

International disputes: In the Himalayan component of the project, the effect of building dams and interlinking rivers will have an effect on the neighboring countries. This will have to be factored in while implementing the project. Bangladesh has opposed the transfer of water from the Brahmaputra to the Ganga.

Groundwater

Groundwater is the water present below the earth's surface and is a vast resource of water. Almost 22 percent of water is below the surface land in the form of groundwater. Groundwater is important as it is used for water supply in rural and urban areas. It is also often used for municipal, industrial and agricultural use by building and operating extraction wells.

- The groundwater is more convenient and less exposed to pollution. So, it is commonly used as water supplies for the public.
- Groundwater makes up about twenty percent of the freshwater supply of the entire world's water, including oceans and permanent ice.

Aquifer

An aquifer is a body of rock and/or sediment that holds groundwater. Aquifers must be both permeable and porous and include such rock types as sandstone, conglomerate, fractured limestone and unconsolidated sand and gravel. Fractured volcanic rocks such as columnar basalts also make good aquifers.

Groundwater Potential

A Glance Several attempts have been made to assess the ground water resources in the country. The National Commission on Agriculture (1976), assessed the total ground water of the country as 67 m. ha m, excluding soil mixture. The usable ground water resource was assessed as 35 m. ha m of which 26 m. ha m was considered as available for irrigation. The first attempt to estimate the ground water resources on scientific basis was made in 1979 when a High Level Committee, known as Ground Water over Exploitation Committee was constituted by Agriculture Refinance and Development Corporation (ARDC).

Based on the norms for ground water resources computations recommended by this committee, the State Governments and the Central Ground Water Board computed the gross ground water recharge as 46.79 m. ha m and the net recharge (70% of the gross) as 32.49 m. ha m.

Norms recommended by the Ground Water Estimation Committee (1984) are currently utilized by the Central Ground Water Board and the State Ground Water Departments to compute the ground water Resources. Based on the recommendations of this committee, the annual replenishable ground water resources in the country work out to be 45.33 m. ha m.

Keeping a provision of 15% (6.99 m. ha m) for drinking, industrial and other uses, the utilisable ground water resource for irrigation was computed 38.34 m. ha m per year. The ground water resources of the country have been estimated for freshwater based on the guidelines and recommendations of the GEC water resources of 97. T

he total annual replenishable ground the country have been estimated as 431 billion cubic meter (BCM). Keeping 35 BCM for natural discharge, the net annual ground water availability for the entire country is 7

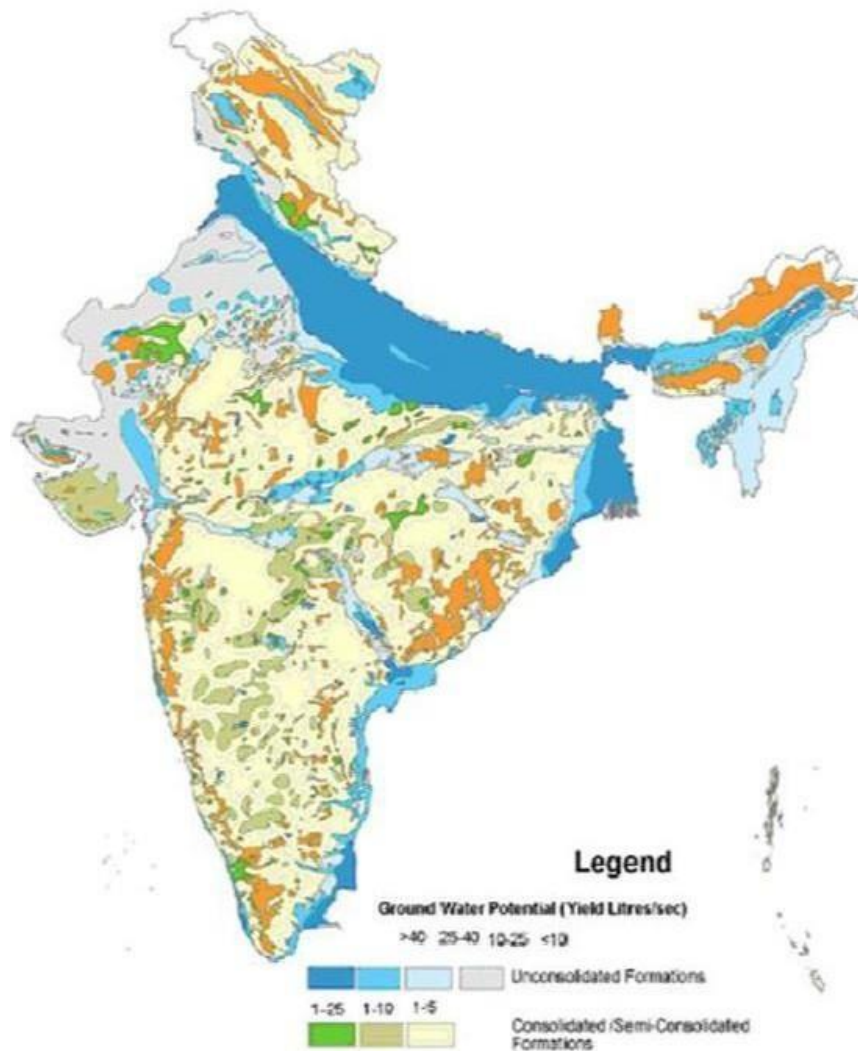


Fig 3.1 hydrogeological Map of India(Source: www.cgwb.in)

Conjunctive use of groundwater

It is harmonious combined use of groundwater and surface water sources in a given irrigation command to maximize economic and Environmental effects of each and also to optimise water demand and supply balance

Table 3.1 Groundwater Potential in India

Sl. No.	States / Union Territories	Annual Replenishable Ground Water Resource					Natural Discharge during non-monsoon season	Net Annual Ground Water Availability	Annual Ground Water Draft			Projected Demand for Domestic and Industrial uses up to	Ground Water Availability for future irrigation	Stage of Ground Water Development (%)
		Monsoon Season		Non-monsoon Season		Total			Irrigation	Domestic and Industrial uses	Total			
		Recharge from rainfall	Recharge from other sources	Recharge from rainfall	Recharge from other sources									
	States													
1	Andhra Pradesh	16.04	8.93	4.20	7.33	36.50	3.55	32.95	13.88	1.02	14.90	2.67	17.65	45
2	Arunachal Pradesh	1.57	0.00009	0.98	0.0002	2.56	0.26	2.30	0.0008	0	0.0008	0.009	2.29	0.04
3	Assam	23.65	1.99	1.05	0.54	27.23	2.34	24.89	4.85	0.59	5.44	0.98	19.06	22
4	Bihar	19.45	3.96	3.42	2.36	29.19	1.77	27.42	9.39	1.37	10.77	2.14	16.01	39
5	Chhattisgarh	12.07	0.43	1.30	1.13	14.93	1.25	13.68	2.31	0.48	2.80	0.70	10.67	20
6	Delhi	0.13	0.06	0.02	0.09	0.30	0.02	0.28	0.20	0.28	0.48	0.57	0.00	170
7	Goa	0.22	0.01	0.01	0.04	0.29	0.02	0.27	0.04	0.03	0.07	0.04	0.19	27
8	Gujarat	10.59	2.08	0.00	3.15	15.81	0.79	15.02	10.49	0.99	11.49	1.48	3.05	76
9	Haryana	3.52	2.15	0.92	2.72	9.31	0.68	8.63	9.10	0.35	9.45	0.60	-1.07	109
10	Himachal Pradesh	0.33	0.01	0.08	0.02	0.43	0.04	0.39	0.09	0.03	0.12	0.04	0.25	30
11	Jammu & Kashmir	0.61	0.77	1.00	0.32	2.70	0.27	2.43	0.10	0.24	0.33	0.42	1.92	14
12	Jharkhand	4.26	0.14	1.00	0.18	5.58	0.33	5.25	0.70	0.38	1.06	0.56	3.99	20
13	Karnataka	8.17	4.01	1.50	2.25	15.93	0.63	15.30	9.75	0.97	10.71	1.41	6.48	70
14	Kerala	3.79	0.01	1.93	1.11	6.84	0.61	6.23	1.82	1.10	2.92	1.40	3.07	47
15	Madhya Pradesh	30.59	0.96	0.05	5.59	37.19	1.86	35.33	16.08	1.04	17.12	1.74	17.51	48
16	Maharashtra	20.15	2.51	1.94	8.36	32.96	1.75	31.21	14.24	0.85	15.09	1.51	15.10	48
17	Manipur	0.20	0.005	0.16	0.01	0.38	0.04	0.34	0.002	0.0005	0.002	0.02	0.31	0.65
18	Meghalaya	0.79	0.03	0.33	0.005	1.15	0.12	1.04	0.00	0.002	0.002	0.10	0.94	0.18
19	Mizoram	0.03	0.00	0.02	0.00	0.04	0.004	0.04	0.00	0.0004	0.0004	0.0008	0.04	0.90
20	Nagaland	0.28	0.00	0.08	0.00	0.36	0.04	0.32	0.00	0.009	0.009	0.03	0.30	3
21	Orissa	12.81	3.56	3.58	3.14	23.09	2.08	21.01	3.01	0.84	3.85	1.22	16.78	18
22	Punjab	5.98	10.91	1.36	5.54	23.78	2.33	21.44	30.34	0.83	31.16	1.00	-9.89	145
23	Rajasthan	8.76	0.62	0.26	1.92	11.56	1.18	10.38	11.60	1.39	12.99	2.72	-3.94	125
24	Sikkim	-	-	-	-	0.08	0.00	0.08	0.00	0.01	0.01	0.02	0.05	16
25	Tamil Nadu	4.91	11.96	4.53	1.67	23.07	2.31	20.76	16.77	0.88	17.65	0.91	3.08	85
26	Tripura	1.10	0.00	0.92	0.17	2.19	0.22	1.97	0.08	0.09	0.17	0.20	1.69	9
27	Uttar Pradesh	38.63	11.95	5.64	20.14	76.35	6.17	70.18	45.36	3.42	48.78	5.30	19.52	70
28	Uttaranchal	1.37	0.27	0.12	0.51	2.27	0.17	2.10	1.34	0.05	1.39	0.06	0.68	66
29	West Bengal	17.87	2.19	5.44	4.86	30.36	2.90	27.46	10.83	0.81	11.65	1.24	15.33	42
	Total States	247.87	69.51	41.84	73.15	432.43	33.73	398.70	212.37	18.05	230.41	29.09	161.06	58
	Union Territories													
1	Andaman & Nicobar	-	-	-	-	0.330	0.005	0.320	0.000	0.010	0.010	0.008	0.303	4
2	Chandigarh	0.016	0.001	0.005	0.001	0.023	0.002	0.020	0.000	0.000	0.000	0.000	0.020	0
3	Dadra & Nagar Haveli	0.059	0.005			0.063	0.003	0.060	0.001	0.008	0.009	0.008	0.051	14
4	Daman & Diu	0.006	0.002	0.000	0.001	0.009	0.0004	0.008	0.007	0.002	0.009	0.003	-0.002	107
5	Lakshadweep	-	-	-	-	0.012	0.009	0.004	0.000	0.002	0.002	-	-	63
6	Pondicherry	0.057	0.067	0.007	0.029	0.160	0.016	0.144	0.121	0.030	0.151	0.031	-0.008	105
	Total Union Territories	0.138	0.075	0.012	0.031	0.597	0.036	0.556	0.129	0.052	0.181	0.050	0.365	33
	Grand Total	248.01	69.59	41.85	73.18	433.02	33.77	399.25	212.50	18.10	230.59	29.14	161.43	58

Groundwater Recharge

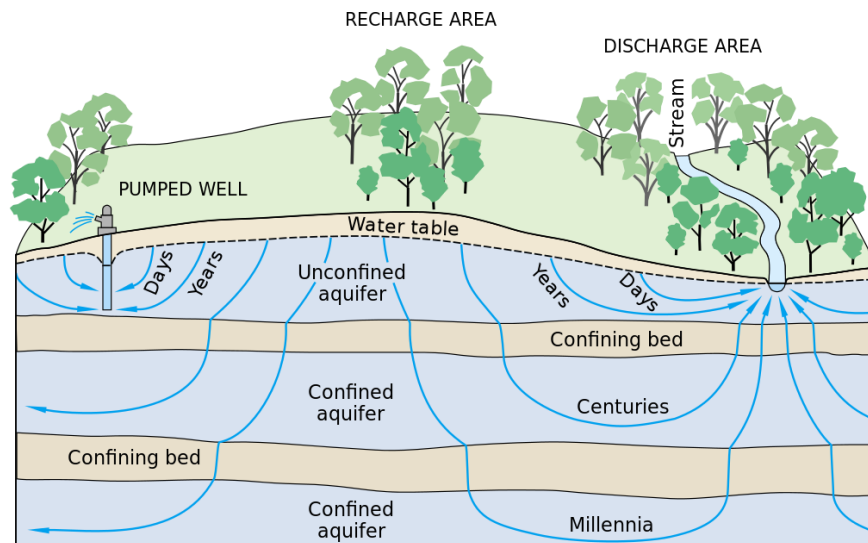
Groundwater recharge is also known as deep percolation or deep drainage. It undergoes the hydrologic process, which moves surface water to groundwater. It is a primary method where water enters an aquifer. The recharge occurs at plant roots and is often known as a flux to the water table surface.

Types of groundwater recharge:

Water Cycle: Naturally, through the water cycle.

Water is recharged naturally by rain and snow melt and to a smaller extent by surface water (rivers and lakes). Recharge may be impeded somewhat by human activities including paving, development, or logging. These activities can result in loss of topsoil resulting in reduced water infiltration, enhanced surface runoff and reduction in recharge. Use of groundwater, especially for irrigation, may also lower the water tables. Groundwater recharge is an important process for sustainable groundwater management, since the volume-rate abstracted from an aquifer in the long term should be less than or equal to the volume-rate that is recharged.

Recharge can help move excess salts that accumulate in the root zone to deeper soil layers, or into the groundwater system. Tree roots increase water saturation into groundwater reducing water runoff. Flooding temporarily increases river bed Permeability by moving clay soils downstream, and this increases aquifer recharge.



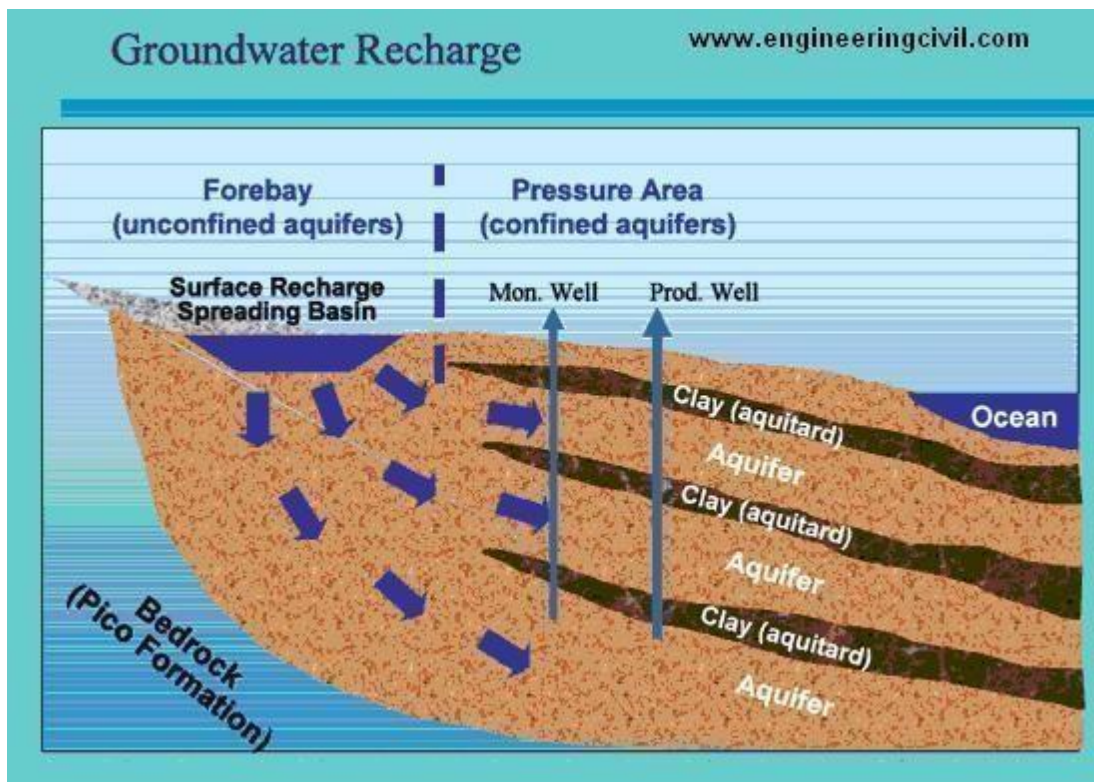
Natural processes of groundwater recharge. Adjustments affecting the water table will drastically enhance or diminish the quality of groundwater recharge in a specific region.

Anthropogenic Processes: Anthropogenic process is also called artificial groundwater recharge, where rainwater and reclaimed water is routed to the subsurface.

Artificial groundwater recharge is becoming increasingly important in India, where over-pumping of groundwater by farmers has led to underground resources becoming depleted. In

2007, on the recommendations of the International Water Management Institute, the Indian government allocated ₹1,800 crore (equivalent to ₹54 billion or US\$680 million in 2023) to fund dug-well recharge projects (a dug-well is a wide, shallow well, often lined with concrete) in 100 districts within seven states where water stored in hard-rock aquifers had been over-exploited. Another environmental issue is the disposal of waste through the water flux such as dairy farms, industrial, and urban runoff.

Pollution in stormwater run-off collects in retention basins. Concentrating degradable contaminants can accelerate biodegradation. However, where and when water tables are high this affects appropriate design of detention ponds, retention ponds and rain gardens.



Contamination of ground water

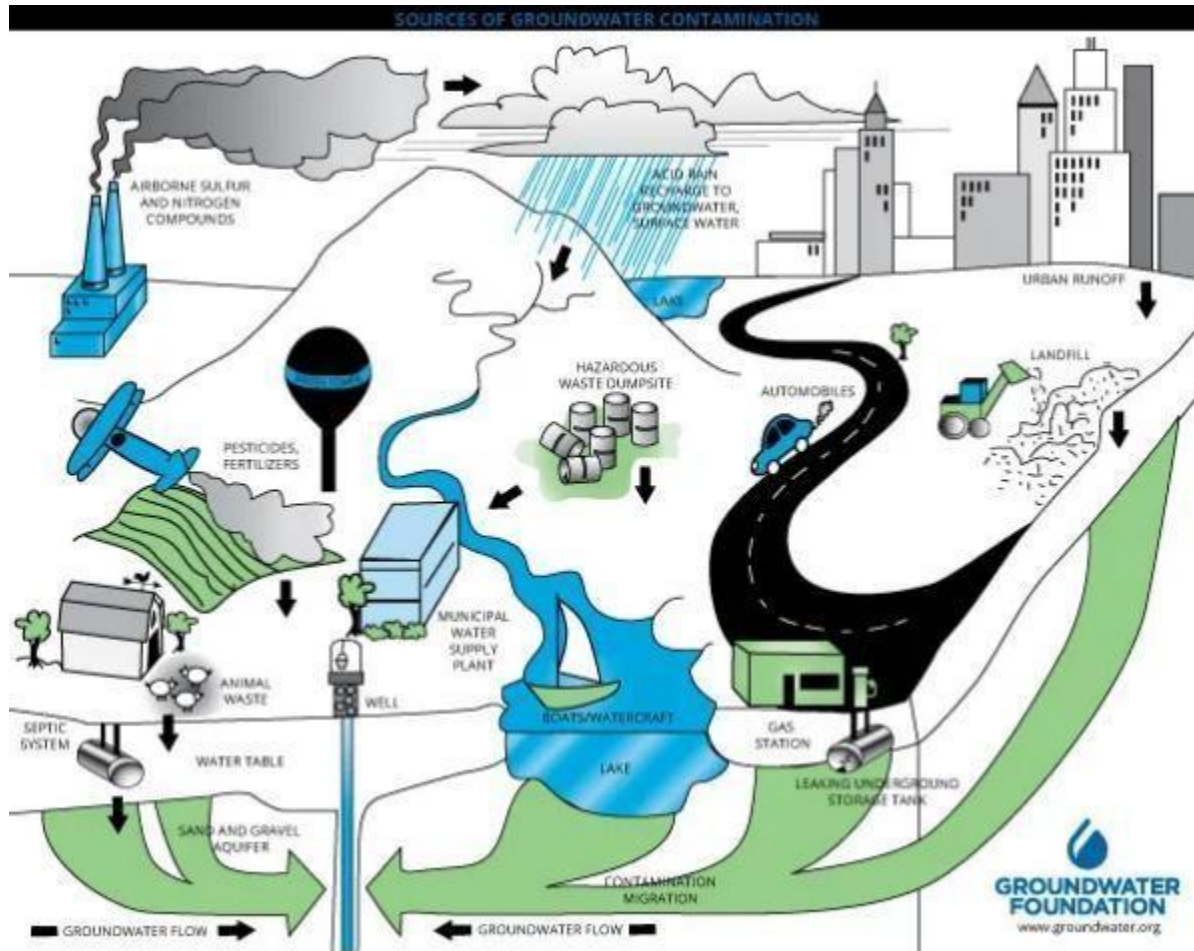
Groundwater contamination occurs when man-made products such as gasoline, oil, road salts and chemicals get into the groundwater and cause it to become unsafe and unfit for human use.

Materials from the land's surface can move through the soil and end up in the groundwater. For example, pesticides and fertilizers can find their way into groundwater supplies over time. Road

salt, toxic substances from mining sites, and used motor oil also may seep into groundwater. In addition, it is possible for untreated waste from septic tanks and toxic chemicals from underground storage tanks and leaky landfills to contaminate groundwater.

Effects of contaminated groundwater

- Drinking contaminated groundwater can have serious health effects. Diseases such as hepatitis and dysentery may be caused by contamination from septic tank waste.
- Poisoning may be caused by toxins that have leached into well water supplies.
- Wildlife can also be harmed by contaminated groundwater. Other long term effects such as certain types of cancer may also result from exposure to polluted water.



Sea water ingress

Seawater intrusion is **the movement of seawater into fresh water aquifers due to natural processes or human activities**. Seawater intrusion is caused by decreases in groundwater levels or by rises in seawater levels.



Saltwater intrusion occurs when saline (salty) water is drawn into a freshwater aquifer. Saltwater intrusion can affect one well, or multiple wells in an aquifer, making the water unpotable (unpleasant to drink). People with hypertension should not drink groundwater with a high salt content. The health of plants and fertility of soil can be negatively impacted if irrigated with saline groundwater. Once saltwater intrusion occurs, the changes in the aquifer may be permanent or may take many years to recover.

What causes saltwater intrusion

- Saltwater intrusion can occur due to either natural processes or human activities. In aquifers adjacent to the coast and on islands like the Gulf Islands, freshwater floats as a lens above the saltwater, forming a wedge that extends inland from the shoreline (see Fig. 1).

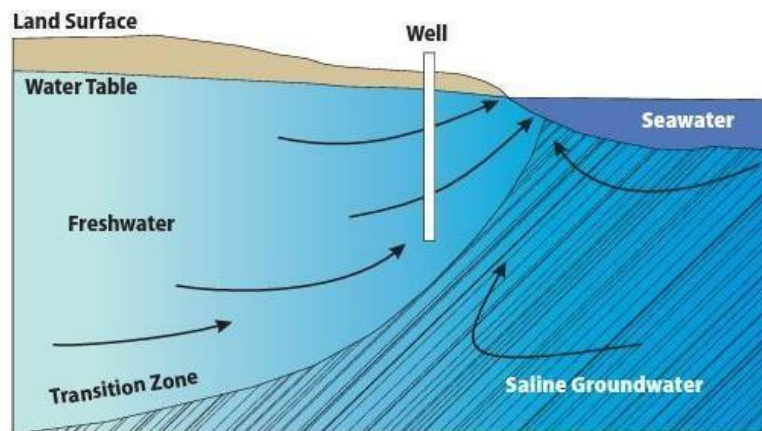


Figure 1: Under non-pumping conditions there is an equilibrium established between fresh and saline groundwater at depth.

- The thickness and depth of the freshwater lens can vary seasonally, or over a longer term due to changes in the amount of precipitation and recharge occurring. Well pumping can also alter the location (depth or distance inland) of the salt water freshwater transition zone (Fig. 2).

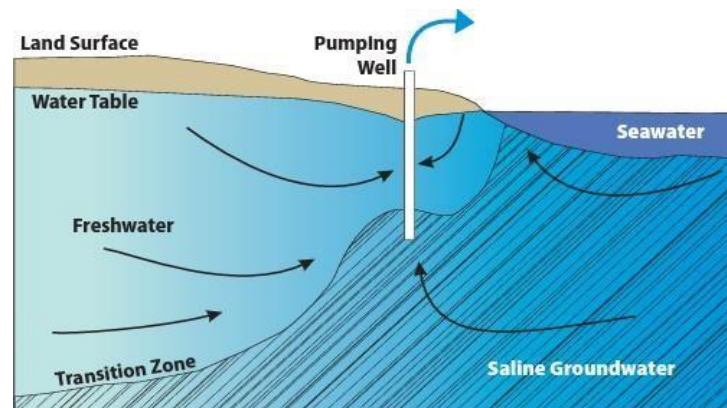


Figure 2: Pumping or other disturbances (e.g. sea level rise, reduced recharge) can lead to upconing or inland movement of the freshwater-saltwater interface. If a single well is over-pumped or multiple wells are pumping, a large area of the aquifer may be impacted by salinity.

- Salinity typically increases gradually at the base of the freshwater lens, but in fractured rock aquifers a single fracture can deliver saltwater to a well (Fig. 3).

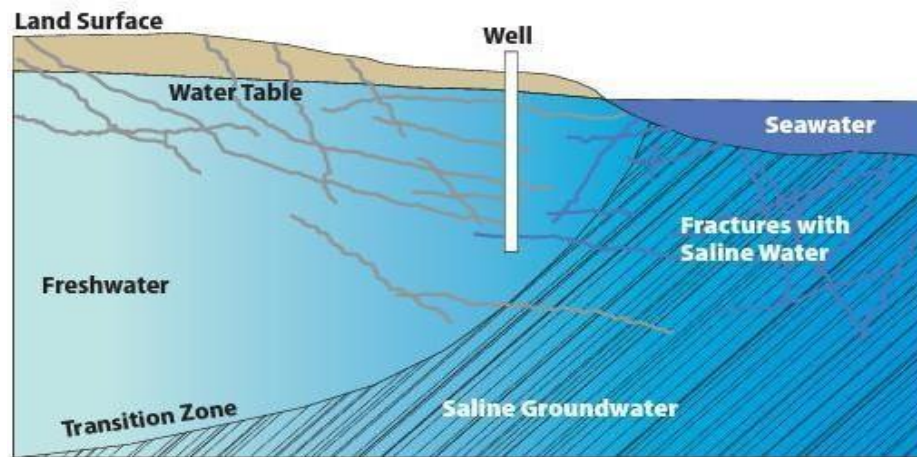


Figure 3: In a fractured bedrock aquifer a single fracture can deliver saltwater to the well.

What are the indicators of saltwater intrusion?

Saltwater intrusion is indicated by elevated concentrations of chloride and higher electrical conductivity of groundwater compared to average conditions in an area. These indicators of salinity are easy to measure, and may vary seasonally, for example, they are likely to be higher during the summer, or may increase over time, related to factors such as pumping. Wells containing groundwater with chloride concentration greater than 150 mg/L, specific conductivity greater than 1000 $\mu\text{S}/\text{cm}$, or total dissolved solids (TDS) >700 mg/L are considered to be affected by saltwater intrusion (see reference 2). For coastal British Columbia these thresholds have been established as operational objectives, meaning, a well should only be pumped if it is capable of producing water of this quality or better.

Problems

What areas are at highest risk?

Areas at highest risk of saltwater intrusion include locations:

- » Close to the coast;
- » Where there is a low to moderate slope;
- » On peninsulas or in areas with a limited source area for groundwater recharge;
- » Where there is a high density of wells;
- » Where there are high rates of pumping from a single well or from multiple wells in a coastal area;
- » Where the static (non-pumping) groundwater level is at or below sea level.

Best management practices in areas at high risk of saltwater intrusion:

Solutions

Best management practices in areas at high risk of saltwater intrusion

Well siting: Avoid drilling in locations immediately adjacent to the coast e.g. within 50 m.

Well depth: Avoid drilling excessively deep within areas proximal to the coast. The depth to the freshwater-saltwater interface varies locally, and drillers often have local knowledge, based on past experience, regarding the depth that they might expect to encounter salty water. There are established formulas for estimating the depth of the transition zone based on static groundwater level e.g. Ghyben-Herzberg, Hubbert (see references 3, 5), although these formulas may be inaccurate for fractured bedrock.

Well alteration: Avoid using technologies such as hydrofracturing in areas <100 m from the coast to reduce risk of opening fractures that are directly connected with the sea.

Know the risks: Be aware of areas that are at risk of saltwater intrusion and educate property owners, site managers or water system operators that their well or locale could be affected

Monitor during drilling: When drilling in coastal areas, drillers should use a hand held meter to measure specific conductivity or salinity to monitor the quality of water encountered during drilling. If there is a significant increase in the measurements during drilling, consider stopping,

and testing the chloride concentration of the groundwater. If a saline zone has been encountered it may be necessary to seal the well below a certain depth to prevent this water from entering shallow freshwater aquifers.

Close wells: Close unusable (e.g. very low yielding) wells or wells that are no longer needed. Abandoned wells, open boreholes, wells with failing surface seals or corroded casings can provide a flow pathway for aquifer cross-contamination and the vertical movement of saline groundwater. Refer to the Water Sustainability Act (reference 6) for the rules regarding well closure.

Get advice: If needed, consult a qualified professional (e.g. hydrogeologist) for help assessing saltwater intrusion risk, interpreting water quality tests, or designing a monitoring program.