Global water Balance

Reservoir	Volume of water (10^6 km^3)	% of total
Ocean	1370	97.25
Ice caps & glaciers	29	2.05
Groundwater	9.5	0.68
Lakes	0.125	0.01
Soil Moisture	0.065	0.005
Atmosphere	0.013	0.001
Streams & rivers	0.0017	0.0001
Biosphere	0.0006	0.00004

BCLE216L	WATER RESOURCE MANAGEMENT	L	T	P	C
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Course Objectives

The objectives of this course is to :

1. Acquire the basic principles of water resources and its planning and management.
2. Enhance the knowledge on recent technologies in assessing the water resources.
3. Identify the challenges facing water management in varied climate types around the world.

CLE3005 - GROUND WATER ENGINEERING

Expected Course Outcome:

Upon completion of this course, the student will be able to :

1) Understand the planning of water resources and need for water resource management.

2) Understand the water resource potential in global, India scenario and explore the water resources using different technologies.

3) Acquire a knowledge international and national water law and its policy.

4) Explain the concept of water in agricultural and economic aspects.

5) Predict the future trends of water demand and its management during crisis.

Module: 1	Water, A Multi-Dimensional Resource	5 hours
Water resources planning-Multi-dimensional management-Water withdrawal and consumption by sector-Stress, international policy-Climate change, oceans, challenges and need for water resource management.		
Module: 2	Global and Indian Scenario for Water Resources	4 hours
Surface Water and Groundwater Global and Indian Scenario-Quality of water resources-Water use and sustainable reuse methods-Usable water resources by continent and country-Water footprint.		
Module: 3	Water Resources Assessment	5 hours
Network design-Stream flow gauging-Weir design-Gauges-Current gauging-Salt dilution-Geophysical exploration-Test drilling-Application of remote sensing techniques.		
Module: 4	Water in Agricultural Systems	7 hours
Water for food production, virtual water trade for achieving global water security, irrigation efficiencies, irrigation methods and current water pricing, water for livestock and processing, water pollution from agricultural production		

Module: 5	Water Economics	8 hours
Economic characteristics of water good and services-Nonmarket monetary valuation methods-Water economic instruments-Policy options for water conservation and sustainable use, pricing, distinction between values and charges- Private sector involvement in water resources management.		
Module: 6	Water Legal and Regulatory Settings	8 hours
National and International Framework for Water Law; Basic structure of water law- An overview of water law in India -Evolution of water law, key features of water law, evolving water law and policy-Water policy for Irrigation, decentralization and participation in irrigation management, and the policy measures proposed to establish water user associations. National level initiatives for regulation of groundwater, State groundwater laws and rainwater harvesting.		
Module: 7	Demand Management	6 hours
Balancing supply and demand-Economic theory of supply and demand-management by use of tariffs-Timing, long- term, operational time-frame-Crisis management-Cost of water-Future trends-Economic value of water-Loss control-Water harvesting.		

Module: 8	Contemporary issues	2 hours
Guest lecture from industry and R & D organisations.		
	Total Lecture Hours	45 hours
Text Book(s)		
1. David Stephenson, Water Resources Management, 2004, A. A. Balkema Publishers, Netherlands.		
Reference Books		
1) Louis Theodore, Ryan Dupont R., Water Resource Management Issues, Basic Principles and Applications, 2020, CRC Press, Taylor & Francis Group, New York. 2) Philippe Cullet and Sujith Koonan, Water Law in India- An Introduction to Legal Instruments, 2017. Second Edition, Oxford University Press, New Delhi. 3) Subramanya. K., Engineering Hydrology, 2020, Fifth Edition, McGraw Hill Education Pvt. Ltd., New Delhi.		

Evaluation Plan

Instrument for Evaluation	Module	Marks (100)	
CAT – I	I, II & III	15	30
CAT – II	III, IV & V	15	
Final Assessment Test	I, II, III, IV, V, VI, & VII	40	
Digital Assignment	I, II, III, IV, V, VI, & VII	30	
	Total	100	

CAT I

Time :1½ Hours Max. Marks : 50

PART – A (5 X 10 = 50 Marks)

Answer any **5** out of **6** questions

Closed Book Examination

CAT II

Time :1½ Hours Max. Marks : 50

PART – A (5 X 10 = 50 Marks)

Answer all 5 questions

Open Book Examination

FAT

Time :3 Hours Max. Marks : 100

PART – A (10 X 10 = 100 Marks)

Answer any ***10*** out of ***11*** Questions

Closed Book Examination

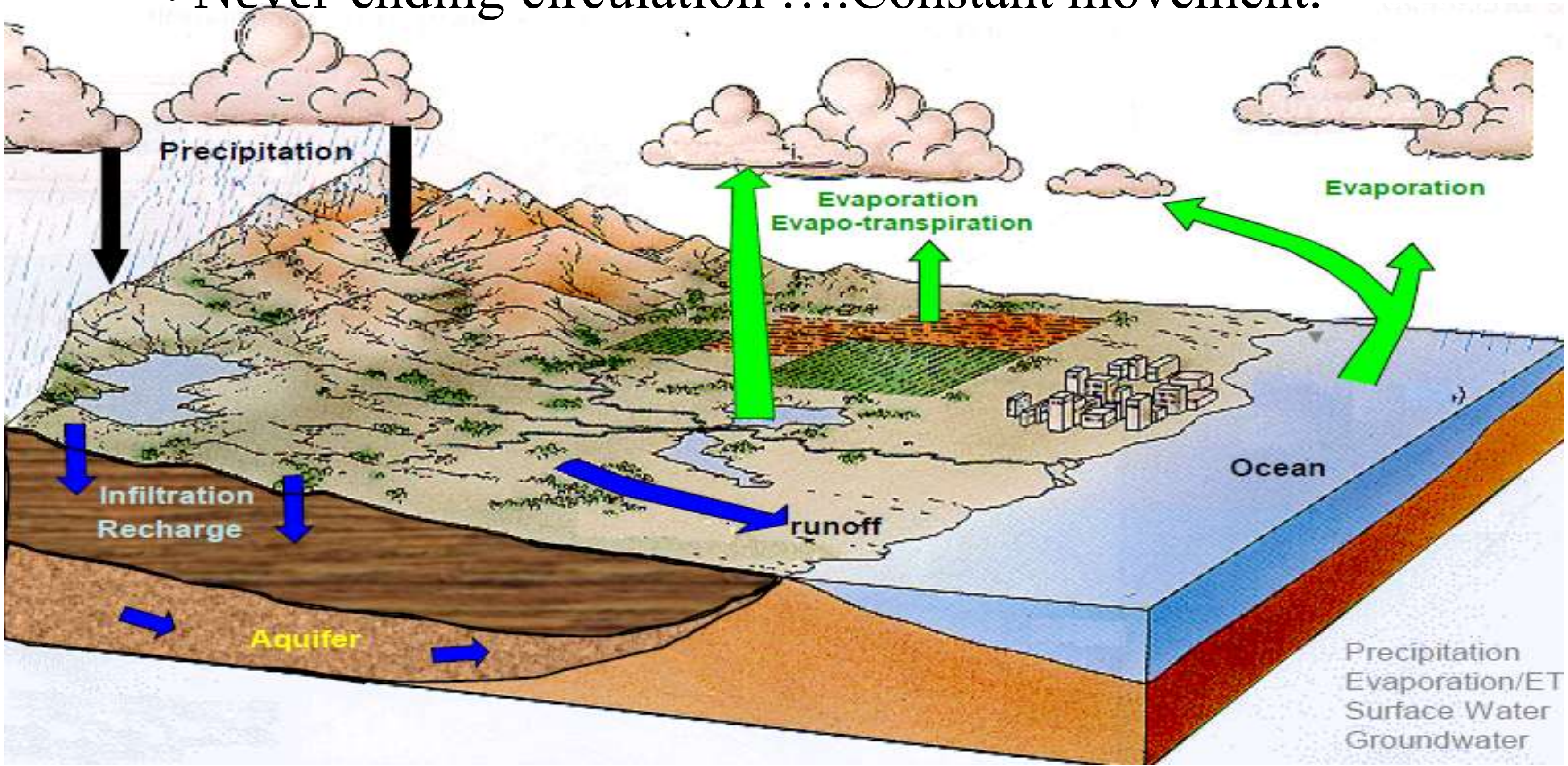
Module: 1	Water, A Multi-Dimensional Resource	5 hours
Water resources planning-Multi-dimensional management-Water withdrawal and consumption by sector-Stress, international policy-Climate change, oceans, challenges and need for water resource management.		

Hydrological cycle

- The hydrologic cycle is a good example of a closed system: the total amount of water is the same, with virtually no water added to or lost from the cycle.
- Water just moves from one storage type to another.
- Distribution and movement of water between the earth and its atmosphere. The model involves the continual circulation of water between the oceans, the atmosphere, vegetation and land. This process is known as Hydrological cycle/Water Cycle.

Hydrological cycle

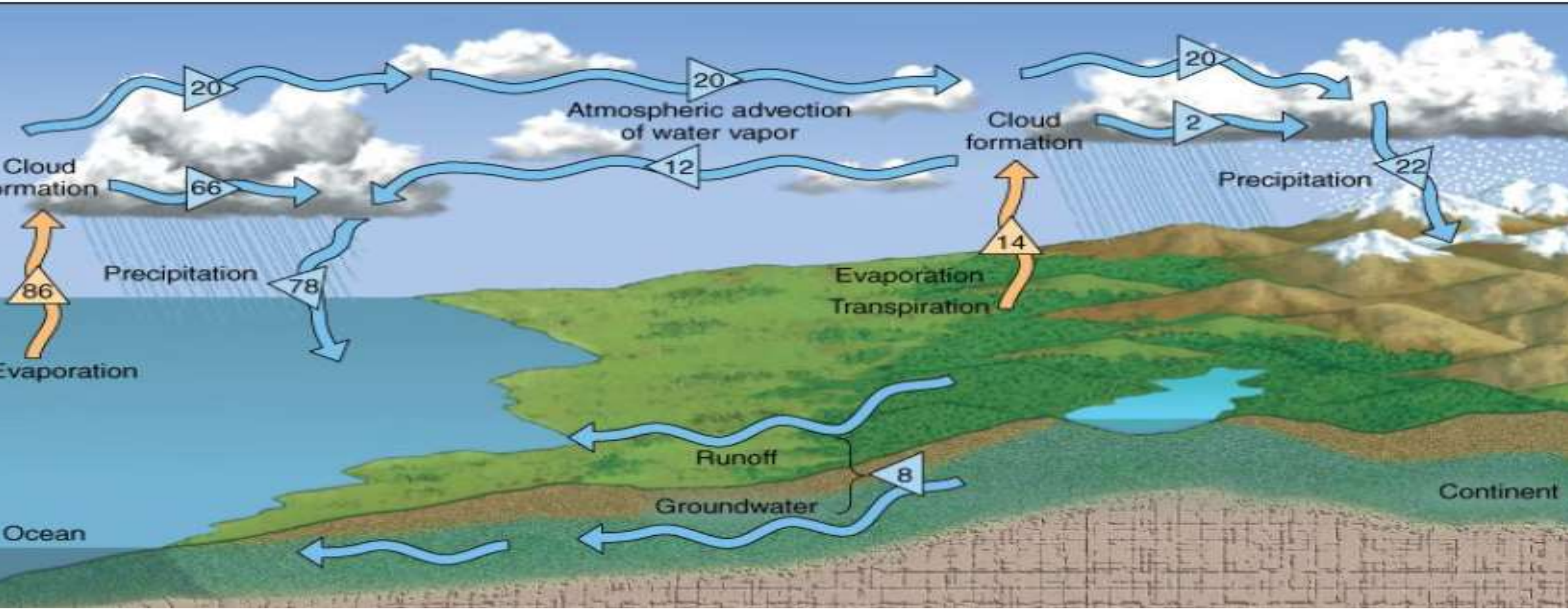
- Never-ending circulation ….Constant movement.



Comp. of Hydrologic Cycle

- Evaporation from water bodies
- Water vapour moves upwards
- Cloud formation
- Condensation
- Precipitate
- Interception
- Transpiration
- Evapo-transpiration
- Infiltration
- Runoff–stream flow
- Deep percolation
- Ground water flow

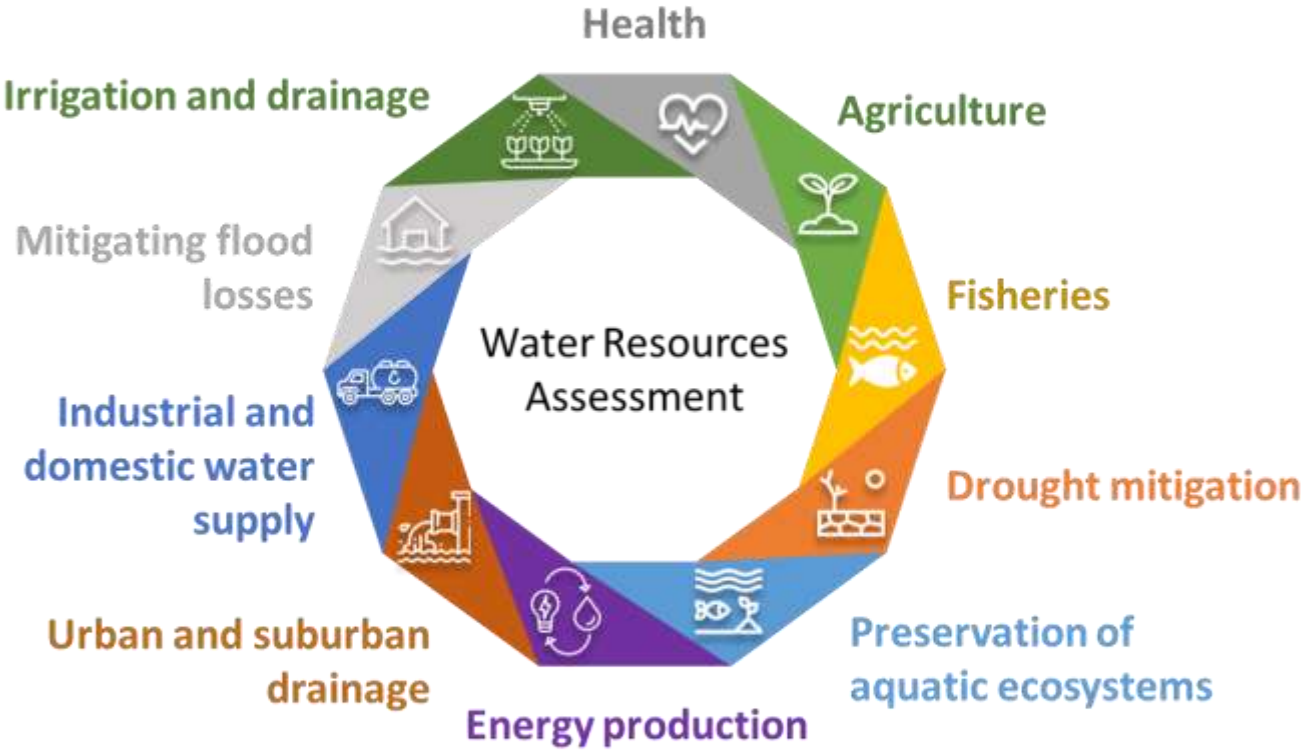
Quantifying the Comp. of Hydrologic Cycle



Quantifying the Comp. of Hydrologic Cycle

- If we assume that mean annual global evaporation equals 100 units, we can trace 86 of them to the ocean. The other 14 units come from the land, including water moving from the soil into plant roots and passing through their leaves.
- Of the ocean's evaporated 86 units, 66 combine with 12 advected (transported) from the land to produce the 78 units of precipitation that fall back into the ocean.
- The remaining 20 units of moisture evaporated from the ocean, plus 2 units of land-derived moisture, produce the 22 units of precipitation that fall over land. Clearly, the bulk of continental precipitation derives from the oceanic portion of the cycle.

Water Resources Planning



Water Resources Planning

Water resources planning is a process that involves the systematic assessment, development, and management of water-related activities to meet the current and future needs of various stakeholders. This planning process aims to ensure the sustainable and efficient use of water resources while considering environmental, economic, social, and technical factors.

Water Resources Planning

Key elements of water resources planning may include:

1) **Demand Assessment:** Evaluate the present and future water demands from various sectors such as agriculture, industry, domestic, and the environment.

2) **Resource Identification:** Identifying available water sources, including surface water bodies, groundwater, and other potential sources.

3) **Infrastructure Development:** Designing and implementing water supply and distribution systems, irrigation networks, and other infrastructure to meet the identified water demands.

4) **Environmental Considerations:** Assessing and mitigating potential environmental impacts of water resource development projects, including measures for conservation and sustainable management.

Water Resources Planning

5) **Stakeholder Involvement:** Involving relevant stakeholders, such as local communities, farmers, government agencies, and NGO, in the planning process to ensure inclusivity and address diverse perspectives.
6) **Multiple Criteria Evaluation:** Considering various criteria, including economic feasibility, social impact, environmental sustainability, and technical feasibility, to make informed decisions.
7) **Risk Assessment:** Identifying potential risks and uncertainties, such as climate change, hydrological extreme, population growth, and water scarcity, and developing strategies to mitigate these risks.
8) **Long-Term Strategy:** Adopting a forward-looking approach to planning that considers the long-term sustainability of water resources and addresses potential challenges.

Water Resources Planning

9) **Integrated Resources Planning**: Coordinating and integrating water planning with other related sectors, such as land use planning, energy planning, and ecosystem management, to achieve a holistic approach.

10) **Legal and Regulatory Compliance**: Adhering to local, regional, and national laws and regulations governing water use and management. This includes obtaining necessary permits and approvals for water-related projects.

Water Resources Planning Approach

Conventional Planning:

This approach primarily aimed at meeting water demands by analyzing supply options and designing systems based on cost efficiency and convenience. It often didn't fully incorporate environmental or social considerations.

Characteristics: It typically involves setting specific objectives within a single dimension (e.g., water quantity for irrigation) without considering broader implications or interconnections with other aspects.

Limitations: Conventional planning can lead to fragmented decision-making, inadequate consideration of environmental impacts, and challenges in addressing complex, interconnected water issues.

Water Resources Planning Approach

Multiple Criteria Planning: Recognizing the limitations of the conventional method, multiple criteria planning considers various factors beyond cost, such as environmental impacts, social equity, sustainability, and community needs. It involves stakeholders in the decision-making process, ensuring a more comprehensive assessment of trade-offs and benefits.

Characteristics: It considers diverse factors, such as economic, social, environmental, and technical aspects, allowing decision-makers to weigh competing interests and identify optimal solutions.

Advantages: Offers a more nuanced and flexible decision-making framework compared to conventional planning by addressing conflicting objectives and incorporating stakeholder preferences.

Water Resources Planning Approach

Integrated Water Resources Planning: This advanced approach involves a holistic and interconnected perspective. It integrates multiple sectors (like agriculture, industry, and environment) and considers the interdependence of water resources, taking into account not just water quantity but also quality, ecosystem health, climate change impacts, and long-term sustainability. It incorporates diverse stakeholder inputs and aims for a balanced, long-term strategy that ensures water security while considering social, economic, and environmental aspects.

Characteristics: It emphasizes the interrelationships between water quantity, quality, ecosystem health, socio-economic factors, and governance, aiming for sustainable water use.

Principles: Principles include stakeholder participation, sustainability, adaptive management, and recognizing the intrinsic linkages between land, water, and other resources.

Water Resources Planning Approach

Multi-dimensional Management: Multi-dimensional water resources planning involves considering a multitude of factors, dimensions, and complexities inherent in managing water effectively and sustainably. It goes beyond a simplistic view of water management and incorporates various facets that influence water resources. These dimensions may include quantitative and qualitative aspects, environmental considerations, social and economic factors, and more.

Characteristics: It offers a flexible approach by accommodating diverse factors influencing water resources management, without necessarily prescribing a specific decision-making framework.

Advantages: Encourages a comprehensive understanding of the complexities of water resources, enabling tailored strategies to address specific challenges while recognizing the multi-faceted nature of water management.

Water Resources Planning Approach

Multi-dimensional water resources planning is a broader concept that encompasses various dimensions without prescribing a specific integration framework. Integrated water resources planning, specifically It is a more structured and holistic approach that explicitly aims to integrate different aspects for sustainable water management. The two concepts can be complementary, and the choice may depend on the specific goals, challenges, and scale of water resources planning initiatives.

Water Withdrawal and Consumption

Water Withdrawal:

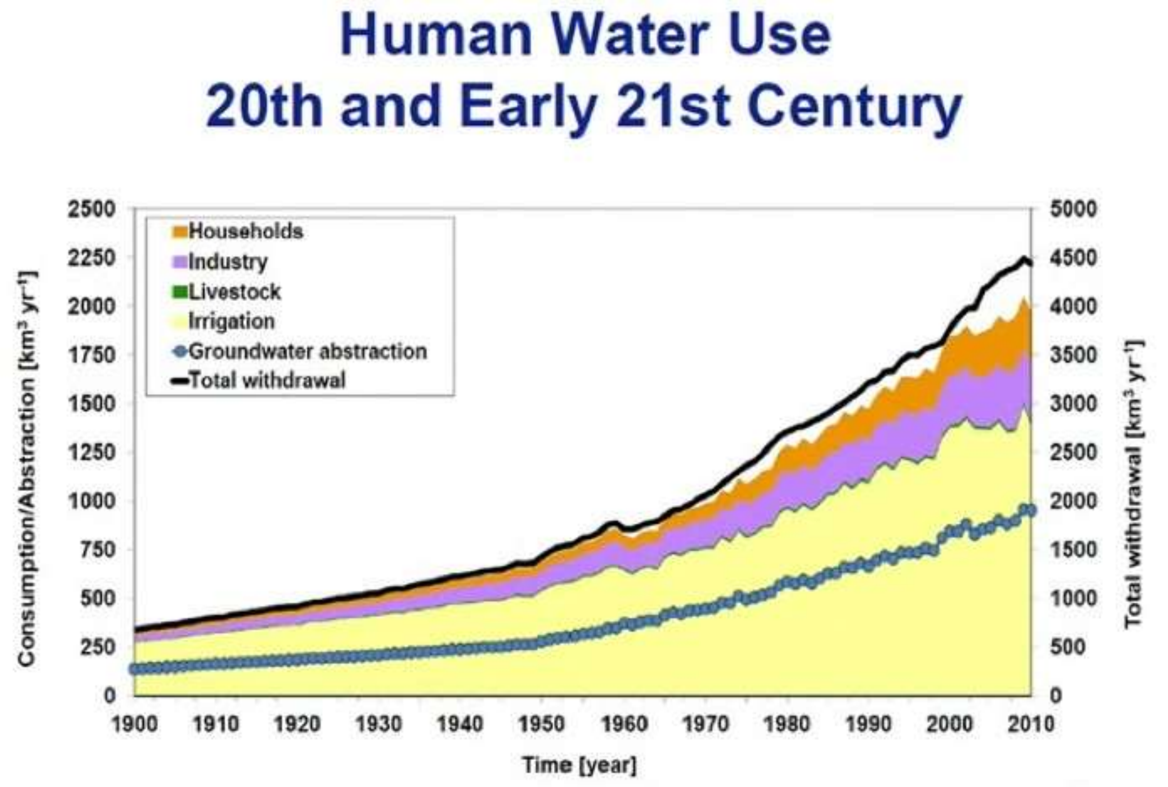
- Water withdrawal refers to the total amount of water taken from a water source, such as rivers, lakes, or aquifers, for various purposes.
- It is typically measured in terms of volume (cubic meters or liters) and can be expressed as the total amount of water abstracted from a source.
- Water withdrawal includes water that is used for agricultural irrigation, industrial processes, municipal water supply, and energy production.
- High levels of water withdrawal can indicate increased pressure on water sources. If withdrawals consistently exceed the sustainable yield of water bodies, it can lead to depletion, reduced river flow, and ecosystem degradation.

Water Withdrawal and Consumption

Water Consumption:

- Water consumption refers to the portion of withdrawn water that is not returned to the original source but is either evaporated, incorporated into products, or otherwise removed from the immediate water cycle.
- Like water withdrawal, water consumption is measured in terms of volume but specifically represents the amount of water that is "used up" and not available for immediate reuse.
- Monitoring water consumption is crucial for assessing the efficiency of water use practices. High consumption without adequate replenishment can lead to water stress and environmental issues.

Water Withdrawal and Consumption



Global trend published in Wada et al (2016)

Water Withdrawal and Consumption

- The ratio between effective water Consumption and actual water withdrawal is known as **Water Use Efficiency (WUE)**
- Agriculture sector withdraws about 80% of all withdrawal
  - India has low water use efficiency compared to the developed countries.
  - The overall irrigation project efficiency in developed countries is 50 – 60% as compared to only 38% in India.
- 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.
- In the domestic water sector the loss of water on account of leakages in mains, communication and service pipes and valves is approximately 30 to 40% of the total flow in the distribution system.
- The present utilization of water can be estimated as about 750 BCM whereas for the year 2050 it is estimated to be 1180 BCM

Water withdrawal and consumption by sector

Agriculture:

Water Withdrawal: Agriculture is the largest consumer of water in India, accounting for the majority of water withdrawals. Surface water and groundwater are both used for irrigation purposes.

Water Consumption: The water consumption in agriculture is significant, as a substantial portion of the withdrawn water is absorbed by crops. However, not all of it is consumed, and a portion may return to the source through runoff or percolation.

Industry:

Water Withdrawal: Industries in India withdraw water for various processes, including manufacturing, power generation, and cooling.

Water Consumption: The water consumed by industries depends on the nature of the processes. Some industries use water in a way that results in high consumption due to evaporation or incorporation into products.

Water withdrawal and consumption by sector

Municipal or Domestic Use:

Water Withdrawal: Municipalities withdraw water from rivers, lakes, or groundwater sources to meet the water needs of households, commercial establishments, and public facilities.

Water Consumption: Domestic water consumption includes water used for drinking, sanitation, and other household activities. Some water is returned to the source through wastewater treatment.

Energy Production:

Water Withdrawal: The energy sector in India withdraws water for cooling in thermal power plants and for other processes in various types of power generation.

Water Consumption: The water consumed in energy production is often associated with evaporative cooling in power plants. Renewable energy sources like hydropower may involve water consumption during electricity generation.

Water withdrawal and consumption by sector

Ecosystems:

Water Withdrawal: Natural ecosystems in India also play a role in water withdrawal, with water extracted for maintaining ecological balance, wetlands, and other natural processes.

Water Consumption: Ecosystems typically return water to the hydrological cycle through transpiration and other natural processes, minimizing water consumption compared to anthropogenic sectors.

Water Stress Assessment:

- Water stress is often assessed by comparing the ratio of water withdrawal to the availability of renewable water resources. It helps identify regions where demand is significantly high compared to the available supply.
- By considering both withdrawal and consumption, authorities can understand the usage patterns in different sectors and assess which sectors contribute more to stress.
- Properly evaluating both withdrawal and consumption allows for a more balanced approach to managing water stress. It facilitates the identification of sectors or regions where consumption rates are high compared to availability.
- This understanding informs policy-making and management strategies to encourage more efficient use, reduce waste, and ensure sustainable water use practices.

International policy

The **Dublin Principles** emerged from the International Conference on Water and the Environment held in Dublin, Ireland, in 1992. This conference aimed to address water scarcity, water quality, and sustainable development. The principles that came out of this conference serve as a framework for integrated water resources management and were later endorsed by the United Nations.

International policy

Dublin Principles

1) Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment
2) Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels
3) Women play a central part in the provision, management and safeguarding of water
4) Water has an economic value in all its competing uses and should be recognized as an economic good

International policy

The World Bank (2002) set out its policy on Water Resources Management based on the "Dublin Principles”:

The ***Ecological Principle*** states that independent management of water by different sectors is not appropriate, and the river basin should become the unit of analysis. Land and water need to be managed together and much greater attention needs to be paid to the environment.

The ***Institutional Principle*** indicates that water resources management is best accomplished when all stakeholders participate. This means state, private sector and society, including women. Actions should be taken at the lowest appropriate level to ensure sustainability.

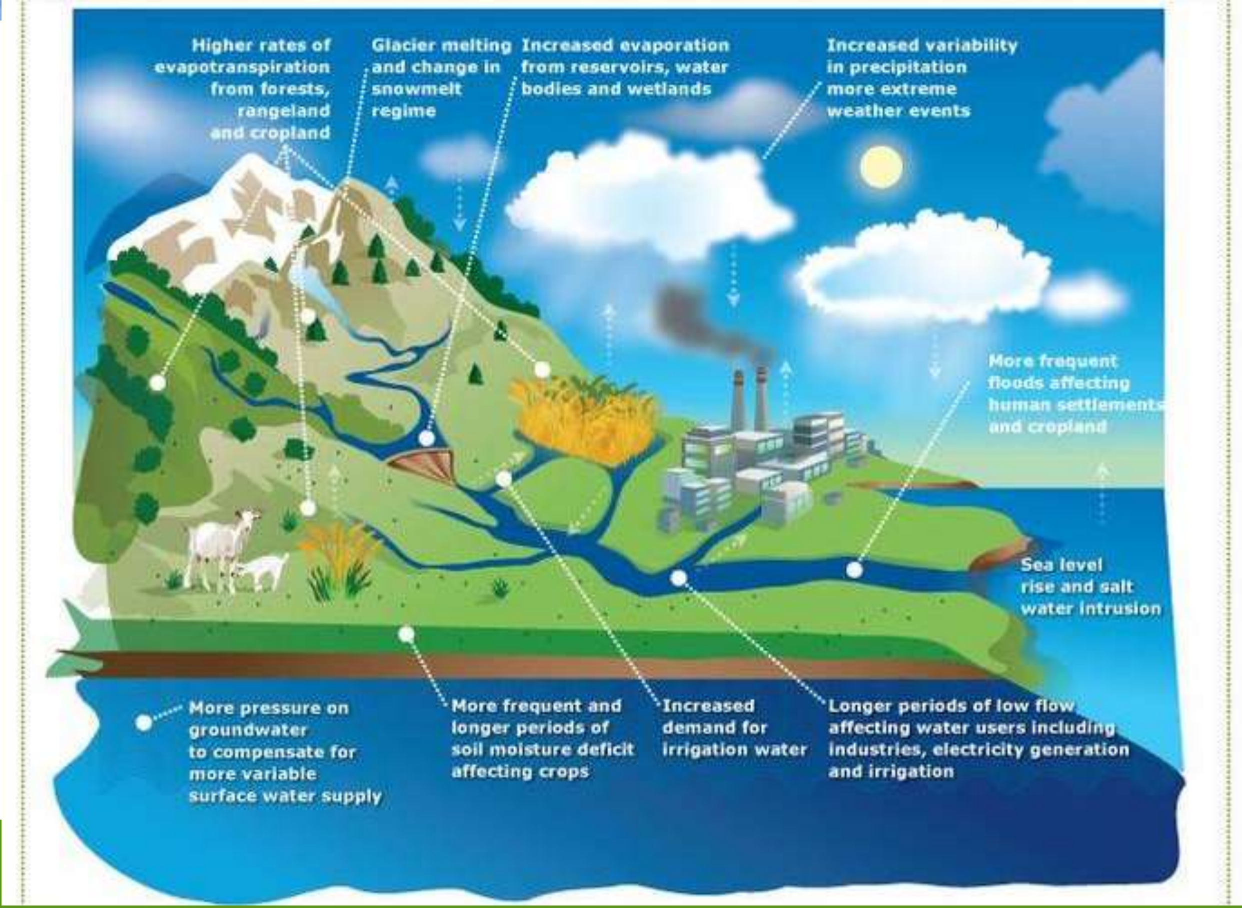
The ***Instrument Principal*** indicates that water is a scarce resource and greater use needs to be made of incentives and economic principles in improving allocation and enhancing quality.

Climate Change

Global Warming is the phenomenon of heating of the planet’s climate system.

Climate Change refers to the long-term changes in the average weather conditions/climate.

Climate Change



Oceans

- Holds about 97.2 % of the Earth's water
- Covers more than 70 % of the Earth's surface
- Contribute around 80% to 90% of the moisture in the Earth's atmosphere
- Ocean temperatures have a significant impact on precipitation and storm patterns (including cyclone formation)
- The warming of oceans and the melting of polar ice contribute to sea level rise
- Increased pumping of groundwater can cause saltwater intrusion, where saltwater flows into these freshwater aquifers
- Sea level rise also contributes to saltwater intrusion
- Desalination plants are used to address freshwater shortages through reverse osmosis, but this can be hindered by biofouling, which is increased by ocean warming

Oceans

- Facilitate the transport of water vapor over long distances.
- Interacts with the atmosphere in two main ways—physically through heat and water exchange.
- Majority of the Earth's heat is absorbed by the ocean along the equator, where incoming solar radiation is approximately twice as intense as that received at the poles.

Need for water resources management

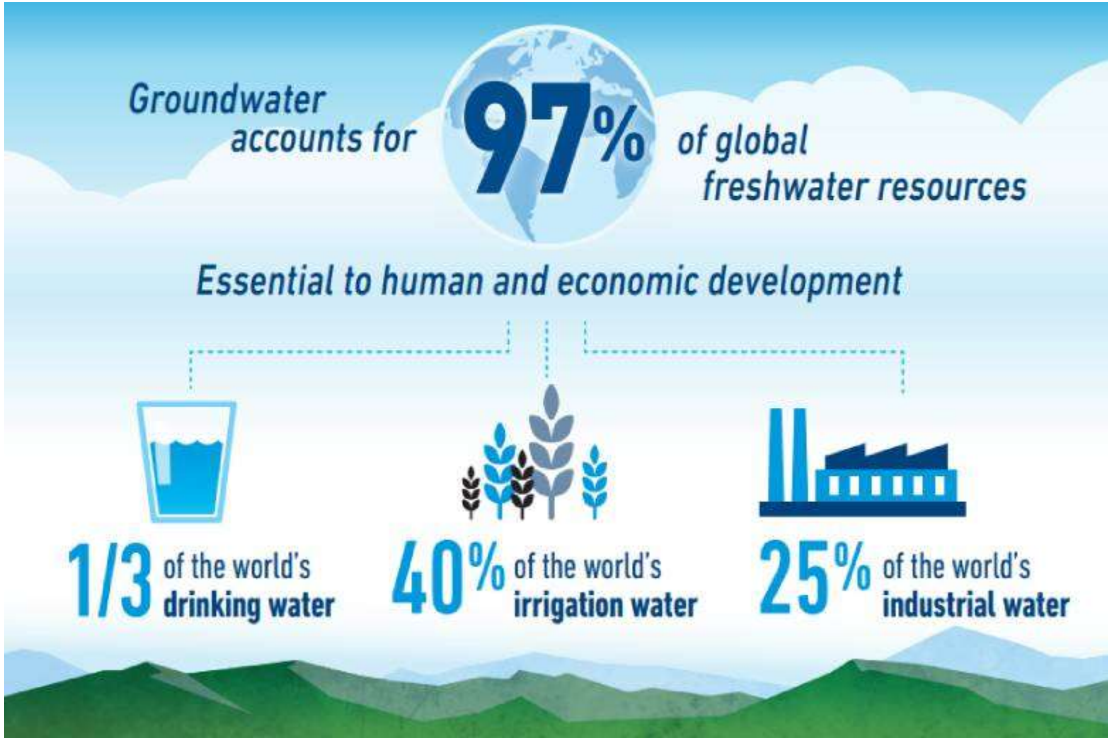
Module: 2	Global and Indian Scenario for Water Resources	

Surface Water and Groundwater Global and Indian Scenario-Quality of water resources-Water use and sustainable reuse methods-Usable water resources by continent and country-Water footprint.

Importance of groundwater protection

The FAO describes groundwater as "**the invisible ingredient in food**", and the US Geological Survey says it is "**one of the world's most important natural resources**".

The World Bank says Groundwater is **absolutely essential to life on Earth.**



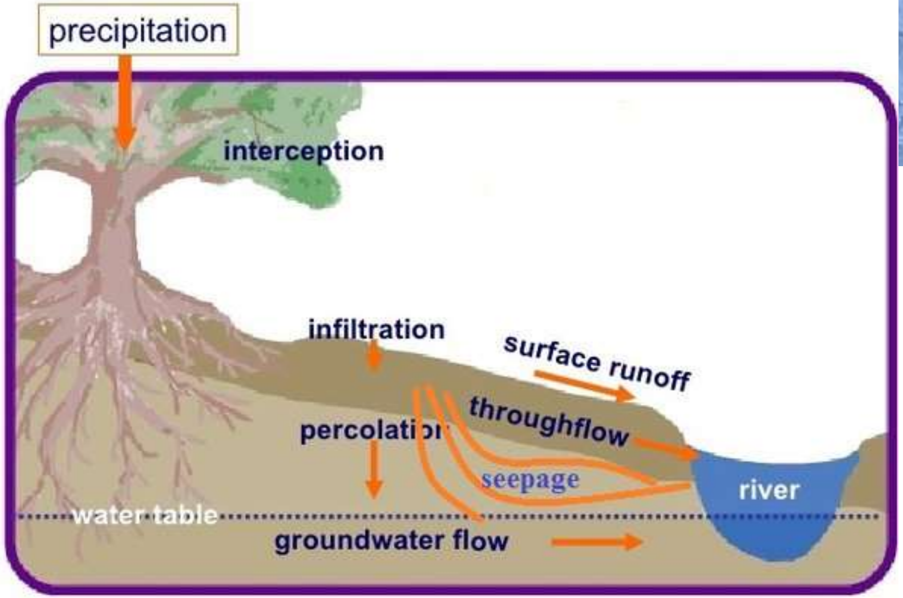
Importance of groundwater protection

- Groundwater, which accounts for 97 percent of global freshwater resources, is essential to human and economic development, but its contamination is more extensive and harmful than previously thought.
- Groundwater quality management is almost universally neglected until the human and economic costs become too obvious to ignore, even though the challenge and cost of cleaning up polluted groundwater, or treating it in perpetuity, is far greater than protecting it in the first place.

Surface Water and Groundwater Interaction

Groundwater and surface water interactions represent an important series of issues in water resources management. The exchange of water between these two different states is an important phenomenon that arises from

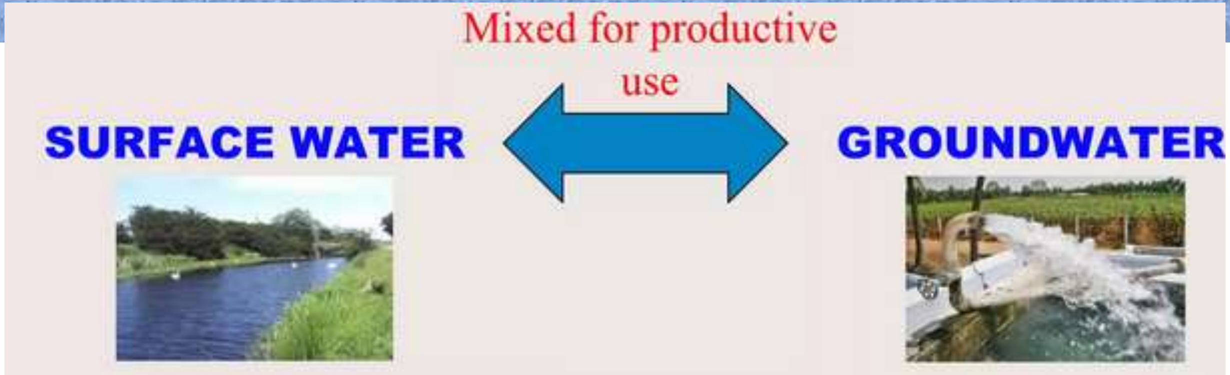
- Infiltration,
- Spring outcrop
- River-Aquifer Interaction : Recharge & discharge,
- Thermal flow,
- Influence on water quality
- Influence on water quantity and
- Seawater intrusion



Top 5 hot spring destinations of India

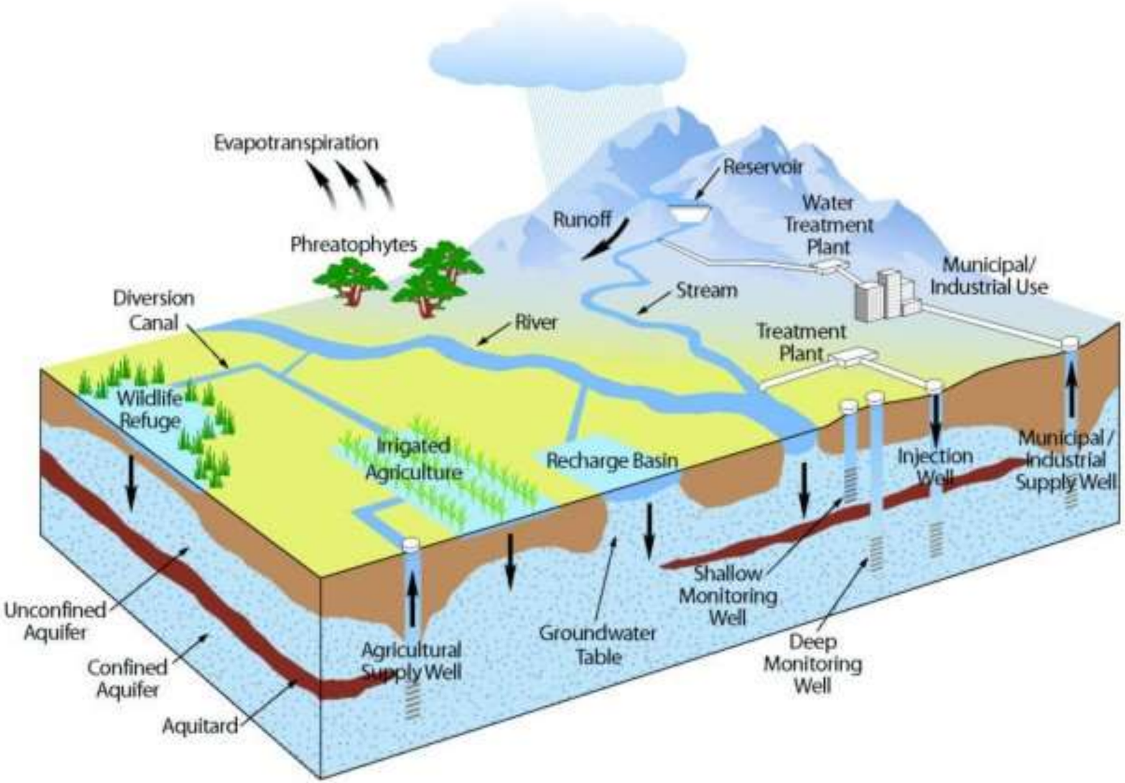
1. Bakreshwar hot spring (Bengal)
2. Gaurikund (Uttarakhand)
3. Deulajhari (Odisha)
4. Manikaran, (Himachal Pradesh)
5. Panamik, (Ladakh)

Surface Water and Groundwater Interaction



Conjunctive use of surface water and groundwater refers to the integrated management and coordinated use of both surface water and groundwater resources to optimize water availability and sustainability. This approach recognizes that these two sources of water are interconnected and that their management should be considered together to achieve more efficient and effective water resource utilization.

Hydrological cycle



Surface Water and Groundwater Global Scenario

Reservoir	Volume of water (10^6 km^3)	% of total
Ocean	1370	97.25
Ice caps & glaciers	29	2.05
Groundwater	**9.5**	**0.68**
Lakes	0.125	0.01
Soil Moisture	0.065	0.005
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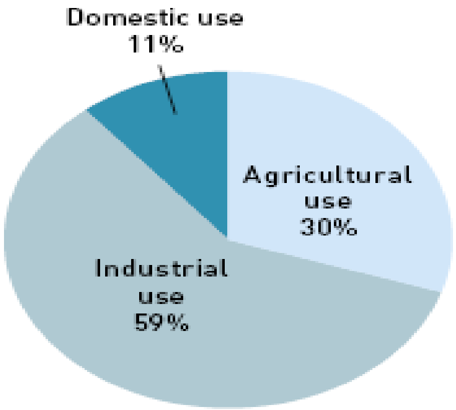
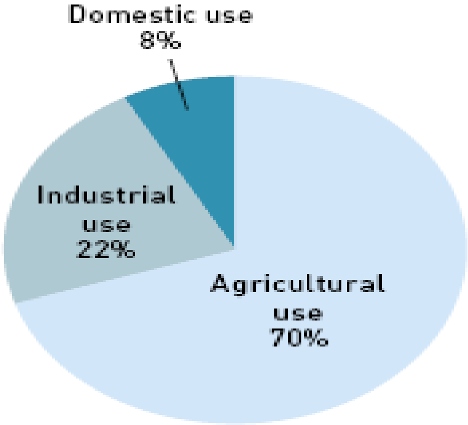
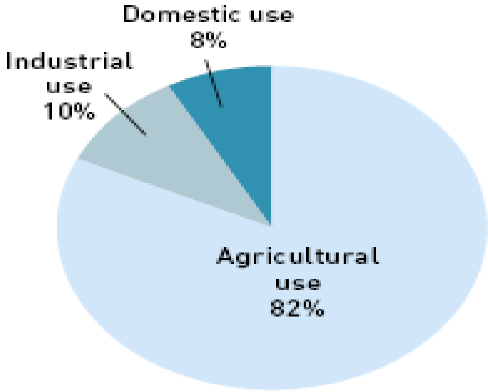
Surface Water and Groundwater Global Scenario



Competing water uses
(high-income countries)



Competing water uses
(world)



Competing water uses
(low- and middle-income
countries)

Surface Water and Groundwater Global Scenario

- According to UN-Water 2.3 billion people live in water-stressed countries
- According to UNICEF, 1.42 billion people – including 450 million children – live in areas of high or extremely high water vulnerability
- 785 million people lack access to basic water services
- The WHO reports that 884 million people lack access to safe drinking water
- Two-thirds of the world's population experience severe water scarcity during at least one month of the year
- The Global Water Institute estimates that 700 million people could be displaced by intense water scarcity by 2030
- 3.2 billion people live in agricultural areas with high water shortages or scarcity
- Approximately 73% of people affected by water shortages live in Asia
- The global water crisis is a women's issue: In what UNICEF calls "a colossal waste of time," women and girls spend an estimated 200 million hours hauling water every day
- Diarrhea kills 2,195 children every day—more than AIDS, malaria, and measles combined—and can be caused by lack of access to clean water and sanitation services

Surface Water and Groundwater Global Scenario

Causes of the Global Water Crisis

- Overuse,
- Urbanization
- Population growth
- Water pollution,
- Lack of infrastructure, and
- Changing weather patterns due to climate change

Surface Water and Groundwater Indian Scenario

Water Stress Ranking: India is identified by the World Bank as one of the most water-stressed countries globally, with only one-third of the water availability compared to the 1950s.

Percapita Water Availability: India's per capita water availability is lower than the global average. According to some estimates, the world average is around 7,600 cubic meters per person per year, while India's per capita availability is approximately 1,500 cubic meters

Projected Water Demand: Niti Aayog in their report has declared the current water scarcity as ‘the worst water crisis’ in Indian history where about 60 crore people are facing high to extreme water stress. By 2030, the country’s water demand is projected to be twice the available supply. This may have serious implications in terms of food security, farmer’s livelihoods and nation’s economic development

Surface Water and Groundwater Indian Scenario

Groundwater Exploitation: Over the past few decades, India has become the second-largest global user of groundwater, extracting 25% of the world's total water.

Wastewater Management Deficiency: India faces challenges in wastewater management, with 80% of global wastewater being released into waterways without adequate treatment.

Population Pressure: India's large and growing population contributes to the challenge of maintaining adequate per capita water availability. The increasing demand for water resources for agriculture, industry, and domestic use exacerbates the situation.

Surface Water and Groundwater Indian Scenario

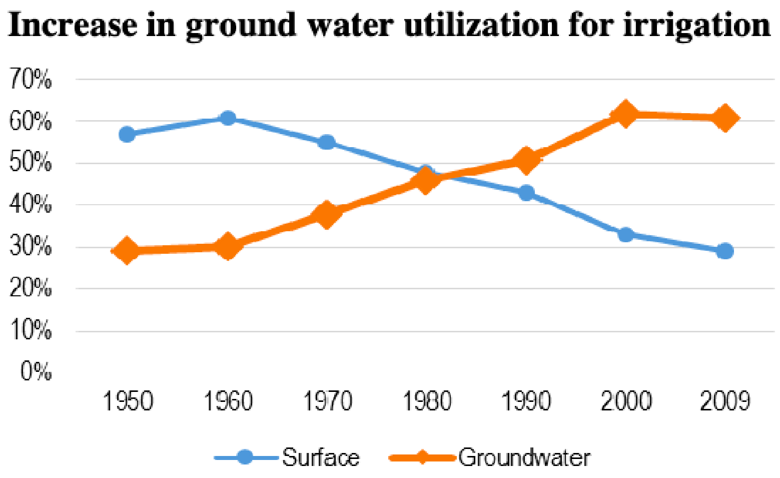
Seasonal Variability: India's water availability is also subject to seasonal variations, with the monsoon playing a crucial role in replenishing water sources. Uneven distribution of rainfall across different regions can contribute to water scarcity during certain times of the year.

Agricultural Water Use: Agriculture accounts for a significant portion of India's annual water use, utilizing nearly 80% of the country's available water, which amounts to 700 billion cubic meters. India has implemented various irrigation schemes and programs to enhance agricultural productivity, improve water use efficiency, and mitigate the impact of water scarcity.

Irrigated Area Increase: In the year 2022-23, out of the total gross sown area of 141 million hectares in India, nearly 73 million hectares, or 52%, had access to irrigation. This marks an increase from 41% in 2016.

Surface Water and Groundwater Indian Scenario

The **increased dependency on groundwater** for irrigation is a significant concern in various regions, including India.



Sources: Agricultural Statistics at Glance 2014, Ministry of Agriculture; PRS.

Surface Water and Groundwater Indian Scenario

Causes: Water Stress

- Households and agriculture both require a lot of water as the population grows.
- India's large agricultural sector consumes the majority of the country's water, leaving less for industry and homes.
- Limited land availability
- **Rapid urbanization:** The high water demand of India's densely populated cities is putting a strain on groundwater and surface water resources.
- **Climate change**: will have a huge impact on Himalayan water resources as well as monsoonal rainfall.
- **Rising temperatures:** will boost evaporation and precipitation, while rainfall will vary more dramatically across the country.
- **Droughts and floods:** may become more common in different places at different periods, and mountainous areas can expect major variations in snowfall and snowmelt.

Surface Water and Groundwater Indian Scenario

Causes: Water Stress

- **Aquifer depletion:** As the world's population grows, many of the world's major aquifers are becoming exhausted. owing to direct human consumption as well as groundwater irrigation for agriculture.
- **Pollution and water protection:** Many pollutants endanger water supplies, but the discharge of raw urban sewage, untreated industrial waste, and agricultural runoff containing pesticides, insecticides, and fertilizers into natural waters is the most common, especially in developing nations.

Surface Water and Groundwater Indian Scenario

Mitigation measures : Water Stress

An integrated approach on water resource management is the need of the day to ensure our future water demands.

Rainwater Harvesting: Securing rainwater either through groundwater recharge or through storage is the most immediate action. Massive campaign on rainwater harvesting is the need in our country.

Improving Irrigation Systems: A shift towards adoption of more water efficient smart irrigation systems such as drip irrigation to manage the water demands is the need of the day.

Managing Floods and Droughts: Knowing about the quantity, geography and flood periods in India, it is necessary to manage the water resources. Better flood management practices may result in scaling up our capacities in terms of water resources.

Surface Water and Groundwater Indian Scenario

Mitigation measures : Water Stress

Recycling and Reusing Wastewater: Wastewater recycling to meet the standard guideline values for effluent discharge is a must to follow. Adoption of new technologies for improving the quality of treated wastewaters is ultimately going to enhance the capacity of recycled water availability for usage.

Awareness and Education: There is a need for increased awareness among farmers about the importance of sustainable groundwater management, water conservation, and adopting water-efficient agricultural practices.

Enforcement and Solutions: To address these issues, there is a need for strict enforcement of the 'Polluter Pays Principle,' with high fines incentivizing industries to invest in wastewater treatment plants rather than paying penalties.

Surface Water and Groundwater Global Scenario

Mitigation measures : Government Initiatives

Jal Jeevan Mission:

The Jal Jeevan Mission aims to provide safe and sustainable drinking water to all rural households in India.

National Water Mission:

Part of the National Action Plan on Climate Change, this mission focuses on water conservation, improving water use efficiency, and sustainable management of water resources.

River Interlinking Projects:

India has considered river interlinking projects to transfer water from water-surplus regions to water-deficit regions, although these projects have been met with various challenges and debates.

Groundwater Management Policies:

States in India are implementing policies to regulate and manage groundwater use, emphasizing sustainable practices.

Quality of Water Resources

- India's surface water resources are polluted to the tune of 70%.
- Wastewater from various sources, intensive agriculture, industrial output, infrastructural development, and untreated urban runoff are all major contributors to water contamination.
- According to the **WHO**, water is responsible for half of India's sickness.
- In India, **54 percent** of rural women had to walk between 200 meters and 5 kilometers every day to get drinking water in 2012.
- Industrial and domestic wastewater discharges were treated that could be recycled and this would reduce demands from fresh water sources by 75%.
- Many situations a relatively small discharge of polluted water can contaminate huge volumes of fresh water so the pollution problem multiplies. On the other hand nature has a capacity to purify water to a limited extent and we should head the limits to enable this facility to be used to its optimum

Quality of Water Resources

Pollutants in water can be **classified** as:

- **Suspended solids** – floating debris, settleable sediment or buoyant, e.g. algae.
- **Dissolved chemicals** – many cations, anions, with different effects, e.g. on health, equipment or toxicity.
- A quality unrelated necessarily to dissolved or suspended solids, e.g. temperature, acidity, colour, odour or taste. The latter are often associated with matter in the water, however.
- Bacteria, pathogens, viruses, organic micropollutants

Quality of Water Resources

Pollution can be from many **sources**:

- Natural, e.g. geochemical, erosion, decay
- Atmospheric, e.g. ionization, windborne, smoke, fumes
- Agricultural, e.g. fertilizers, weed killers, decaying crops, animals, increased erosion
- Industrial and mining, e.g. wastes (solid and liquid), spoil, storage
- Human and domestic e.g. sewage, wastes, litter
- Urban, e.g. vehicles, energy generation, wastes, partly or untreated.

Quality of Water Resources : Impacts on Public Health

Water quality has direct impacts on public health. It can pose a variety of risks to individuals, communities, and entire populations. Here are some key ways in which water pollution affects public health:

Waterborne Diseases:
Contaminated water is a breeding ground for pathogenic microorganisms such as bacteria, viruses, and parasites. Consumption of water contaminated with pathogens can lead to waterborne diseases, including cholera, typhoid, dysentery, and gastroenteritis.

Gastrointestinal Infections:
Ingesting water contaminated with fecal matter or pathogenic microorganisms can cause gastrointestinal infections, leading to symptoms like diarrhea, vomiting, abdominal cramps, and dehydration.

Quality of Water Resources : Impacts on Public Health

Chemical Contaminants:

Water pollution may introduce various chemical pollutants, including heavy metals, pesticides, and industrial chemicals, into water sources. Exposure to these contaminants can have long-term health effects, such as organ damage, developmental issues, and an increased risk of chronic diseases.

Toxic Algal Blooms:

Water bodies contaminated with excessive nutrients (eutrophication) can experience toxic algal blooms. Some algae produce harmful toxins, leading to water contamination that, when consumed, can cause neurological and gastrointestinal problems.

Heavy Metal Poisoning:

Contaminants like lead, mercury, and arsenic, if present in water, can result in heavy metal poisoning. These substances can negatively impact the nervous system, kidneys, and other organs.

Quality of Water Resources : Impacts on Public Health

Antibiotic Resistance:

The presence of pharmaceutical residues and antibiotics in water can contribute to the development of antibiotic-resistant bacteria, posing a serious threat to public health by reducing the effectiveness of medical treatments.

Vector-Borne Diseases:

Stagnant or polluted water bodies can serve as breeding grounds for disease vectors, such as mosquitoes. This can contribute to the spread of vector-borne diseases like malaria and dengue.

Impact on Vulnerable Populations:

Vulnerable populations, including children, the elderly, and individuals with compromised immune systems, are often more susceptible to the health impacts of water pollution. Contaminated water can exacerbate existing health disparities.

Quality of Water Resources : Water Quality Standards

- Water quality standards are guidelines or criteria set by regulatory authorities to define the acceptable levels of various physical, chemical, and biological parameters in water.
- These standards are established to protect public health, aquatic ecosystems, and ensure the safe use of water for various purposes.
- Different countries may have their own sets of water quality standards, and these standards can vary based on the intended use of the water (e.g., drinking water, recreational use, industrial processes).

Quality of Water Resources : Water Quality Standards

. Here are some reasons why water quality standards for global and India may differ:

1) Local environmental conditions
2) Available resources
3) Public health priorities
4) Industrial and agricultural practices
5) Population density and water demand
6) Cultural and dietary practices
7) Regulatory frameworks
8) Resource availability and infrastructure
9) Risk assessments and prioritization
10) International agreements and treaties
11) Government policies and economic considerations

Quality of Water Resources : Parameters

Here are some common parameters covered by water quality standards:

Physical Parameters:

Temperature: Specifies acceptable temperature ranges to maintain aquatic habitat.

Turbidity: Measures the cloudiness or haziness of a fluid, indicating the presence of suspended particles.

Chemical Parameters:

pH: Indicates the acidity or alkalinity of water. The standard range is typically between 6.5 and 8.5 for freshwater.

Dissolved Oxygen (DO): Essential for aquatic life, standards set minimum levels to support fish and other organisms.

Total Dissolved Solids (TDS): Represents the concentration of inorganic salts and minerals in water.

Nitrate and Nitrite: Regulates levels to prevent contamination from agricultural runoff and wastewater.

Heavy Metals (e.g.,mercury, arsenic): Establishes permissible concentrations to prevent toxicity.

Chlorine and Chloramines: Specifies acceptable levels for disinfection in drinking water.

Quality of Water Resources : Parameters

Biological Parameters:

Coliform Bacteria: Indicates microbial contamination, with specific limits for drinking water.

Fecal Coliform and E. coli: These bacteria are used as indicators of fecal contamination.

Nutrients:

Total Phosphorus and Total Nitrogen: Regulates nutrient levels to prevent eutrophication in water bodies.

Pathogens:

Giardia and Cryptosporidium: Standards for these protozoa help ensure the safety of drinking water.

Radioactive Substances:

Radionuclides (e.g., radium, uranium): Standards limit exposure to radioactive elements in drinking water.

Pesticides and Herbicides:

Maximum allowable concentrations for various agricultural chemicals to protect against water contamination.

Quality of Water Resources : Parameters

Organic Chemicals:

Benzene, toluene, ethylbenzene, and xylene (BTEX): Standards set limits for these hydrocarbons.

Polycyclic Aromatic Hydrocarbons (PAHs): Limits to prevent contamination from these compounds.

Suspended Solids:

Standards to control the presence of suspended particles in water.

Specific Conductance:

Measures the ability of water to conduct an electric current, often used as an indicator of total dissolved salts.

Water Use and Sustainable Reuse Methods

Water use refers to the amount of water consumed or utilized for various purposes in different sectors such as agriculture, industry, domestic, and environmental.

Major sectors of water use:

1) Agricultural water use
2) Industrial water use
3) Domestic water use
4) Environmental water use
5) Recreational water use

Water Use and Sustainable Reuse Methods

The availability of water on Earth is theoretically sufficient to meet the needs of its population. However, the challenges lie in the distribution of water in terms of space, time, and affordability.

Annual global river runoff	= 40,000 km^3
Annual global domestic use	= 200 km^3
Annual global industry use	= 2000 km^3
Annual global agriculture use	= 4000 km^3

Water Use : Challenges

Spatial Distribution

Uneven spatial availability

Uneven population density

Unavailability of land

Temporal Distribution

Seasonal variation

Climate change

Increased frequency of extreme events

Water Use : Challenges

Affordability and Infrastructure

Inadequate storage and management

Economic factors

Water Quality Issues

Pollution

Poor water treatment

Environmental water quality standard

Population Growth and Urbanization

Increasing demand

Land Use Changes

Water Use : Volumes Required Depends

1) Domestic water use

- Water quality
- Income
- Standard and type of living, e.g. bungalows versus apartments
- Size of dwelling unit and stand
- Climate
- Type of supply, e.g. communal or multiple household connections
- Water price
- Whether it is metered
- Who pays, e.g. public water is not paid for by the user
- Pressure
- Type of sanitation, e.g. waterborne
- Social customers
- Availability from the supplier, e.g. intermittent

Water Use : Volumes Required Depends

1) Domestic water use

Domestic water usage in warm climates – according to standard of housing

(i)	Areas of high quality housing	200 – 250 ℓ/c/d
(ii)	City residential areas including high standard flats	160 – 200 ℓ/c/d
(iii)	Suburban; tenement dwellings; low cost housing	90 – 100 ℓ/c/d
(iv)	Urban areas served by standpipes	50 – 70 ℓ/c/d
(v)	Rural: standpipes	30 – 50 ℓ/c/d
(vi)	Rural: distance to source > 1 km	10 – 30 ℓ/c/d

Water Use : Volumes Required Depends

2) Agricultural water use

- Crop characteristics
- Government policy and frame work
- Irrigation practices
- Period of cultivation
- Soil characteristics
- Farmers income
- Area of crop
- Climate of the region
- Topographic
- Water quality
- Social customers
- Water price
- Water availability

Water Use : Volumes Required Depends

3) Industrial water use

- Type of industry
- Production processes
- Size of industry
- Environmental policy and frame work
- Source of water
- Water quality
- Social customers
- Water price
- Water availability
- Technological advances
- Location

Water Use : Volumes Required Depends

4) Environmental water use

- Ecosystem health
- River flow and wetlands
- Climate of the region
- Topographic
- Water quality

5) Recreational water use

- Tourist activities
- Type of activities
- Water quality
- Income
- Social customers

Sustainable Reuse Methods

Water reuse, also known as water recycling or reclaimed water, is an important strategy for sustainable water management. Reusing water can help reduce demand on freshwater sources, conserve resources, and mitigate environmental impacts.

Greywater recycling

Greywater is wastewater from non-toilet plumbing systems such as hand basins, washing machines, showers and baths.

Reuse: Treated water reused for non-potable purposes, such as landscape irrigation, toilet flushing, car, road, etc..

Rainwater harvesting

Rainwater harvesting involves collecting and storing rainwater runoff from roofs or other surfaces.

Reuse: Harvested rainwater can be used for various non-potable purposes, landscape irrigation, recharge ground water, toilet flushing, washing cloth, house, car, road, etc. Water may be used for potable purposes after disinfection treatment if the roof is clean and green.

Sustainable Reuse Methods

Storm water harvesting

Storm water harvesting differs from rainwater harvesting in that runoff from non-building surfaces is collected.

Reuse: It can be treated and used for various purposes, such as groundwater recharge, landscape irrigation, or industrial processes.

Wastewater treatment

Wastewater from industrial, municipal, or agricultural sources can undergo treatment processes to remove contaminants and pathogens.

Reuse: Treated wastewater, also known as reclaimed water, can be used for a variety of non-potable purposes, including irrigation, industrial processes, and even some environmental applications.

Sustainable Reuse Methods

Tertiary treatment for potable reuse

Tertiary treatment involves advanced processes such as filtration, reverse osmosis, and ultraviolet disinfection to further purify reclaimed water to meet drinking water standards.

Reuse: Treated water is used as a direct source of potable purposes such as, drinking water, bathing, washing cloth, house, etc..

Aquifer Recharge

Storm, treated and grey water can be intentionally introduced into underground aquifers to replenish groundwater resources.

Environmental benefits: Aquifer recharge not only helps store water but also contributes to maintaining ecosystem health by sustaining base flows in rivers.

Sustainable Reuse Methods

Constructed wetlands

Constructed wetlands use natural processes within wetland environments to treat wastewater.

Environmental benefits: Wetlands can help remove pollutants and nutrients from wastewater, making it suitable for non-potable uses like irrigation.

Onsite Water Reuse Systems:

Some buildings incorporate onsite water reuse systems that treat and reuse grey water or rainwater for specific purposes within the building.

Sustainable water reuse practices require careful planning, appropriate treatment technologies, and adherence to health and environmental standards. Regulations and guidelines vary by location, and community acceptance and education play a crucial role in the successful implementation of water reuse initiatives

Usable water resources

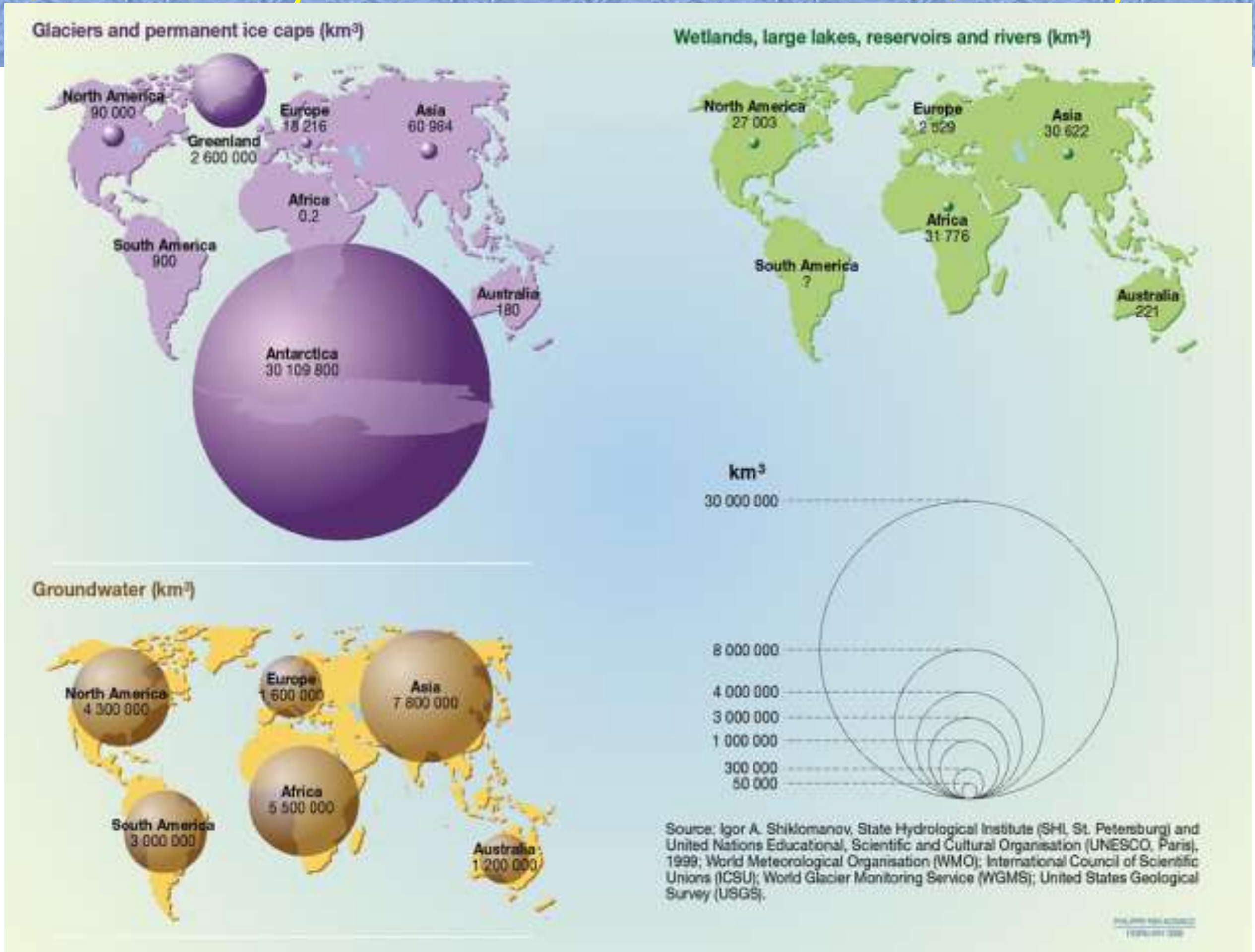
Usable water is water that we find in streams, lakes, ponds, rivers, creeks, and underground in aquifers.

Water sources can include: Surface water (for example, a lake, river, or reservoir) Ground water (for example, well, an aquifer)

Freshwater can be defined as the water with less than 500 parts per million (ppm)

Usable water resources by continent and country

At the continental level, **America** has the largest share of the world's total freshwater resources with 45 %, followed by Asia with 28%, Europe with 15.5 % and Africa with 9 %.



Usable water resources by continent and country

The available surface fresh water is not equally distributed throughout the world. Brazil, Russia, Canada, Indonesia, China, Colombia, and the United States have most of the world’s surface freshwater resources. As a result, approximately one-fifth of the world’s population lives in water-scarce areas where, on average, each person receives less than 1,000 cubic meters (35,315 cubic feet) of water a year. This lack of water affects people’s access to clean, usable water, as well as the economic development and geopolitics of different areas.

Usable water resources by continent and country

1) Brazil has highest freshwater resources in the world which is accounts for approximately 12% of the world's freshwater resources. It is just because Amazon region this country contains 70% of the total freshwater.

2) Russia has second largest freshwater reserve which is approximately **1/5 of freshwater in the world.**

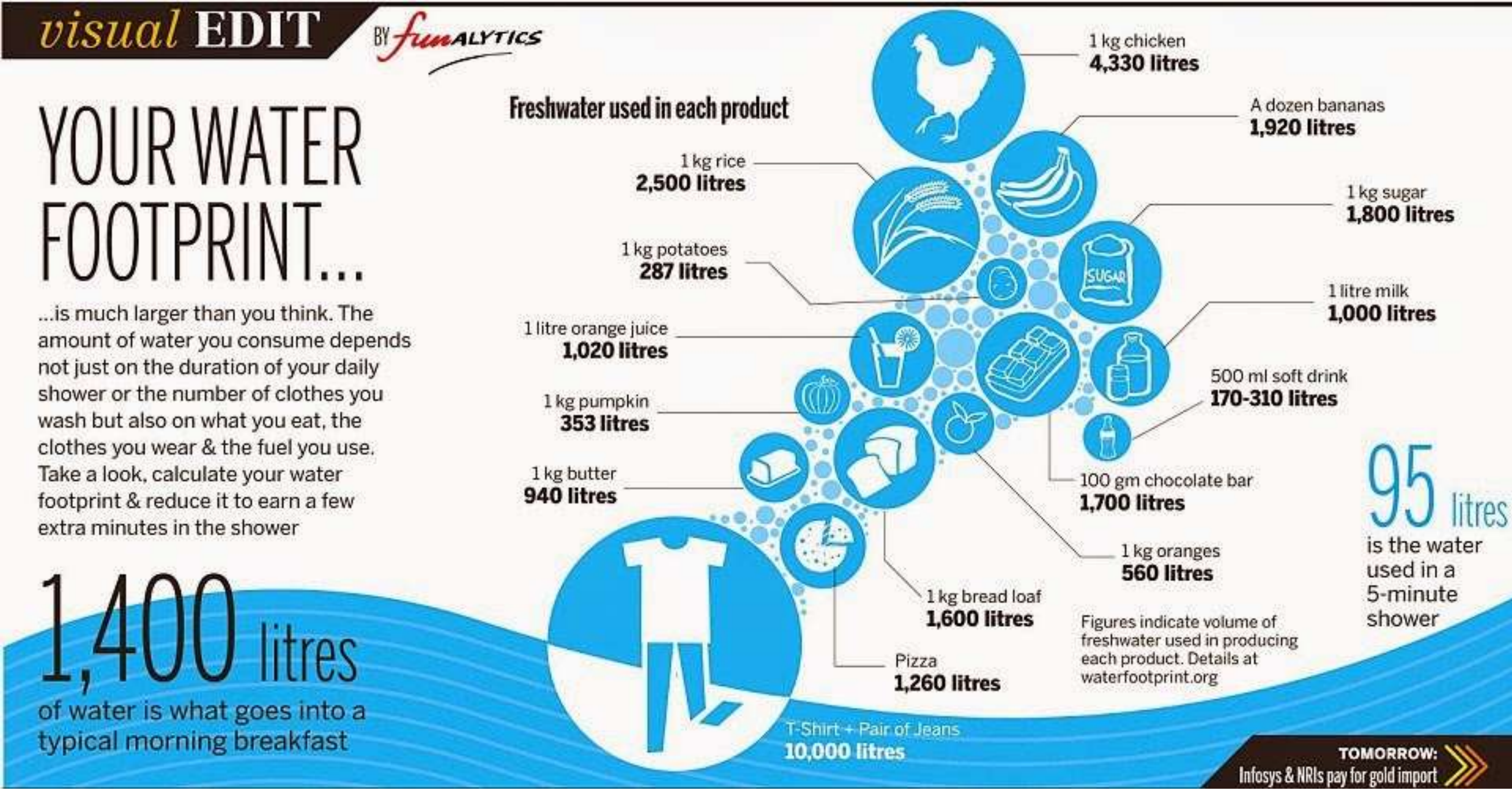
3) USA is the third country in the world which has largest freshwater reserve. There are more than 100 lakes; and **Lake Superior, Lake Ontario, Lake Michigan, and Lake Erie** are the major lakes.

4) Canada is the fourth country in the world which has largest freshwater reserve. Here, freshwater is found in its diverse river system and lakes. **Lake Superior, Lake Ontario, Great Bear Lake, Lake Huron, Lake Eerie and Lake Winnipeg** are some of the freshwater lakes of Canada. In fact Canada has the largest number of lakes in the whole world standing at 879,800 lakes. **The Great Bear Lake** is the largest freshwater lake of Canada that is solely within Canada and not shared with USA.

Virtual water

- Virtual water refers to the water that is "hidden" in the entire lifecycle of products, services, and processes.
- This water consumption is not apparent to the end-user, but it plays a crucial role in the creation and delivery of the product or service.
- Virtual water is consumed at various stages of the value chain, including the production, processing, manufacturing, and transportation of goods and services.
- It encompasses the total water used in the entire supply chain, reflecting the water intensity of different economic activities.
- Source for virtual water : Blue, green and grey water

Virtual water



Water Footprint

- The water footprint measures the amount of water used to produce each of the goods and services we use.
- The water footprint of a consumer (the sum of virtual water contained in the products he/she buys), a business (via the products it manufactures), a nation (taking into account footprint of local product, imports and exports) , etc...
- It is focused not only on the water content of products but also to various factors such as the country of production, origin of the water, time of use, geopolitics, economical consideration, etc...
- The footprint of a product varies from country to country.

Water Footprint and Virtual water

Let's consider the example of a cotton T-shirt to illustrate the concepts of virtual water and water footprint:

Virtual water in a cotton T-shirt

Cotton cultivation
Processing and manufacturing
Transportation including wholesale and retail outlets

Water footprint of a cotton T-shirt

Direct water use
Indirect water use
Global supply chain

Water Footprint and Virtual water

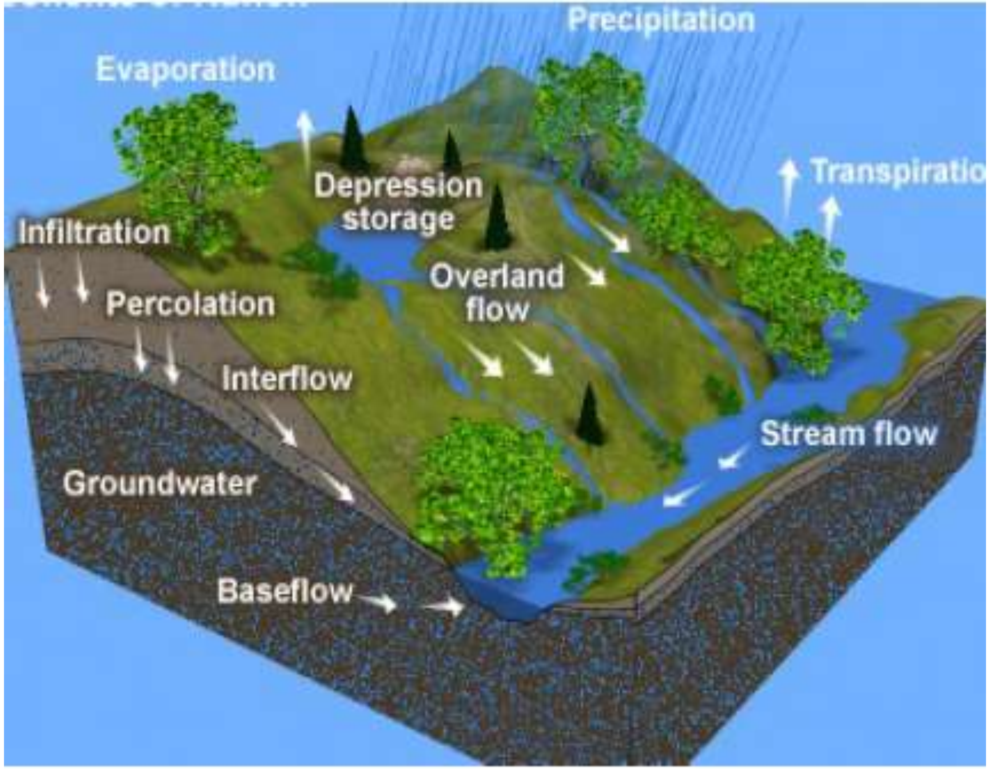
Reduce water footprint

- Reduce daily water usage
- Optimize workforce efficiency through the integration of automation and technology.
- Water conservation in Irrigation
- Implement crop rotation and diversify the types of crops grown
- Cultivate less base period and high yield crops
- Eat sustainable food and cut consumption of those foods that require more water, like meat and processed food.
- Support sustainable and local agriculture, cattle-production and fishing.
- Opt for responsible consumption and the circular economy.
- Implement an environmental quality system.
- Encourage recycling, reuse and ecological consumption at the heart of the company.
- Use suppliers who are committed to reducing the water footprint.
- Digitalise as far as possible to save paper, for instance (paperless offices).

Module: 3	Water Resources Assessment	
Network design-Stream flow gauging-Weir design-Gauges-Current gauging-Salt dilution-Geophysical exploration-Test drilling-Application of remote sensing techniques.		

Hydrological Abstractions

It is the term used to describe the amount of rainfall that doesn't turn into runoff.



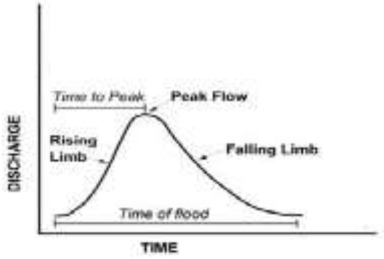
Hydrological Abstractions

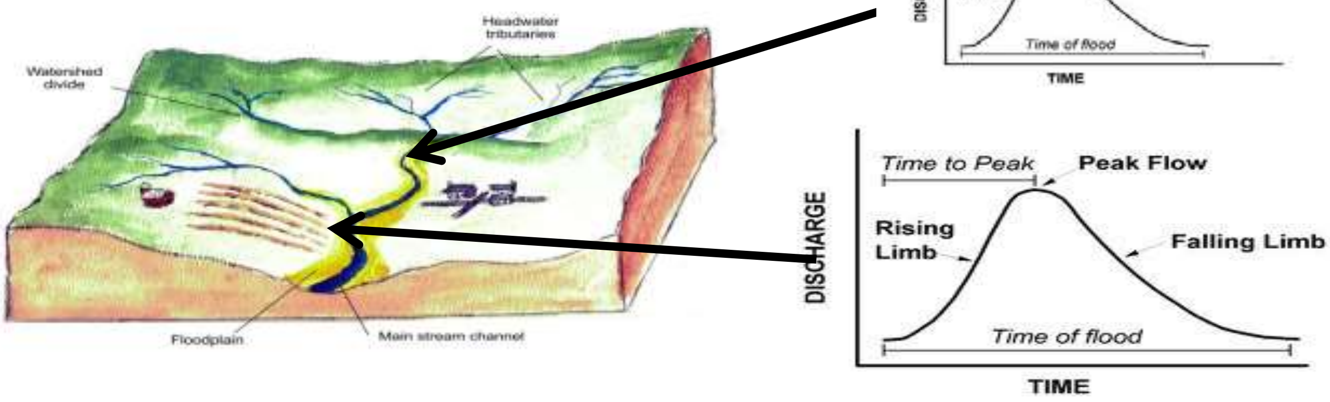
Run-off = Rainfall – Losses (or Abstractions)

1. Interception
2. Depression storage
3. Evaporation
4. Transpiration
5. Evapotranspiration
6. Infiltration

Stream flow

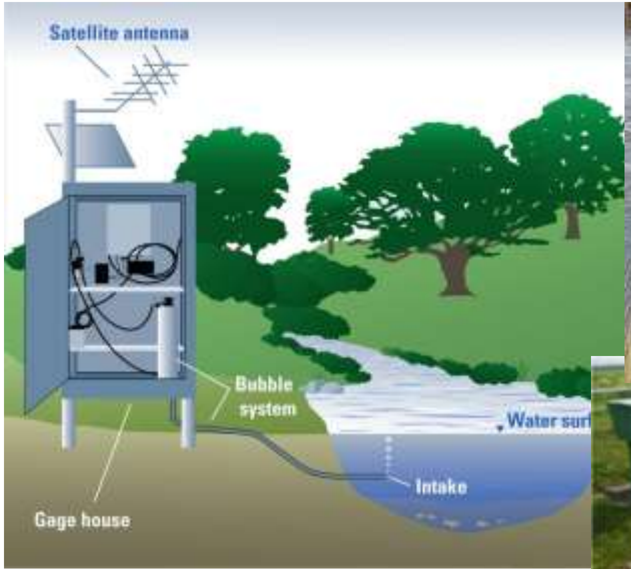
Stream flow, is the discharge at a designated point over a fixed time. It is often expressed as cubic feet per second (m^3/sec). Discharge refers to the volume of water flowing through a river or stream at a specific point and time. The flow of a stream is directly related to the amount of water moving off the watershed into the stream channel.





Stream flow measurement

A stream gauge, streamgage or gauging station is a technique / process of measurement of water flowing in a stream / nallah / river / canal



Stream flow network

The spacing and sampling intervals depends on

1) Stream characteristics
2) Available annual flow and rainfall
3) purpose of the study
4) expected accuracy
5) geographic configuration of the study region;
6) economic consideration
7) collaboration and standardization
8) Legal guidelines

Stream flow network

The World Meteorological Organization (WMO) recommendations you provided outline the suggested minimum gauging densities based on different climatic and geographical conditions. These guidelines are important for establishing a network of gauge stations to monitor river discharge effectively. Here's a summary of the recommended minimum gauging densities:

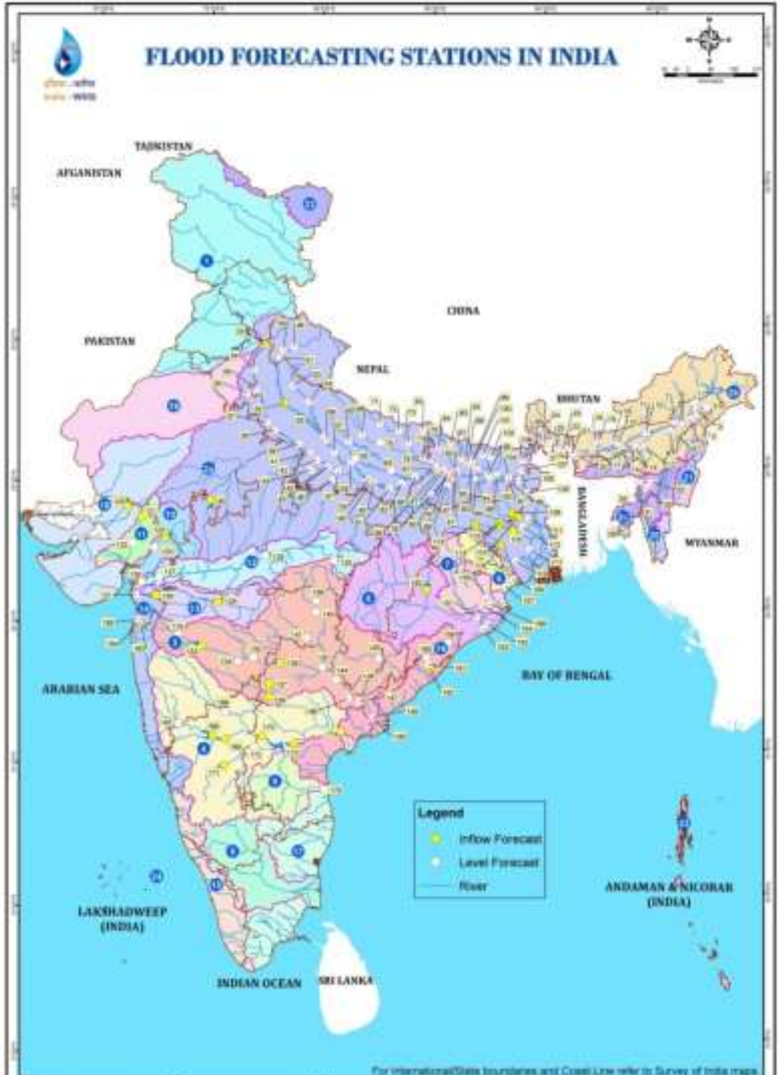
1) For temperate and tropical climates, plains regions 1 gauge per 3,000 - 5,000 km^2
2) For mountainous basins in temperate and tropical zones 1 gauge per 1,000 km^2
3) For desert regions and polar zones 1 gauge per 1,000 km^2

Stream flow network

Selection of suitable section of a stream:

Following point shall be considered in selection of section

1) The bank of stream should be stable. It should not be prone to bank erosion
2) Bed of the stream should be stable.
3) Section should be free from vegetation growth.
4) Section should be straight no curve shape.
5) It should be conveniently accessible. Well connected with road.
6) Information on existing gauging stations in the stream.
7) Safety of instruments and personnel employed.



Central Water Commission (CWC) National Flood Forecasting Network

CWC issues short range (upto 24 hours) flood forecast based on gauge to gauge correlation and medium range (up to 7 days) advisory flood forecast based on models to the concerned stakeholders at 338 stations (200 Level Forecast Stations + 138 Inflow Forecast Stations) across the country, including the State of Haryana.

Methods of stream flow measurements

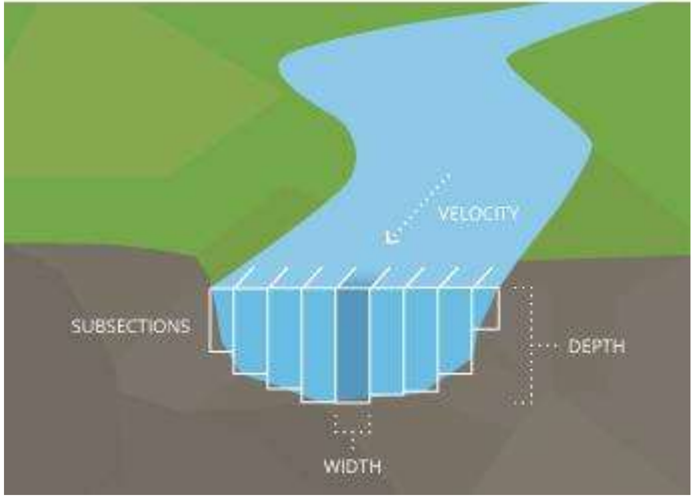
Various methods are adopted for stream flow measurements some are

1. Velocity-area methods
    a) Float method
    b) Dilution techniques
    c) Current meters
    d) Electromagnetic method
    e) Ultrasonic method
2. Discharge measurement using artificial structures
    a) Weirs
    b) Flumes
3. Indirect determination of stream flow
    c) Slope-area method
    d) Stage-discharge rating curve

Stream flow measurements : Velocity-Area methods

Discharge is the product of cross-sectional area and velocity of water. The velocity-area methods involve measuring the flow area and velocity and these are multiplied to get discharge:

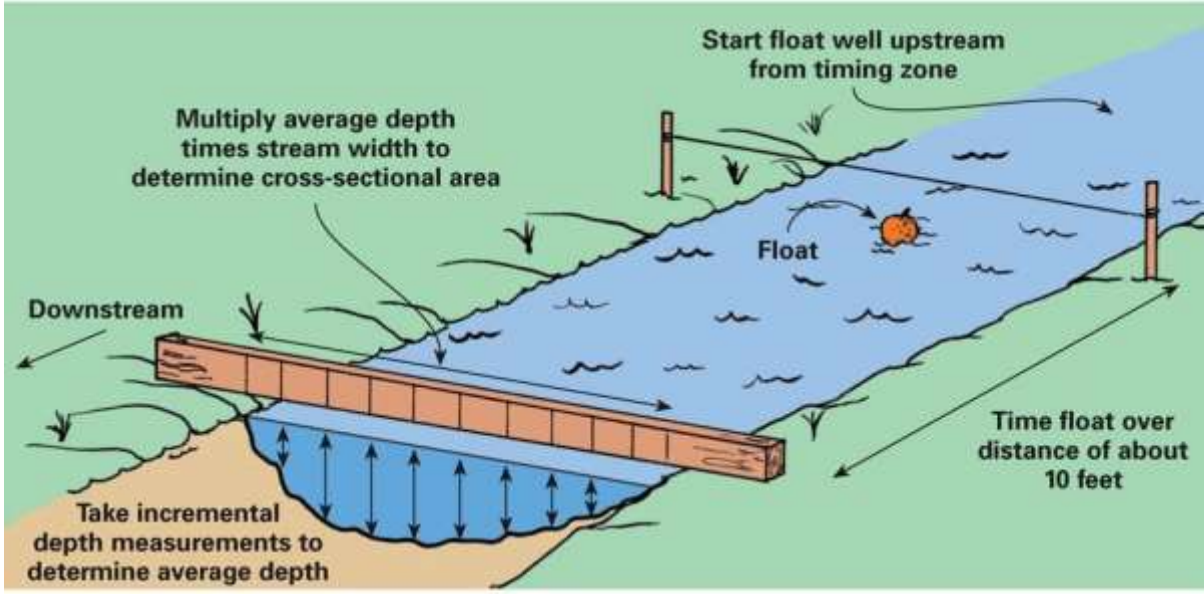
$$\text{Discharge} = \text{Area} \times \text{Velocity}$$



Velocity-Area methods : Float method

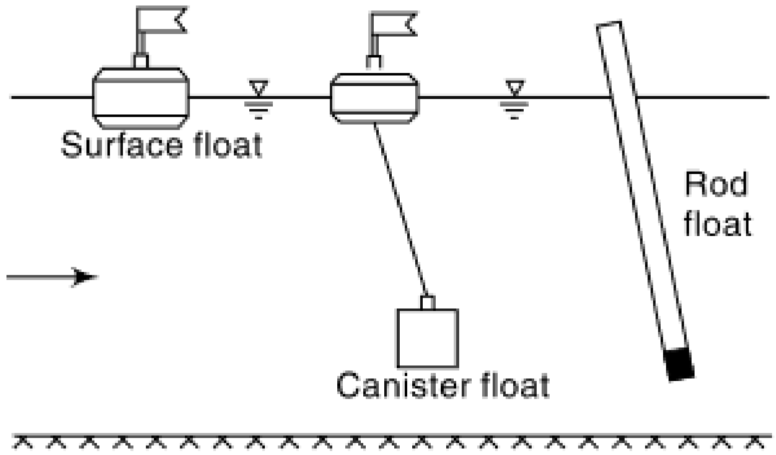
The measurement is made by measuring the time that it takes a floating object to travel a specified distance downstream. The method is only used for a rough estimation of the discharge due to the high level of inaccuracy of the results.

Discharge = Area X Velocity



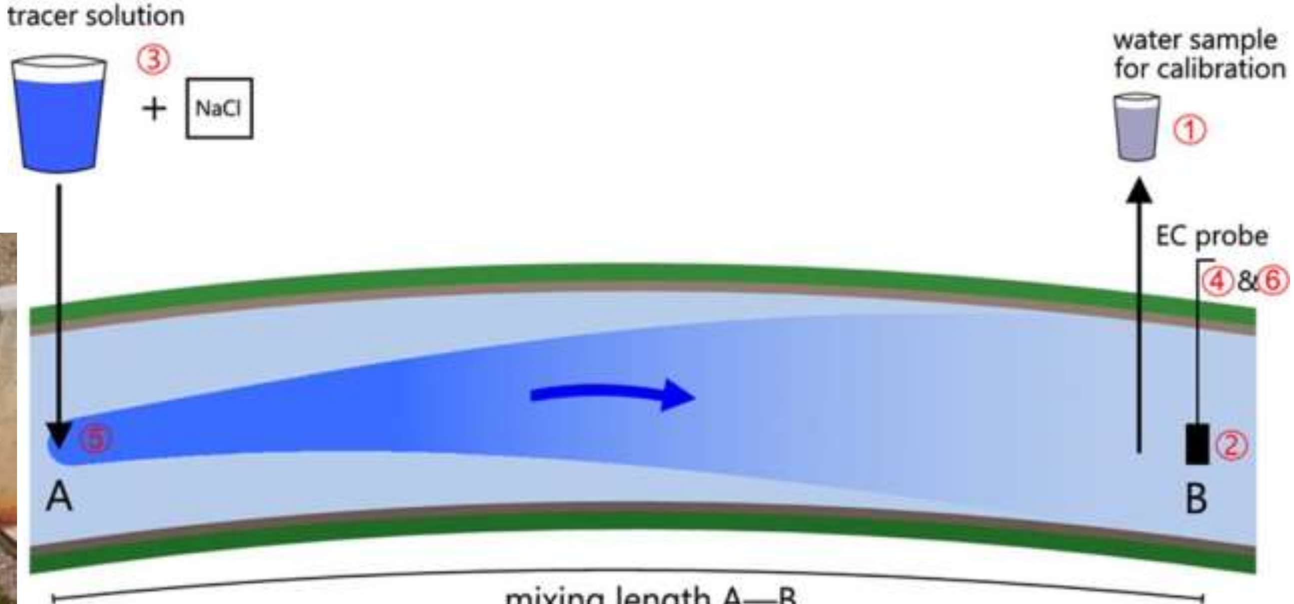
Velocity-Area methods : Float method

A simple float moving on stream surface is called surface float. It is easy to use and the mean velocity is obtained by multiplying the observed surface velocity by a reduction coefficient. However, surface floats are affected by surface winds. To get the average velocity in the vertical directly, special floats in which part of the body is under water are used. Rod float, in which a cylindrical rod is weighed so that it can float vertically, belongs to this category.



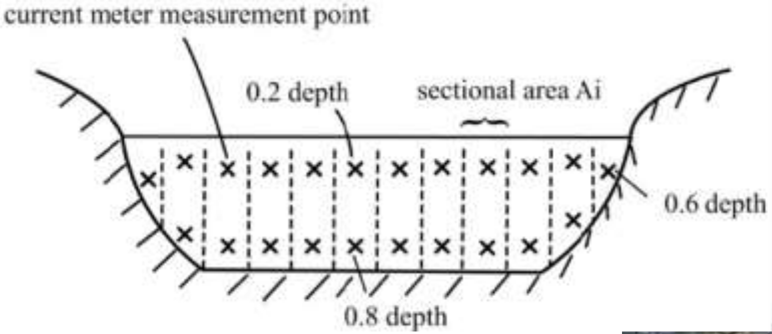
Velocity-Area methods : Dilution techniques

Dye, or chemical is injected into the water and its time concentrated development is used to determine the flow rate. In selecting a dye/ chemical, it is important to make sure that the dye is bio-degradable or otherwise approved for the application.



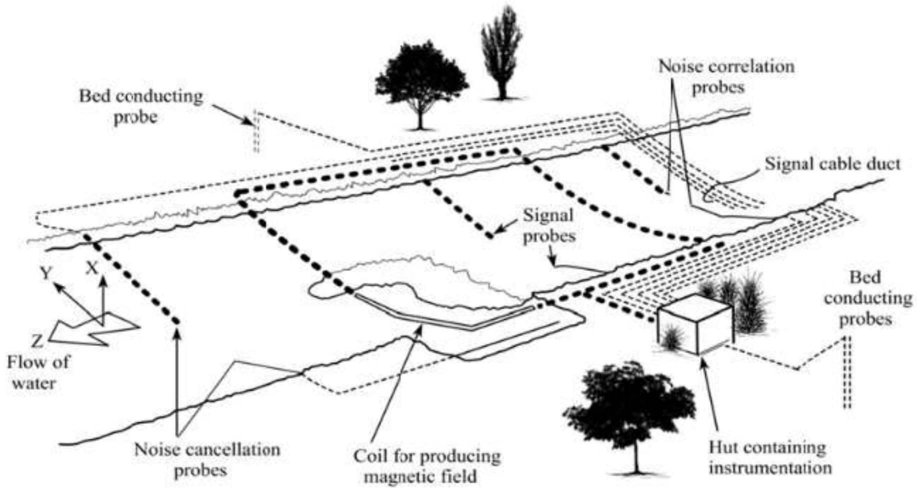
Velocity-Area methods : Current meters

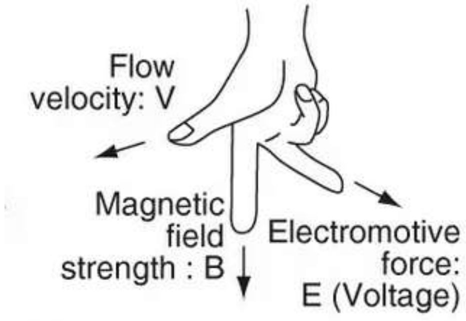
Current meter is the most commonly used instrument to measure the velocity of flowing water. Accurate measurements of the velocity profile of the stream cross section are made by current meters.



Velocity-Area methods : Electromagnetic method

The electromagnetic gauge operates on a principle similar to that of an electric dynamo. If a conductor of certain length moves through a magnetic field, a voltage is generated between the ends of the conductor.

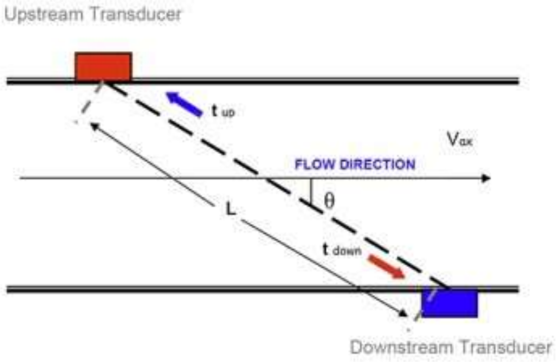




Faraday's law of electromagnetic induction

Velocity-Area methods : Ultrasonic method

Ultrasonic sound : frequency of **20 kHz and higher**



A typical transit-time ultrasonic liquid flow meter utilizes two ultrasonic transducers that function as both ultrasonic transmitter and receiver. The ultrasonic flow meter operates by alternately transmitting and receiving a burst of ultrasound between the two transducers by measuring the transit time that it takes for sound to travel between the two transducers in both directions. The difference in the transit time (Δ time) measured is directly proportional to the velocity of the liquid in the pipe

Discharge measurement using artificial structures

- Structures like notches, weir, flumes and sluice gates for flow measurements in hydraulic laboratories are well known.
- These conventional structures are used in the field conditions but their use is limited by the ranges of head, debris or sediment load of the stream and the backwater effects produced by the streams.
- The basic principle governing the use of these structure is that these structure produce a unique control section in the flow. At these structure the discharge Q is the function of the water surface elevation measured from the specified datum.

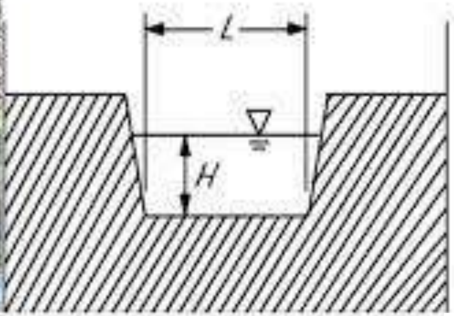
$$Q = f(H)$$

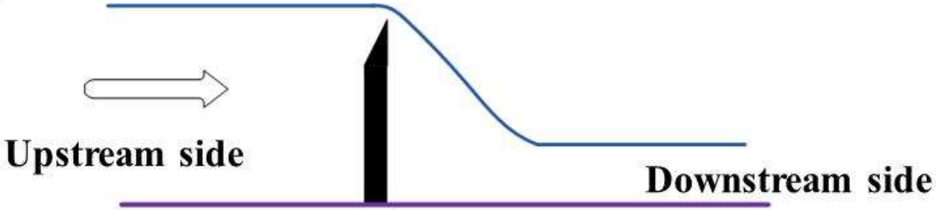
H= water surface elevation measured from the specified datum

Weirs

A weir is a small barrier built across a stream or river to control and raise the water level slightly on the upstream side, essentially a small-scale dam.

$$Q = f\,(H)$$





Weirs

Rectangular notch

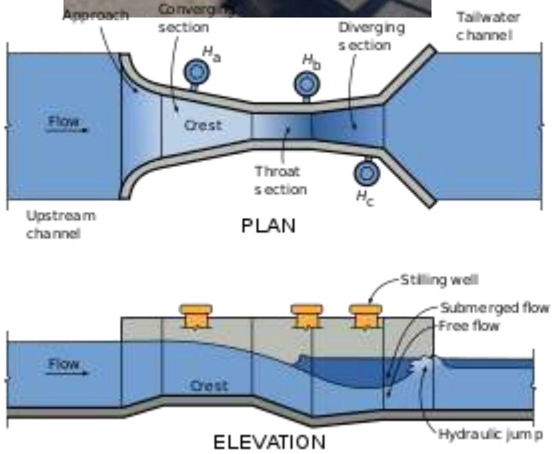
Triangular notch

Trapezoidal notch

$$Q = K\,H^n$$

Flumes

Flumes are specially shaped, engineered structures used to measure the flow of water in open channels. Flumes are static in nature - having no moving parts - and develop a relationship between the water level in the flume and the flow rate by restricting the flow of water in various ways.

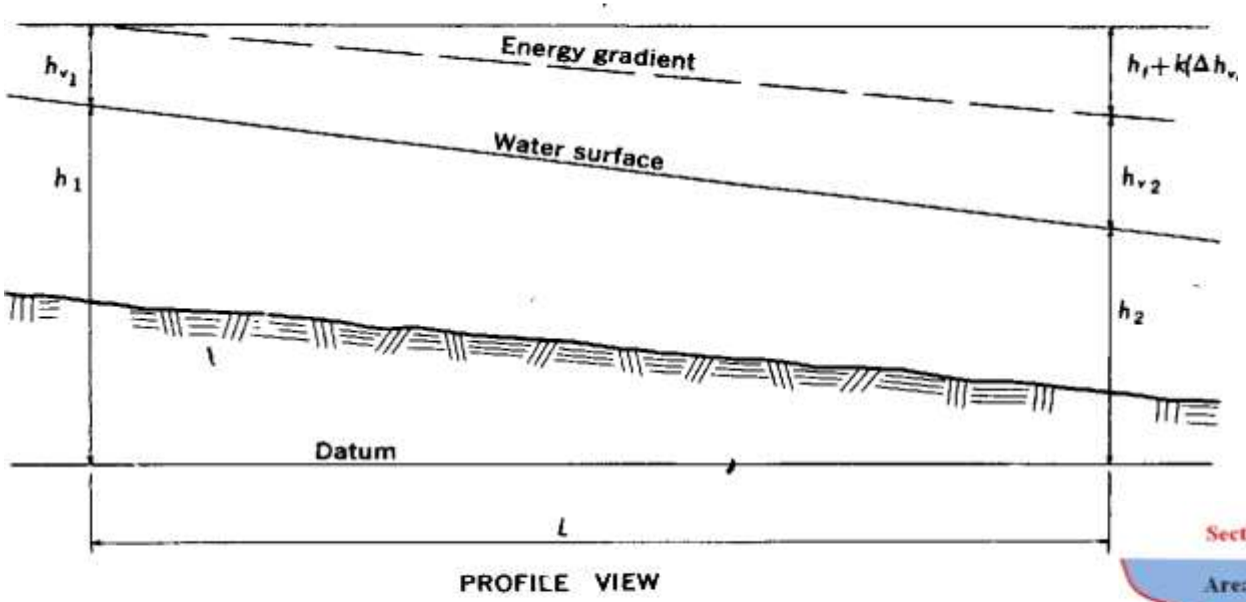


Indirect determination of stream flow

These methods make use of the relationship between the flow discharge and the water surface slope and depth at specified locations.

Slope- Area method

Slope-area method is an approximate and indirect method of discharge estimation which is used when measurement by more accurate methods, such as the velocity-area method, is not possible.



Slope- Area method

The Manning equation

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S_f^{\frac{1}{2}}$$

Where

Q = discharge (m^3/s)

n = Manning's roughness coefficient (range between 0.01 and 0.75)

A = cross-section area (m^2)

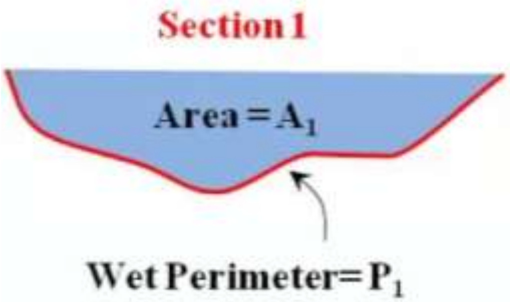
R = the hydraulic radius, equal to the area divided by the wetted perimeter (m)

S = the head loss per unit length of the channel, approximated by the channel slope

R=A/P

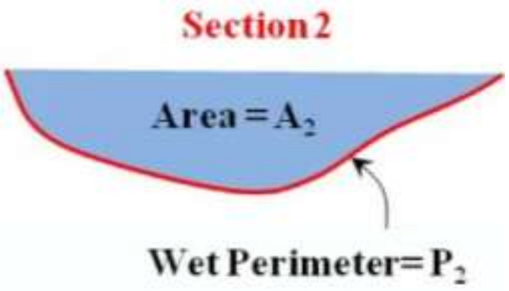
P = witted parameter

Slope- Area method



$$R_1 = \frac{A_1}{P_1}$$

$$K_1 = A_1 \frac{1}{n_1} R_1^{2/3}$$

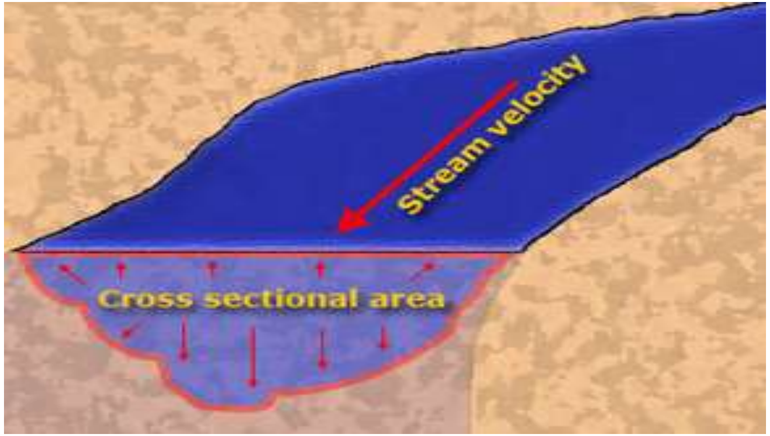


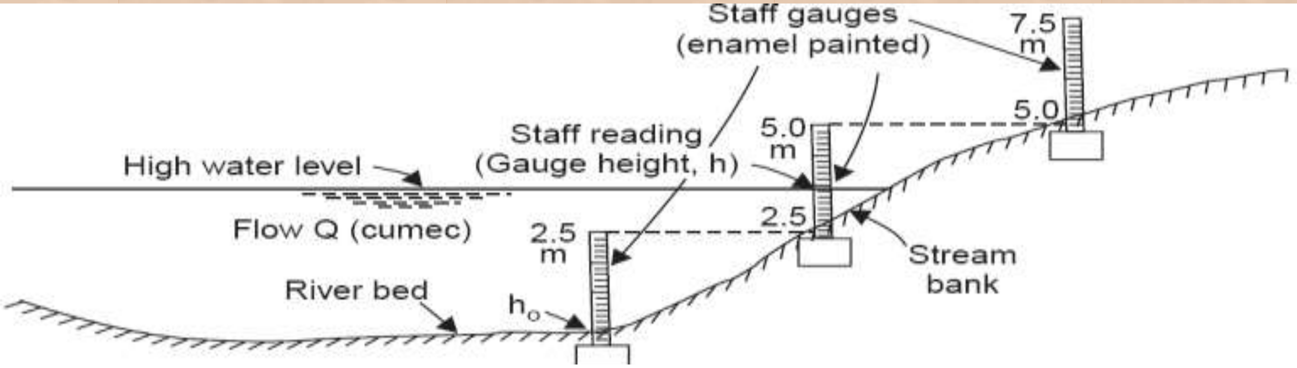
$$R_2 = \frac{A_2}{P_2}$$

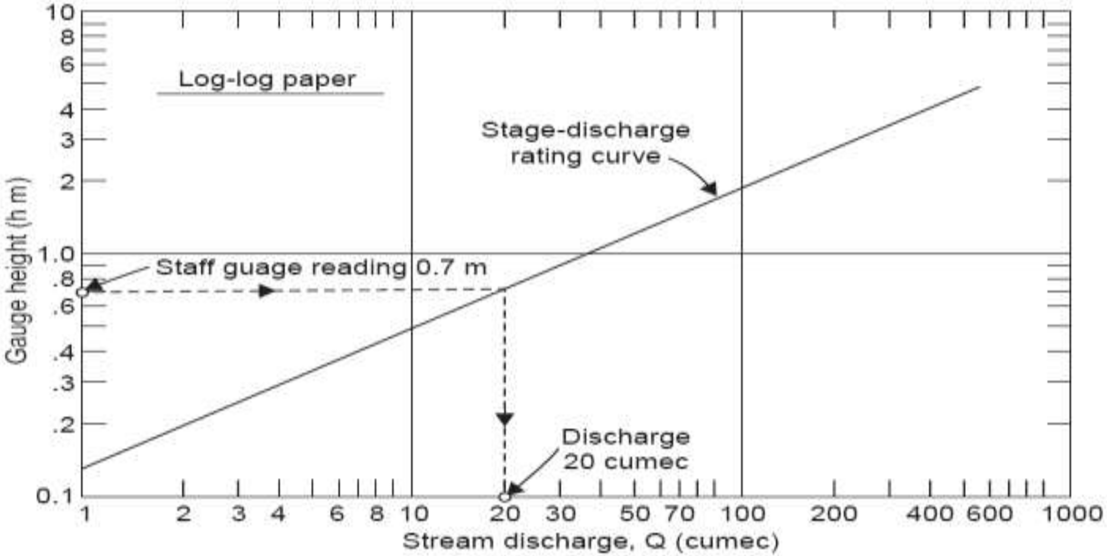
$$K_2 = A_2 \frac{1}{n_2} R_2^{2/3}$$

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S_f^{\frac{1}{2}}$$

Stage discharge method







Rating curve

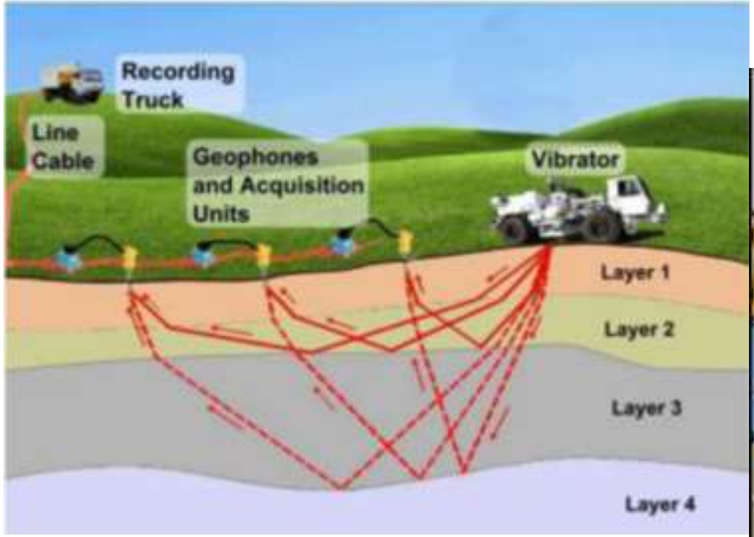
Geophysical exploration

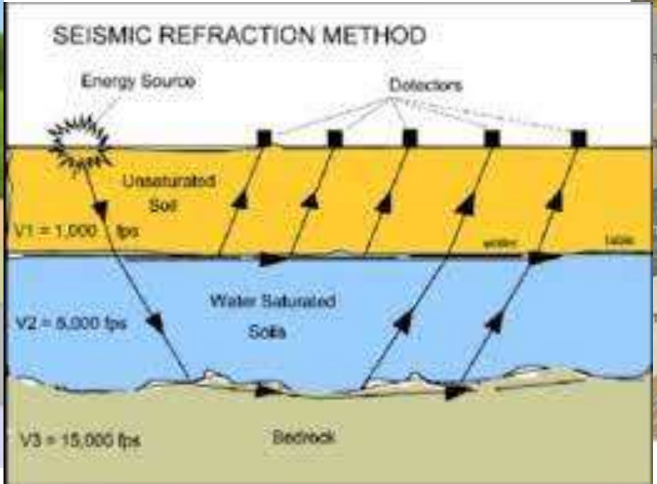
Geophysical exploration is a branch of earth science that involves studying the Earth's subsurface using the principles and techniques of physics. These methods are employed to gather information about the composition, structure, and properties of the Earth's interior. Geophysical exploration is widely used in fields such as mineral, groundwater, mining, oil and gas exploration, environmental studies, and engineering projects.

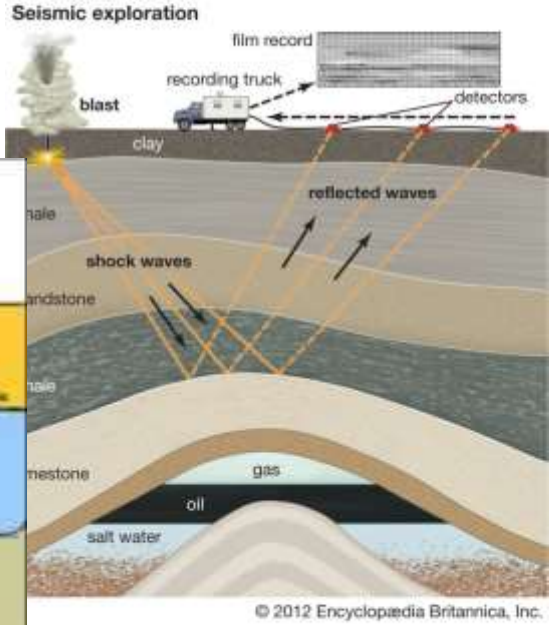
Geophysical exploration

Key methods and techniques used in geophysical exploration include:

Seismic Exploration: This method involves sending seismic waves into the ground and recording their reflections to create images of subsurface structures. It is widely used in oil and gas exploration, as well as in geological studies.







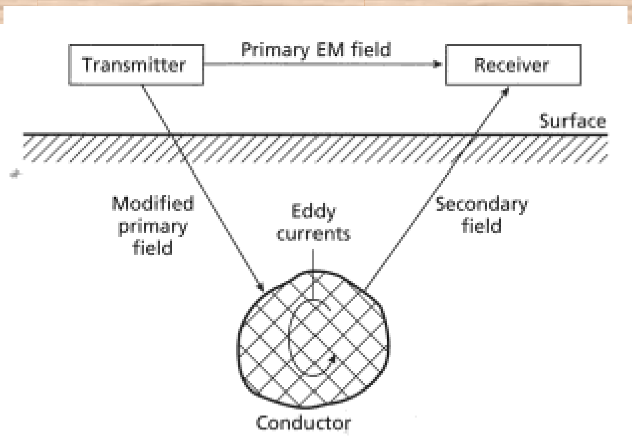
Geophysical exploration

Magnetic Exploration: The magnetic method was one of the first geophysical methods used for mineral exploration. It measure variations in the Earth's magnetic field to detect subsurface structures or mineral deposits with contrasting magnetic properties.

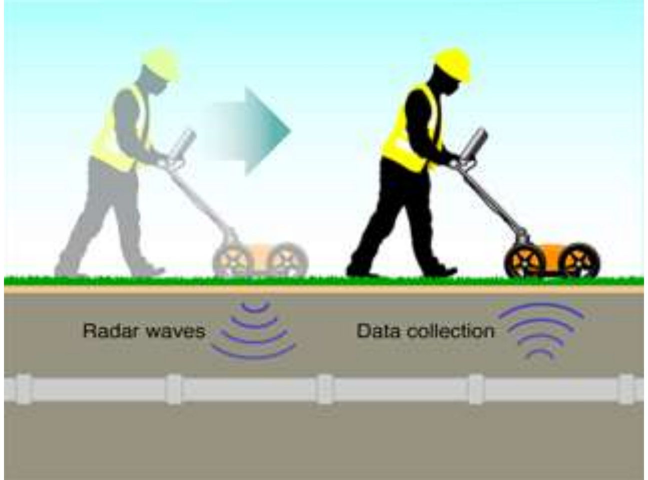
Gravity Exploration: Gravity surveys measure variations in gravitational forces to identify subsurface density variations. This method is used in geological studies and to locate subsurface structures.

Geophysical exploration

Electromagnetic (EM) Exploration: In EM exploration, an electric current is transmitted through the Earth and the response of the current as it travels back out of the Earth is measured. Conductivity and resistivity are the inverse of each other. Resistive zones will return a weak response whereas conductive zones will return a strong response

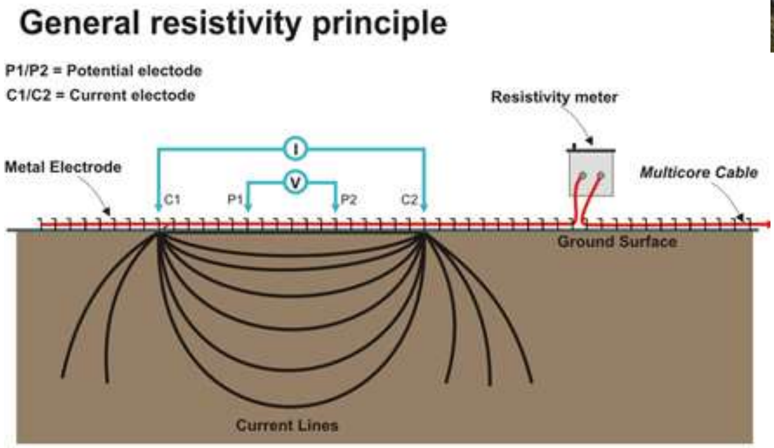


Ground Penetrating Radar (GPR): GPR is a geophysical locating method that uses radio waves to capture images below the surface of the ground in a minimally invasive way. The huge advantage is that it allows crews to pinpoint the location of underground utilities without disturbing the ground.



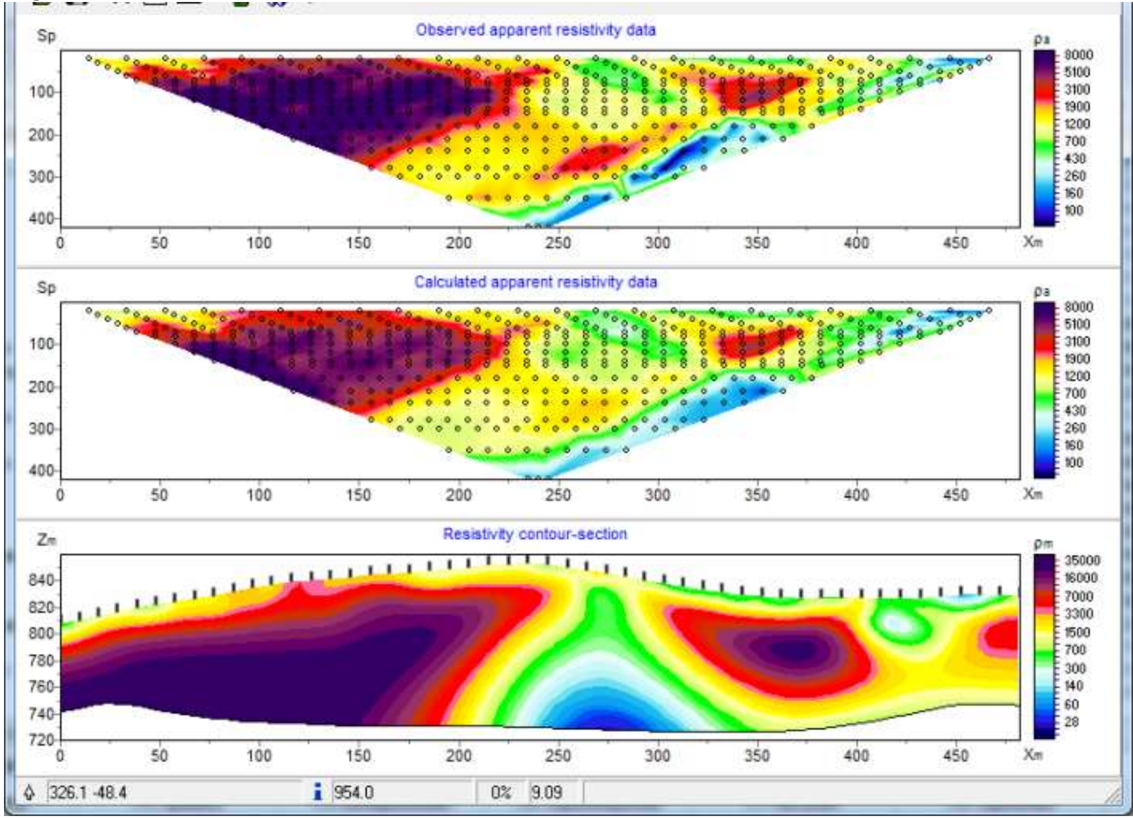
Geophysical exploration

Electrical Resistivity Tomography (ERT): ERT or electrical resistivity imaging (ERI) is a geophysical technique for imaging sub-surface structures from electrical resistivity measurements made at the surface, or by electrodes in one or more bore holes.



Geophysical exploration

Electrical Resistivity Tomography (ERT):



Applications

- Fault Investigation
- Ground water table investigation
- Soil moisture content
- Soil characteristics such as permeability, porosity, etc.
- Mining
- Pollution monitoring
- Determination and many Others.

Geophysical exploration

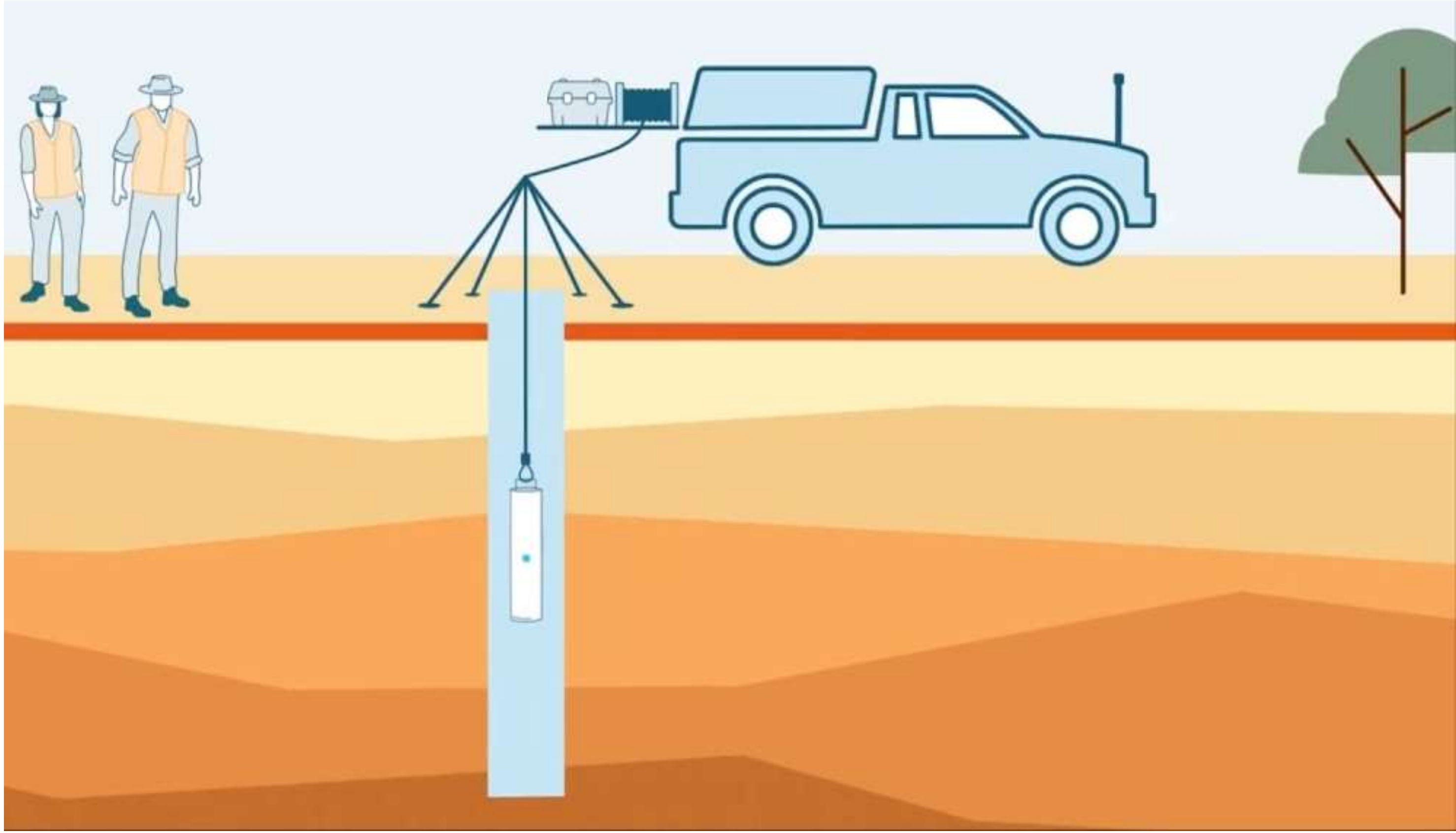
Borehole Geophysics or Test drilling:

Borehole geophysics involves the analysis of geophysical data that are collected within boreholes, wells, or test holes. Boreholes provide access to the subsurface, and borehole methods can produce continuous, in situ records of the properties of intersected formations, formation fluids, borehole fluids, and well construction. Data collected using borehole methods are diverse and may provide more physical and chemical information about the subsurface than available from drilling, sampling, or surface geophysics alone.

It is used in ground-water and environmental investigations to obtain information on well construction, rock lithology and fractures, permeability and porosity, and water quality.

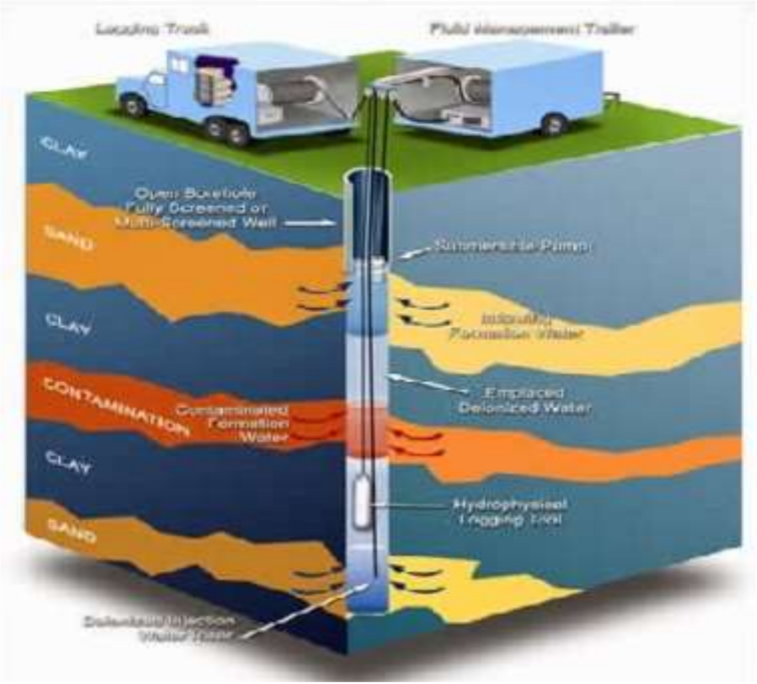
Geophysical exploration

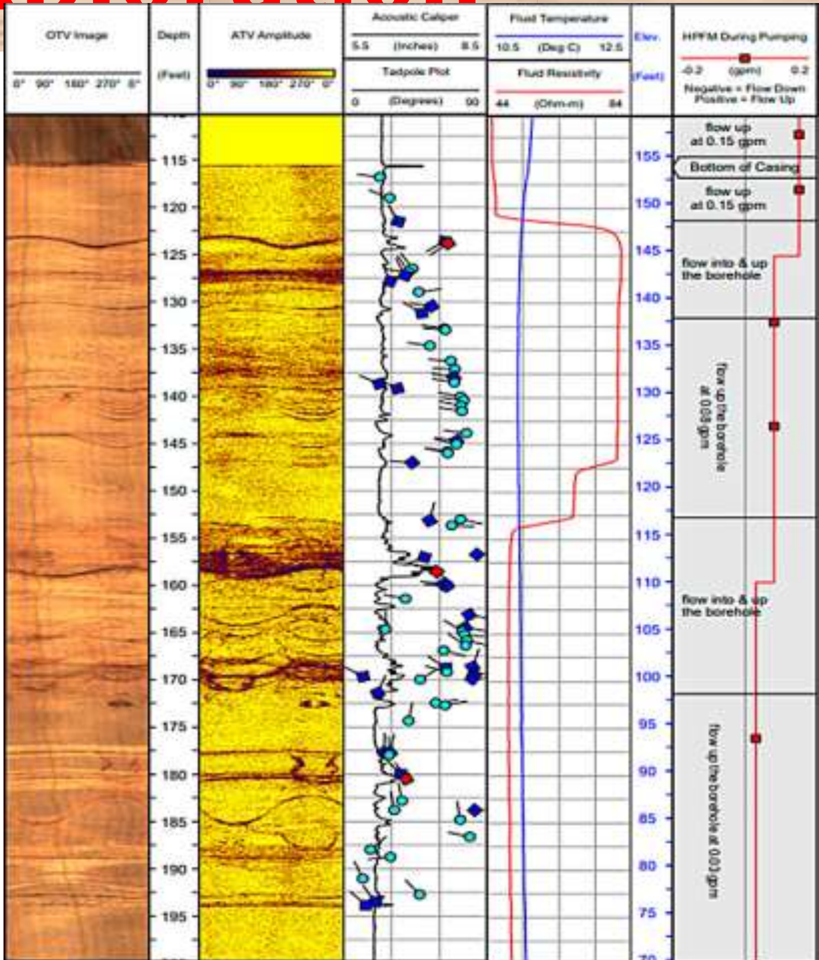
Borehole Geophysics or Test drilling:



Geophysical exploration

Borehole Geophysics or Test drilling:

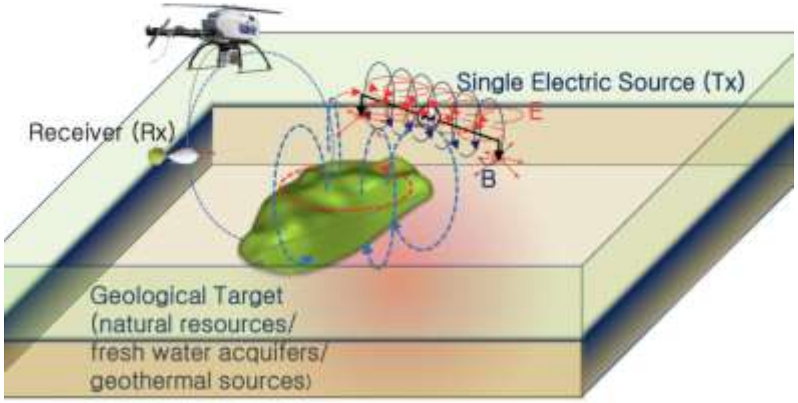




Geophysical exploration

Application of remote sensing techniques

Geophysical remote sensing is a scientific approach that involves the use of various sensing technologies to gather information about the Earth's surface and subsurface from a distance. This field utilizes sensors, often mounted on aircraft or satellites, to measure and analyze the physical properties of the Earth's features. The collected data can provide insights into geological, environmental, and natural phenomena without direct physical contact.



Application of remote sensing techniques

Key aspects of geophysical remote sensing include the following:

Data Collection: Instruments such as cameras, spectrometers, radar systems, and lidar sensors are used to capture data in different parts of the electromagnetic spectrum.

Remote Sensing Platforms: Data is often collected from airborne or satellite platforms, enabling the coverage of large areas and the monitoring of inaccessible or hazardous regions.

Physical Properties: Geophysical remote sensing focuses on measuring physical properties such as light reflection, absorption, emission, and interaction with electromagnetic waves. Different features on the Earth's surface and subsurface exhibit distinct signatures in the collected data.

Application of remote sensing techniques

Applications: The collected data is applied to various fields, including geology, environmental science, agriculture, forestry, urban planning, and disaster management. It aids in mapping and monitoring natural resources, land cover changes, geological structures, and environmental conditions.

Interpretation: Data analysis and interpretation involve extracting meaningful information from the collected sensor data. This may include identifying specific land cover types, mapping geological formations, or assessing environmental changes over time.

Overall, geophysical remote sensing plays a crucial role in scientific research, resource exploration, environmental monitoring, and decision-making processes by providing a comprehensive and non-invasive means of studying the Earth's surface and subsurface.

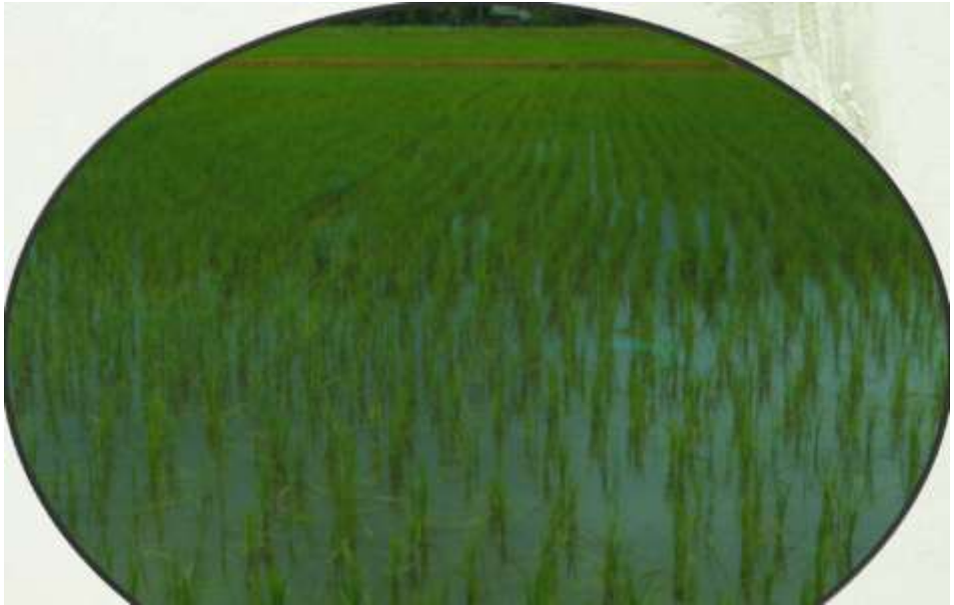
Geophysical exploration

Module: 4	Water in Agricultural Systems	

Water for food production, virtual water trade for achieving global water security, irrigation efficiencies, irrigation methods and current water pricing, water for livestock and processing, water pollution from agricultural production

Irrigation

- Irrigation is the artificial application of water to the soil for the purpose of supplying the moisture essential for plant growth.
- It is used to assist in growth of agricultural crops, maintenance of landscapes, and revegetation of disturbed soils in dry areas and during periods of inadequate rainfall.



Irrigation

Irrigation engineering: involves

- Conception,
- Planning,
- Design,
- Construction,
- Operation and
- Management

of an irrigation system.

Irrigation

This is a list of countries by irrigated land area based on The World Fact book

Rank	Country/Region	Irrigated land (km²)	Date of information
-	World	3,263,413	2010
1	**India**	**558,080**	**2003**
2	China	545,960	2003
3	United States	223,850	2003
4	Pakistan	182,300	2003
-	European Union	168,050	2003

Irrigation

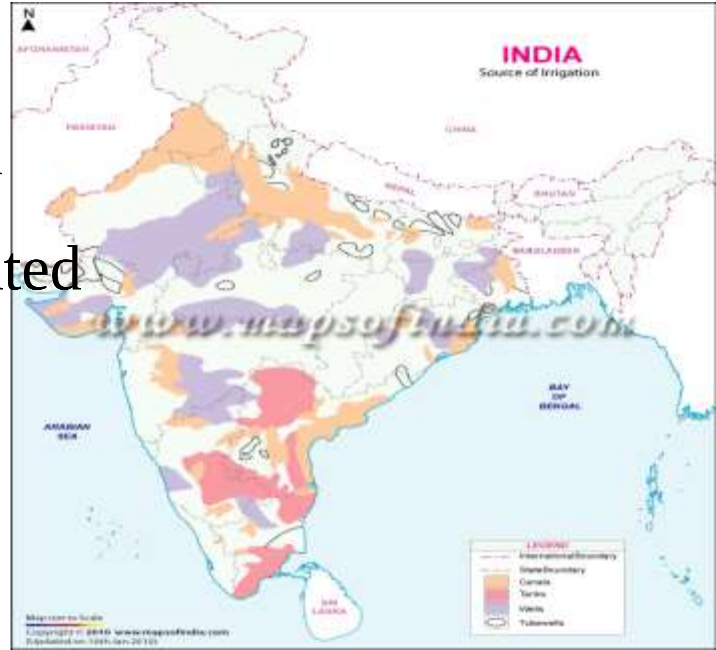
Important of Irrigation in India

Annual total usage of water = 630 b.cu. m

Annual irrigation usage of water = 500 b.cu.m

Using it only 45% of gross cropped area irrigated

Irrigated land in India = 558,080 km^2



Need for Irrigation in India

1. About 80% of the total annual rainfall of India occurs in four months, i.e. from mid-June to mid-October.
2. Monsoons are unpredictable
3. It does not rain equally in all parts of the country
4. Soils of some areas are sandy and loamy and therefore porous for which a major portion of rainwater sinks down very quickly
5. The rain-water flows down very quickly along the slopes of hillsides.
6. In India 70% of people depend on agriculture
7. Reduction of rural poverty
8. Climate change adaptation

Benefits of irrigation

1. Increase in crop yield (nearly increases yield by 5 times)
2. Protection from famine
3. Water Conservation
4. Cultivation of superior crops
5. Elimination of mixed cropping
6. Economic development
7. Increase Farm Income
8. Consistent Quality
9. Crop Diversity
10. Extended Growing Seasons
11. Provide rural employability
12. Hydro power generation
13. Domestic and industrial water supply

Irrigation Methods

1. Based on the sources of water

2. Based on the water application

Based on the sources of water

1. Gravity flow Irrigation

2. Lift Irrigation

Based on the sources of water

Lift irrigation	Gravity flow irrigation
1. Costly means of irrigation 2. Less manorial silt in water 3. Working dependent on operation of machinery 4. Higher water rates. 5. Lift irrigation is a complex system and by and large costly.	Cheapest means of irrigation Silt in water has manorial value Lifting equipment is not involved Lowest water rates Simple and economical system of irrigation.

Classification of Irrigation based on the water application

1. **Surface Irrigation**
2. **Sprinkler Irrigation**
3. **Drip or Trickle Irrigation**
4. **Sub-Surface Irrigation**

Classification of Irrigation based on the water application

1. **Surface Irrigation**
2. **Sprinkler Irrigation**
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1. Surface Irrigation

- In all the surface methods of irrigation, water is either ponded on the soil or allowed to flow continuously over the soil surface for the duration of irrigation.
- Often called *flood irrigation*.
- Generally low water application efficiency
- Not suitable for uneven surfaces
- Most common form of irrigation throughout the world.
- This method of irrigating is covered above 70% land in India.
- Low land preparation and operating costs
- In India farmers familiar with this method


Low levees surrounding

Mulching Irrigation


©Farmers Guardian

Border flooding

Basin flooding

Classification of Irrigation based on the water application

1. Surface Irrigation

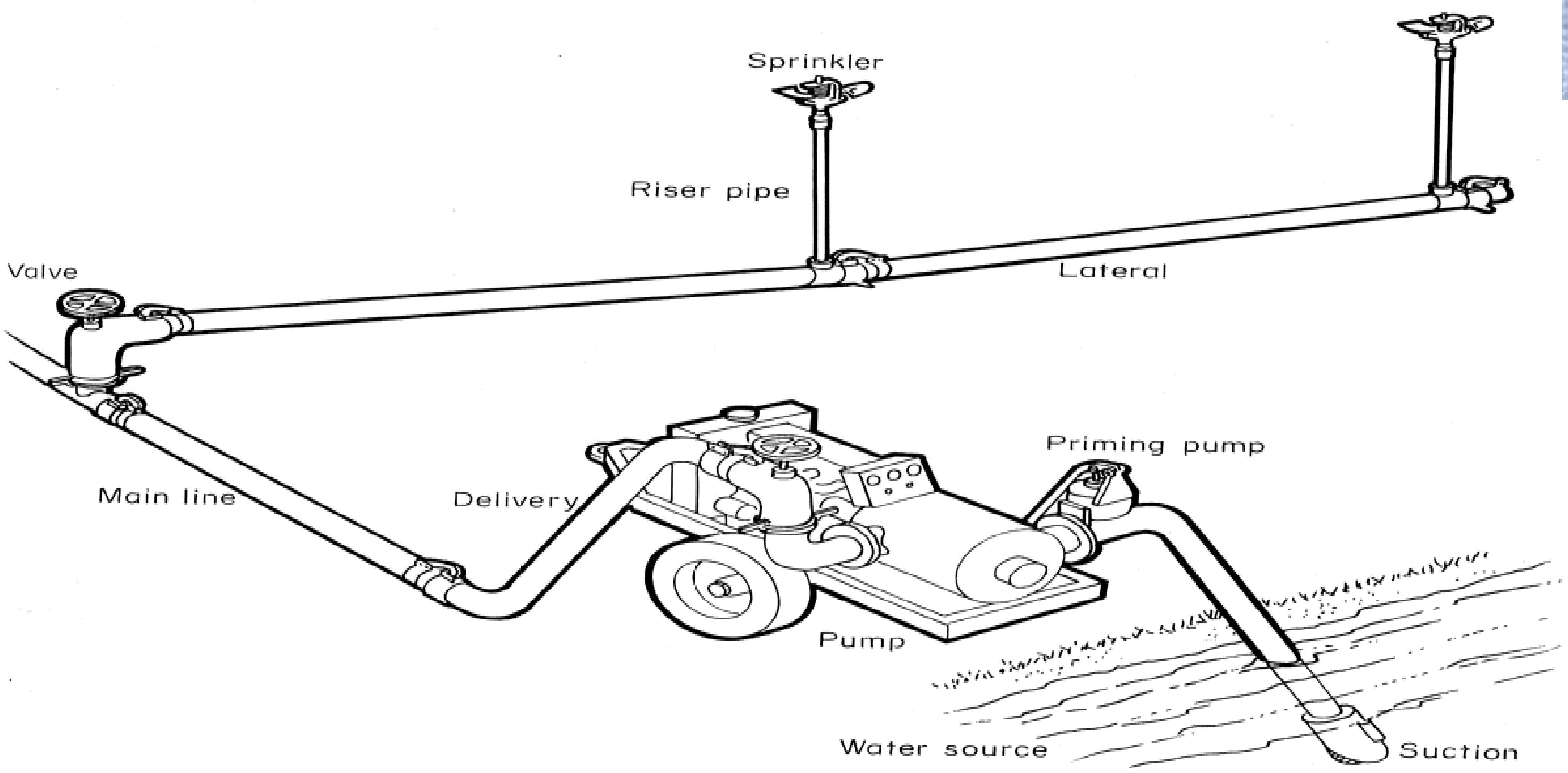
2. **Sprinkler Irrigation**

3. Drip or Trickle Irrigation

4. Sub-Surface Irrigation

Sprinkler Irrigation

- The sprinkler system is ideal in areas where water is scarce.
- A Sprinkler system conveys water through pipes and applies it with a minimum amount of losses.
- Water is applied in form of sprays sometimes simulating natural rainfall.
- The difference is that this rainfall can be controlled in duration and intensity.
- If well planned, designed and operated, it can be used in sloping land to reduce erosion where other systems are not possible.



Sprinkler
Riser pipe
Valve
Lateral
Main line
Delivery
Priming pump
Pump
Water source
Suction

Sprinkler Irrigation

Advantages

- ✓ A Sprinkler system conveys water through pipes and applies it with a minimum amount of losses.
- ✓ Land levelling not required
- ✓ Suitable for sloping ground
- ✓ No loss of land – no ditches, levees etc
- ✓ High water application efficiency about 80%
- ✓ Less labour involvement
- ✓ Less water needed

Disadvantages

- ✓ They are hard to control in windy areas and they wet plant leaves.
- ✓ Initial and operating costs are high
- ✓ Not suitable for crops requiring standing water eg. Rice
- ✓ Required electric power to operate
- ✓ In area of high temperature and high wind velocity, considerable evaporation loss may take place

Sprinkler Irrigation

Center pivot with drop sprinklers in USA

A traveling sprinkler at Millets Farm Centre, United Kingdom.

Classification of Irrigation based on the water application

1. Surface Irrigation

2. Sprinkler Irrigation

3. **Drip or Trickle Irrigation**

4. Sub-Surface Irrigation

Drip or Trickle Irrigation

In this irrigation system:

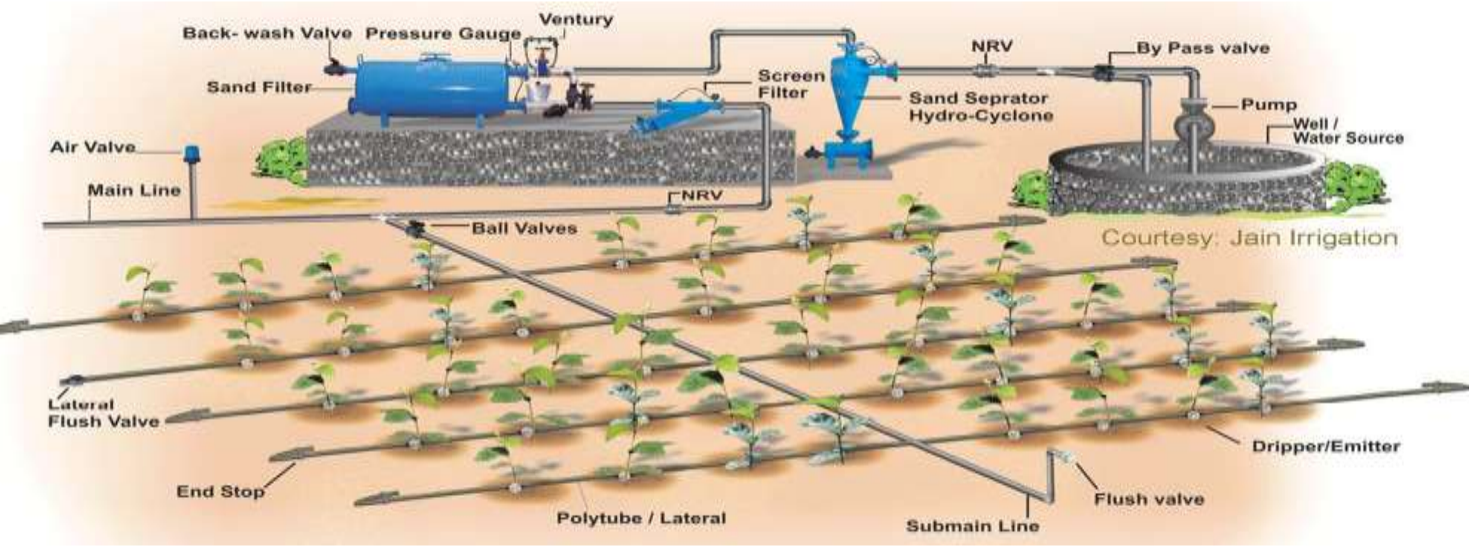
- ✓ Drip irrigation, also known as trickle irrigation, functions as its name suggests.
- ✓ Water is delivered at or near the root zone of plants, drop by drop.
- ✓ This method can be the most water-efficient method of irrigation, if managed properly, since evaporation and runoff are minimized.
- ✓ In modern agriculture, drip irrigation is often combined with plastic mulch, further reducing evaporation, and is also the means of delivery of fertilizer.
- ✓ Weeds are controlled because only the places getting water can grow weeds.
- ✓ There is a low pressure system.
- ✓ There is a slow rate of water application somewhat matching the consumptive use. Application rate can be as low as 1 - 12 l/hr.
- ✓ There is reduced evaporation, only potential transpiration is considered.
- ✓ There is no need for a drainage system.

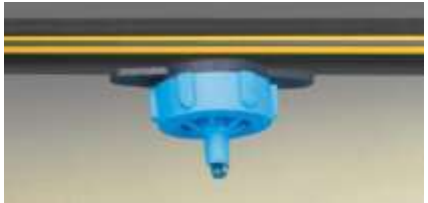
Drip or Trickle Irrigation

The Major Components of a Drip Irrigation System include:

a) **Head unit** which contains filters to remove debris that may block emitters; fertilizer tank; water meter; and pressure regulator.

b) **Mainline, Laterals, and Emitters** which can be easily blocked.





Drip or Trickle Irrigation

Drip or Trickle Irrigation

Advantages

- ✓ Delivers water slowly.
- ✓ Minimizes water loss due to runoff.
- ✓ Low seepage losses
- ✓ Useful in windy areas.
- ✓ Less evaporation.
- ✓ Less splash that may spread fungal.
- ✓ High water application efficiency

Classification of Irrigation based on the water application

1. Surface Irrigation

2. Sprinkler Irrigation

3. Drip or Trickle Irrigation

4. **Sub-Surface Irrigation**



Sub-Surface Irrigation

Irrigation to crops by applying water from beneath the soil surface either by constructing trenches or installing underground perforated pipe lines.

Sub-Surface Irrigation

1. Natural sub-surface irrigation

✓Leakage water from river, channel, canal etc. goes underground and during passage through the sub soil it may irrigate land

✓Sometimes high water table reaches the plant root by capillary action

✓It is an natural process without any additional efforts and coast

2. Artificial sub-surface irrigation

✓ Artificial joint drains laid below surface

✓ Water is supplied to the plant by capillarity

✓ Very costly process

✓ Adopted In India on a very small area

Natural sub-surface irrigation

Artificial sub-surface irrigation

Conditions that favor subsurface irrigation

- An impervious subsoil at a depth of 2 m or more.
- A very permeable subsoil of reasonably uniform texture permitting good lateral and upward movement of water.
- Permeable loam or sandy loam surface soil.
- Uniform topographic conditions and moderate slope.
- Existence of high water table.
- Irrigation water is scarce and costly.
- Soils should be free of any salinity problem.
- *It must be ensured that no water is lost by deep percolation.*

Sub-Surface Irrigation

Suitable crops

- Various types of crops, particularly with shallow root systems are well adapted to subsurface irrigation system.

Advantages

- Maintenance of soil water at favorable tension
- Loss of water by evaporation is held at minimum
- Can be used for soils with low water holding capacity and high infiltration rate where surface irrigation methods cannot be adopted and sprinkler irrigation is expensive.

Sub-Surface Irrigation

Limitations

Presence of high water table.

- Poor quality irrigation water cannot be used-good quality water must be available.
- Chances of saline and alkali conditions being developed by upward movement of salts with water.
- Soils should have a good hydraulic conductivity for upward movement of water.

Classification of Irrigation based on the water application

1. Surface Irrigation
2. Sprinkler Irrigation
3. Drip or Trickle Irrigation
4. Sub-Surface Irrigation

Irrigation Efficiencies

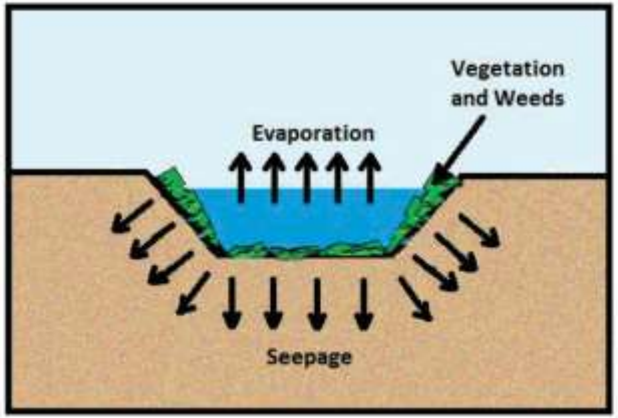
- Efficiency is the water output to the water expressed as percentage

Water losses in canals

1) Deep percolation to soil layers underneath the canals
2) Evaporation from the water surface
3) Seepage through the bunds of the canals
4) Overtopping the bunds
5) Bund breaks
6) Runoff in the drain
7) Rat holes in the canal bunds

Irrigation Efficiencies

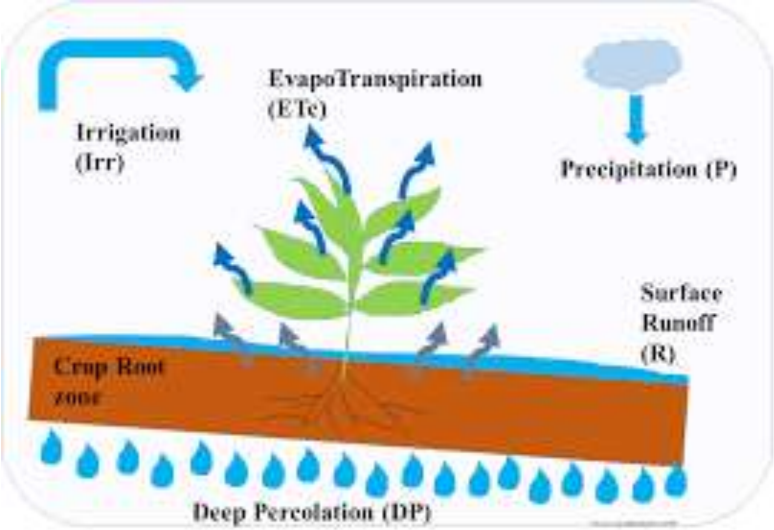
Water losses in canals



Irrigation Efficiencies

Water losses in the field

1. Surface runoff, whereby water ends up in the drain
2. Deep percolation to soil layers below the root zone



Irrigation Efficiencies

1. Water Conveyance efficiency
2. Water application efficiency
3. Water use efficiency
4. Water storage efficiency

Irrigation Efficiencies

- ***Water Conyenance Efficiency***

It indicates the efficiency with which water is conveyed from source of supply to the field. It estimates the conveyance losses. It is expressed as

$$Ec = \frac{Wf}{Wr} \times 100$$

Where,

Ec = Water conveyance efficiency (%)

Wf= Water delivered at the field

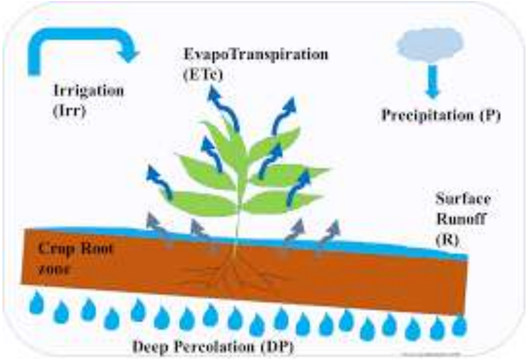
Wr= Water delivered at the source (river)

Irrigation Efficiencies

- ***Water Application Efficiency:***

The percentage of water delivered to the field out of which water stored in the root zone soil.

$$\text{Water application efficiency} = \frac{\text{Water stored in the root zone (Ws)}}{\text{Water delivered to the field (W}f\text{)}} \times 100$$



Irrigation Efficiencies

➢ ***Water use Efficiency:***

Percentage of water delivered to the field that is used beneficially..

$$\text{Water use efficiency} = \frac{\text{Water used beneficially (Wu)}}{\text{Water delivered to the field (W}f\text{)}} \times 100$$

Irrigation Efficiencies

- ***Water Storage Efficiency*:**

This parameter estimates whether the amount of water necessary for the crop is stored in the root zone or not. It is expressed as the percentage of water needed in the root zone prior to irrigation to that stored in the root zone during irrigation.

$$\text{Water storage efficiency} = \frac{\text{Water stored in the root zone}}{\text{Water needed in the root zone}} \times 100$$

Irrigation Efficiencies

Overall Irrigation Efficiency:

Overall irrigation efficiency combines conveyance efficiency, distribution efficiency, and application efficiency to assess the overall effectiveness of the entire irrigation system, from water source to crop root zone. It provides a comprehensive measure of how efficiently water is used in agricultural irrigation practices

$$\text{Overall efficiency} = \frac{\text{Water stored in the root zone}}{\text{Water delivered at the source}} \times 100$$

Irrigation Efficiencies

A value of scheme over all irrigation efficiency **between 50% and 60% is considered good; 40% is reasonable, while a scheme irrigation efficiency of 20%–30% is poor**.

➢Factors affecting Irrigation efficiency

1. Nature of the plant
2. Nature of soil
3. Climatic Conditions
4. Soil Moisture Content
5. Fertilizers
6. Plant population
7. Method of Irrigation
8. Water losses in canals
    1. Deep percolation to soil layers underneath the canals
    2. Evaporation from the water surface
    3. Seepage through the bunds of the canals
    4. Overtopping the bunds
    5. Bund breaks
    6. Runoff in the drain
    7. Rat holes in the canal bunds
9. Water losses in the field
    1. Surface runoff, whereby water ends up in the drain
    2. Deep percolation to soil layers below the root zone

National Water Policy

National Water Policy is formulated by the Ministry of Water Resources of the Government of India to govern the planning and development of water resources and their optimum utilization. The first National Water Policy was adopted in September, 1987. It was reviewed and updated in 2002 and later in 2012.

National Water Policy

➢The major features are National Water Policy 2012

- The main emphasis is to treat water as economic good which the ministry claims to promote its conservation and efficient use
- The privatization of water-delivery services
- To ensure access to a minimum quantity of potable water for essential health and hygiene to all citizens, available within easy reach of the household.
- To curtail subsidy to agricultural electricity users.
- Setting up of Water Regulatory Authority.
- To keep aside a portion of the river flow to meet the ecological needs and to ensure that the low and high flow releases correspond in time closely to the natural flow regime.
- To give statutory powers to Water Users Associations to maintain the distribution system.
- Project benefited families to bear part of the cost of resettlement & rehabilitation of project affected families.
- To remove the large disparity between stipulations for water supply in urban areas and in rural areas.
- To support a National Water Framework Law.

Water pricing

- The set of prices, charges and taxes used to generate revenue and
- The rules and regulations which govern their use
- In July 2010, the UN general assembly proclaimed access to safe drinking water and sanitation as a **human right**. At the same time, water and sanitation are also **economic goods**.
- A **water pricing** is the tariff assigned to water supplied by a public utility generally for both freshwater supply and wastewater collection & treatment.
- Water pricing as an important economic instrument for improving water use efficiency, enhancing social equity and securing financial sustainability of water utilities and operators.
- In many countries consumers pay to little for water services. Revenue from water charges does not even cover operation and maintenance of water utilities, let alone re-investment for the infrastructure.

Water pricing

Residential water pricing , consists of either:

Fixed charge (not based on measured water use)

a) Periodic fixed charge
b) Periodic block-type charge

Volumetric charge (based on measured water use)

a) Uniform price : Single price
b) Block-type structures : two or more prices

Water pricing : Irrigation

Water pricing is a good policy measure for the optimum use of water resource. Water pricing might influence the quantity of consumption of both surface and groundwater. Pricing of water allows the farmers to extract the quantity of water and power necessary to irrigate their land area. Surface water pricing provide the sufficient fund for the proper maintenance of tanks and percolation ponds. These practices facilitate Rain Water Harvesting (RWH) and the conservation of water. The pricing of water selects the suitable crop for the particular type of land and availability of water.

Water pricing : Irrigation

How is the price of irrigation water fixed in India?

- It is one of the sensitive issue in irrigation sector
- No systematic and uniform rules are followed in setting price for irrigation water
- Prices are fixed by a mix of social, economic and political factors

Main Criteria followed for Fixing Water Price

- Farmers ability to pay (determined by output)
- Volume of water used (area irrigated)
- Quality of irrigation (dependability, season)
- Recovery (at least to cover OM cost)

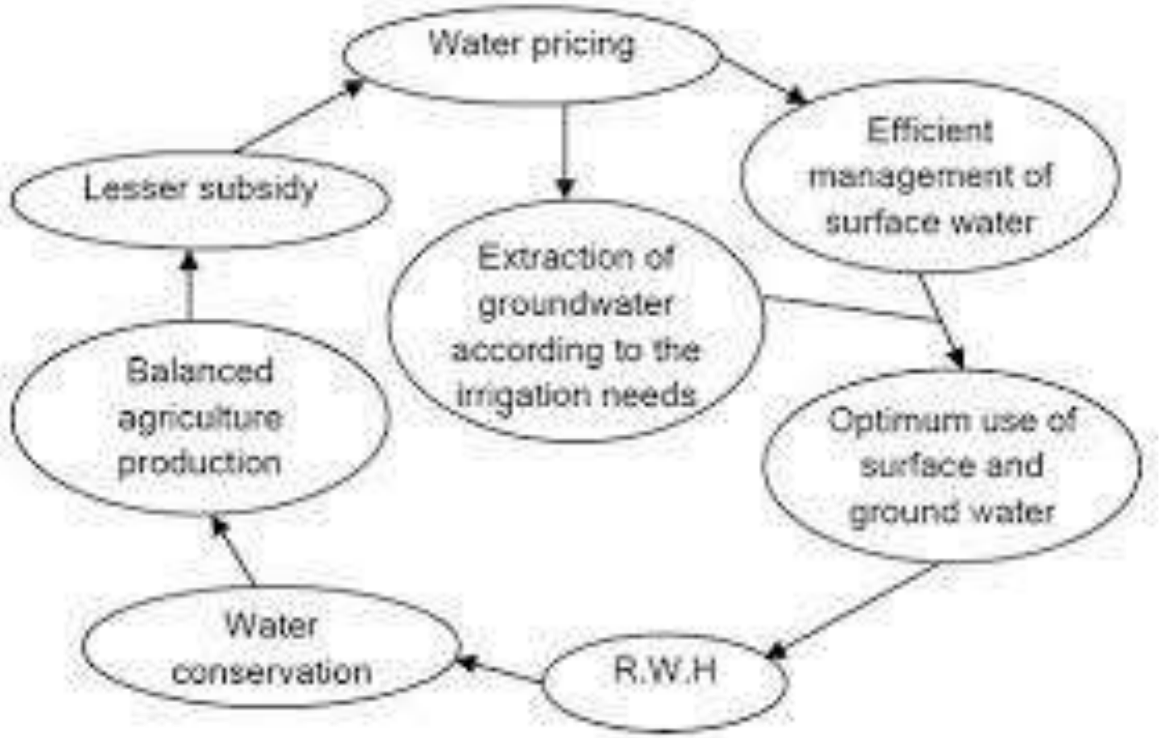
Water pricing : Irrigation

Ideally, irrigation water pricing should be keyed to:

- Type of crops (Food vs. Cash),
- Season and crop water requirement crop
- Type of irrigation method (gravity, lift and drip/sprinkler)
- Land character (Wet vs. Dry) and varies with state
- Type of water sources
- Availability of water
- Financial capacity of farmers
- Scale of irrigation project (large, medium, small) and
- Water resources vulnerability
- Rate is fixed based on area irrigated
- Expected water quality

Water pricing : Irrigation

Benefits of Water Pricing



Virtual water

- Since the Dublin conference in 1992 it is widely accepted that water is a scarce resource that should be treated as an economic good.
- The term ‘virtual water’ was introduced by Tony Allan in the early 1990s (Allan, 1993; 1994).
- The water consumed in the production process of an agricultural or industrial product has been called the 'virtual water' contained in the product (Allan, 1998).

Virtual water

- This water consumption is not apparent to the end-user, but it plays a crucial role in the creation and delivery of the product or service.
- Virtual water is consumed at various stages of the value chain, including the production, processing, manufacturing, and transportation of goods and services.
- Renault (2003) proposes to look at the virtual water content of a proper substitute of the product considered. If the definition of virtual water content is approached in this way, one can even argue that seawater fish contains virtual freshwater even though this fish doesn’t depend on freshwater at all. In order to compute the virtual freshwater content of seawater fish, Renault (2003) proposes to apply the principle of nutritional equivalence, according to which the virtual water content of a product can be calculated as the virtual water content of an alternative product having the same nutritional value.

Virtual water

- If one country exports a water intensive product to another country, it exports water in virtual form.
- For water-scarce countries it could be attractive to achieve water security by importing water-intensive products instead of producing all water demanding products domestically (WWC, 1998).
- In this way some countries support other countries in their water needs. Reversibly, water-rich countries could profit from their abundance of water resources by producing water-intensive products for export.

Virtual water

- Trade of real water between water-rich and water-poor regions is generally impossible due to the large distances and associated costs, but trade in water-intensive products (virtual water trade) is realistic (Hoekstra and Hung, 2002).
- Virtual water trade between nations and even continents could thus ideally be used as an instrument to improve global water use efficiency, to achieve water security in water-poor regions of the world and to alleviate the constraints on environment by using best suited production sites (Turton, 2000).

Virtual water

- During 2014-15, India exported 37.2 lakhs tonnes of basmati rice and to export this India used approximately 10 trillion litres of water. This means India exported 10 trillion litres of water. From India, highest virtual water trade is to Asian countries.

Virtual Water Trade For Achieving Global Water Security

- Tony allan from the beginning of the virtual water debate, virtual water trade can be an instrument in solving geopolitical problems and even prevent wars over water.
- Virtual water trade between nations can be an instrument to increase ‘global water use Efficiency’
- Alternative to real, inter-basin water transfers
- Sustainable and environmentally friendly alternative to real water transfer scheme.
- Store water in its virtual form.
- Tells about environmental impact of consuming this product

Water Pollution from Agricultural Production

- ✓ Agriculture, which accounts for 70 % of water abstractions worldwide, plays a major role in water pollution.
- ✓ Except for water lost through evapotranspiration, agricultural water is recycled back to surface water and/or groundwater.




Water Pollution from Agricultural Production

- ✓ Pollutants from agriculture greatly affect water quality and can be found in lakes, rivers, wetlands, estuaries, and groundwater. Pollutants from farming include **sediments, nutrients, pathogens, pesticides, metals, and salts.**
- ✓ Farms discharge drainage into water bodies or ground water .
- ✓ The resultant water pollution poses demonstrated risks to aquatic ecosystems, human health and productive activities.
- ✓ Nitrate from agriculture is the most common chemical contaminant in the world's groundwater.

Water Pollution from Agricultural Production

Water pollution from agricultural production **occurs** due to various factors inherent in modern farming practices:

1) Intensive farming
2) Mono-cropping
3) Livestock farming
4) Excessive irrigation
5) Soil erosion
6) Lack of buffer zones:
7) Climate change
8) Regulatory gaps
9) Lack of water quality monitoring
10) Lack of farmers awareness
11) Excessive pesticide and fertilizer applications

Water Pollution from Agricultural Production

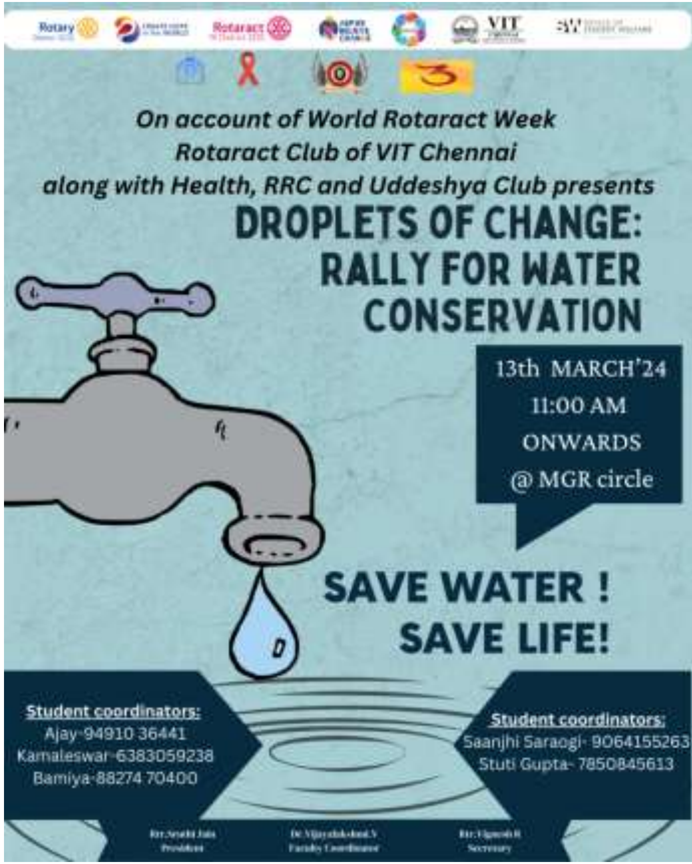
Mitigation measures for Water Pollution from Agricultural Production

- ✓ Conservation tillage
- ✓ Cover crops
- ✓ Crop rotation
- ✓ Precision agriculture
- ✓ Buffer strips and riparian vegetation
- ✓ Nutrient management:
- ✓ Integrated pest management
- ✓ Livestock management practices
- ✓ Irrigation management
- ✓ Erosion control measures
- ✓ Wetland restoration and conservation
- ✓ Education and outreach
- ✓ Regulatory measures
- ✓ Incentive programs

Module: 5	Water Economics	

Economic characteristics of water good and services-Nonmarket monetary valuation methods-Water economic instruments-Policy options for water conservation and sustainable use, pricing, distinction between values and charges- Private sector involvement in water resources management.

Water Economics ????



Water Economics ????

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Water woes | A searing crisis in Karnataka and its IT capital, Bengaluru

As Karnataka battles what is said to be the worst drought in over three decades, read all the special stories and developments related to the crippling water crisis here

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THE HINDU BUREAU

Economic characteristics of water good and services-

Water is the most important natural resource on the planet and without it no human or any other life could survive. Water resources, however, are finite, and in many areas water is becoming increasingly scarce.

In a market economy the allocation of scarce natural resources (such as coal, oil, fish, crops, and timber) is typically determined by trade in markets. However, water resources have a number of unique characteristics which mean that traditional market mechanisms can lead to inefficient and inequitable allocations. This creates questions over whether water should be considered a public or a private good.

Economic characteristics of water good and services-

Water provides goods &

Water provides services

Water plays distinct roles in each context

Economic characteristics of water good and services-

Water is considered an economic good due to several reasons includes:

- Scarcity
- Demand and supply dynamics
- Utility and benefits
- Production costs
- Trade and market transactions
- Sustainability
- Quality standard
- Water availability across space and time
- Promote water treatment and recycling
- Promote rainwater harvesting
- Promote water conservation

Economic characteristics of water good and services-

Challenges in Assessing the Economic Value of Water:

1) The UN designated access to safe drinking water and sanitation as a fundamental human right in 2010, recognizing that water cannot be treated solely as a economic goods to prevent morally unacceptable outcomes affecting survival.
2) However, once basic water needs are met, additional water use becomes discretionary. For instance, household activities such as filling swimming pools, watering lawns, or taking long showers exceed basic needs and are considered private goods. In such cases, optimal allocation, like other private goods, is achieved through market mechanisms.

Economic characteristics of water good and services-

3) Water in its natural state often lacks clearly defined property rights, making it an open access resource or common-pool resource.
4) The absence of ownership leads to the overuse of common-pool water resources, as users withdraw water without considering the impact on availability for others.

According to *Dublin Principles* “Water has an economic value and should be recognized as an economic good, taking into account affordability and equity criteria”

3) This creates questions over whether water should be considered a **public or a private good** .
4) Policy and governance constraints

Economic characteristics of water good and services-

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6) Policy and governance constraints

Economic characteristics of water good and services-

7) Valuation Methodologies
8) Spatial and Temporal Variability
9) Externalities and Non-Market Values
10) Data Limitations and Uncertainties
11) Equity and Distributional Impacts
12) Price varies with purpose of use
13) Price varies with quality standard
14) Price varies with water sources

Nonmarket monetary valuation methods

Valuation of market goods

vs

Valuation of Non-market good

Nonmarket monetary valuation methods

Nonmarket monetary valuation methods for water are techniques used to assign a monetary value to water resources and related ecosystem services that do not have readily observable market prices. These methods are employed to assess the economic importance of water for various uses, including drinking water supply, agriculture, industry, recreation, and ecosystem health. Here are some common nonmarket monetary valuation methods for water:

Nonmarket monetary valuation methods

There are many ways to approach non-market valuation as highlighted as follows:

1) Contingent valuation method (CVM)
2) Travel cost method (TCM)
3) Hedonic pricing method
4) Production function method
5) Damage cost avoided method
6) Replacement cost method

Nonmarket monetary valuation methods

1) **Contingent valuation method (CVM)**
    - Involves surveying individuals or households
2) **Travel cost method (TCM)**
    - Evaluates the expenses incurred travelling to make use of a good, service, or resource

Nonmarket monetary valuation methods

3) Hedonic pricing method

Economic value of water-related amenities, such as water quality, proximity to water bodies, or access to water resources, by examining their influence on property prices in real estate markets.

4) Production function method

Analyzes how the quantity and quality of water inputs affect the production of goods and services in different sectors of the economy.

Nonmarket monetary valuation methods

5) Damage cost avoided method

- Estimates the economic value of water quality improvements by assessing the costs avoided through the prevention or mitigation of water-related damages.

6) Replacement cost method

- Estimates the economic value of water by calculating the cost of alternative water supply or treatment options.

Water economic instruments

Encouraging water users to adopt more sustainable practices is crucial for achieving water security. Economic instruments offer an effective approach to drive this change. These instruments leverage pricing mechanisms and other market-based measures to enhance water management and utilization. By aligning economic incentives with public interest, they motivate water users to employ water judiciously, effectively, and in accordance with sustainability principles. While economic incentives yield positive outcomes by rewarding users who appreciate water's true value, they also discourage wasteful and detrimental water consumption through penalties.

Water economic instruments

Economic instruments are of the following types

a) Tariffs and charges are paid by water users
b) Abstraction charges
c) Water markets
d) Tradable pollution permits
e) Pollution charges
f) Subsidies
g) Payments for environmental services

Water economic instruments

Advantages

1) Efficient resource allocation
2) Conservation incentives
3) Revenue generation
4) Flexibility
5) Tailored solutions
6) Market-based approach
7) Sustainable management
8) Adaptability
9) Cost recovery
10) Investment opportunities

Water economic instruments

Challenges

1) Affordability concerns
2) Equity issues
3) Enforcement challenges
4) Regulatory complexity
5) Inequitable distribution
6) Administrative burden
7) Market distortions
8) Potential for unintended consequences
9) Social disparities
10) Impact on vulnerable communities

Policy options for water conservation

Water conservation policies are crucial for addressing water scarcity, promoting sustainable water management, and safeguarding freshwater resources. These policies typically involve a combination of regulatory measures, incentives, public awareness campaigns, and technological innovations.

- Policy analysts typically categorize water conservation efforts into two primary components: the **supply side** and the **demand side**.

Policy options for water conservation

Water supply-side conservation measures focus on optimizing water availability, identify the source, reducing losses, and improving the efficiency of water supply infrastructure

1) Water infrastructure upgrades
2) Reservoir management
3) Desalination and water recycling
4) Rainwater harvesting
5) Increases water transport efficiency
6) Water Transfer Agreements:
7) Water body and Wetland restoration
8) Non-revenue water reduction
9) Smart water management technologies
10) Water-energy nexus
11) Public awareness and education.

Policy options for water conservation

Water demand-side conservation measures focus on reducing the amount of water used by consumers, businesses, and industries

a) Water-efficient fixtures and appliances
b) Behavioral change programs
c) Landscaping practices
d) Improve irrigation efficiency
e) Rainwater harvesting and grey water recycling
f) Water pricing and incentives
g) Water audits and leak detection
h) Regulations and restrictions
i) Industrial and commercial practices
j) Community engagement

Policy options for water conservation in India

a) Water conservation projects are primarily managed by State Governments due to water being a state subject in India.
b) The Government of India supports these efforts by providing technical and financial assistance through various schemes and programs.
c) Key schemes and programs include MGNREGS, Atal Bhujal Yojana, PMKSY, AMRUT, and others aimed at both rural and urban areas.
d) The Ministry of Jal Shakti has launched the "**Jal Shakti Abhiyan - Catch the Rain**" campaign to promote rainwater harvesting across the country.
e) States and Union Territories are encouraged to utilize grants from the 15th Finance Commission for rooftop rainwater harvesting in government buildings.
f) The Master Plan for Artificial Recharge to Groundwater-2020 aims to construct numerous rainwater harvesting and artificial recharge structures nationwide.

Policy options for water conservation in India

f) The government organizes workshops, seminars, and awards to promote water conservation and rainwater harvesting and encourages public participation.

g) The Central Ground Water Authority advises states to promote and adopt artificial recharge to groundwater/rainwater harvesting.

h) Traditional methods of water conservation and rainwater harvesting vary across regions, and the government promotes best practices and encourages their replication.

i) Overall, the government emphasizes the importance of water conservation and rainwater harvesting through policy measures, financial support, and public awareness initiatives.

Policy options for water sustainable use and pricing

Policy options for promoting sustainable water use and pricing typically aim to balance economic, social, and environmental considerations while ensuring efficient allocation and conservation of water resources.

a) Water pricing mechanisms
b) Subsidy reform
c) Water conservation programs
d) Regulatory measures
e) Integrated water resource management
f) Water rights and allocation
g) Climate change adaptation

Distinction between values and charges

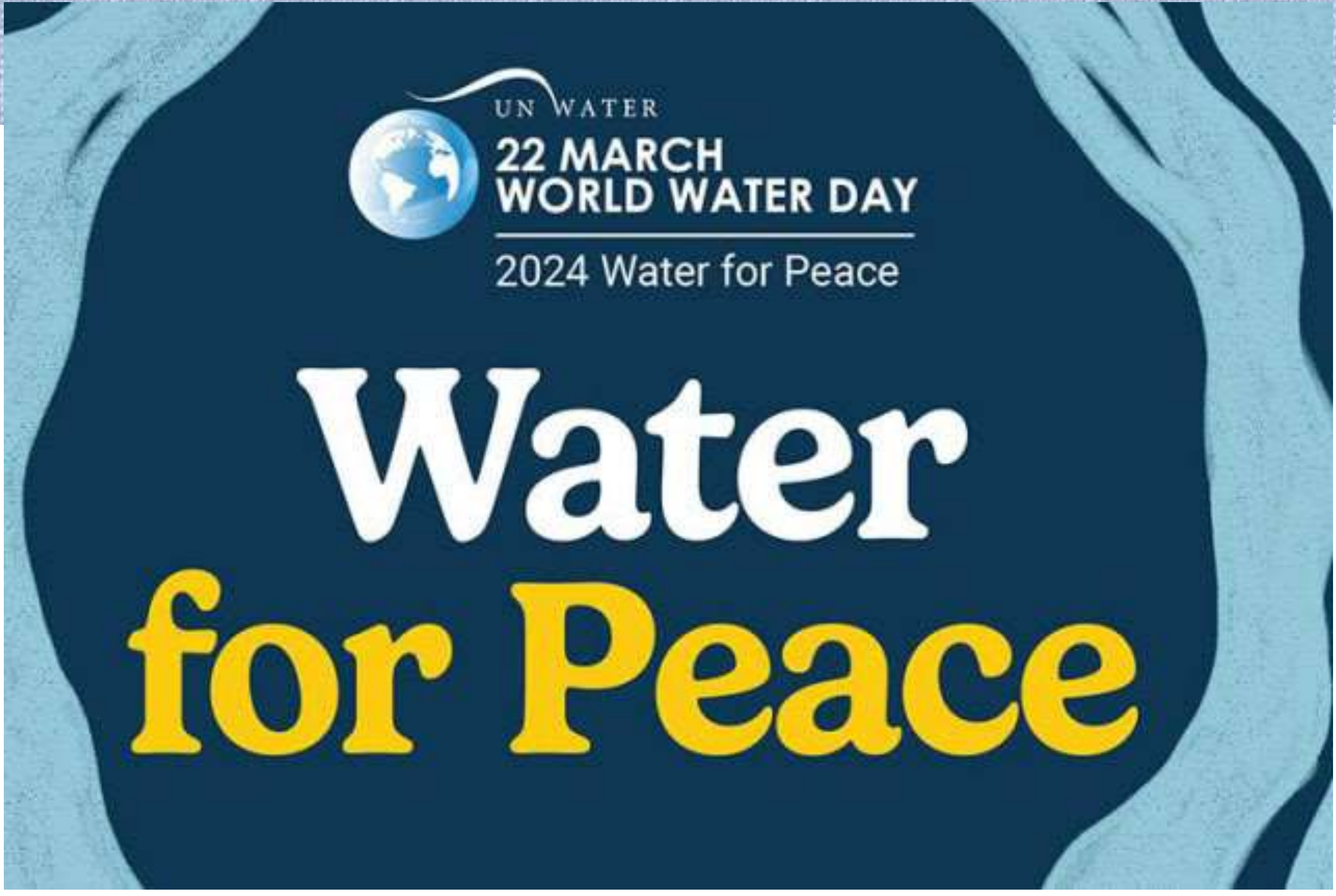
Cost/charges : The expenses incurred by a seller in producing and offering a product or service for sale. This typically includes factors such as raw materials, labor, overhead costs, and any other expenses associated with production and distribution.

Value: The perceived worth of the product or service to the buyer. It is subjective and can be influenced by various factors such as quality, brand reputation, functionality, customer experience, and personal preferences.

Price: The amount of money a buyer pays to acquire a product or service. It's determined by factors such as supply and demand, production costs, competition, and market dynamics.

Policy options for water conservation in India

- **Water values** refer to the broader societal, environmental, and cultural significance of water, including non-economic considerations such as sustainability and equity.
- **Water charges**, on the other hand, are monetary payments for the use or consumption of water, reflecting the economic cost of water supply and management.
- While water values encompass qualitative aspects, water charges are quantifiable and aim to recover the costs associated with water infrastructure and services.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Private sector involvement in water resources management

Private sector involvement in water resources management

Privatisation of water services means transfer of ownership, property or the business of water services from the government to the private sector. This includes services such as operation and maintenance of water services, bill collection, metering, revenue collection, etc.

- Water vital, UN recognizes as human right. 2006 report
- Enough for all, scarcity from mismanagement, corruption, lack of infrastructure.
- Econ process shifts resources to tradable.
- Privatization driven by fear of scarcity, need for efficiency.
- Critics cite state inefficiency, advocate market governance.
- Vandana Shiva: privatization denies poor water rights.

Myths of privatization

There are several myths associated with the concept of privatisation, the most popular being:

- Privatisation saves money.
- Private company does a better job than those in the public sector.
- Privatisation will lead to lower prices and better standards of service.
- Turning the public utilities into private companies results in a dramatic improvement in their performance and efficiency.
- Privatization needs to be accompanied by minimal regulation.
- Privatization allows governmental entities to better anticipate and control budgetary costs.
- Privatization allows governmental entities more administrative flexibility.
- The public still maintains control over a privatized asset or service and the government retains the ultimate ability to make related public policy decisions.
- If anything goes wrong, the government can easily fire the contractor or adjust the contract.
- Companies are chosen for privatization contracts on the merits, not based on political or financial connections.

Background of water privatization: International experience

- Water privatization began in Latin America in the early 1990s and spread globally to developing nations.
- The World Bank and IMF played significant roles by pressuring governments to adopt structural reforms favoring private sector involvement.
- Developing nations faced pressure to privatize water as a condition of receiving loans and through trade agreements.
- The water sector was targeted for privatization through international trade rules established by the WTO and GATS.

Impact of privatization

- Improvement in water service quality.
- Improvement in water production efficiency.
- Diminished water losses.
- Strengthening of management of the water sector,
- Enhancement of customer care.
- Increased water prices
- Exacerbate socioeconomic inequalities
- Lack transparency and accountability
- Profit-driven motives of private companies may lead to over extraction of water resources and inadequate environmental stewardship
- Water privatization has been a source of social conflict

Modes of privatisation

Privatisation of Water Supply and Sanitation (WSS) can be several levels and can be of various types.

1) Service Contracts
2) Lease/Management Contract:
3) Build Own Operate Transfer (BOOT) Contracts
4) Concessions
5) Divestures

Water privatisation in India

- Water privatization in India began in the late 1990s, with the government's collaboration with international financial institutions like the World Bank and Asian Development Bank.
- The entire paradigm of the water sector is seeing modifications manifesting in changes in water policies, laws and institutions.
- Private companies often violate operation standards, leading to price fixing, disconnections, and contamination of water sources, disproportionately affecting the poor.
- The Sheonath river project in Chhattisgarh was one of the initial water privatisation projects in India. Thousands of people protested against the government;s decision to hand over 23 kms of the river to private companies and the banning of the locals from using the river water. In this case, privatisation was not limited to the water service but extended to the river itself.

Water privatisation in India

1) Private Sector Involvement: Major global players like Suez, Vivendi, Thames Water, and Bechtel are involved in numerous privatization projects across India, as documented by organizations like Manthan.
2) Influence of Aid Agencies: Agencies like DFID, AusAID, and USAID advocate for privatization, while centrally sponsored initiatives like JNNURM mandate urban reforms, potentially including water privatization, for receiving funds.
3) Irrigation Sector: Privatization extends to canal operations and comprehensive schemes, often under the guise of Participatory Irrigation Management (PIM).
4) Future Trends: Concepts like tradable water entitlements and pollution permits raise concerns about the potential concentration of water resources among those with purchasing power.

Module: 6	Water Legal and Regulatory Settings	

National and International Framework for Water Law; Basic structure of water law- An overview of water law in India

-Evolution of water law, key features of water law, evolving water law and policy-Water policy for Irrigation, decentralization and participation in irrigation management, and the policy measures proposed to establish water user associations. National level initiatives for regulation of groundwater, State groundwater laws and rainwater harvesting.

International Framework for Water Law

The International Framework for Water Law encompasses a set of principles, agreements, and guidelines designed to govern the management, allocation, and protection of water resources on a global scale. It aims to provide a cohesive framework for addressing water-related challenges, promoting cooperation among nations, and ensuring equitable access to water for all stakeholders. This framework may include treaties, conventions, protocols, and other legal instruments that establish norms and standards for the sustainable use and conservation of water resources across international boundaries.

International Framework for Water Law

Key guidelines for the International Framework for Water Law typically include:

Equitable Allocation: Ensuring fair distribution of water resources among different users, regions, and countries, taking into account social, economic, and environmental factors.

Sustainable Management: Promoting the sustainable use and management of water resources to meet current needs without compromising the ability of future generations to meet their own needs.

Cooperation and Collaboration: Encouraging cooperation and collaboration among riparian states and other stakeholders to address transboundary water issues, resolve disputes, and implement joint management strategies.

Protection of Ecosystems: Recognizing the intrinsic value of aquatic ecosystems and establishing measures to protect and restore them, including maintaining water quality, preserving habitats, and promoting biodiversity.

International Framework for Water Law

Participation and Engagement: Facilitating the participation of all relevant stakeholders, including local communities, indigenous peoples, and marginalized groups, in decision-making processes related to water management and governance.

Adaptation to Climate Change: Incorporating measures to adapt to the impacts of climate change on water resources, such as increasing variability in precipitation patterns, rising temperatures, and changing hydrological cycles.

Compliance and Enforcement: Establishing mechanisms for monitoring, compliance, and enforcement to ensure that water-related laws, regulations, and agreements are effectively implemented and adhered to by all parties involved.

Data Sharing and Information Exchange: Promoting the exchange of data, information, and expertise among countries and stakeholders to improve water resource management, enhance decision-making, and build mutual trust and confidence.

Conflict Resolution: Providing mechanisms for the peaceful resolution of disputes over water resources, including negotiation, mediation, arbitration, and adjudication, with the goal of preventing conflicts and promoting stability and cooperation.

National Water Policy

National Water Policy is formulated by the Ministry of Water Resources of the Government of India to govern the planning and development of water resources and their optimum utilization. The first National Water Policy was adopted in September, 1987. It was reviewed and updated in 2002 and later in 2012.

National Water Policy

- The major features are National Water Policy 2012

•The main emphasis is to treat water as economic good which the ministry claims to promote its conservation and efficient use

•The privatization of water-delivery services

•To ensure access to a minimum quantity of potable water for essential health and hygiene to all citizens, available within easy reach of the household.

•To curtail subsidy to agricultural electricity users.

•Setting up of Water Regulatory Authority.

•To keep aside a portion of the river flow to meet the ecological needs and to ensure that the low and high flow releases correspond in time closely to the natural flow regime.

•To give statutory powers to Water Users Associations to maintain the distribution system.

•Project benefited families to bear part of the cost of resettlement & rehabilitation of project affected families.

•To remove the large disparity between stipulations for water supply in urban areas and in rural areas.

•To support a National Water Framework Law.

Key features of water law

The principal characteristics of water law in India include:

1) **Dual Ownership**
2) **Federal Structure**
3) **Riparian Rights**
4) **Prior Appropriation Doctrine**
5) **Regulatory Framework**:
6) **Public Trust Doctrine**
7) **Community-Based Management**

National Water Policy

Recent reforms in India's water law have been driven by following factors:

Water Scarcity and Pollution: Increasing water scarcity and pollution levels in many parts of the country have necessitated reforms to enhance water management practices and ensure sustainable use.

Inter-State Water Disputes: Disputes over the sharing of inter-state rivers, such as the Cauvery and Krishna rivers, have highlighted the need for a more robust legal framework and dispute resolution mechanisms.

Climate Change: The impacts of climate change, including altered precipitation patterns and increased frequency of extreme weather events, have underscored the importance of adaptive water management strategies.

National Water Policy

Urbanization and Industrialization: Rapid urbanization and industrial growth have put pressure on water resources, leading to the need for regulations to prevent overexploitation and pollution.

International Commitments: India's international commitments, such as the Sustainable Development Goals (SDGs) and international agreements on climate change, necessitate reforms to align domestic water laws with global standards and best practices.

Technological Advancements: Advances in technology, such as remote sensing and Geographic Information Systems (GIS), have enabled more accurate assessment and monitoring of water resources, driving the need for updated regulations to incorporate these tools.

National Water Policy

Public Awareness and Advocacy: Increased public awareness of water-related issues, coupled with advocacy efforts by civil society organizations, has exerted pressure on policymakers to enact reforms that prioritize equitable access to water and environmental sustainability.

Increased population
Water availability
Sustainability initiatives
Improved service life
The River-Linking Projects
Human Rights
Social and Environmental Aspects of Water

Overall, recent reforms in India's water law aim to address emerging challenges while promoting efficient and sustainable water management practices across the country

Decentralization and Participation in Irrigation Management

Decentralization primarily refers to the distribution of authority, responsibility, and decision-making power from a central/state level to local levels. In the context of irrigation management, decentralization involves transferring control over water resource management, infrastructure development, and decision-making processes from central government agencies to local stakeholders, such as communities, user groups, or regional authorities. Decentralization aims to empower local actors, leverage local knowledge, and tailor management practices to the specific needs and conditions of different regions or communities .

Participation, on the other hand, focuses on the involvement of stakeholders in decision-making processes. It emphasizes engaging a diverse range of actors, including farmers, water users, local communities, government agencies, NGOs, and other relevant parties, in the planning, implementation, and evaluation of irrigation projects and policies. The goal of participation is to ensure that the voices and perspectives of those affected by irrigation decisions are heard and considered, leading to more inclusive, equitable, and sustainable outcomes.

Decentralization and Participation in Irrigation Management

Decentralization can facilitate participation: By devolving decision-making authority to local levels, decentralization creates opportunities for greater stakeholder participation in irrigation management.

Participation supports effective decentralization: Active stakeholder participation helps ensure that decentralized decision-making processes are transparent, accountable, and responsive to the needs of local communities.

National level initiatives for regulation of groundwater

The Indian government has recognized the importance of regulating groundwater to address issues of over-extraction, depletion of aquifers, and water scarcity. Over the years, several initiatives and policies have been implemented to regulate groundwater usage and promote sustainable management practices. Here are some key initiatives undertaken by the Indian government:

The National Water Policy (2012)

The National Water Mission (NWM)

The Central Ground Water Board (CGWB)

The Groundwater Management and Regulation Scheme

The National Hydrology Project (NHP)

The Atal Bhujal Yojana (ABHY)

Rainwater Harvesting and Artificial Recharge of Groundwater

State-Level Initiatives

Module: 7	Demand Management	

Balancing supply and demand-Economic theory of supply and demand-management by use of tariffs-Timing, long- term, operational time-frame-Crisis management-Cost of water-Future trends-Economic value of water-Loss control- Water harvesting.

Rain Harvesting

Rain Harvesting

The availability of water on Earth is theoretically sufficient to meet the needs of its population. However, the challenges lie in the distribution of water in terms of space, time, and affordability.

Annual global river runoff	**= 40,000 km^3**
Annual global domestic use	= 200 km^3
Annual global industry use	= 2000 km^3
Annual global agriculture use	= 4000 km^3

Rain Harvesting

- Rainwater harvesting (RWH): technology used for collecting and storing rainwater for human use from rooftops, land surfaces or catchments.
- One of the world's most important ancient water supply techniques (practiced for more than 4,000 years), is beginning to enjoy a resurgence in popularity.
- Rainwater is an important water source in many areas with significant rainfall but lacking any kind of conventional, centralised supply system.
- Rainwater is also a good option in areas where good quality fresh surface water or groundwater is lacking.
- It could be used as a supplement to piped water supply e.g. for toilet flushing, washing and garden spraying
- RWH is a decentralised, environmentally sound solution, which can avoid many environmental problems often caused in centralised conventional large-scale water supply projects.

Basic Components of RWH

1. Rainfall

2. Collection of water from surface catchment

3. Water storage or Groundwater Recharge

4. Distribution of water

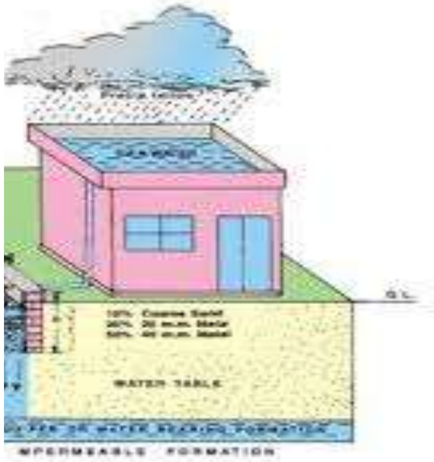
Rain Harvesting : Storage

1. Store in tanks, sums, reservoir, pond, check dam, lake, etc
2. Recharge the under groundwater

Rainwater Harvesting - Techniques

1. Capturing runoff from rooftops – Roof water harvest
2. Capturing runoff from local catchments – Land harvest
3. Capturing seasonal rain waters from local streams
4. Conserving rain water through watershed management

Capturing runoff from rooftops



Gutter

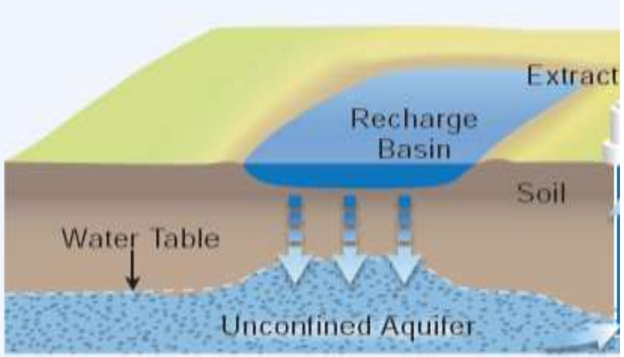
Downspout

Capturing runoff from rooftops

This method of rainwater harvesting involves collecting rainwater directly from rooftops, which serve as the catchment area.

1) **Catchment area (roof)**: decide which portion of your roof will collect rainwater. Ensure the roof material is suitable for harvesting (avoid asbestos & painting in roofs).
2) **Gutters and downspouts**: install gutters along the edges of the roof to collect water and direct it to downspouts.
3) **Filters and screens**: use mesh screens to prevent debris from entering the storage tank. Install a first flush diverter to divert initial runoff that contains pollutants.
4) **Storage tanks**: Assessing water needs (i.e. demand) and potential collection capacity (i.e. availability) is a crucial step in designing an effective rainwater harvesting system at home. This assessment helps determine the necessary storage capacity for harvested water.

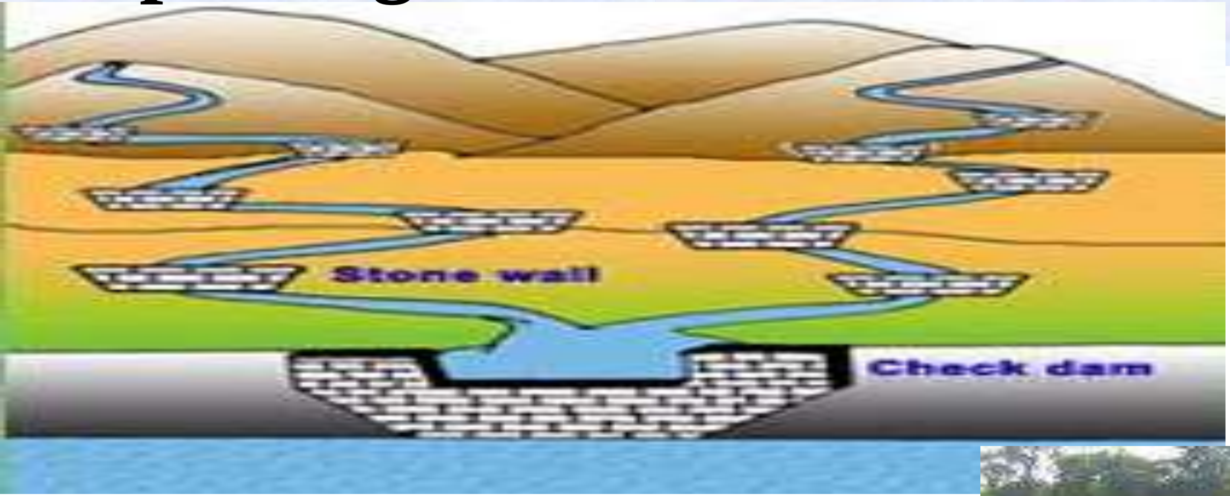
Capturing runoff from local catchments – Land harvest



Capturing runoff from local catchments – Land harvest

Capturing runoff from local catchments involves various methods to collect and manage rainwater from various surfaces like roads, parking lots, and open land before it enters larger water systems. Techniques include constructing retention ponds, installing vegetated ditches, building rain gardens, and implementing permeable pavement. These approaches help mitigate flooding, improve water quality, and enhance groundwater recharge in urban and suburban areas.

Capturing seasonal floodwaters from local streams



Check Dam

Capturing seasonal rain waters from local streams

- Capturing seasonal rainwaters from local streams with check dams involves strategically placing low, temporary barriers across the stream channel to slow down water flow and allow sediment deposition.
- Diverting water into floodplain areas or using detention basins or ponds helps absorb floodwaters by providing temporary storage and allowing gradual release.
- These techniques technique helps retain water during floods, reducing downstream erosion and providing opportunities for groundwater recharge and soil moisture retention.

Conserving rain water through watershed management

Conserving water through watershed management

- Conserving rainwater through watershed management via dams and reservoirs involves capturing and storing excess rainfall for later use.
- Dams are built across rivers to create reservoirs, which store water during rainy seasons and release it gradually during dry periods.
- This stored water serves various purposes, including irrigation, drinking water supply, flood control, hydropower generation, and recreation. By strategically managing water resources in this way, communities can enhance water security, mitigate floods, and support sustainable development.
- Shortcomings in this approach include large submergence of land, environmental disruption, social displacement, siltation reducing storage capacity, water allocation conflicts, vulnerability to climate change, high construction coast, and operational complexities.

Advantages of implementing rain-water harvesting

These techniques can serve the following the following purposes:

Reduced Water Bills: Rainwater harvesting systems are cost-effective, provide high-quality water, lessens dependence on wells and are considerably easy to maintain since they are not utilized for drinking, cooking or other sensitive uses.

Ecological benefit: Storing water underground is environment-friendly. The ecological benefits of rainwater harvesting are immense.

Reduces erosion and flooding around buildings: It reduces soil erosion and flood hazards by collecting rainwater and reducing the flow of storm water to prevent urban flooding.

An adequate means for Irrigation purpose: Harvesting rainwater allows the collection of large amounts of water and mitigates the effects of drought.

Reduces demand on Ground Water: Another vital benefit is that it increases the productivity of aquifer resulting in the rise ofgroundwater levels and reduces the need for potable water

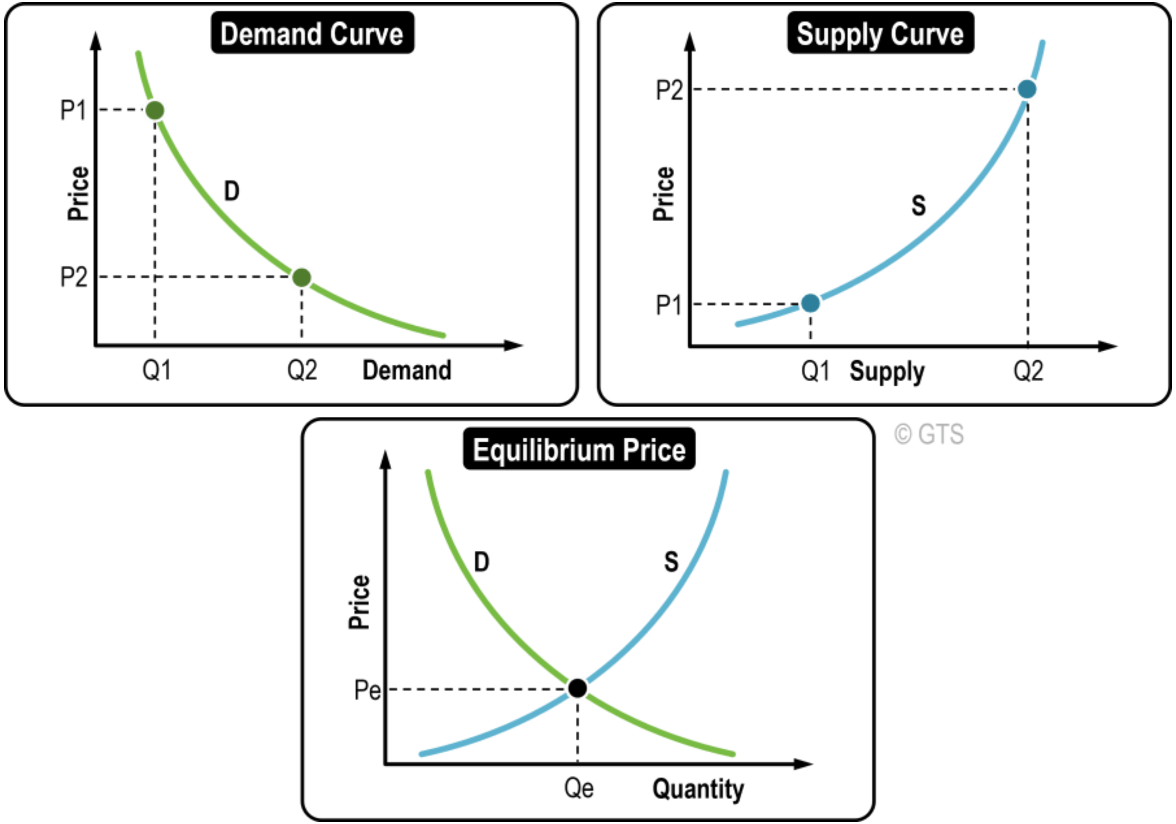
Advantages of implementing rain-water harvesting

- ✓ Provides self-sufficiency to water supply
- ✓ Reduces the cost for pumping of groundwater
- ✓ Provides high quality water, soft and low in minerals
- ✓ Improves the quality of ground water through dilution when recharged
- ✓ Reduces soil erosion in urban areas
- ✓ Rooftop rain water harvesting is less expensive
- ✓ Rainwater harvesting systems are simple which can be adopted by individuals
- ✓ Rooftop rain water harvesting systems are easy to construct, operate and maintain.
- ✓ In hilly terrains, rain water harvesting is preferred
- ✓ In saline or coastal areas, rain water provides good quality water and when recharged to groundwater, it reduces salinity and also helps in maintaining balance between the fresh-saline water interface

Limitations of RWH

- Complex constructions, there is a requirement for high costs, trained professionals.
- Maintenance costs may add to the monetary burden.
- If not maintained properly then it can cause various problems in terms of algal or bacterial growth.
- The water availability is limited by the rainfall intensity and available roof area.
- Mineral-free rainwater has a flat taste, which may not be liked by many.
- The poorer segment of the population may not have a roof suitable for rainwater harvesting.
- Domestic RWH will always remain a supplement and not a complete replacement for city-level piped supply or supply from more ‘reliable’ sources.

Balancing supply and demand by use of tariffs



Balancing supply and demand by use of tariffs

- A fundamental concept in economics is the law of supply and demand. According to the law, as the price of water increases (moving along the supply curve from left to right), producers are willing to supply more water because they can earn higher revenue from each unit sold. This relationship reflects the positive correlation between price and quantity supplied.
- Conversely, as the price of water increases (moving along the demand curve from left to right), consumers' demand for water decreases because higher prices make water more expensive relative to other goods and services. This relationship reflects the inverse correlation between price and quantity demanded.
- With increasing price, the reduction decreases because further reductions may require changes in behavior that are inconvenient or contrary to personal or social norms. And at even higher prices, there will be no reduction at all if it means cutting into essential uses like cooking and waste disposal. At low prices people will buy and use more water, but there is a limit on how much water anyone can use, even if it is free. So again as price falls, demand eventually drops off as well

Balancing supply and demand by use of tariffs

- The point where the supply and demand curves intersect represents the equilibrium price and quantity of water in the market. At this equilibrium point, the quantity of water supplied by producers matches the quantity demanded by consumers, resulting in market equilibrium. Changes in supply or demand conditions can shift the equilibrium point, leading to changes in the equilibrium price and quantity of water exchanged in the market.
- Overall, the law of supply and demand provides insights into the pricing mechanism and allocation of water resources in the market, highlighting the interplay between producers' willingness to supply water at different prices and consumers' willingness to demand water at those prices.

Timing of water tariff establishment

There are three stages during which the tariff for water needs consideration.

a) Long-term (planning and design)
b) Operational time-frame
c) Crisis management

Timing of water tariff establishment

Long-term (planning and design)

Capital Cost Evaluation: Before constructing a water scheme, the primary economic concern is the capital cost of the project. This includes the cost of building dams, conduits, and other infrastructure required for the scheme.

Running Costs Addition: The average running costs of operating the water scheme are added to the discounted capital cost of various alternative schemes. This helps in selecting the most economical option among different alternatives.

Rationing Consideration: If rationing (limiting the amount of water available to consumers) is being considered as an alternative to building larger resource schemes, its economic implications need to be evaluated. This involves assessing the true economic cost to consumers due to water shortfall.

Consumer Economic Cost: The economic cost to consumers due to water shortfall should be taken into account. This goes beyond just the income generated for the water supplier, as consumers may face additional expenses or inconveniences due to water shortages.

Timing of water tariff establishment

Operational time-frame

After a water scheme is commissioned, there's a shift in perspective as day-to-day operations and annual supply rates come into play.

Tariff Revision: With the commissioning of the water scheme, annual supply rates typically change. This may lead to tariff revisions, as the supply rate increases or decreases.

Operational Policy for Reservoirs: An operational policy for reservoirs may be designed to conserve water during droughts or periods of low supply. This policy could involve controlling usage through tariffs, among other measures.

Tariff Structure: The tariff structure may be consumer-oriented or tiered. A consumer-oriented tariff typically charges a fixed rate regardless of usage, while a tiered tariff system charges different rates based on levels of consumption

Timing of water tariff establishment

Crisis management

During a water shortage crisis (i.e. drought), authorities often face the challenge of meeting fixed costs while managing reduced water supply. Here are some crisis management strategies that can be considered. The tariff may have to be increased. Here are some crisis management strategies that can be considered:

Penalties Tariffs: Authorities may impose higher tariffs or penalties on water usage above a certain threshold to discourage excessive consumption during shortages. This approach aims to incentivize water conservation and generate additional revenue to cover fixed costs.

Purchase System: In a free market scenario, consumers could negotiate and purchase different allocations of water among themselves. This system allows for flexibility and efficient allocation of available water resources based on individual needs and preferences.

Timing of water tariff establishment

Crisis management

Shortfall Surcharge: To cover fixed costs despite lower water sales, water authorities may implement a shortfall surcharge by increasing tariffs in proportion to the shortfall in revenue. This ensures that the costs of providing water services are adequately covered, even during periods of reduced consumption.

Each of these strategies has its advantages and challenges. Implementing a combination of approaches, tailored to the specific circumstances and needs of the community, can help authorities effectively manage water shortages while ensuring the financial sustainability of water utilities. Additionally, public communication and stakeholder engagement are essential to garner support for these measures and promote water conservation behaviors among consumers.

Cost of Water

To control use of water by means of tariffs requires estimating the marginal value of water as well as the marginal cost.

- Capital costs
- Operating and maintenance costs
- Quality control, purification, pressure maintenance, supply rate including back-up for droughts.
- Funding of indirect projects such as redistribution of wealth or national improvement in health and economy.
- Deterrents for conserving resources such as a premium to reduce usage of water.
- Components to pay for environmental protection or reclamation.
- Community funding including training.
- Reserves for future expansion and to ensure continuity of supply or jobs.
- To cross-fund, e.g. other department’s shortfalls, or redistribution of charges.