Lecture 10

Replenishable but Depletable Resources: Water

Replenishable but Depletable Resources: Water

- Introduction
- The Potential for Water Scarcity
- The Efficient Allocation of Scarce Water
- The Current Allocation System
- Potential Remedies
- GIS and Water Resources

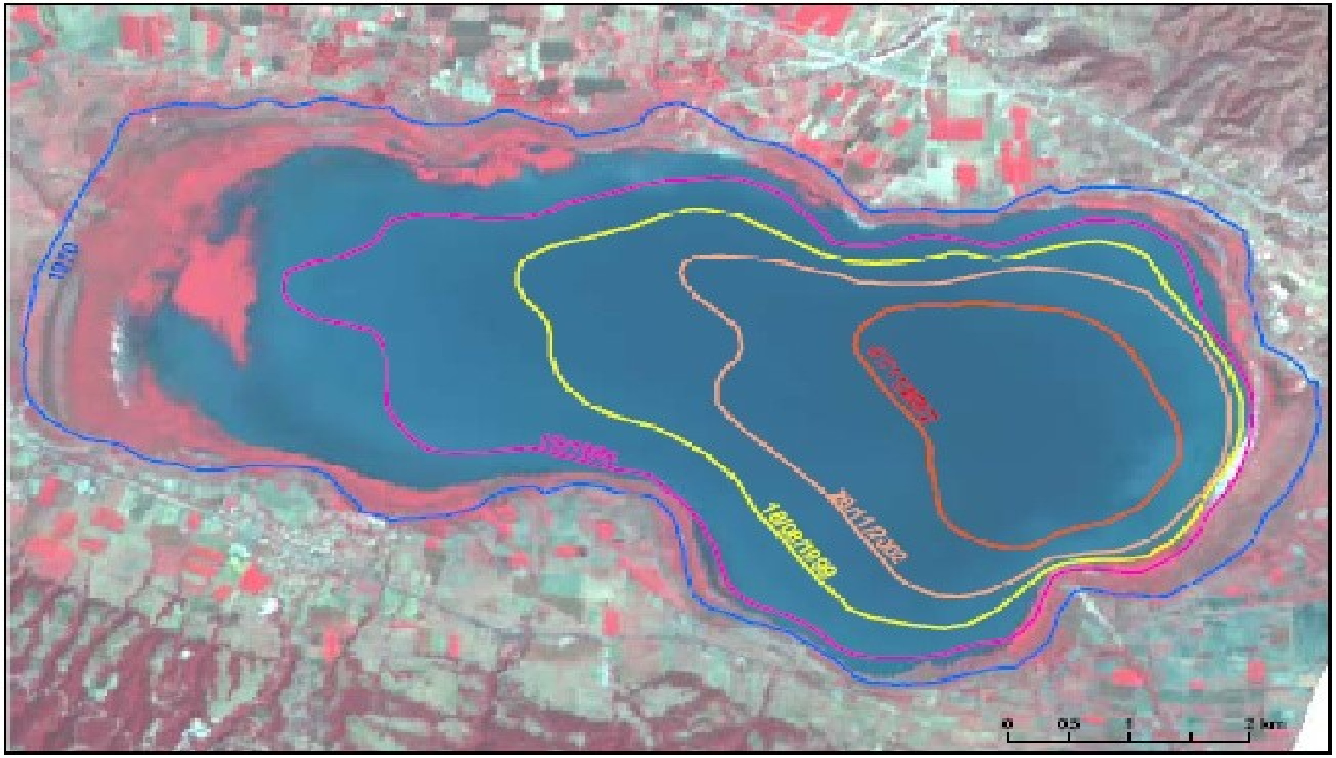
Introduction

- Example of water problems: Lake Koronia

In the early 70s it covered an area of 46 km^2 with max depth of 8m

By 1995, it had shrunk to $30km^2$

In 2002 it dried up completely , but in the next few years, due to heavy rainfall, it went up to 10 km^2 with max depth of 1m

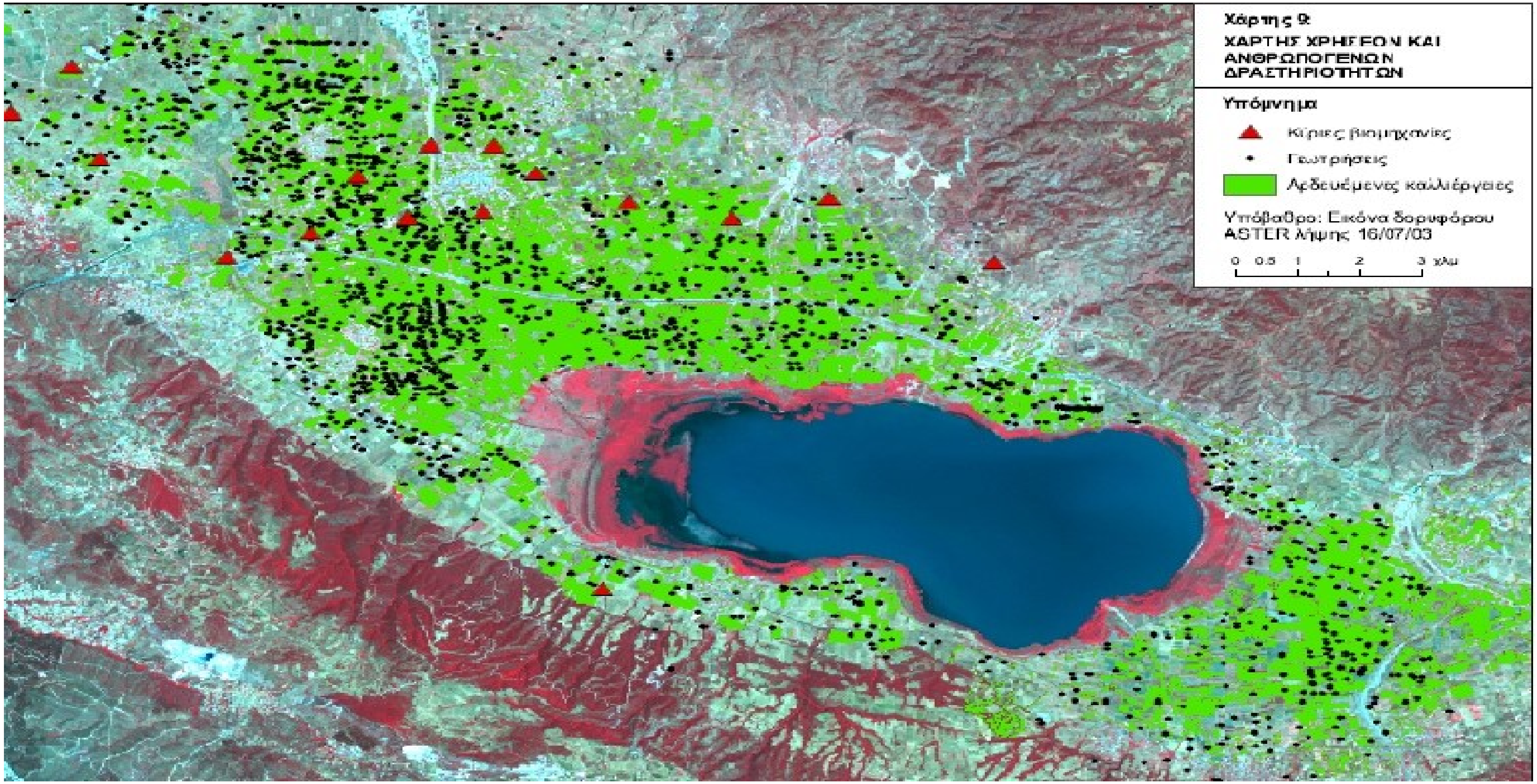


Introduction

In June 2011 it reached 11km^2 with max depth of 1.5m

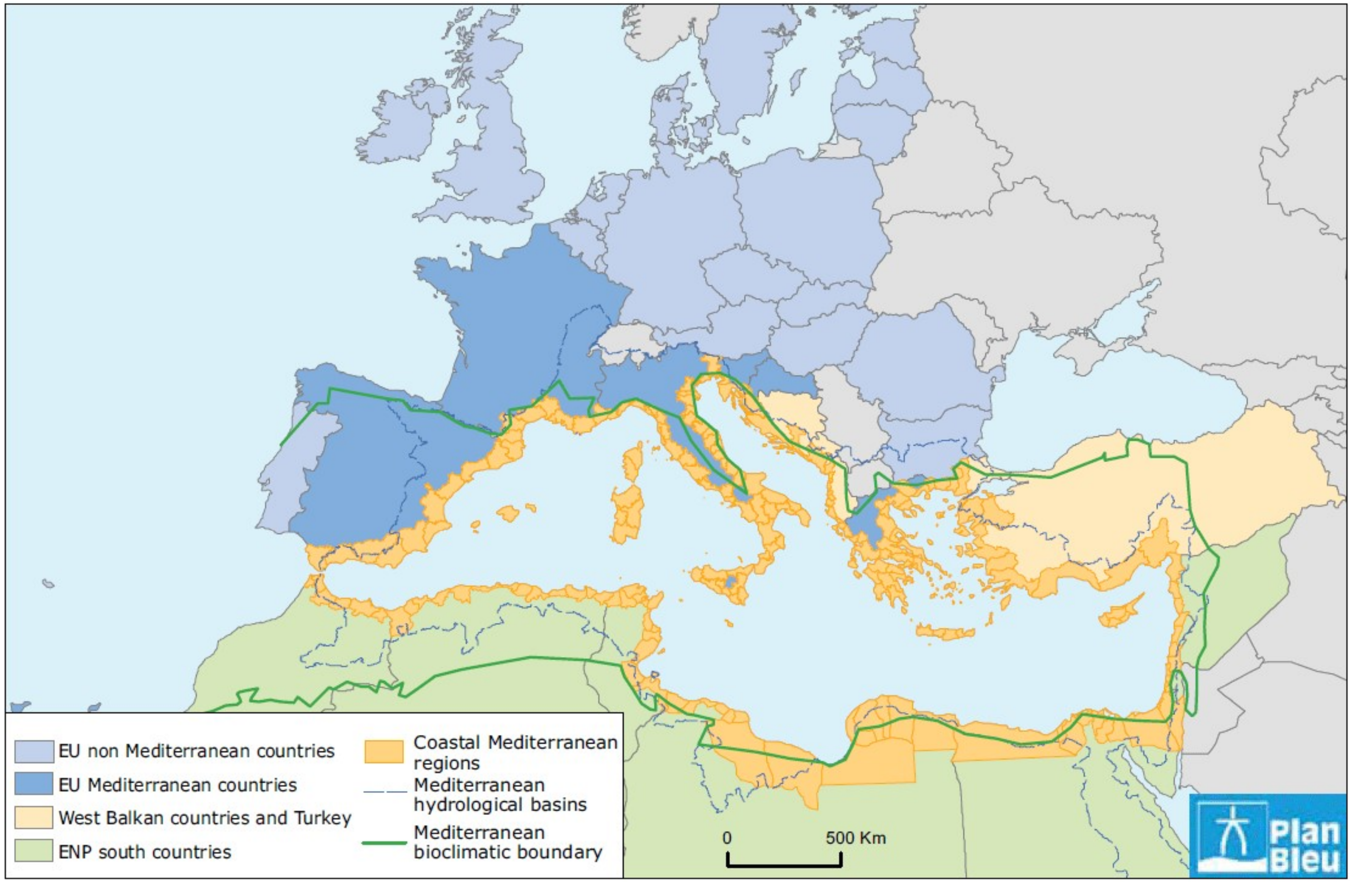
Google image May 2014

Introduction



The estimated number of wells in the surrounding area is 2500 – 3000 of which only 250 are licensed. Most of them exist before any license was required.

Introduction

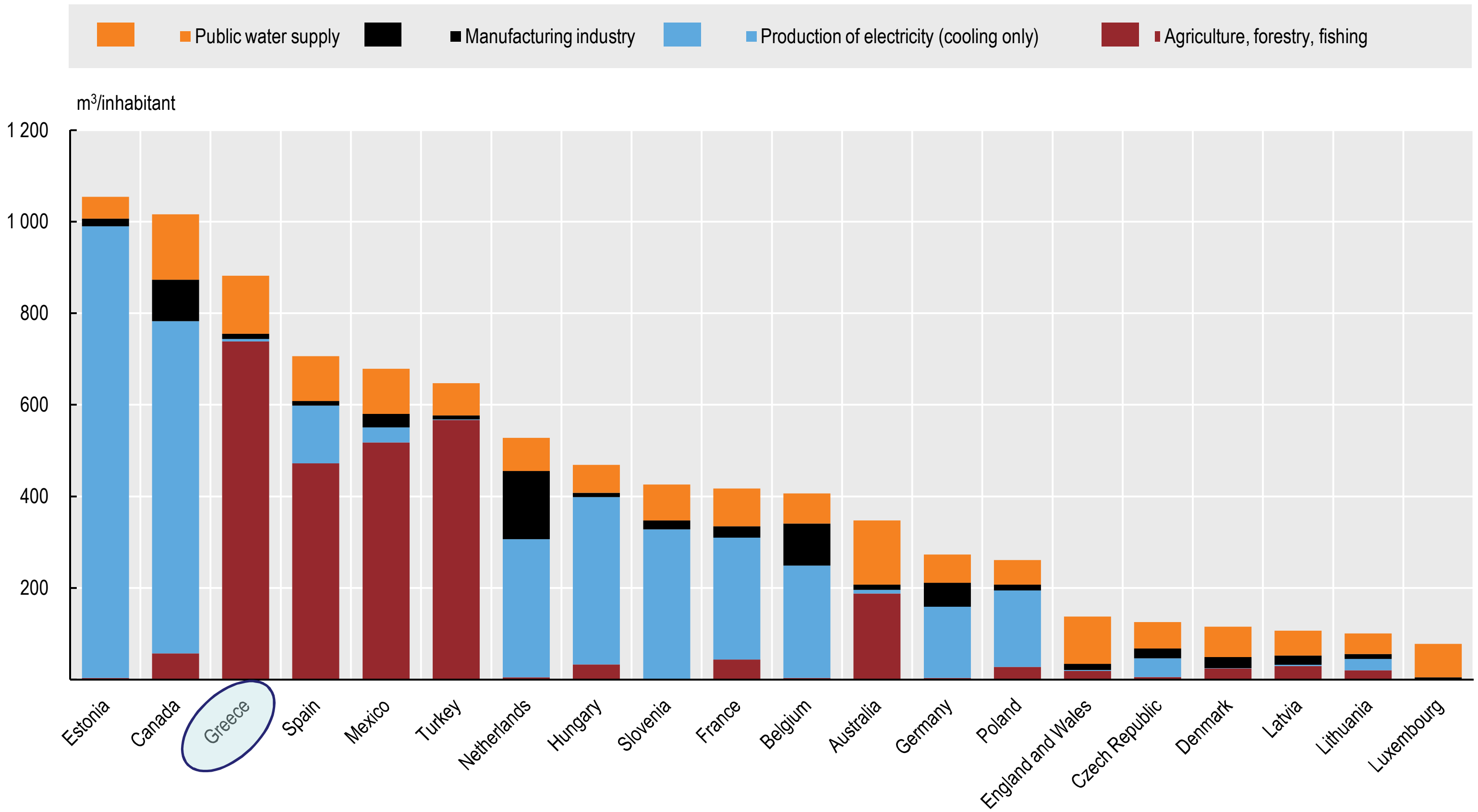


- **Coastal hydro-logical basins**
- Seventy five hydrological basins in the Mediterranean bordering countries are considered as coastal (Figure I.7). Their population consists of about 250 million of inhabitants (55 % of the total population). In the ENP-South region, 65 % of the population (i.e. around 120 million inhabitants) is concentrated in the Mediterranean coastal hydrological basins.

Introduction

- **All economic sectors need water; agriculture, industry and most forms of energy production are not possible without water.**
- The most important uses, in terms of total abstraction, have been identified as urban (households and industry connected to the public water supply system), industry, agriculture and energy (cooling in power plants). On average, 44 % of total water abstraction in Europe is used for agriculture, 40 % for industry and energy production (cooling in power plants), and 15 % for public water supply. The main water consumption sectors are irrigation, urban, and manufacturing industry.
- Southern European countries use the largest percentages of abstracted water for agriculture. This generally accounts for more than two-thirds of total abstraction. Irrigation is the most significant use of water in the agriculture sector in these countries.
- Central European and the Nordic countries use the largest percentages of abstracted water for cooling in energy production, industrial production and public water supply.

Introduction



Source: OECD (2018), "Water: Freshwater Abstractions", *OECD Environment Statistics* (database); OECD (2018), "Environmental Performance Indicators", *OECD Environment Statistics* (database).

Greek data for water use

- Some 80-85% of freshwater resources are in the form of surface water and the rest are groundwater.
- Per capita consumption of water is around 830 m^3 with peaks recorded during heat wave days and days of intensive snow fall.

- Greece does not present a balanced scheme of water uses, as the rural usage takes the lion's share of 86%

- https://www.worldometers.info/water/greece-water/#water-use

Introduction

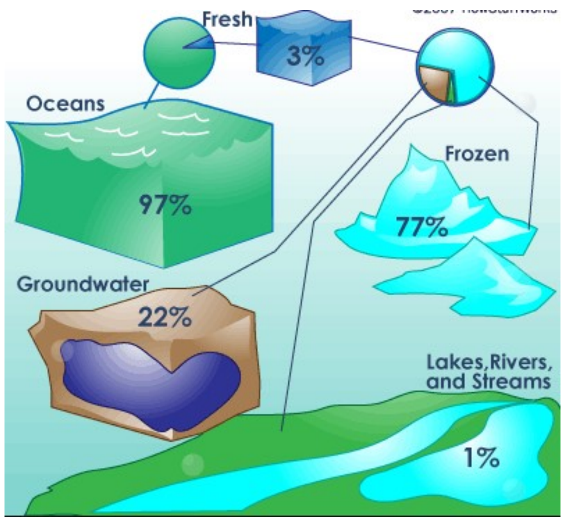
- This chapter deals with the efficient allocation of surface water and groundwater resources over time.
- This chapter examines the economic and political institutions that have traditionally governed water resource management.
- Sources of inefficiency are highlighted, as are potential remedies and opportunities for institutional reform.

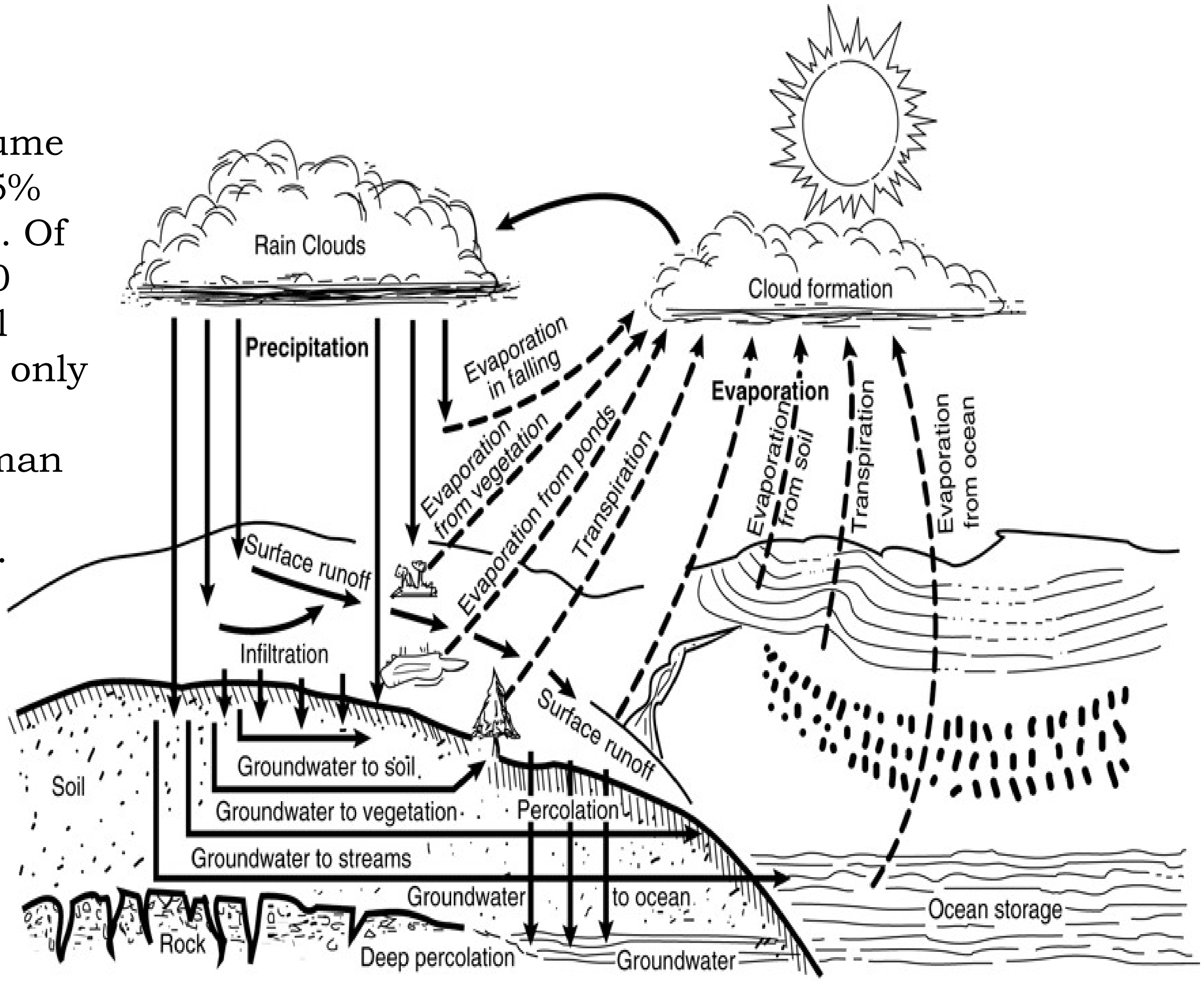
The Potential for Water Scarcity

- Surface water is a renewable resource consisting of rivers, lakes and reservoirs.
- Groundwater is water that collects underground in aquifers. Some aquifers are nonrecharging and are thus nonrenewable resources.
- In many parts of the world, excess demand for water is causing great stress.
- Groundwater levels have also been declining in many areas due to intensive pumping.
- Water quality is also a growing problem.

The Hydrologic Cycle

Of the estimated total volume of water on earth, only 2.5% (1.4 b. km^3) is fresh-water. Of this amount, only 200,000 km^3, or less than 1% of all freshwater resources (and only 0.01% of all the water on earth), is available for human consumption and for ecosystems (Gleick, 1993).





Source: Council on Environmental Quality, *Environmental Trends* (Washington, DC: Government Printing Office, 1981), p. 210.

The Hydrologic Cycle

Process Definitions:

Condensation
The transformation of water vapor to liquid water droplets in the air, creating clouds and fog.

Deposition
Also known as desublimation, is a thermodynamic process, a phase transition in which gas (vapor) transforms into solid (ice).

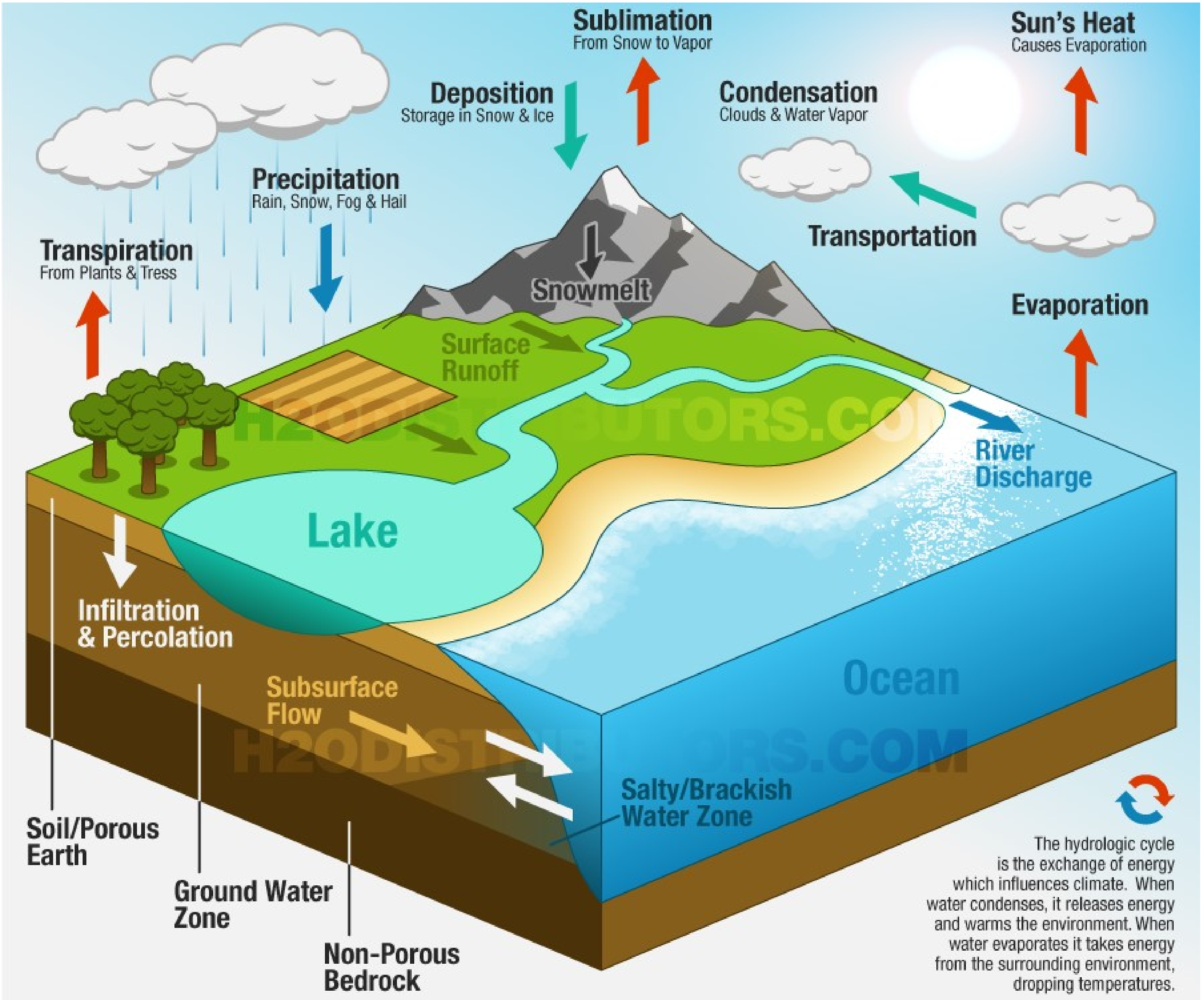
Evaporation
The transformation of water from liquid to gas phases as it moves from the ground or bodies of water into the overlying atmosphere.

Percolation
Water flows horizontally through the soil and rocks under the influence of gravity.

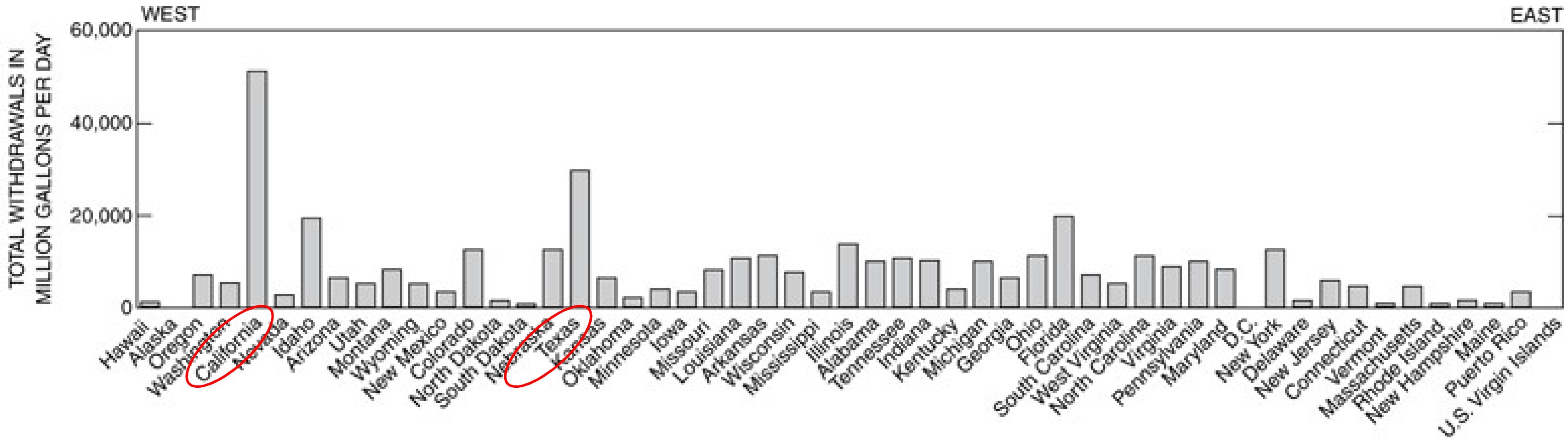
Precipitation
Condensed water vapor that falls to the Earth's surface. Most precipitation occurs as rain, but also includes snow, hail, fog drip, graupel, and sleet.

Sublimation
The state change directly from solid water (snow or ice) to water vapor.

Transpiration
The release of water vapor from plants and soil into the air. Water vapor is a gas that cannot be seen.

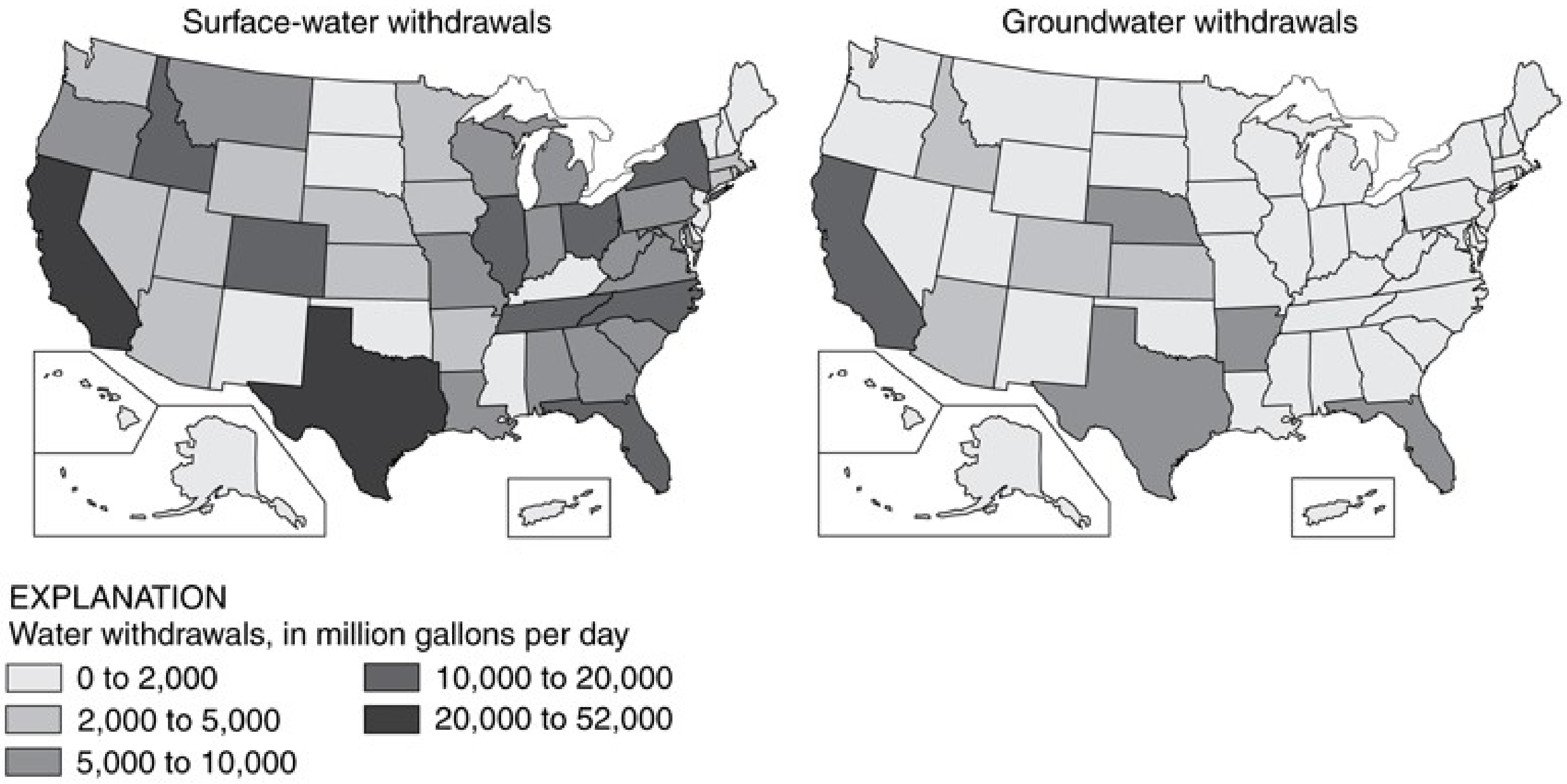


Estimated Use of Water in the US in 2000 (Surface & Groundwater Withdrawals)



In 2000 water withdrawals in the United States amounted to 262 billion gallons per day. Of this, approximately 83 billion gallons per day came from groundwater. Water withdrawals, both surface- and groundwater, vary considerably geographically. Figure 9.2 shows how surface- and groundwater withdrawals for the US vary by state. California, Texas, Nebraska, Arkansas, and Florida are the states with the largest groundwater withdrawals.

Estimated Use of Water in the US in 2000 (Surface & Groundwater Withdrawals)



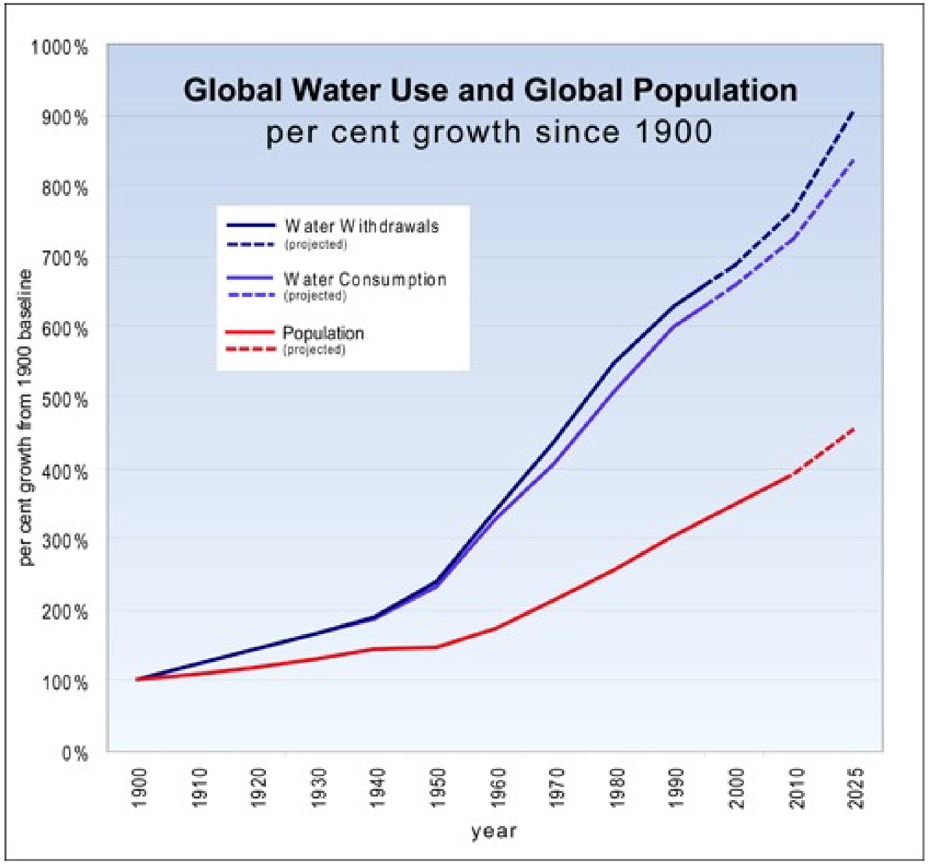
Source: United States Geological Survey (USGS), 2000.

World’s water challenges

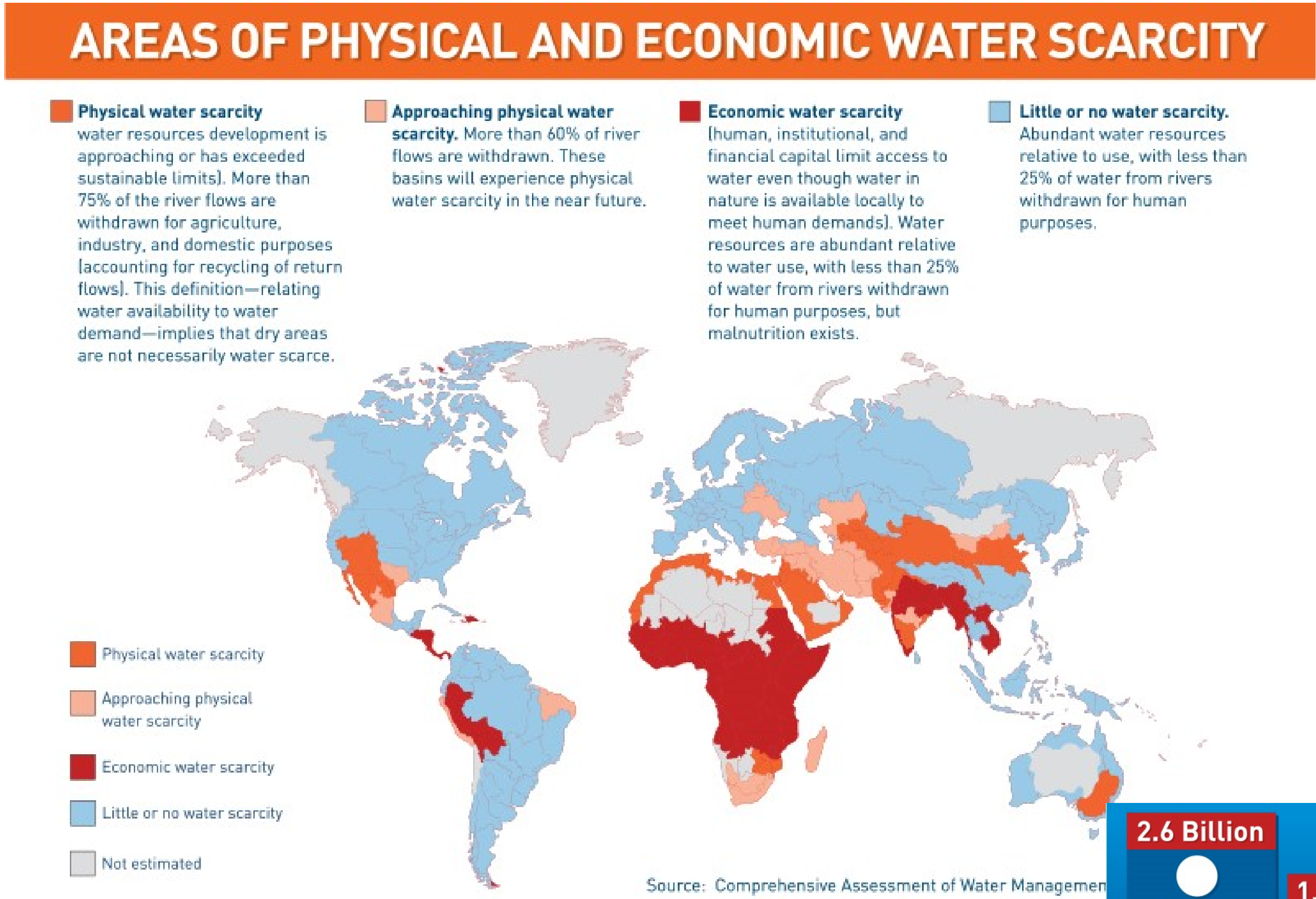
6 CLEAN WATER AND SANITATION

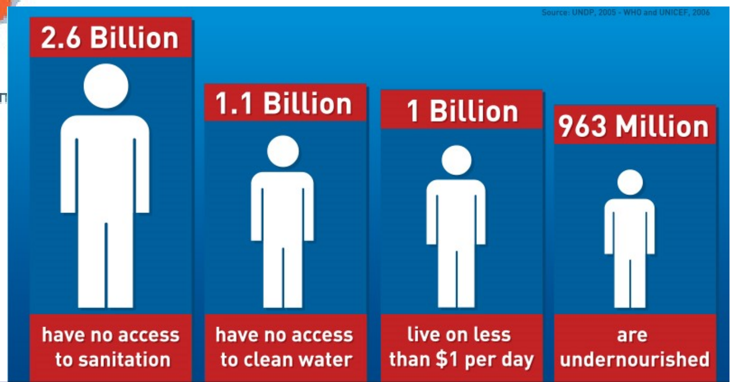
- Today we are putting more pressure on freshwater resources than ever. Between a rapidly growing population and a shifting climate, water stress – and therefore water risk – is increasing around the world.

- The sixth U.N. Sustainable Development Goal is focused on water, with several sub-goals related to different water challenges.
We have seen promising progress, but there is much work to be done to make water sustainability a reality before the SDG target date of 2030.

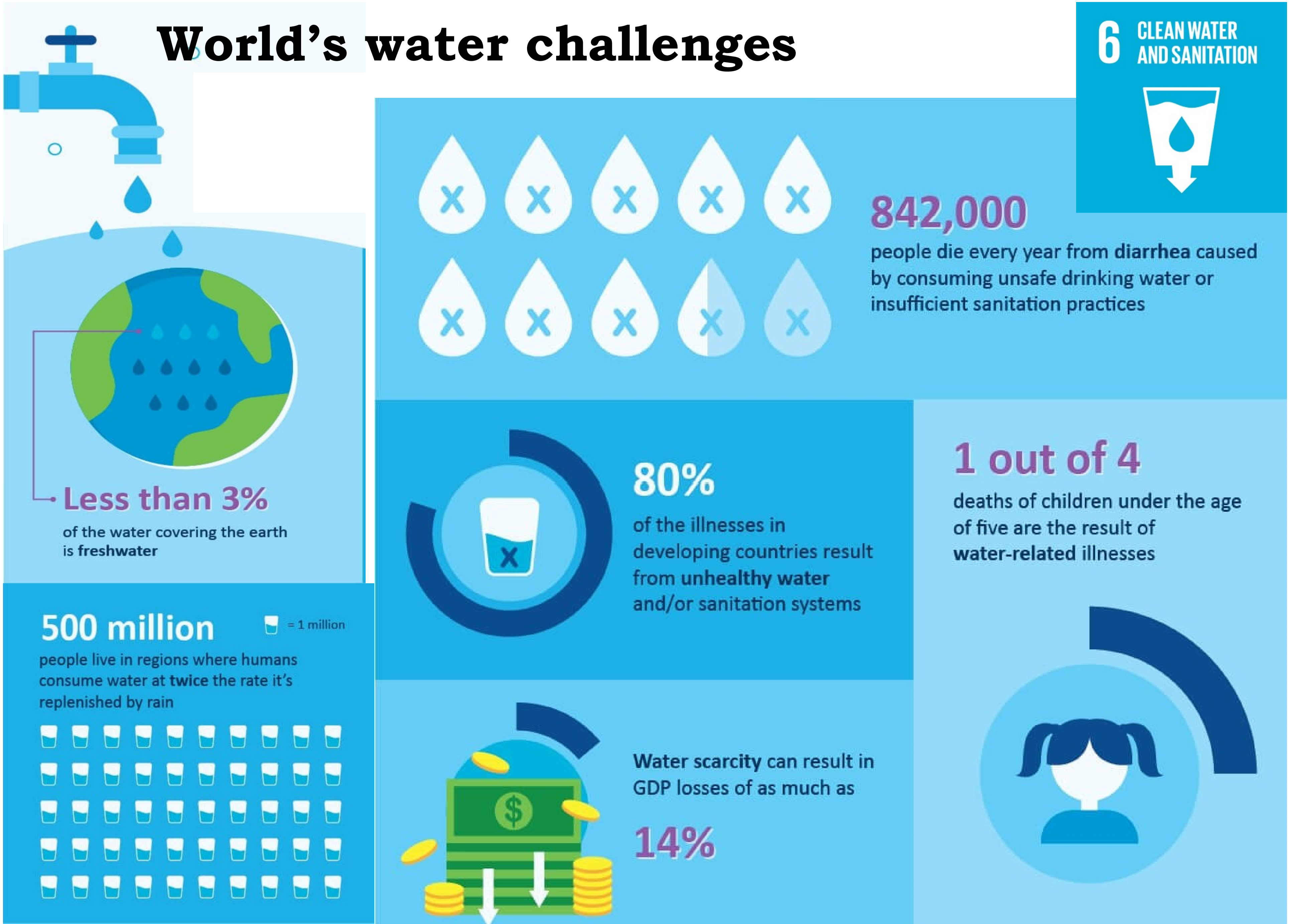


World's water challenges





World's water challenges

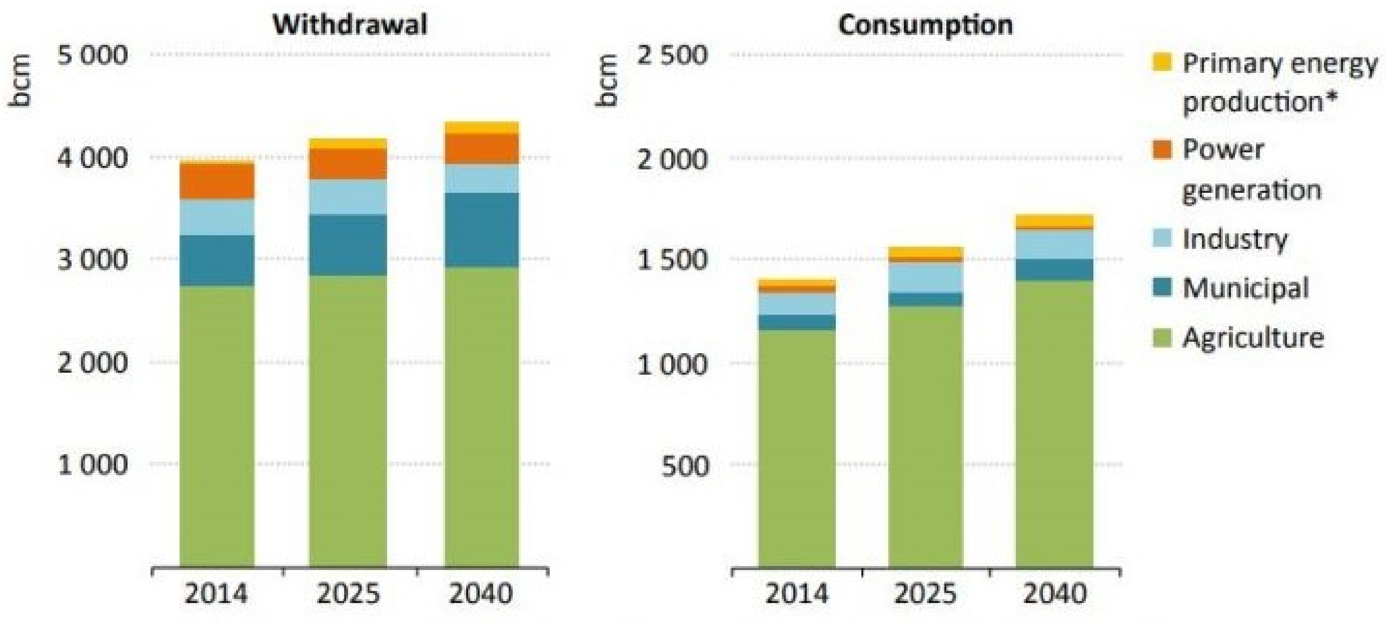


World's water challenges

• Humans withdraw about four thousand cubic kilometers of water globally every year – approximately the volume of all the water in Lake Michigan. This is triple what we withdrew 50 years ago, and withdrawals continue to increase at a rate of about 1.6 %/y.

• Much of this new demand will be driven by agriculture, which already accounts for 70% of global freshwater use. Food production must grow by 69% by 2035 to feed the growing population, which will expand agricultural water needs.

• Energy production currently accounts for less than 10% o global water consumption. However the projected increase in energy by 35% by 2035, will increase the energy sector's wat consumption by 60



World's water challenges

- The growing demand presents a growing challenge for meeting all of humanity's water needs. Due to the combination of population growth, unsustainable water withdrawals, and poor infrastructure and governance, in many parts of the world there is already insufficient safe water supply.

- Today 1.7 billion people live in river basins where water demand outstrips supply, known as water-stressed areas. By 2050, this is expected to jump to 2.3 billion.

- Nearly all human uses of water, from agricultural to industrial to municipal, result in water pollution. Currently, over 80 percent of the world's wastewater is discharged back into rivers, streams, and oceans without any treatment, causing widespread damage to ecosystems and contamination of critical human water sources.

The Efficient Allocation of Surface Water

- Surface Water

- An efficient allocation of surface water must

1. strike a balance among a host of competing users

   The former issue is acute because so many different potential users have legitimate competing claims. Some (such as municipal drinking water suppliers or farmers) withdraw the water for consumptive use, while others (such as swimmers or boaters) use the water, but do not consume it.

2. supply an acceptable means of handling the year-to-year variability in water flow.

   The variability challenge arises because surface-water supplies are not constant from year to year or month to month. Since precipitation, runoff, and evaporation all change from year to year, in some years less water will be available for allocation than in others. Not only must a system be in place for allocating the average amount of water, but also above-average and below-average flows must be anticipated and allocated.

The Efficient Allocation of Surface Water

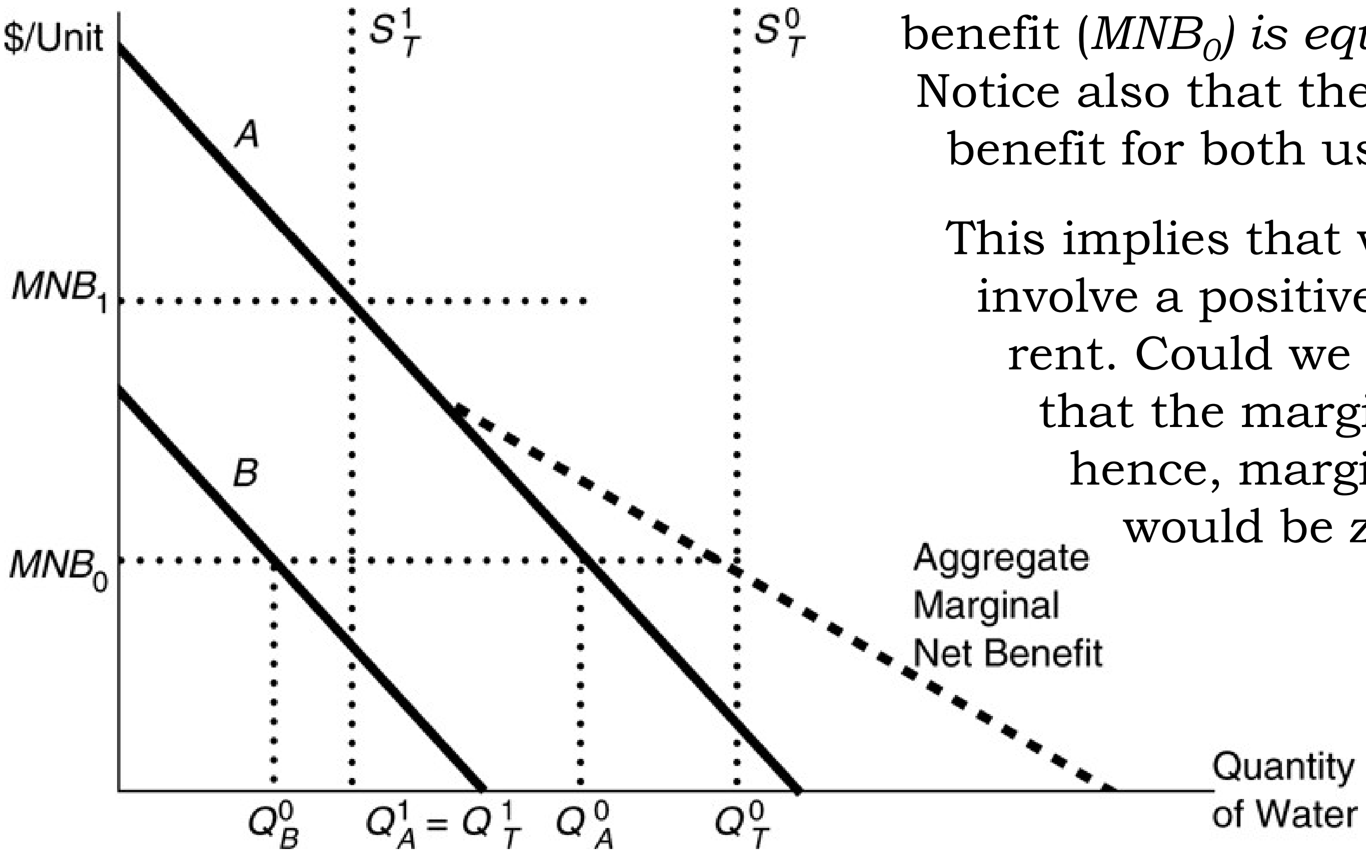
- Surface Water
  - An efficient allocation of a renewable resource involves a contemporaneous opportunity cost or the cost imposed on an alternate user.
  - Efficiency in the presence of competing uses implies that the marginal net benefit should be equalized across all users.
    - With respect to allocating among competing users, the dictates of efficiency are quite clear—the water should be allocated so that the marginal net benefit is equalized for all uses. (Remember that the marginal net benefit is the vertical distance between the demand curve for water and the marginal cost of extracting and distributing that water for the last unit of water consumed.)
  - If water were not scarce, scarcity rents would be zero.
  - Water is also a highly variable resource in terms of the timing of flows. Thus, a system must be able to deal with interannual variation in flows.

The Efficient Allocation of Surface Water

Two individual marginal net benefit curves (*A and B) are depicted along with the* aggregate marginal net benefit curve for both individuals. The amount of water available is Q^0_T. An efficient allocation would give Q^0_B to user *B* and Q^0_A to *A.*

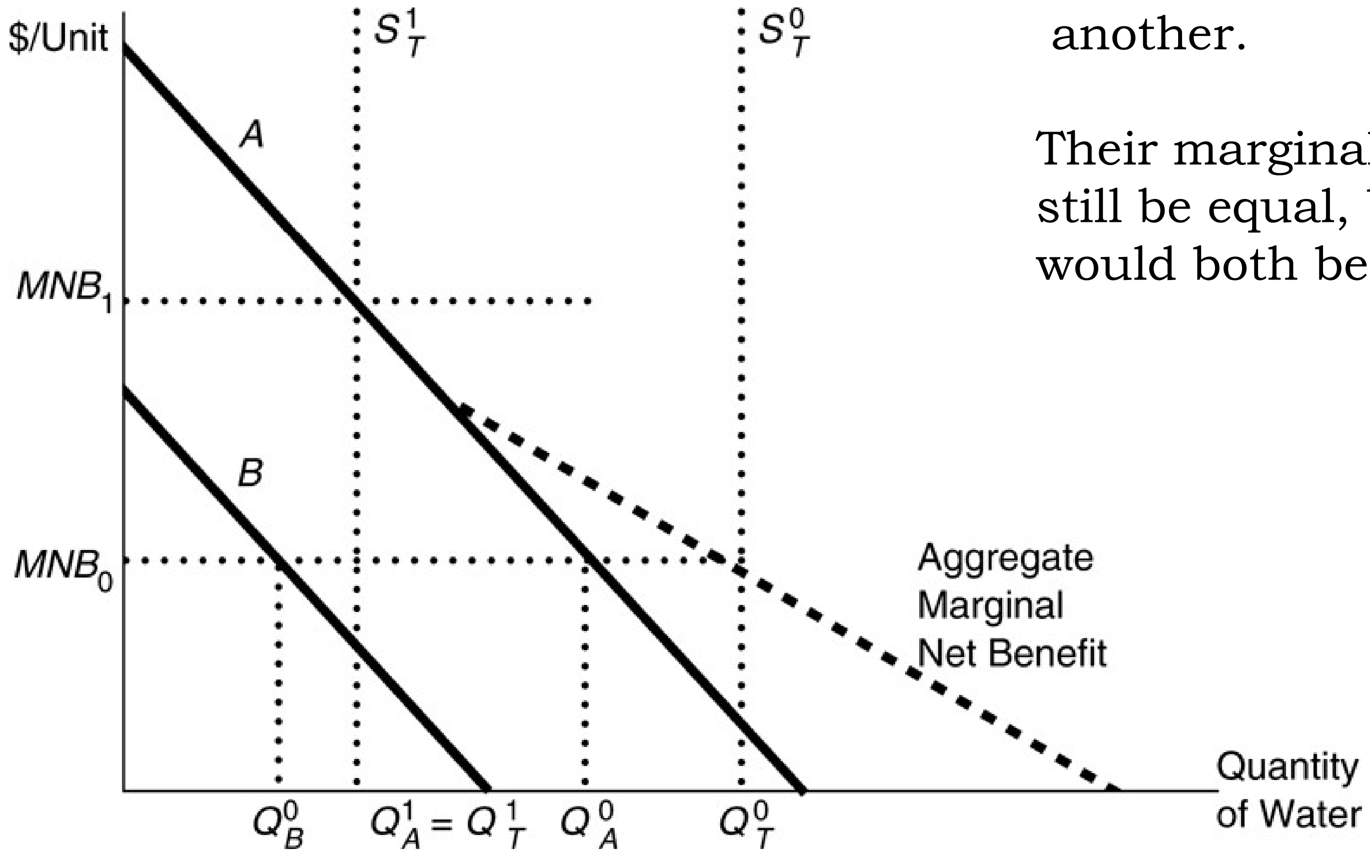
By construction, $Q^0_A + Q^0_B = Q^0_T$ *. For this allocation, notice that* the marginal net benefit (MNB_0) *is equal for the two users.* Notice also that the marginal net benefit for both users is positive.

This implies that water sales should involve a positive marginal scarcity rent. Could we draw the diagram so that the marginal net benefit (and, hence, marginal scarcity rent) would be zero? How?



The Efficient Allocation of Surface Water

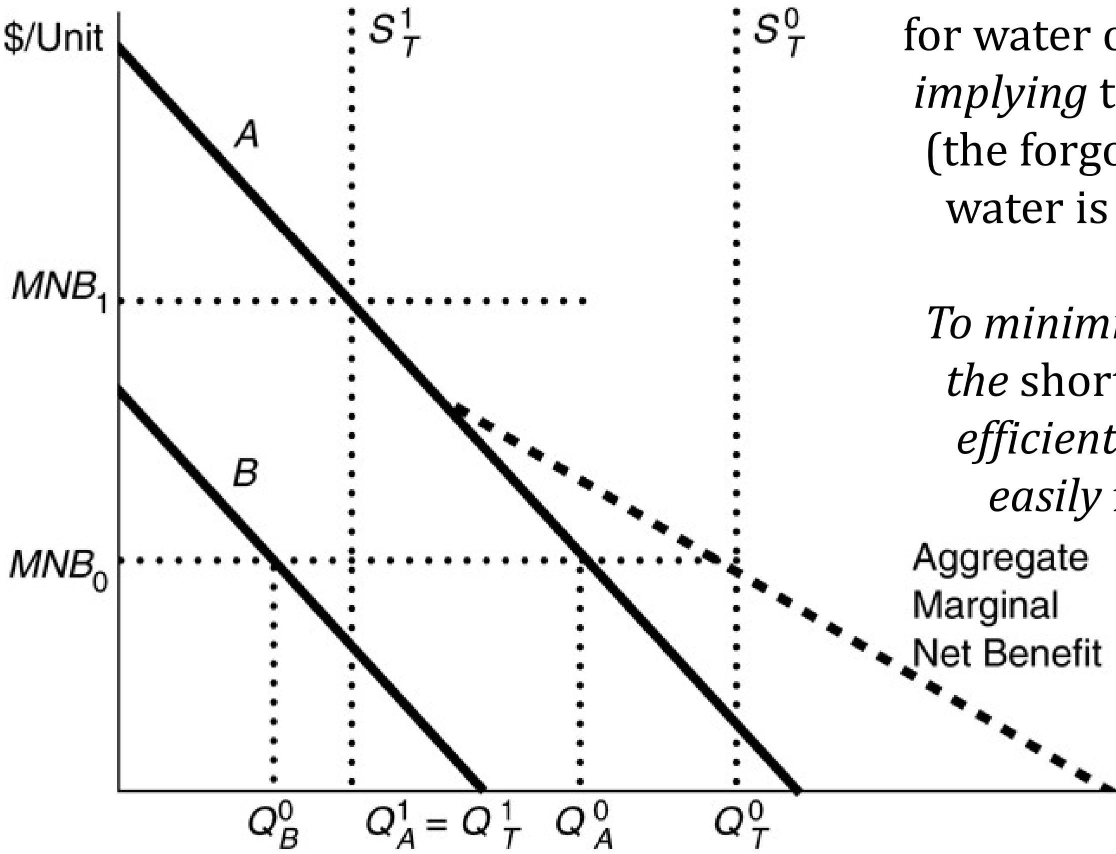
Marginal scarcity rent would be zero if water were not scarce. If the availability of water as presented by the supply curve was greater than the amount represented by the point where the aggregate marginal net benefit curve intersects the axis, water would not be scarce. Both users would get all they wanted; their demands would not be competing with one another.



Their marginal net benefits would still be equal, but in this case they would both be zero.

The Efficient Allocation of Surface Water

Now let's consider the problem of supply fluctuations. Suppose that now the water supply is $S^1{}_T$ a situation of restricted supply with a different efficient allocation: user *B receives no water, while use A receives it all.* Why does the efficient allocation change so radically?



The answer lies in the shape of the two demand curves for water. The MNB curve for water of user *A lies above that for B, implying* that as supplies diminish, the cost (the forgone net benefits) of doing without water is much higher for *A than for B.*

To minimize this cost, more of the burden of the shortfall is allocated to *B than A. In an efficient allocation, users who can most easily* find substitutes or conserve water receive proportionately smaller allocations when supplies are diminished than those who have few alternatives.

Efficient Allocation of Groundwater

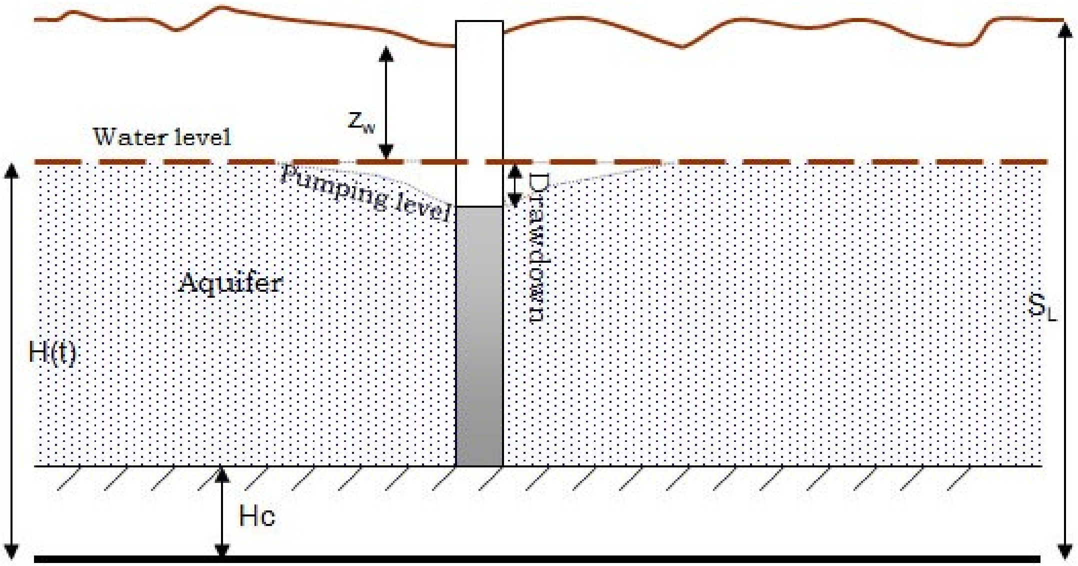
- Groundwater

- The analysis of groundwater requires that the depletable nature of groundwater supplies be explicitly taken into account. When withdrawals exceed recharge from a particular aquifer, the resource will be mined over time until either supplies are exhausted or the marginal cost of pumping additional water becomes prohibitive.

- The similarity of this case to the increasing-cost, depletable-resource model discussed earlier allows us to exploit that similarity to learn something about the efficient allocation of groundwater over time.
  - For groundwater, there is a marginal user cost reflecting the intertemporal opportunity cost.
  - For groundwater sources for which withdrawals exceed recharge, the resource will be mined over time until it is depleted or until the marginal extraction cost reaches a prohibitive level.
  - In some regions, groundwater and surface water are not physically separate and management must consider the linkages.

Efficient Allocation of Groundwater

- Groundwater
- the groundwater resource is determined by a single variable such as the volume of water remaining in the aquifer or the height of the aquifer (water table). Throughout this type of aquifer -- which is often called "bathtub" -- the water table and its fluctuation are both considered as uniform.
- Within this framework, the pumping level z_w in a well is defined by the following equation,
  $z_w = S_L - H_t$, where S_L is the height of the ground surface level and H_t is the height of water table at time t.
- We assume that the marginal cost, $MC_t = AC_t$, *of pumping* water at time *t*, *depends only on the pumping level,* z_w.



Efficient Allocation of Groundwater

- On the production side, yield is a function of the amount of groundwater, q, with all other variables held constant (model the relationship between crop yield and water use as a simple crop-water production function):

$$f(q_{r,t}) = a_r q_{r,t} - b_r q_{2r,t} + g_r \,,$$

where $q_{r,t}$ is the per hectare annual volume of water applied (m^3/ha) for each type of crop (r = 1, 2). $a > 0$, $b > 0$ and $g > 0$ are the fitting coefficients specific to each type of crop, which depend on climate conditions, soil properties, agronomic management practices in the reference area and irrigation methods.

- For the effect of farming on the water table we assume that the rate of change in the height of the water table, dH/dt, *is a function of the* total volume of water used in irrigated agriculture (total water pumped), as well as of certain hydrological conditions in the reference area, described by the following differential equation,

$$\dot{H} = \frac{1}{AS}\left[N - (1-a)Q_t\right], H(0) = H_0, H(T) \geq H_c$$

where N is the constant natural recharge of the aquifer, a is the constant return flow coefficient ($0 < a < 1$), Q_t is the total volume of water pumped and used at time t, A is the uniform at all depths surface area of the groundwater reservoir, S is the storativity coefficient, H_c is the height of the bottom of the aquifer and $H(0)$ is the initial height of the water table.

Efficient Allocation of Groundwater

- From the depletable-resource model, the first transferable implication is that a marginal user cost is associated with mining groundwater, reflecting the opportunity cost associated with the unavailability in the future of any unit of water used in the present. An efficient allocation considers this user cost.

- When the demand curve is stable over time (not shifting out due to population or income increases), the efficient extraction path involves temporally declining use of groundwater. The marginal extraction cost (the cost of pumping the last unit to the surface) would rise over time as the water table falls. Pumping would stop either when (1) the water table ran dry or (2) the marginal cost of pumping was either greater than the marginal benefit of the water or greater than the marginal cost of acquiring water from some other source.

- Abundant surface water in proximity to the location of the groundwater could serve as a substitute for groundwater, effectively setting an upper bound on the marginal cost of extraction. The user would not pay more to extract a unit of groundwater than it would cost to acquire another source of water

The Current Allocation System

- Riparian and Prior Appropriation Doctrines
  - Riparian rights allocate the right to use water to the owner of the land adjacent to the water.
    - This was a practical solution because by virtue of their location, these owners had easy access to the water. Initially there was abundance of water so that virtually all who sought water could be accommodated. With population growth and the consequent rise in the demand for land, this allocation system became less appropriate.
  - The prior appropriation doctrine allows the transfer of water away from the stream for beneficial use (“use-it-or-lose-it”).
    - The miners needed to divert water so they established the custom that the first person to arrive had the superior (or *senior) claim on the water. Later claimants hold junior (or subordinate)* claims. In practice, this severed the relationship that had existed under the riparian doctrine between the rights to land and the rights to water. As this new doctrine became adopted in legislation, widespread diversion of water based on prior appropriation became possible.
  - Water rights are usufruct rights which are rights to *use*, not rights to own.
  - The federal role in water resources has been very large.
    - The Reclamation Act of 1902

The Current Allocation System

- Sources of Inefficiency
  - Restrictions on Transfers
    - If property rights are well-defined, efficiency will result from the direct transferability of rights.
    - The existing system limits the transferability and results in inefficiencies.
    - The “use-it-or-lose-it” characteristic of the prior appropriation doctrine exacerbates the inefficiency since there is no incentive to conserve.
    - The preferential-use doctrine gives certain uses the highest priority for allocation during shortage regardless of the marginal net benefit of that use.
    - Small amount of water withdrawn from a stream also causes difficulty.

- By diminishing, and in some cases eliminating, the ability to transfer rights from so-called “high preferential use” categories to “lower preferential use” categories during times of acute need, the damage caused by shortfalls is higher than necessary. In essence, the preferential-use doctrine fails to adequately consider the marginal damage caused by temporary shortfalls, something a well-structured system of property rights would do automatically.

The Current Allocation System

- Sources of Inefficiency (contd.)
  - Federal Reclamation Projects and Agricultural Water Pricing
    - The federal government has subsidized many water projects even when the project failed a benefit-cost analysis
    - The pricing of the subsidized water also leads to inefficiencies.
  - Municipal and Industrial Water Pricing
    - Efficient pricing requires price to equal marginal cost.
    - Low prices leads to a significant amount of waste.

    - The prices charged by water distribution utilities do not promote efficiency of use either. Both the level of prices and the rate structure are at fault. In general, the price level is too low and the rate structure does not adequately reflect the costs of providing service to different types of customers.

The Current Allocation System

- Sources of Inefficiency (cont.)
  - Instream Flows
    - Conflicts between instream use and off-stream use is not uncommon.
    - Nonmarket resources compete with agricultural users creating conflicts.
    - Currently instream flow rights do not exist in many states.
  - Common Property Problems
    - Many users can create an open access problem.
    - Tapping an open-access resource will tend to deplete it too rapidly; users lose the incentive to conserve. The marginal scarcity rent will be ignored.
    - Pumping costs will rise too rapidly.
    - Future users will carry the larger burden.

Potential Remedies

- Water Transfers and Water markets
  - Relaxing "use-it-or-lose-it" restriction would encourage conservation and allow water to move to higher valued uses by allowing owners to sell conserved water.
  - Water markets and water banks are being increasingly utilized to treat both inefficiencies and scarcity in the short term or on a long-term basis.

Tradable water permits are commonly considered as one of the most efficient market-based instruments for groundwater allocation. Water permit markets could yield the right price and lead to the efficient allocation with limited costs for overall planning and management. Assuming the existence of well-defined water rights, the institutions for distributing them and the appropriate monitoring infrastructure, a water permit market would ensure that water goes to the higher value use. Water permits are also consistent with the EU guidelines for water policy that promote the use of economic instruments providing water use efficiency and financial incentives.

Potential Remedies

- Water Transfers and Water markets (Contd.)
  - Instream Flow Protection
    - The prior appropriation doctrine also fails to provide adequate protection for instream flows.

- Water Transfers and Water markets (Contd.)
  - Water Prices
    - Pricing reform by the elimination of subsidies would also reduce inefficiencies.
    - Water conservation and various charge rate structure

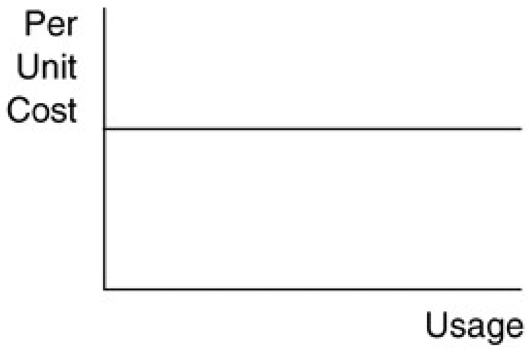
Pricing Methods and Their Properties

Pricing Scheme	Implementation	Efficiency Achieved	Time Horizon of Efficiency	Ability to Control Demand
Volumetric	Complicated	First-Best	Short-Run	Easy
Output	Relatively Easy	Second-Best	Short-Run	Relatively Easy
Input	Easy	Second-Best	Short-Run	Relatively Easy
Per-Area	Easiest	None	N.A.	Hard
Block-Rate (Tiered)	Relatively Complicated	First-Best	Short-Run	Relatively Easy
Two-Part	Relatively Complicated	First-Best	Long-Run	Relatively Easy
Water market	Difficult without Preestablished Institutions	First-Best	Short-Run	N.A.*

* Not applicable.

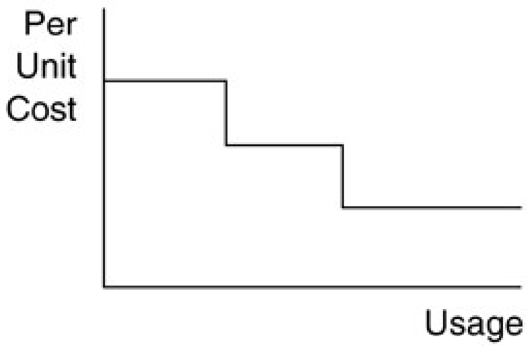
Source: "Pricing Methods and Their Properties" by Ariel Dinar, Richard Doukkali, Terry Roe, and Tsur Yacov, from PRICING IRRIGATION WATER PRINCIPLES AND CASES FROM DEVELOPING COUNTRIES.

Variable Charge Rate Structures



UNIFORM RATE STRUCTURE

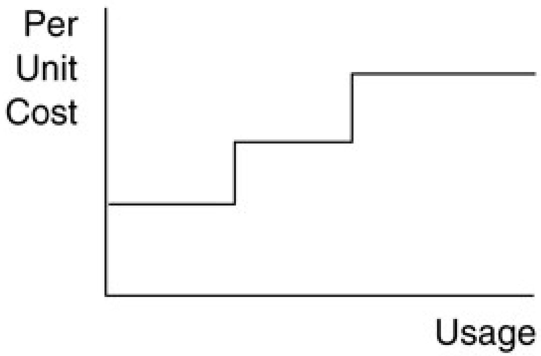
The cost per unit of consumption under a uniform rate structure does not increase or decrease with additional units of consumption.



DECLINING BLOCK RATE STRUCTURE

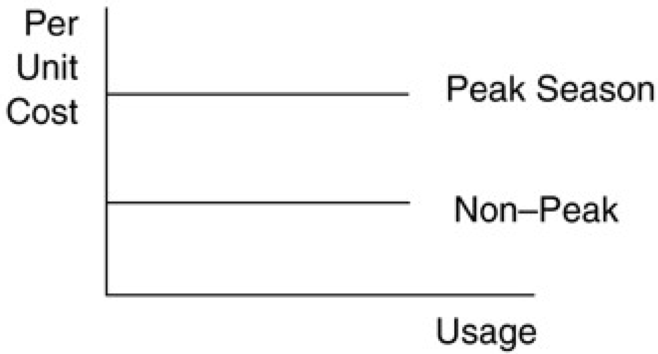
The cost per unit of consumption under a declining block rate structure decreases with additional units of consumption.

Variable Charge Rate Structures



INVERTED BLOCK RATE STRUCTURE

The cost per unit of consumption under an inverted block rate structure increases with additional units of consumption.



SEASONAL RATE STRUCTURE

The cost per unit of consumption under a seasonal rate structure changes with time periods. The peak season is the most expensive time period.

Source: Four examples of consumption charge models from WATER RATE STRUCTURES IN COLORADO: HOW COLORADO CITIES COMPARE IN USING THIS IMPORTANT WATER USE EFFICIENCY TOOL, September 2004, p. 8 by Colorado Environmental Coalition, Western Colorado Congress, and Western Resource Advocates.

Pricing Structures for Public Water Systems in the US (1982–2008)

	1982	1987	1991	1996	1998	2000	2002	2004	2006	2008
	%	%	%	%	%	%	%	%	%	%
Flat Fee	1	—	3	—	—	—	—	—	–	–
Uniform Volume Charge	35	32	35	32	34	36	37	39	40	32
Decreasing Block	60	51	45	36	35	35	31	25	24	28
Increasing Block	4	17	17	32	31	29	32	36	36	40
Total	100	100	100	100	100	100	100	100	100	100

Source: Raftelis Rate Survey, Raftelis Financial Consulting.

World Cities and Rate Structures

Rate Type	Number of Cities	Percentage
Fixed fee	4	1.5
Flat rate	119	43.9
Increasing block rate	139	51.3
Declining block rate	6	2.2
Other	3	1.1
Total	271	100

Source: OECD, http://www.oecd-ilibrary.org/environment/pricing-water-resources-and-water-and-sanitation-services_9789264083608-en;jsessionid=5q1ygq2satyj.delta; and Global Water International, 2010 Tarrif survey, http://www.globalwaterintel.com/tariff-survey/

Potential Remedies

- Desalination
  - Reverse osmosis: pumping seawater at high pressure through permeable membranes
  - Significantly reduced price of desalinized water due to technological advances in reverse osmosis, nanofiltration, and ultrafiltration methods

Summary

- Efficiency requires the equalization of marginal net benefits of water use for replenishable water.
- The efficient allocation of groundwater should account for the user cost.
- Inefficiency is evident in current system.
- Reforms are possible.