Into Thin Air

EVAPORATION LOSSES FROM DAM RESERVOIRS IN IRAQ

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Save the Tigris is a civil society advocacy campaign aiming to save and protect the heritage and water resources of Mesopotamia from the impact of large dams and other mega projects, and to promote sustainable management of the Tigris River and its tributaries. We seek to link groups and movements concerned with the adverse impacts of megaprojects on the Tigris and Euphrates. We advocate for policies that secure the sustainable and equitable use of water for all who live in the region. Our campaign believes a paradigm shift is necessary: instead of being a source of rivalry, water could be force for peace and cooperation between all the countries and peoples of the Tigris-Euphrates basin. Our advocacy and awareness activities involve all relevant actors: local communities; civil society organisations; media; national and local institutions; societies of experts and intellectuals; research centres; universities and others.

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Introduction

Iraq is facing a mounting water crisis. With temperatures rising, drought conditions becoming more extreme, and riparian states further restricting flows into Iraq, the country's water supply is shrinking even as demand is rising. In response, Iraq has doubled down on dam construction. Not only does this renewed emphasis on dams diverge from the detailed plans of the Strategy for Water and Land Resources in Iraq (Ministry of Water Resources of Iraq, 2014), but it is proceeding without the required transparency and public consultation.

As Save the Tigris reported in June 2020, the Kurdistan Region of Iraq (KRI) could see 245 dams constructed in the coming years in addition to the 17 already in operation. If completed, this programme would leave no river in KRI undammed. On top of this, the Iraqi government earlier this year commenced construction of Makhoul Dam on the Tigris River in Saladdin Governorate. The expected storage capacity of the Makhoul reservoir is more than 3 billion m3.

The adverse impacts of dam projects on the environment and the affected communities are well documented, including, for example, loss of habitat for fish and wildlife as well as loss of property, livelihood, and cultural heritage for people who live in and around the area to be flooded. What is more, dams lose significant amounts of water through evaporation. It is estimated that evaporation from Iraq's reservoirs decreases the country's total water supply by more than 10% each year (Iraq Energy Institute, 2018). As a general rule, the bigger the reservoir, the larger the share of water transferred from the surface into the atmosphere.

This paper reviews the currently available estimates of evaporation losses from dam reservoirs in Iraq

This paper reviews the currently available estimates of evaporation losses from dam reservoirs in Iraq and other countries with semi-arid to arid climates. It concludes with an appeal to the Government of Iraq (GoI) and the Kurdistan Regional Government (KRG) to update and adhere to the nation's strategy for water and land resources in addressing Iraq's water crisis. This means, first and foremost, that both the GoI and KRG should remove large dam projects from regional and national water management strategies and that the GoI should stop construction of the Makhoul Dam immediately. Other recommendations include the establishment of a framework for consistent monitoring of evaporation and raising awareness about water resource conservation (e.g., efficient irrigation, avoiding over-extraction, replenishing aquifers). Finally, we urge the GoI and KRG to explore ecologically sustainable methods to reduce excessive loss of water through evaporation, while ensuring that people in each part of the country enjoy reliable, sufficient, and convenient supplies of clean water. To solve this crisis, Iraq will need to make radical changes in its strategy for water resources management.

Evaporation from Iraq's Reservoirs

The impact of evaporation on the volume of stored water depends upon several factors, including atmospheric evaporative demand (the amount of water that the atmosphere pulls from the surface), the size of the water store, and the storage method (Craig, 2005). The highest rates of evaporation are observed in large bodies of water, including artificial reservoirs, due to the exposure of large amounts of water to sunlight and air currents.

Iraq has 6 large dams, 5 of which are on the Tigris River and 1 on the Euphrates. Most of these were built in the second half of the 20th century. Additionally, Iraq's climate ranges generally from semi-humid areas in the north to arid in the west, the centre and the south, and semi-arid to arid in and around the marshlands. Rates of evaporation are extremely high in arid and semi-arid environments. Currently, Iraq loses an estimated 61% of its total precipitation to evaporation (Atiaa and Abdul-Qadir, 2012). The Iraq Energy Institute (2018) estimates that Iraq's total water supply in 2015 was approximately 76 billion m3 and that the total loss of water through evaporation from artificial lakes built for flood control was more than 8 billion m3. The Ministry of Water Resources of Iraq (2014) projected a total evaporative loss of 9,7 billion m3 from Iraq's reservoirs in Iraq 2015.

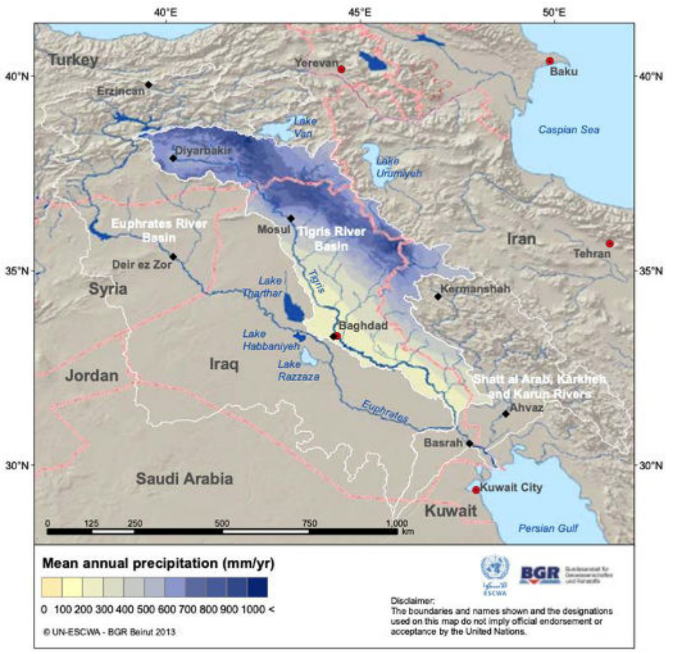
In recent decades, public authorities have monitored the level of evaporation throughout Iraq across various meteorological stations.

Despite the limited reliability of available data, it is clear that Iraq is suffering from increasingly inadequate water supply and is susceptible to drought. As mean temperatures continue to rise and the population grows (projected to reach 50 million by 2035), the increasing imbalance between water supply and demand will pose grave threats to the socio-ecological systems of the country, including lower productivity, loss of income, diminished food supply, migration, and disputes over increasingly scarce resources.

Unfortunately, the reported evaporation measurements for Iraq are not well constrained, as demonstrated by the following review of currently available data.

1.
The Strategy for Water and Land Resources in Iraq projects significant decline in evaporative losses, from 9,7 billion m3 in 2015 to 4,3 billion m3 in 2035. This projection is based at least in part on a strategy to reduce the volume of water stored in reservoirs at the end of the summer. However, the information currently available is not adequate to validate the projection.

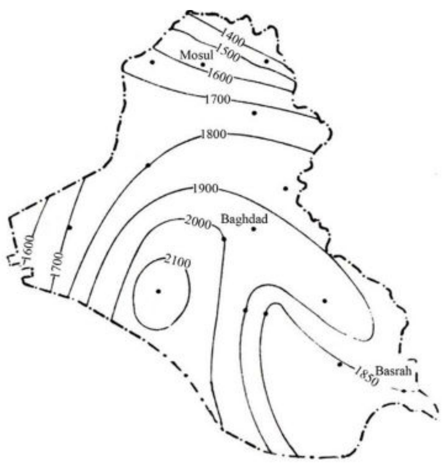
The Tigris basin experiences a mean annual precipitation (Figure 1) ranging between 400 mm and 600 mm, but annual precipitation can be as low as 150 mm in central and southern Iraq and reach as high as 800 mm in the north (UN-ESCWA and BGR, 2013).



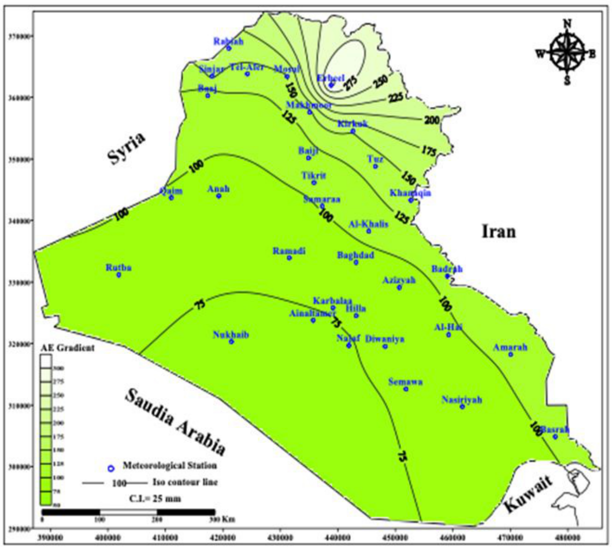
Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011.

According to research from 2018, Iraq's high rates of evaporation result in an annual loss of about 2,5 m from the level of the country's lakes and wetlands. This research is based on data from two natural lakes (Tharthar and Habanyah) and three dam reservoirs (Hemrin, Dukan, and Darbandikhan), as well as marshes in two regions of the country, in the period 2001 to 2012 (Dawood et al., 2018). Other recent research (Chabuk et al., 2020) claims the average annual evaporation from open bodies of water in Iraq reduces their surface level by approximately 1,4 m.

Al Barrak (1964) reported that the annual average observed pan evaporation at Baghdad's meteorological station for the period of 1956-1961 varied from 191,4 inches (4862 mm) to 196,1 inches (4981 mm). Pan evaporation integrates the effects of diverse climate elements, including temperature, humidity, rainfall, drought dispersion, solar radiation, and wind.



Average annual evaporation (mm) in Iraq
Source: Al-Ansari, N., (2013), Management of Water Resources in Iraq: Perspectives and Prognoses, Engineering.



Contour map of annual evapotranspiration (AE) in Iraq.
Source: Al Soudani (2019)

Yaseen et al (2020) examined evaporation data from Baghdad and Mosul meteorological stations for the period 1999-2009. Over this period, the mean temperature in July in Baghdad ranged from 23,5 to 44,0°C. Annual rainfall in Baghdad for this period was 244 mm, and annual evaporation was 3200 mm. In Mosul the mean temperature for July ranged from 24,8 to 43,0°C, while annual precipitation and evaporation were 729 mm and 3900 mm, respectively.

Al-Ansari (2013) reports lower figures for annual average evaporation, ranging between 1900 mm and 2000 mm in central Iraq and between 1400 and 1700 mm in the north (see Figure 2 on the previous page).

Analysing data for a much longer period, Al Sudani (2019) reported potential evapotranspiration (ETp) and actual evapotranspiration (ETa) for 32 Iraqi meteorological stations (see Figure 3). For Baghdad, ETp was calculated to be 1674.4 mm and ETa 92 mm (based on a 30-year record), and for Mosul, ETp was 1327,3 mm and ETa was 148 mm (based on a 70-year record).

Haditha Dam is located on the Euphrates River, 7 km upstream from the town of Haditha (Central-Western Iraq) in Anbar Governorate. At the operational water level of 147 m, the area of the reservoir is 500 km2, and the storage volume at that level is 8,25 billion m3.

Haditha Dam is an earth-fill dam on the Euphrates, north of Haditha, Iraq

Danboos et al. (2018) report that the Haditha Dam Reservoir declined from close to the full operational level of 147 m in 2006 to approximately 123 m in 2009, and the estimated average annual evaporation loss from the reservoir declined from approximate 1,8 million m3 in 2006 to approximately 1,5 million m3 in 2009.

Mosul Dam, located on the Tigris River, is the largest dam in Iraq. It experiences its highest evaporation rate in the month of July. Based on data recorded at the meteorological station of Mosul between 1980 and 2013, the mean evaporation rate that month was 365,5 mm. According to Figure 4 below, monthly mean evaporation at the Mosul Dam totals approximately 2 meters' evaporation loss annually. This is approximately 50 percent more than annual ETp for Mosul reported by Al Sudani (2019) and 50 percent less than the estimate reported by Yaseen et al. (2020).

2.
It should be noted that the following section shows that in Egypt and Turkey, approximately 6-7% of a reservoir's water store is lost through evaporation, while the figures above indicate that evaporation accounts for approximately 0,02 percent of the potential storage capacity of Iraq's Haditha Dam.

Evaporation Losses from Dam Reservoirs in Other Countries

By examining published data on evaporation losses in the Middle East and Australia, we can gain a general estimate of the relative magnitude of evaporative losses from dam reservoirs.

Egypt

Lake Nasser in Egypt has a total capacity of about 162 billion m3 of water. The total annual water loss to evaporation as of 2021 has been estimated to be between 12,3 and 13,6 billion m3/year (Abd-Elhamid et al., 2021).

Turkey

According to Gökbulak and Özhan (2006), toward the beginning of this century, Turkey had available water resources totalling approximately 107,3 billion m3. Based on 1999 data, total evaporation loss has been estimated at 6.8 billion m3 per year, of which 4,1 billion m3 per year was from reservoirs and 2,7 billion m3 per year from lakes. Thus, the amount of water loss through evaporation was greater than:

Annual groundwater abstractions (6 billion m3)
Annual domestic water consumption (5,7 billion m3)
Annual industrial water consumption (4 billion m3)

In the early 2000s, the amount of water loss through evaporation in Turkey was almost one-fourth of the 29,2 billion m3 of water used for irrigation (Gökbulak and Özhan, 2006). As these figures are 2 decades old, the magnitude of evaporation losses relative to total available water in Turkey has likely increased due to climate change. What is more, Turkey now holds a higher proportion of its available water in reservoirs, which increases the likelihood that a larger proportion of this water will evaporate.

In 2020, the average annual evaporation from open water bodies in Turkey was estimated at a level of 1050 mm (Chabuk et. al. 2020

Iran

According to recent research (Chabuk et. al., 2020), evaporation lowered the level of open water bodies in Iran on average by an estimated 720 mm per annum. It is estimated that evaporation reduces the cumulative volume of dam reservoirs in Iran by 3 billion m3 annually, according to the head of the Iranian water technology development workgroup at the Presidential Office for Science and Technology ("Need to Reduce Water Evaporation in Iran Dams", Financial Tribune, 18 January 2020).

Australia

The mean annual rainfall in Australia is less than 500 mm and declining, while its annual evaporation exceeds 2000 mm. On such a hot, dry continent, it has been estimated that up to 95% of rainfall is re-evaporated and does not contribute to runoff. Australia has several million farm dams which account for an estimated 9% of the total water stored, or approximately 7 million m3 (Environment Australia, 2000). Assuming that these small dams on average contain water only 50% of the time, and assuming that 40% of the stored water is lost due to evaporation, it can be argued broadly that the total agricultural water lost to evaporation is probably around 1400 million m3 (Craig, 2005).

Evaporation Losses likely to Increase

Across the globe, lakes and reservoirs are facing the threat of shrinkage (Danboos et al., 2018), and as climate change continues, quickening rates of evaporation will draw attention to the need for urgent action to safeguard the balance of surface water accumulated in the world's freshwater lakes, reservoirs and wetlands, as well as streams and rivers. The need to preserve this balance has become more significant in water resources management (Atiaa, Abdul-Qadir, 2012). In the Middle East, temperatures are forecast to increase steadily (Abbas, Wasimi, Al-Ansari, & Sultana, 2018). Drought conditions in Iraq are expected to intensify in the coming years, and evaporation will likely remove an increasing share of the water held in the country's dam reservoirs.

Iraq Iraq Should Stop Building Large Dams

Considering the various adverse environmental impacts of dams, including the higher rates of evaporation of larger reservoirs, stockpiling water in artificial reservoirs will not resolve the water crisis in Iraq. Indeed, as the above survey of research suggests, building more dams within the KRI will increase the share of water transferred to the atmosphere as temperatures rise and the total surface area of the region's reservoirs expands. The level of inefficiency is alarming, but the KRG and the Government of Iraq continue to build dams.

While the Government of Iraq has previously indicated that it would reduce the role of large dams in its water management strategy, it has recently resumed construction of the Makhoul Dam in the Governorate of Saladdin. With an expected capacity of more than 3 billion m3, this project threatens to flood much of the Ashur World Heritage Site and reduce the flow of water to the Ahwar in the south.

It is also troubling that both the Kurdistan Regional Government and the Government of Iraq have expressed interest on several occasions in finishing the construction of the Bekhme Dam. Construction of this large dam on the Greater Zab River started in 1987 but was suspended due to controversy.

With a projected capacity of 17 billion m3, Bekhme would be one of the largest and strategically most significant dams in Mesopotamia and would lose an estimated 480 million m3 of water annually through evaporation. This is more than the water consumption of the 3 largest cities in the Kurdistan Region combined (Mustafa, 2012).

Recommendations

Management of the Tigris-Euphrates rivers requires a basin-wide approach, and dam builders across Iraq and particularly in the Kurdistan Region need to evaluate carefully the cumulative impacts of water infrastructure projects on imbalances within the hydrologic cycle, including increasing loss of water through evaporation. We urge the GoI and KRG to update and adhere to the nation's strategy for water and land resources as they act to resolve the water crisis, and we offer the following recommendations to reduce evaporation:

01.

First, in keeping with the National Action Plan (NAP) to mitigate the effects of climate change and the updated national strategy for managing water resources, the GoI and KRG should eliminate the construction of large dams from their plans and cease construction of the Makhoul Dam.

02.

Second, establish a framework for systematic monitoring of climatic parameters, including air temperature, atmospheric pressure, humidity, precipitation, solar radiation, and evaporation across the country. Periodic data on water reserves and detailed information about methods of data collection should be made available to the public for independent and rigorous analysis. The results of independent analyses should also be considered in assessing the environmental and economic impacts of any dams still planned for construction.

03.

Third, while the KRG contains many small storage and water harvesting dams, it should also consider harvesting rainwater in networks of small ponds.

04.

Fourth, the KRG and GoI should act urgently to improve the efficiency of water distribution and consumption: Raise public awareness of the consequences of extracting more water from the aquifer than is replenished through infiltration; prioritize practices that replenish shallow wells; and provide training and incentives to help farmers reduce water consumption by using drip and sprinkler methods in place of flood irrigation.

05.

Fifth, GoI and KRG should commission studies to evaluate the feasibility of adapting the design of traditional Mesopotamian qanats – underground tunnel systems that bring infiltrated groundwater, surface water, or spring water to the earth's surface using only gravitational force – for the development of water storage and transportation networks that minimise evaporation.

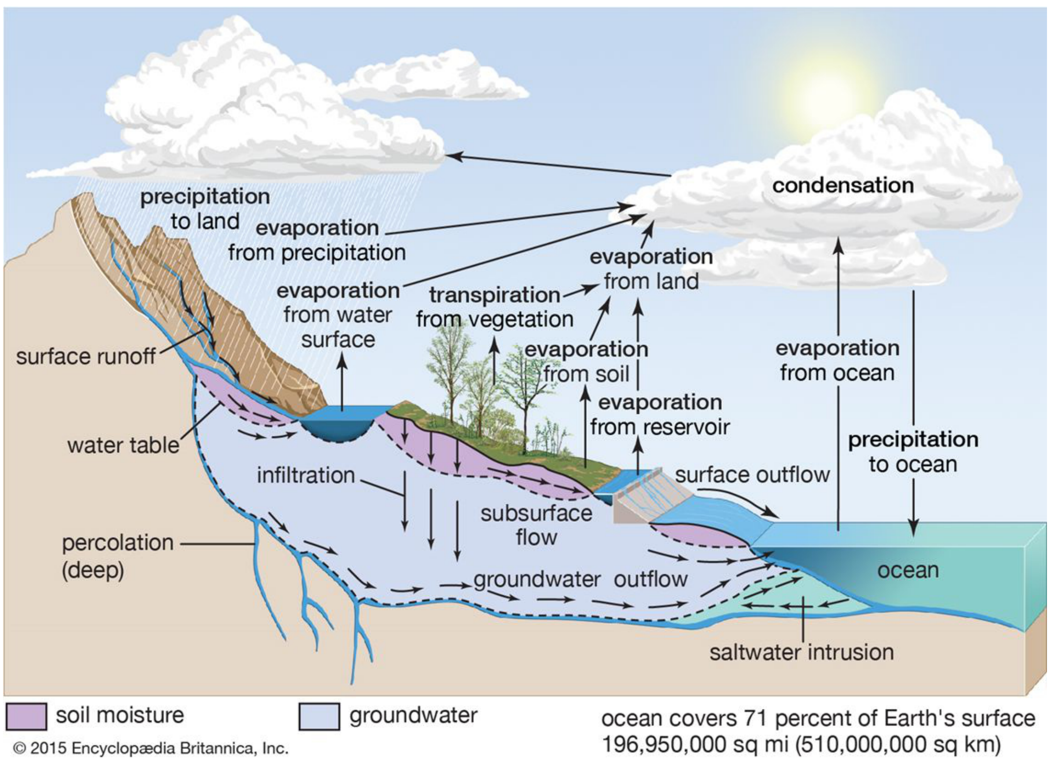
Addressing Iraq’s increasingly severe water crisis will require radical changes in the country’s strategy for safeguarding water stored in lakes, wetlands, and artificial reservoirs (Save the Tigris Campaign, 2020).

Without a multifaceted approach for mitigating the impact of evaporation on the country’s water supply, Iraq’s leaders will find it difficult, if not outright impossible, to ensure that Iraqi citizens are able to access clean water for use at home, on farms and industries.

Appendix: The Hydrologic Cycle

Evaporation is one component of the cyclic movement of water on, above, and below the surface of the earth. Water from oceans and lakes escapes into the air through evaporation (E) and is carried off as water vapor by air currents, and through transpiration (T) water from the ground is transferred to the atmosphere via the leaves of plants. (The terms evaporation and transpiration are often combined together as evapotranspiration, ET) Eventually water vapor in the air condenses into clouds and falls back to the surface of the earth as precipitation (P). Some of this water is impounded in lakes, reservoirs, and wetlands. Some water flows through rivers back toward the oceans (runoff, R), and some seeps into the ground (infiltration, I), replenishing (or recharging) the aquifer. The entire process is known as the hydrologic cycle. The hydrologic balance of flows can be expressed with the equation P=ET+R+I.

The diverse types of flows and contexts where water is accumulated are shown in Figure 5 below.



In theory, each type of flow within the hydrologic cycle is observable and measurable. While in certain circumstances, the amount of water removed from a lake or reservoir through infiltration and transpiration from the area surrounding the water body may be significant, these flows are difficult to measure.
In practice, therefore, water resource managers / conservationists may focus on periodic monitoring of readily measurable terms (e.g., precipitation, total water body volume, volume of withdrawals for local/regional consumption, and outflows for downstream consumption) to estimate the volume of water removed through evaporation.

Evapotranspiration

Evapotranspiration is the combination of evaporation (of water from water bodies and from the surface of the soil) and transpiration from the ground through plants (via tiny openings or "stomata" on the surface of leaves). Three important conditions are required for evapotranspiration to take place:

Water availability: There must be water at the surface.
Heat: There must be sufficient energy available to allow the change from liquid into aeriform.
Wind/air current: There must be a transport mechanism supporting the movement of evaporated water from the area (turbulent motions, i.e., winds), thus avoiding the saturation of the atmosphere, which would prevent further evaporation.

Moreover, the term potential evapotranspiration (ETp) designates the rate of evapotranspiration that would occur (e.g., annually) assuming an adequate supply of soil moisture at all times. Actual evapotranspiration (ETa), by contrast, is less than or equal to potential evapotranspiration. ETa is affected mainly by meteorological factors, whereas ETp depends on plant and soil conditions.

Due to the lack of reliable information on transpiration in the Tigris-Euphrates basin, the transfer of surface water through vegetation to the atmosphere is beyond the scope of the current article, which focuses primarily on the impact of evaporation on dam reservoirs.

(For bibliographies on the various methods of estimating evaporation and evapotranspiration, see Bear & Chang, 2010 and Craig, 2005.)

Calculating the Hydrologic Balance

In order to monitor the different movements or flows of water in the hydrologic cycle, conservationists and water resource managers define a “control volume” by designating the spatial limits within which fluctuations in the quantity of water accumulated can be measured. A control volume is defined arbitrarily; it could comprise an entire river basin or part of it. Changes in the amount of water accumulated in the control volume are calculated by measuring the flows into and out of the control volume. These flow components are:

- Precipitation (from the atmosphere to the surface of the soil and water bodies, e.g., rain, snow)
- Surface runoff (along the earth's surface)
- Infiltration (from water bodies and the surface of the soil into the ground)
- Groundwater flow (within aquifers)
- Transpiration (from the ground to the atmosphere via vegetation)
- Evaporation (from the earth’s surface to the atmosphere)

Water accumulation components include:

- Soil moisture
- Groundwater storage (the non-flowing component)
- Water in the oceans
- Surface water (streams, lakes, etc.)

As noted above, the relationship between flows and accumulation within a control volume is known as the hydrologic balance, which can also be expressed as:

$\Delta V = P - ET - R - I$

Where Delta V refers to the variation of the volume of water accumulated within the control volume, P is precipitation, R is surface runoff, ET is evapotranspiration (the sum of evaporation and transpiration), and I is infiltration.

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