# Advancing Groundwater Recharge: Harnessing Man-Made Conveyances for Sustainable Aquifer Enhancement

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**ABSTRACT**

The process of improving naturally occurring groundwater supplies by means of artificial conveyances such as infiltration basins, trenches, dams, or injection wells is known as groundwater recharge. One particular kind of recharge that increases groundwater resources and recovers water for later use is called aquifer storage and recovery, or ASR. Water moves through the saturated zone in a complicated process that might be facilitated by hydraulic or gravity forces. Large errors in recharge estimates and unmetered groundwater consumption are common in groundwater modeling studies, and these can have an influence on ecosystems that depend on groundwater, extractive industries, and sustainable yields. In order to artificially recharge aquifers, surface water is placed in basins or furrows, where it seeps into the ground and descends to replenish it. Permeable surface soils are necessary for this technique, which is being employed more and more for subterranean storage. Test basins and field research are required to forecast system functionality. The quality of the water is assessed, with a focus on geochemical reactions in the aquifer and fouling layers on basin bottoms. Periodically pump recharge wells to backwash clogging layers.

*Keywords- Water, Groundwater, Recharge, Aquifer, Sustainability*

## 1. INTRODUCTION

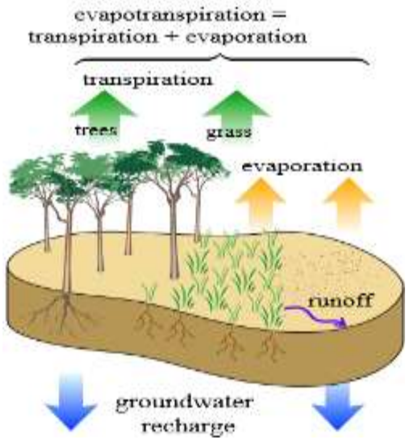
The growing global population, expansion of irrigated agriculture, and economic development are contributing to an escalating worldwide demand for water resources. While surface water sources can potentially meet this demand, regional disparities result in water scarcity issues in various parts of the world. Currently, more than 2 billion people, equivalent to 35% of the global population, grapple with severe water stress. In regions prone to recurring water stress and possessing vast aquifer systems, groundwater often serves as an additional water supply. However, if the rate of groundwater extraction surpasses the rate of groundwater replenishment over extensive areas and an extended period, it can lead to overexploitation or persistent groundwater depletion. Replenishing groundwater or aquifers is imperative, encompassing natural recharge as part of the natural hydrological cycle, as well as human-induced recharge, achieved either directly through methods like spreading basins or injection wells, or indirectly due to human activities such as irrigation and waste disposal. The practice of artificial recharge with surplus surface water or treated wastewater is on the rise in various regions, playing an increasingly significant role within the overall hydrological cycle.

Evaluating the water quality prior to recharge plays a pivotal role in evaluating the risks linked to human exposure to chemical pollutants and pathogenic microorganisms that might be present in the source water. The depletion of groundwater can yield devastating consequences, impacting natural streamflow, groundwater-dependent wetlands, and ecosystems. In deltaic regions, this depletion may result in land subsidence and the intrusion of saltwater.

The report offers a comprehensive global assessment of groundwater depletion, achieved by analyzing groundwater recharge through a global hydrological model and deducting estimates of groundwater extraction. The analysis is specifically focused on regions with sub-humid to arid climates to mitigate issues tied to increased discharge capture and enhanced recharge resulting from groundwater pumping. Furthermore, the report examines the challenges and uncertainties linked to the artificial recharge of groundwater using source waters of compromised quality. This adds an additional dimension to the practice of groundwater recharge and its associated techniques.

# 1.1 GROUND WATER RECHARGING

Groundwater recharge, also known as deep drainage or deep percolation, is a hydrological process characterized by the downward movement of water from surface sources to replenish underground water reserves. It serves as the primary means through which water enters an aquifer and typically takes place in the vadose zone, which is located below the depth reached by plant roots. This phenomenon is usually quantified as water flowing towards the surface of the water table. Groundwater recharge also encompasses the movement of water into the deeper regions of the saturated zone, moving away from the water table. Recharge is a multifaceted process, occurring both naturally as a part of the water cycle and through human activities, often referred to as "artificial groundwater recharge." In the latter case, methods involve diverting rainwater or treated water into the subsurface to enhance groundwater resources.




(source: - google)
Figure 1. Evapotranspiration

### 1.2 NEED FOR GROUND WATER RECHARGING

Natural recharge can vary from being virtually non-existent to capturing almost all of the runoff from a specific drainage area. In cases where water resources are available, artificial recharge methods can be utilized to supplement the natural recharge processes. The application of recharge procedures should be tailored to fit the specific conditions of a particular situation. In this Technical Release, our primary focus will be to provide an overview of general procedures and methods. For more comprehensive and detailed information on the various phases of groundwater recharge, we recommend referring to the listed references.

Additional guidance on service policies and groundwater studies can be located in Hindering Memorandum 51, the Watershed Protection Handbook, as well as Sections 8, 15, 16, and 18 of the National Engineering Handbook. Moreover, valuable insights are offered through various guides and memoranda prepared by the Regional Technical Service Centers and individual states. A list of pertinent technical books, reports, and research studies can be found in the concluding section of this Technical Release. The technical aspects of drilling, testing, sampling, permeability assessments, groundwater hydrology, hydraulics, and economic evaluations are comprehensively covered in the referenced materials, and will only be further explained where they have specific relevance to groundwater recharge.

**1.3 OBJECTIVES**

1. To guarantee the controlled utilization and efficient, responsible management of groundwater resources.

2. To execute extensive, integrated groundwater recharge programs.

3. To efficiently implement the coordinated use of both surface water and groundwater.

4. To pinpoint regions with groundwater contamination, ensuring the provision of safe drinking water supplies.

**1.4 SCOPE AND LIMITATION OF STUDY**

**1.4.1 SCOPE:**

Groundwater plays a central role in fulfilling the daily water needs of both urban and rural communities, particularly in areas where surface water sources are scarce. Groundwater extraction is a year-round activity, leading to an ongoing reduction in groundwater levels and the consequent environmental repercussions. To tackle this challenge and establish a sustainable balance between groundwater usage and replenishment, a project has been launched. The project is centered on the college campus and has been shaped by research conducted in three distinct study areas. The insights from these studies inform the strategies implemented for the effective management of groundwater resources.

**1.4.2 LIMITATIONS:**

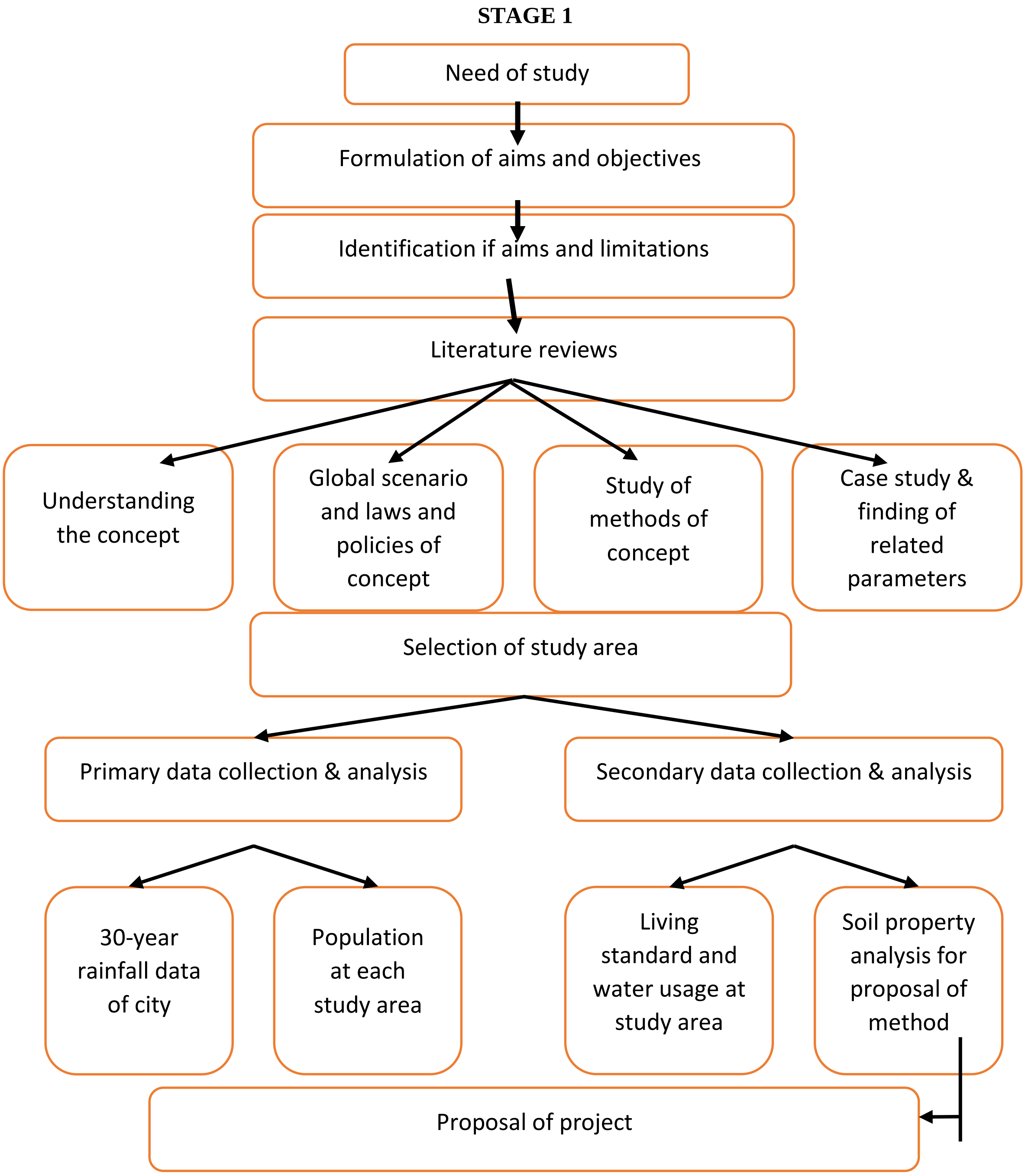
This project presents a particular challenge that revolves around the essential procedures to ensure the safety, cleanliness, and convenience of water.

• This entails the identification of a suitable catchment area for rainwater collection and the establishment of a network of pipes or channels for directing the collected water into the ground. It also requires the implementation of a diversion system to preserve water purity and facilitate filtration.

• Additionally, the project's feasibility is contingent upon the local climate conditions. In regions with consistent and abundant rainfall, the groundwater catchment system is relatively straightforward and uncomplicated. However, in many areas, the rainy seasons can be highly unpredictable, resulting in periods when residents may face water shortages.

• It's important to emphasize that this project is specifically designed for Dhule city, where the unpredictability of the rainy season is a key consideration. As indicated in Table 3.1, there are significant variations in annual rainfall in the area.

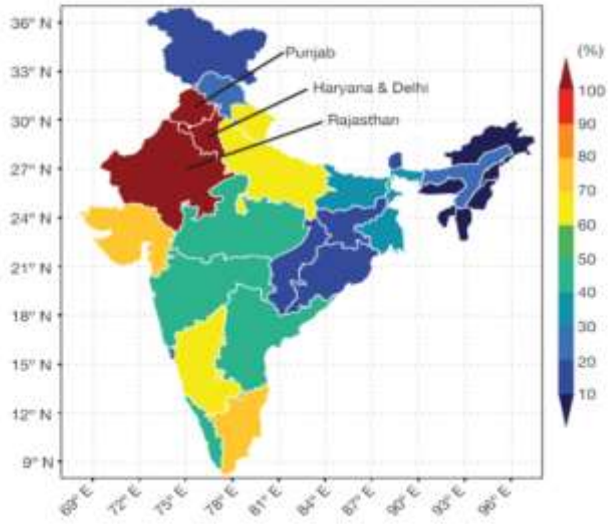
**1.5 METHODOLOGY:**




**2.1 INDIAN SCENARIO**

Groundwater in the Indian states of Rajasthan, Punjab, Haryana, and Delhi is experiencing a depletion rate of approximately 4.0 +/- 1.0 centimeters per year (equivalent to a height of water), which amounts to around 17.7 +/- 4.5 cubic kilometers per year. This depletion is equivalent to a net loss of 109 kilometers of water, which is double the capacity of India's largest surface-water reservoir. The available evidence strongly suggests that the unsustainable utilization of groundwater for irrigation and various human activities is the likely cause. If immediate measures are not implemented to ensure the sustainable use of groundwater, the region's 114 million residents may face consequences such as reduced agricultural productivity and drinking water shortages, leading to significant socioeconomic pressures.

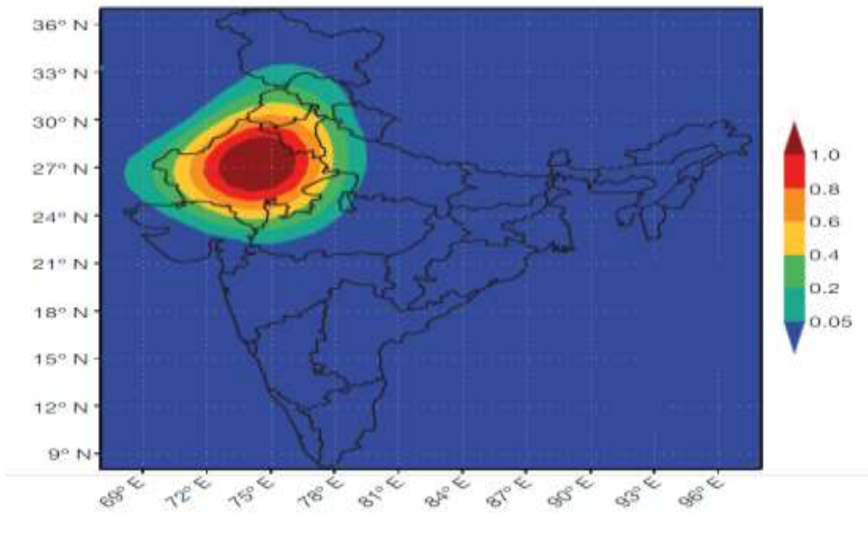
Groundwater responds at a slower pace to meteorological conditions compared to the surface components of the terrestrial water cycle. Its residence time can range from months in shallow aquifers to over a million years in deep desert aquifers. India currently grapples with severe water shortages in numerous states, exacerbated by pollution and mismanagement of surface water resources, which has led to an overreliance on groundwater in areas with abundant annual rainfall.




Source: - (Sengupta, S., 'In India, water crisis means foul sludge', New York Times, 29 September2006)

Figure 2.2 State level estimate of annual withdrawal &recharge report by Indian Ministry of Resource

India is confronting a significant water scarcity issue attributed to unsustainable rates of groundwater extraction, which is vital for agriculture and has implications for neighboring Pakistan. In 1986, the Indian government established a central Ground Water Authority to oversee groundwater development. However, implementing a well-coordinated response is challenging, primarily due to the interconnected nature of both political and aquifer boundaries. Comprehensive regional assessments of groundwater resources are essential for shaping appropriate policies and advancing hydrologic research. Nonetheless, generating such assessments based on well surveys can be quite challenging. The Gravity Recovery and Climate Experiment (GRACE) satellite mission, initiated in 2002, measures temporal fluctuations in the gravity field, enabling the estimation of changes in terrestrial water storage. GRACE possesses the advantage of detecting water stored at various levels, including groundwater, and can be utilized to isolate variations in groundwater storage from the GRACE data. A series of anomalies in groundwater storage was compiled for the semi-arid to arid regions of Rajasthan, Punjab, and Haryana, covering the period from August 2002 to October 2008. These areas receive an average annual rainfall of 50 cm.



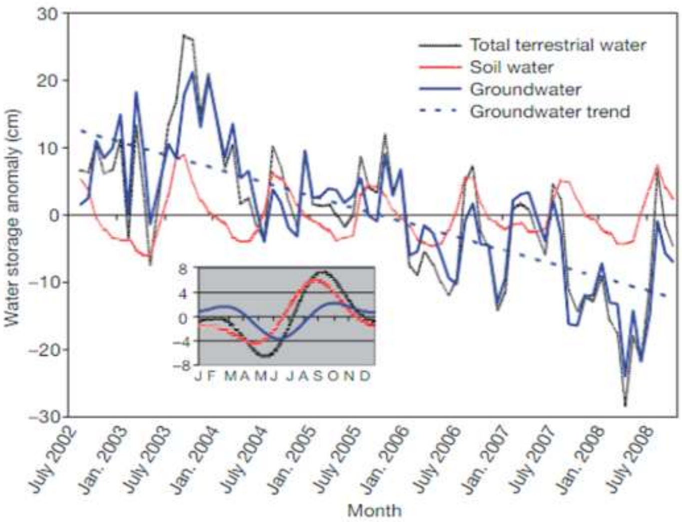

(source: - Sengupta, S., 'In India, water crisis means foul sludge', New York Times, 29 September2006)

Figure 2.3 Satellite map shows terrestrial changes in storage of water by GRACE

The 'green revolution' in India has had a substantial impact on the region, leading to the improved groundwater production for irrigation and benefiting approximately 114 million residents. The study area is situated above the Indus River plain aquifer, an expansive porous alluvial formation covering 560,000 square kilometers, which stretches across the border between India and Pakistan. The climate in this region is characterized by warmth and shallow groundwater, with infrequent snowfall. Nevertheless, the presence of glaciers in the Himalayas accounts for approximately 15% of the observed trend in Total Water Storage (TWS) and is attributed to glacier retreat.

Surface water storage also plays a significant role in water availability within the region. There are a total of 203 major reservoirs located within or on the borders of the three states, along with a substantial Salt Lake in Rajasthan. These reservoirs collectively cover an area of 4,320 square kilometers and possess a gross storage capacity of 39.5 cubic kilometers. Notably, seven of the largest reservoirs exhibited a net increasing trend of 0.5 cubic kilometers per year during the study period. The region boasts an extensive area of rice paddies, spanning 38,061 square kilometers, accounting for about 8.7% of the total region. However, these paddies are seasonally flooded and comprise shallow-water areas that dry out annually.

Estimates of soil-water storage variations were derived from five simulations provided by the Global Land Data Assimilation System (GLDAS). These simulations indicated that sub-root-zone soil experiences drying primarily through processes of gravity drainage or diffusion toward drier layers above. A 6-year time series of monthly groundwater storage anomalies closely aligned with the trends observed in Total Water Storage (TWS) and soil-water, revealing no significant trend within the root zone.




(source: - Shajan, B., 'NGOs welcome High Court order on water table' (http://www.thehindu.com/2004/01/15/stories/2004011509010400.htm), The Hindu, 15 January 2004).

Figure 2.4 Monthly time series of water storage anomality's in north western India

The investigation centered on an analysis of groundwater storage in Rajasthan, Punjab, and Haryana, employing GLDAS model-derived soil-water data that encompassed variables such as precipitation, solar radiation, and air temperature. The results revealed a trend of 0.4 centimeters per year in simulated soil-water storage, suggesting that the decline in groundwater levels was not attributable to natural climate fluctuations. The study's ultimate finding was that groundwater reserves are being depleted at a rate ranging from 4.0 to 6.0 centimeters equivalent water height, equating to a range of 17.7 to 64.5 cubic kilometers.

According to data from the Indian Ministry of Water Resources, there exists a deficit of 13.2 cubic kilometers between annual available groundwater recharge and the volumes withdrawn. The majority of the withdrawn groundwater is lost through increased runoff or evapotranspiration. Over the period spanning August 2002 to October 2008, the region witnessed the depletion of 109 cubic kilometers of groundwater, a figure double the capacity of India's most extensive reservoir and nearly three times the capacity of the largest man-made reservoir in the United States, Lake Mead. Unless effective measures are taken to control groundwater demand, or unless the supply and quality of this resource are compromised, the depletion is anticipated to persist. This could lead to severe shortages of potable water, diminished agricultural productivity, conflicts, and substantial hardships for the affected population.

**2.2 GROUND WATER LAWS AND POLICIES IN INDIA**

Water, a vital natural resource, assumes its true worth only when its absence is felt. Water sources primarily encompass surface and groundwater, and their utilization varies depending on their availability. Groundwater, due to its reliability, extensive distribution, ease of accessibility near points of use, and natural purity, has gained preference over surface water for irrigation, domestic, and industrial purposes.

However, the contribution of public surface irrigation has been dwindling due to insufficient dam storage capacities and inadequate maintenance of public irrigation infrastructure. Meanwhile, private groundwater resources have taken on an increasingly prominent role, catering to around 65 percent of irrigation and 90 percent of domestic and industrial water demands. Unfortunately, this invaluable resource has often been incorrectly perceived as limitless and inexhaustible by users. This has led to the neglect of critical aspects related to groundwater, such as scientific management, conservation, and augmentation.

India's legal framework concerning water is not treated as a distinct policy area with a comprehensive water code or a single body of water-related case law. Many of its core legal principles have remained rooted in the British legal system, and the structure governing groundwater rights has seen minimal change since the colonial era. India has largely inherited its water law system from the Common English Law.

**2.2.1 INTERNATIONAL COMMITMENT ON GROUND WATER**

International law has traditionally paid little attention to groundwater, with international treaties predominantly focusing on surface waters or entirely overlooking groundwater. However, as groundwater gains increasing significance as a source of high-quality freshwater in the face of the global water crisis, the necessity for international legal standards governing groundwater management and protection becomes more apparent. The United Nations International Law Commission (ILC) has included groundwater in its work on Shared Natural Resources, and there is a growing trend to address groundwater in international agreements, non-binding instruments, and interstate compacts, addressing both resource management and environmental concerns.

The principles of international watercourse law are embodied in various international agreements, including the 1997 Convention on the Law of Non-navigational Uses of International Watercourses, the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes, and the 1999 Protocol on Water and Health to the Convention. International declarations, specifically Goal no. 13, interlink human rights, developmental, and environmental discourse, recognizing the right to water as a fundamental human right derived from other core rights. Governments bear the responsibility of ensuring safe, affordable, and sufficient access to potable water through policies and strategies that create the necessary economic, social, and ecological conditions for access, whether managed by private entities.

The UN Committee on Economic, Social, and Cultural Rights has outlined various criteria for determining the adequacy of water concerning the right to water, encompassing factors such as availability, quality, non-discriminatory accessibility, and the dissemination of information.

**2.2.2 NATIONAL LAWS AND POLICIES ON GROUND WATER**

2.2.2.1 Legal Framework on Ground Water:

The legal framework governing groundwater in India is intricate and involves multiple layers of constitutional and statutory provisions, encompassing both central and state levels. Traditionally, the right to groundwater is perceived as derivative of the right to land; however, it is subject to challenges due to the public interest aspect of groundwater utilization. In 1996, the Supreme Court mandated the establishment of the Central Groundwater Authority (CGWA) to oversee and manage groundwater development. Within the Constitution, water resources, including groundwater, are categorized under the state List, granting states the authority to regulate and control groundwater. The central government has also made efforts to assist states by introducing the Model Groundwater Bill.

2.2.2.2 Model bill and Policies on Ground Water:

In India, the central government does not possess direct legislative authority over groundwater, which distinguishes it from areas like air quality, coastlines, and environmental matters. In 1970, the central government introduced a model groundwater bill, known as the Model Bill to Regulate and Control the

Development and Management of Groundwater (the "Model Bill"), as a reference document for states. This Model Bill is designed to establish a Ground Water Authority, recognize the right to water as a fundamental right, and propose an institutional framework for the protection, conservation, and regulation of groundwater. It also introduces a new legal framework to ensure effective regulation of large-scale groundwater usage, encompassing industrial, commercial, and infrastructure applications. The Model Bill advocates for the conjunctive use of groundwater and surface water, identifies and safeguards critical natural groundwater recharge zones, and outlines an aquifer-based groundwater security plan. It incorporates stricter penalties for violations. The first National Water Policy in 1987 explicitly outlined water allocation priorities, but the 2002 policy deviated from this by expanding the scope to include ecology, navigation, and categorizing industry into agriculture-related and non-agriculture sectors. The more recent National Water Policy of 2012 underscores the treatment of water as an economic resource to promote conservation and efficient utilization, with a greater emphasis on supporting the basic livelihoods of the underprivileged and ensuring national food security. The draft of this policy asserts that water should be managed as a communal resource held by the state under the public trust doctrine to achieve food security, livelihood enhancement, and equitable, sustainable development for all.

### 2.2.3 IMPLEMENTATION OF NATIONAL POLICIES

1. The National Water Board is tasked with developing an action plan based on the National Water Policy, which has been endorsed by the Water Resources Council, and should consistently oversee its execution.

2. State Water Policies may necessitate formulation or adjustment in accordance with this policy, while taking into consideration fundamental considerations and principles, as well as maintaining a unified national perspective.

### 2.2.4 FIVE YEAR NEW CONSERVATION AND PROTECTION FOR Gr. WATER

Satellite data reveals a consistent annual decline of 4 centimeters in groundwater levels in Northern India between 2002 and 2008, signifying a significant increase in water extraction rates of over 70.0% compared to the previous decade. This downward trend is notably prominent in regions with limited natural groundwater recharge capabilities. The lack of coordination and regulation among competing users has further aggravated the issue, leading to uncontrolled drilling for groundwater and resulting in the mismanagement of this critical resource.

While rural areas have received drinking water supply provisions, the number of habitations experiencing water scarcity has risen due to the extensive tapping of aquifers for irrigation purposes. This has contributed to the depletion of wetlands and rivers, with harmful substances contaminating water sources. Water quality problems also arise from chemical pollution, stemming from excessive fertilizer use and the irresponsible discharge of untreated waste into rivers.

Furthermore, inadequate maintenance and siltation have caused the erosion of over a million water bodies, including lakes, reservoirs, and tanks. Efforts to rejuvenate these water bodies are imperative, necessitating their desilting and rehabilitation through the treatment of their catchment areas. Sustainable groundwater management practices should be promoted to enhance land productivity, particularly in the Eastern and North Eastern regions, which possess substantial untapped groundwater resources.

### 2.2.5 JUDICIAL EFFORTS TOWARDS GROUND WATER

1. The Indian Constitution confers legislative authority upon states in managing water resources, encompassing various domains like water supplies, irrigation, canals, drainage, embankments, water storage, and power. In cases where the jurisdiction isn't explicitly delegated to states, it falls under the central government's purview.

2. The Supreme Court of India has played a pivotal role in reshaping the nation's groundwater regulations. It recognized the denial of access to clean drinking water as a violation of the right to life, as enshrined in Article 21. However, the exact extent of Article 21 rights concerning non-potable water purposes remains a subject of uncertainty.

3. The Supreme Court has yet to provide definitive rulings on the application of Article 21 rights to agricultural and commercial uses. In the case of Venkatagiriyappa v. Karnataka Electricity Board, the Karnataka High Court refrained from extending Article 21 protections to non-drinking water uses. Conversely, in M.C.

Mehta v. Union of India, precedence was given to considerations of life, public health, and ecological well-being over concerns of unemployment and revenue loss.

4. Back in 1972, the Ministry of Agriculture established the Central Ground Water Board (CGWB) with the responsibility of overseeing groundwater exploration, investigation, management, and development. Subsequently, the central government enacted the Environmental Protection Act, 1986 (EPA), thereby expanding its role in regulating water-related matters. The pivotal case of M.C. Mehta v. Union of India prompted the Supreme Court to direct the central government to establish a federal regulatory body dedicated to addressing issues related to groundwater extraction.

5. In the aftermath of the M.C. Mehta case, the central government established the Central Ground Water Authority (CGWA) to enforce federal regulations governing groundwater. The Plachimada Coca Cola case raised questions regarding the authority of Gram Panchayats to regulate the rights of private individuals or companies to extract groundwater.

6. The Kerala High Court ruled that both the Panchayat and the State bear an obligation to protect groundwater from excessive exploitation, even in the absence of specific legislation governing it. It underscored that groundwater beneath an individual's land is not their exclusive right, as it represents a customary entitlement for landowners to access water for domestic and agricultural needs.

7. The court recommended that the Supreme Court reevaluate the concept of groundwater as private property and instead focus on addressing human rights violations in cases like Plachimada. It also suggested the invocation of the Polluter Pays Principle from environmental law jurisprudence in India to ensure compensation for affected parties.

8. India's groundwater crisis presents a multifaceted challenge impacting a vast population. Adapting the legal framework to meet the contemporary needs of the country is an imperative task. An Expert Group has suggested that rather than altering the fundamental legal structure governing groundwater, the primary focus should be on enforcing existing measures while introducing innovative approaches.

### 2.3 TYPES OF GROUND WATER RECHARGING

#### 2.3.1 NATURAL GROUND WATER RECHARGING:

Groundwater recharge plays a pivotal role in the sustainable management of groundwater resources, aiding in the movement of excess salts from the root zone into deeper soil layers or the groundwater system. Human activities like urban development, construction, and deforestation can hinder recharge by reducing water infiltration, increasing surface runoff, and lowering water tables. Ensuring sustainable development requires that the long-term volume of groundwater abstracted from an aquifer remains equal to or less than the volume that is recharged.

Various techniques have been employed to estimate natural groundwater recharge, including the water level fluctuation method, the water balance method, linear regression models, and nonlinear regression models. These methods have yielded average recharge percentages of approximately 15.09%, 14.92%, 14.62%, and 14.57%, respectively, for the watershed under study. To address stressed aquifers resulting from intense agricultural pumping, a modified Water-Table Fluctuation (WTF) method has been developed. This method quantitatively characterizes regional groundwater discharge patterns and introduces two new parameters: infiltration efficiency and discharge modulus, which convey supplementary information derived from observed data. An optimization procedure is applied to estimate these parameters based on continuous groundwater head measurements and precipitation records. The WTF method considers both recharge and discharge simultaneously, accounting for infiltration characteristics while estimating regional-scale discharge. It further organizes results from individual wells into groups aligned with local land use patterns and cropping structures.

#### 2.3.2 ARTIFICIAL GROUND WATER RECHARGING

The estimated annual water resources within our river basins amount to 1,869 billion cubic meters (BCM), of which approximately 1,086 BCM are considered usable. Within this resource pool, around 690 BCM takes the form of surface water, while the remainder exists as groundwater. This water primarily originates from rainfall and snowfall, and the significant storage of groundwater is a result of the percolation of rain and snowmelt water through various soil and rock layers.

However, the extent of this percolation varies significantly from region to region, even within the same area. It is influenced by a multitude of factors, including the amount and distribution of rainfall, the duration and intensity of rainy periods, soil and rock characteristics, the nature of the terrain, and climatic variables such as temperature and humidity. Consequently, the availability of subsurface water reservoirs varies considerably from one location to another.

In regions characterized by low rainfall, surface water resources are so scarce that communities heavily rely on groundwater for both agricultural and domestic needs. Excessive groundwater extraction, particularly in drought-prone districts of certain states, has resulted in alarming declines in groundwater levels. This situation is further aggravated by widespread urbanization and the expansion of large cities, which have significantly reduced open areas for natural recharge. Even within hard rock regions, there are significant disparities in groundwater availability between neighboring villages.

To address the issue and enhance groundwater resources, it becomes essential to artificially recharge depleted groundwater aquifers. Fortunately, there are accessible, cost-effective, and sustainable techniques that can be employed, many of which can be implemented by individuals and local communities using locally available materials and labor.

**2.3.2.1 ADVANTAGES OF ARTIFICIAL RECHARGE**

• No large storage structures are needed for water retention; instead, smaller and cost-effective structures suffice.

• This approach improves the dependable output of wells and hand pumps.

• It results in minimal losses compared to those associated with surface storage methods.

• The water quality is enhanced through the dilution of harmful chemicals and salts.

• Adverse effects like extensive surface area flooding and crop loss are avoided.

• There is no displacement of the local population.

• The energy cost for water lifting is reduced, especially when groundwater levels significantly rise.

• Surplus surface runoff, which would otherwise go to waste, is effectively utilized.

**2.3.3 SOURCES OF WATER FOR RECHARGE**

Before initiating a recharge project, it's essential to evaluate the availability of adequate water for recharge. The primary sources to be identified and assessed for sufficiency include:

- Precipitation (rainfall) in the designated area.
- Significant roof areas capable of collecting and channeling rainwater for recharge.
- Canals originating from large reservoirs, providing water suitable for recharge.
- Natural streams from which surplus water can be redirected for recharge without affecting the rights of other users.
- Municipally and industrially treated wastewater, which should only be utilized following a comprehensive quality assessment.

While in-situ precipitation is a universally available resource, its suitability for recharge may vary. In cases of insufficiency, water from alternative sources can be transported to the recharge site. Assessing available water sources requires consideration of the following factors:

- The quantity of readily available water.
- The duration during which the water will be accessible.
- Water quality and any necessary pre-treatment measures.
- The conveyance system needed to transport water to the recharge site.

### 2.3.4 INFILTRATION CAPACITY OF SOIL

The effectiveness of a recharge scheme, as well as the rate at which the vadose zone becomes saturated, is significantly influenced by the soil's infiltration capacity. Field tests to assess the infiltration capacity of different soil types are typically carried out by State Agriculture Departments and Land Use Survey Organizations. This valuable data, including maps displaying infiltration rates, is often documented in their periodic departmental reports and can be obtained from the District Agriculture Officer. At the district level, this information is also available in the departmental reports of the Central and State Ground Water Boards.

Aquifer Suitability is primarily determined by factors like storage coefficient, available storage space, and permeability. Excessive permeability can result in the loss of recharged water through subsurface drainage, while low permeability can reduce the recharge rate. To achieve an optimal recharge rate and retain recharged water for a sufficient duration to meet demands during dry periods, a moderate permeability level is essential. Favorable areas for recharge include older alluvial deposits, buried channels, alluvial fans, dune sands, glacial outwash, and similar geological formations. In hard rock regions, fractured, weathered, and cavernous rocks have the capacity to absorb significant amounts of water. Basaltic rocks, formed by lava flows, often contain substantial local pockets capable of accepting recharge water.

### 2.3.5 HYDRO-METEOROLOGICAL STUDIES

These investigations aim to comprehend the patterns of rainfall and evaporation losses, allowing for the determination of the volume of water obtainable from a specific catchment and the appropriate size of storage facilities. Key factors to take into account include:

- The minimum annual rainfall over the past decade.
- The frequency of rainy periods within a rainy season and the duration of each period.
- The quantity of rainfall in each rainy period.
- The maximum rainfall intensity, such as 3-hour or 6-hour intervals, as pertinent to the region.

As a general guideline, the selection should favor the rainfall pattern that results in significant runoff and localized flooding. This information is often accessible through District Statistical Reports released by the District Statistical Organization. Nevertheless, the most crucial data source is the India Meteorological Department. When it comes to rainwater harvesting, readily available secondary data is typically sufficient. Another source of this data can be found in the reports of major, medium, or minor irrigation projects that have recently been completed, are under construction, or are in the planning stage within the region.

### 2.3.6 HYDROGEOLOGICAL STUDIES

A thorough hydrogeological analysis of the project site, coupled with a grasp of the broader regional hydrogeological conditions, is essential for identifying favorable locations for groundwater recharge and for selecting the suitable structures to be built.

### 2.3.7 GEOPHYSICAL STUDIES

Conducting an extensive hydrogeological examination of the project area, in conjunction with a thorough understanding of the regional hydrogeological setting, is essential for identifying potential sites for groundwater recharge and selecting the most suitable structures for implementation.

### 2.3.8 QUALITY OF SOURCE WATER

A. Chemicals and Salts
The main challenges related to groundwater recharge are primarily associated with the quality of untreated water available for recharge. This often requires some form of treatment before its utilization in recharge systems. Furthermore, these challenges are linked to changes in soil structure and biological processes occurring during infiltration, which can lead to environmental concerns. Therefore, it is essential to perform chemical and bacteriological analyses on both source water and groundwater.

B. Sediment Load
An essential requirement for water used in recharge projects is its freedom from silt. Silt can be defined as the concentration of undissolved solid matter, typically measured in milligrams per liter (mg/l), which settles in stagnant water or in flowing water with velocities not exceeding 0.1 meters per hour.

## 2.4 METHODS OF ARTIFICIAL RECHARGE

### 2.4.1 CHANNEL SPREADING

This method entails the creation of small 'L' shaped embankments within a stream channel, which redirects water along an extended route, enhancing natural recharge. It is particularly effective in areas where a narrow, flowing channel traverses a broader valley. However, it is not suitable for regions where rivers or streams are susceptible to sudden flash floods, as the embankments (levees) may be vulnerable to destruction.

Figure 2.5 Channel spreading

### 2.4.2 DITCH AND FURROW METHOD

In areas with irregular topography, the use of shallow ditches or furrows with flat bottoms, closely spaced together, provides an extensive surface area for contact with recharge water from a source stream or canal. This approach requires less soil preparation compared to recharge basins and is less prone to silting issues. Typically, it involves a network of interconnected ditches originating from a supply ditch and following the natural slope of the topography towards the stream. Generally, three distinct patterns of ditch and furrow systems are utilized.

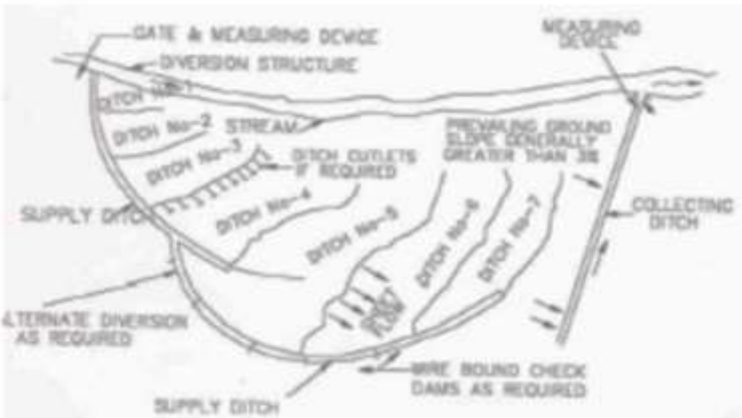


Figure 2.6 Ditches and furrow

### 2.4.3 PERCOLATION TANKS OR SPREADING BASIN

As mentioned earlier, these structures are extensively utilized in India for the purpose of replenishing groundwater reservoirs, including areas with alluvial and hard rock formations. They are notably more efficient and viable in hard rock formations characterized by significant fracturing and weathering. States such as Maharashtra, Andhra Pradesh, Madhya Pradesh, Karnataka, and Gujarat have implemented percolation tanks in regions with basaltic lava flows and crystalline rocks. Percolation tanks have also proven to be workable in areas situated at the foothills of mountains with prevalent talus scree deposits. Notably, they have shown remarkable effectiveness in the Satpura Mountain front region of Maharashtra. Furthermore, percolation tanks equipped with wells and shafts are employed in cases where shallow or surface formations have high impermeability or clay content, aiming to recharge deeper aquifers.

### 2.4.4 RECHARGE OF DUG WELLS AND HAND PUMPS

In both alluvial and hard rock regions, numerous dug wells exist, some of which have either dried up or experienced a significant decline in water levels. These dug wells can serve as structures for replenishing groundwater reservoirs (refer to Figure 9.3). Various sources of water, including stormwater, tank water, and canal water, can be redirected into these structures to directly recharge the depleted aquifer. This approach reduces soil moisture losses during the typical artificial recharge process. To ensure effective recharge, the water is channeled through a pipe to the well's bottom, positioned below the water level to prevent bottom scouring and the entrapment of air bubbles in the aquifer. It's important to consider the quality of the source water, including its silt content, to prevent any deterioration in the quality of the groundwater reservoir.

Figure 2.7 Recharge of dug wells and hand pumps

### A. INJECTION WELLS

Injection wells share a visual resemblance with tube wells, yet they are specially designed to facilitate the storage of surface water in a confined aquifer by pressurized pumping. These wells offer significant advantages in situations where land availability is limited. They provide a direct means to introduce water into depleted aquifers, using conduits such as tube wells, shafts, or connector wells.

The injection method is the exclusive approach for artificially replenishing confined or deep-seated aquifers that have poorly permeable overburden. The selection of suitable locations for these structures relies on factors such as the configuration of the confined aquifers, the hydraulic gradient, and the proximity of an available surface water source. Typically, constructing injection wells closer to the water source is more economically feasible.

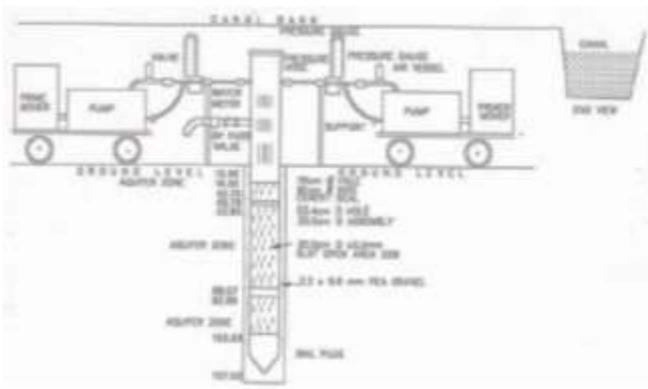


Figure 2.8 Injection wells

### B. INDUCED RECHARGE

This technique involves an indirect method of artificial recharge by hydraulic means. It includes the process of pumping water from an aquifer that is hydraulically linked to surface water to encourage recharge into the groundwater reservoir. When the cone of depression intersects the river boundary, a hydraulic connection forms with the surface source, causing it to contribute to the extracted yield. In these methods, there isn't a direct artificial buildup of groundwater storage. Instead, the surface water moves through the aquifer to reach the pump. In this context, it could be viewed more as a groundwater augmentation approach rather than a full-fledged artificial recharge measure.

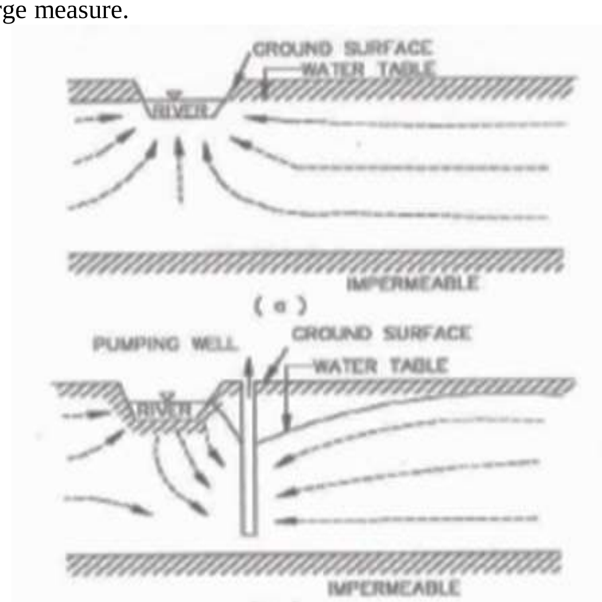



Figure 2.9 Induced recharge wells

## 3. STUDY AREA

ANNUAL RAINFALL DATA-

Table 3 Annual rainfall data for city

| Year | Rainfall(mm) | Year | Rainfall(mm) |
|---|---|---|---|
| 1990 | 1393.33 | 2005 | 318.00 |
| 1991 | 1021.56 | 2006 | 727.00 |
| 1992 | 1060.33 | 2007 | 668.00 |
| 1993 | 1124.68 | 2008 | 492.00 |
| 1994 | 1474.42 | 2009 | 568.00 |
| 1995 | 1110.90 | 2010 | 641.00 |
| 1996 | 1386.43 | 2011 | 545.50 |
| 1997 | 1354.78 | 2012 | 397.00 |
| 1998 | 1190.32 | 2013 | 699.80 |
| 1999 | 1033.56 | 2014 | 520.9 |
| 2000 | 814.78 | 2015 | 448.2 |
| 2001 | 823.46 | 2016 | 412.00 |
| 2002 | 787.50 | 2017 | 588.60 |
| 2003 | 718.50 | 2018 | 411.80 |
| 2004 | 857.00 | 2019 | 728.50 |

(Source - 1990-2016 = agrimaha.com, and from 2017-2019=Hydro.imd.gov.in)

**Average Annual Rainfall = 24310.85/30**

**= 810.36 mm/year**

**3.1 CASE STUDY 1**

Collection Method - Roof Top Rain water.

Recharge Method - Vertical Shaft (bore well recharging)

- Site Name - Bungalow.
- Location - Agrawal Nagar, Behind OM Hospital, Dhule.
- Area of site - 110.00 $m^2$
- Population – 4 persons
- Water Demand (W1) = 150 * Population
  = 150 * 4
  = 600 LPCD
- Water Demand for Year = W1 * 365 Days
  = 600 * 365
  = 219000 lit/year.
- Volume of Water Collected = Area *Average rainfall
  = 110.00 *810.36

  = 89,139 lit.

**(Thus, Water collected or recharged per year from roof top rain water harvesting is 89139.6 liter which is less than the water used per year by the community. As up to 50% of the water requirement for the community is full fill by the municipal corporation and remaining is done by bore well.)**

**3.2 CASE STUDY 2**

Collection Method - Roof Top Rain water.

Recharge Method - Vertical Shaft (bore well recharging)

- Site Name - Wadhava House.
- Location - Behind VWS College, Sakri Road, Dhule.
- Area of site - 223.32 $m^2$
- Population – 9 persons
- Water Demand (W1) = 150 * Population
  = 150 * 9
  = 1350 LPCD
- Water Demand for Year = W1 * 365 Days
  = 1350 * 365
  = 492750 lit/year.
- Volume of Water Collected = Area *Average rainfall
  = 223.32 *810.36

  = 1,80,969.59 lit.

**(Thus, Water collected or recharged per year from roof top rain water harvesting is 180969.59 liter which is less than the water used per year by the community. As up to 50% of the water requirement for the community is full fill by the municipal corporation and remaining is done by bore well.)**

**3.3 CASE STUDY 3**

Collection Method - Roof Top Rain water.

Recharge Method - Vertical Shaft (bore well recharging)

- Site Name - Apartment.
- Location - Agrawal Nagar, Behind OM Hospital, Dhule.
- Area of site - 284.28 $m^2$
- Population – 24 persons (expected)
- Water Demand (W1) = 150 * Population
  = 150 * 24
  = 3600 LPCD (expected)
- Water Demand for Year = W1 * 365 Days
  = 3600 * 365
  = 1314000 lit/year. (expected)
- Volume of Water Collected = Area *Average rainfall
  = 284.28 * 810.36

  = 230369.14 lit.

**(Thus, Water collected or recharged per year from roof top rain water harvesting is 230369.14 liter which is less than the water used per year by the community. As up to 50% of the water requirement for the community is full fill by the municipal corporation and remaining is done by bore well.)**

**(Note:- in case study 3 the results are expected not perfectly define as the apartment is not yet in use)**

**4. CONCLUSION**

The study findings indicate a deficit between water usage and the amount discharged into the ground through vertical shafts due to limited rainfall and excessive consumption. Only about 30% to 35% of the water is directed towards aquifer recharging. To address this, the study suggests reducing water consumption and promoting water reuse for various purposes like kitchen, bathing, handwashing, gardening, and flushing. Achieving a balance between water supply and demand is critical, particularly in areas facing water stress and groundwater depletion. To maintain this equilibrium, it is beneficial to explore alternative water sources, such as rainwater harvesting during the rainy seasons, which can be employed for collective purposes like recharging, gardening, and flushing within the campus to lower water consumption. Another option involves using water from basins or sinks for flushing toilets and urinals, albeit this requires treatment and incurs higher costs. The wastewater from these areas is typically directed to the municipal sewer system. In conclusion, artificial recharge represents one facet of a holistic approach for optimizing overall water resource management. It's important to consider pretreatment, soil-aquifer treatment, and post-treatment strategies, tailored to the specific source and site conditions, to make use of impaired-quality water as a viable source for artificial groundwater recharge.

- Artificial recharge using impaired-quality source waters is a viable choice, especially when the goal is to manage saltwater intrusion, mitigate land subsidence, sustain base flows in streams, or fulfill similar subsurface functions.
- This method carries minimal health risks, and it enjoys strong public acceptance, making it particularly well suited for non-potable purposes like landscaping irrigation.
- The government has historically operated on the principle of sourcing water from the most desirable and feasible sources, a rationale that remains valid.
- However, the discharge of treated wastewater into natural water sources or underground has made such sources less appealing for potable water use, given the increased treatment requirements compared to untreated natural water sources.

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