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Economics in Context Initiative

Water: Economics and Policy

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An ECI Teaching Module on Social and Environmental Issues in Economics

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NOTE – terms denoted in **bold face** are defined in the **KEY TERMS AND CONCEPTS** section at the end of the module.

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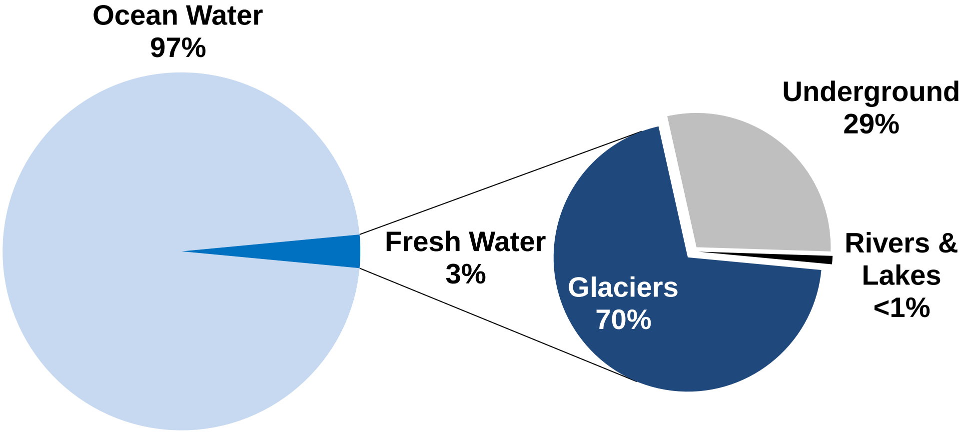
1. GLOBAL SUPPLY AND DEMAND FOR WATER

Water is a unique natural resource that forms the basis for life on earth. Ninety-seven percent of the Earth's water is salt water and only 3 percent is freshwater, of which 70 percent is in solid form, captured by the polar ice caps and by glaciers (Figure 1). Of the 30 percent of freshwater that is available in its liquid form, most is in underground aquifers. The freshwater that makes up all of the terrestrial sources such as rivers and lakes only represent 1 percent of the planet's freshwater.

Figure 1. *The Composition of the Planet's Water*

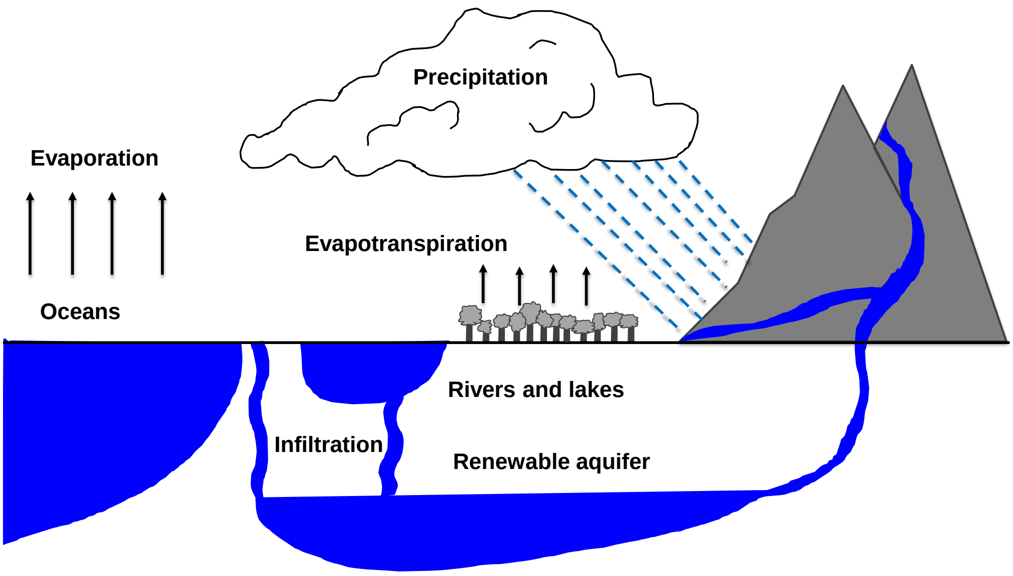


Source: World Business Council for Sustainable Development, 2005.

Water can be characterized as a renewable resource, since it can generally be reused indefinitely as long as it is not severely polluted. Also, water is continually purified in a process known as the **hydrologic cycle** (see Figure 2). (Hydrology is the scientific study of the distribution and movement of water on the earth's surface, underground, and in the atmosphere.) Water evaporates into the atmosphere from lakes, rivers, oceans, and through the evapotranspiration of plants and other living organisms, then returns to the earth's surface as precipitation that replenishes freshwater sources.

hydrologic cycle the natural purification of water through evaporation and precipitation.
stock the quantity of a variable at a given point in time, such as the amount of water in a lake, or the amount of timber in a forest, at a given time.
flow the quantity of a variable measured over a period of time, including physical flows, such as the flow of a river past a given point measured in cubic feet per second, or financial flows, such as income over a period of time.

Figure 2. *The Hydrologic Cycle*



Many of the principles of renewable resource management apply to water systems, but although surface water can be considered a renewable resource, it is still available in limited supply. The **flows** of freshwater that are recycled in the hydrologic cycles can become **stocks** in two types of natural reservoirs: bodies of surface water such as lakes and rivers, and stocks of groundwater, which are found in aquifers.

While aquifers are replenished as a result of surface water infiltration, most aquifers have very long replenishment times, making them essentially nonrenewable resources on a human time scale. Aquifers under the Sahara, for example, are thousands of years old and are sometimes referred to as "fossil water." The analysis of water systems thus combines elements of renewable and nonrenewable resource theory.

Evaporation fueled by the sun's energy lifts 500,000 cubic kilometers of moisture into the atmosphere each year—86 percent from the oceans and 14 percent from the land. An equal amount falls back to earth as rain, sleet, or snow, but it is distributed in different proportions: whereas the continents lose about 70,000 cubic kilometers through evaporation, they gain 110,000 through precipitation. As a result, roughly 40,000 cubic kilometers are transferred from the sea to the land each year.[1]

The total available supply of 40,000 cubic kilometers is equivalent to about 5,500 cubic meters per person per year. Hydrologists have established that, considering the water needs of modern societies, a threshold of 2,000 cubic meters per person per year represents the level above which a population can be sustained comfortably. But while the total global water supply is sufficient to meet human needs, not all water can be captured for human use. As much as two-thirds of

[1] See Figures 1 and 2; Postel, 1992.

the total water supply runs off as floods. Some water must also be allocated to meet ecological demands, such as supplying wetlands and wildlife habitat.

Most important, water is not evenly distributed geographically and seasonally. Some regions of the world have abundant water resources, while others suffer from a scarcity of water. A country that has an available water supply between 1,000 and 1,700 cubic meters per person per year is classified as **water stressed**.[2] If water supplies are below 1,000 cubic meters per person per year, the country is classified as **water scarce**, causing a severe constraint on food production, economic development, and protection of natural systems. A country faces a situation of **absolute water scarcity** when freshwater supplies drop below 500 cubic meters per person per year.

water stressed term used for countries where freshwater supplies are between 1,700 and 1,000 cubic meters per person per year.
water scarce term used for countries where freshwater supplies are less than 1,000 cubic meters per person per year.
absolute water scarcity term used for countries where freshwater supplies are less than 500 cubic meters per person per year.

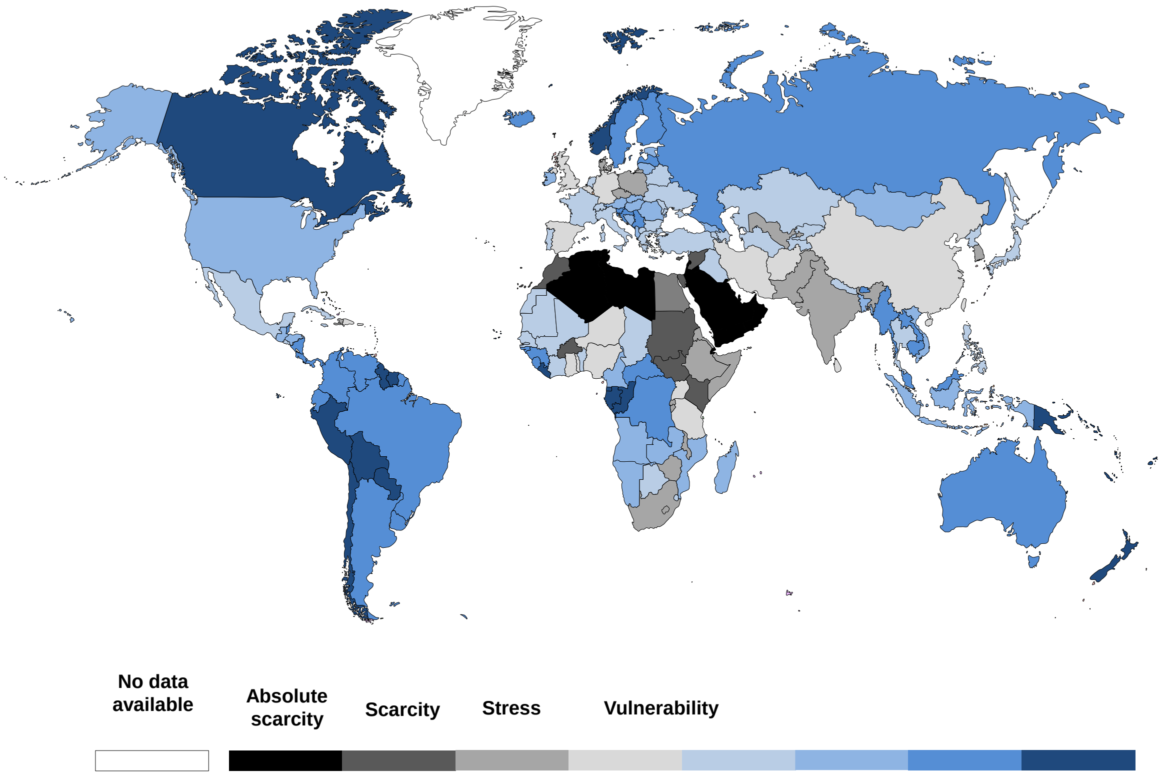
Figure 3 displays national averages of freshwater supplies available per person per year. Table 1 shows freshwater availability in major regions of the world. The Middle East and North African region already experiences a situation of absolute water scarcity (average 500 cubic meters per person per year) with a current population of 512 million (in 2020) expected to increase to 735 million in 2050.[3] Sub-Saharan Africa suffers from water scarcity (1,000 cubic meters per person per year) with a population of 1094 million (in 2020) expected to double (2117 million) by 2050.[4] UNEP's projections were already dire in 2008, and current projections have confirmed these warnings:

> [According to projections], more than 2.8 billion people in 48 countries will face water stress or scarcity conditions by 2025. Of these countries, 40 are in West Asia, North Africa or sub-Saharan Africa. Over the next two decades, population increases and growing demands are projected to push all the West Asian countries into water scarcity conditions. By 2050, the number of countries facing water stress or scarcity could rise to 54, with a combined population of four billion people.[5]

Water shortages will be exacerbated in some regions because of climate change. The Intergovernmental Panel on Climate Change (IPCC), comparing several projection scenarios, has stated that "broadly, water resources are projected to decrease in many mid-latitude and dry subtropical regions, and to increase at high latitudes and in many humid mid-latitude regions."[6]

[2] Center for Strategic and International Studies, 2005.
[3] UN Population Division, 2020 https://population.un.org/wpp/Download/Standard/Population/
[4] UN Population Division, 2020.
[5] UNEP, 2008.
[6] IPCC, 2014, p. 251.

Figure 3. *Total Renewable Water Resources per Capita*



Source: UNESCO World Water Assessment Program, with data for 2013 from the FAO AQUASTAT database, reproduced in United Nations World Water Development Report, 2015.
Note: Blue shading denotes water availability per person (the darker the blue, the more water-abundant).

Table 1. *Water Availability per Region, 2012*

Region	**Average Water Availability (cubic meters/person)**
Middle East and North Africa	500
Sub-Saharan Africa	1,000
Caribbean	2,466
Asia/Pacific	2,970
Europe	4,741
Latin America	7,200
North America (including Mexico)	13,401

Sources: FAO, Aquastat, 2013; UNESCO, 2015, http://vitalsigns.worldwatch.org.

Assuming an increase in global average temperature of 2°C above the 1980–2010 mean, and combining five climate models with 11 hydrological models (55 scenarios), the IPCC shows that there is a strong likelihood of a decrease of 30–50 percent in runoff for the following regions of the world: Southern Europe, Eastern Europe and the Ukraine, North Africa (Morocco, Algeria, Tunisia), Middle East (Turkey, Syria, Lebanon, Israel, Palestine, Jordan, Iraq, Iran, Afghanistan), South Africa, Southern Latin America (Chile, Southern Brazil, Uruguay, Paraguay, Argentina), Southwest Australia. At the opposite side of the spectrum, wet regions like India and Bangladesh are likely to experience an increase of 30–50 percent in runoff.

As warmer temperatures speed up the hydrological cycle, wet areas will tend to become wetter, increasing the likelihood of flooding (particularly in the Indian subcontinent). Currently arid and semiarid areas are likely to become drier, increasing the probability of droughts.[7] (For more on the impact of climate change on precipitation patterns in the western United States, see Box 1.) The UN Secretary General has warned that by 2030, an estimated 700 million people worldwide could be displaced by intense water scarcity.[8]

BOX 1: THE WESTERN UNITED STATES: ONE HUNDRED YEAR DROUGHT?

Drought conditions have been widespread in the Western United States since the beginning of the twenty-first century. Nine states have experienced severe droughts in recent years: California, Arizona, Colorado, Kansas, Nevada, Oklahoma, Oregon, Texas, and Utah. One third of the West is experiencing what the U.S. Drought Monitor identifies as "extreme" or "exceptional" drought, which is a major contributor to record wildfires activities in California and Colorado. In 2020, nationwide, 72.5 million people were in areas directly affected by droughts. NASA projections for the future predict that there is a strong likelihood that "droughts in the U.S. Southwest and Central Plains during the last half of this century could be drier and longer than drought conditions seen in those regions in the last 1,000 years."

Assuming no significant policy changes, projections by the Intergovernmental Panel on Climate Change indicate that *average* rainfall in the American West will be less than the average during the 2000–2004 drought. Climate change models "suggest that a coming megadrought—a prolonged, multidecade period of significantly below-average precipitation—is possible and likely in the American West."

Emergency measures instituted during recent droughts, such as lawn-watering and other restrictions, may need to be made permanent. The extent of irrigated agriculture may need to be reduced. While there may still be time to avoid the risk of megadroughts, "there can be little doubt that what was once thought to be a future threat is suddenly, catastrophically upon us."

***Sources*: Schwalm *et al.*, 2012; NASA, 2014; Frohlich and Lieberman, 2015; Cappucci, 2020; U.S. Drought Monitor, https://droughtmonitor.unl.edu/**

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[7] Dore, 2005; United Nations, 2019, https://www.un.org/press/en/2019/sgsm19503.doc.htm.
[8] Secretary General's message on World Water Day, 22 March 2019.

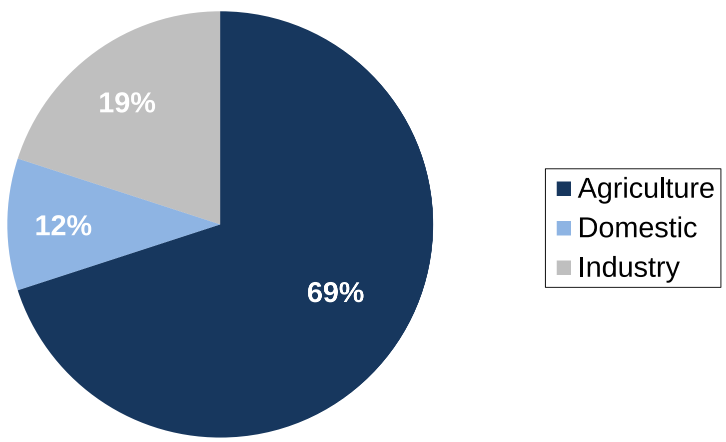
1.1 Water Demand, Virtual Water, and Water Footprint

To consider these challenges in more depth, we turn to a detailed analysis of the uses of water in modern societies. Water demand can be measured in a number of ways; the simplest is the amount of total freshwater withdrawal for various sectors of the economy.

The largest water consuming sector is agriculture. Although 80 percent of the world's cropland is rain fed, the 20 percent that requires irrigation produces 40 percent of the world's food supply.[9] The water needed for irrigated agriculture amounts to 69 percent of global water withdrawals.[10] Another 19 percent of global water withdrawals is for industrial demands, including electricity generation. Only 12 percent of water is used to meet municipal and domestic demands[11] (see Figure 4).

These percentages are global averages, but they vary significantly from country to country. In the United States, for instance, irrigation amounts to 41 percent of the nation's total freshwater withdrawals, while industry accounts for up to 46 percent of water withdrawals, especially for thermoelectric power generation, which needs large amounts of water cooling for steam-driven turbine generators.[12] In the developing world, freshwater withdrawals are often mostly used for agriculture (for example, agriculture accounts for 86 percent of water withdrawals in Egypt, 94 percent in Ethiopia, and 95 percent in Vietnam).

Figure 4. *Global Water Withdrawals for Agricultural, Industrial, and Municipal Use*



Source: FAO, Aquastat (updated January 2021) http://www.fao.org/nr/water/aquastat/tables/WorldData-Withdrawal_eng.pdf.

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[9] Worldwatch Institute, November 2012, quoted in Croplife, 2012.
[10] United Nations, UN-Water, 2021.
[11] FAO, 2016. http://www.fao.org/nr/water/aquastat/tables/WorldData-Withdrawal_eng.pdf
[12] Gleick *et al*., 2014, pp. 227–235.

In order to analyze the full impact of human activity on water resources, scientists have proposed the concept of **virtual water**,[13] which takes into account water that is used throughout the production process for a particular good or service. Agricultural goods need water to grow plants and to raise cattle and other livestock. Industrial goods require water as raw material or as part of the production process. Both agricultural and industrial sectors also consume water indirectly through their demand for energy, which is particularly water-intensive.

Virtual water water embedded in goods or services, based on water used as an input throughout the production process.

The energy sector uses water at all stages of energy extraction, production and consumption. Conventional natural gas is the least water intensive fuel, using only one-fifth as much water as conventional oil, whereas the use of unconventional oil tar sands requires 20 times more water than conventional oil. Natural gas produced by hydraulic fracturing, or "fracking," also requires much larger amounts of water than conventional natural gas production. Biofuels produced from irrigated fields of corn or soy require 3,000 times more water than conventional oil.

As an example of virtual water use through energy use, a roundtrip by car between New York City and Washington D.C. requires an amount of energy equal to 2 million BTUs (British Thermal Units), which would translate into 5 gallons of virtual water if the trip was done with a vehicle running on natural gas, 32 gallons of water if it was running on gasoline from conventional oil, but 616 gallons of water if the gasoline was derived from tar sands. If the vehicle was running on biofuels, this roundtrip would require 35,616 gallons of water using corn-based biofuel, and 100,591 gallons of water using soy-based biofuel.[14] Table 2 presents the amount of virtual water embedded in some common goods.

Measures of virtual water can be used to develop the concept of a **water footprint**. The water footprint of an individual, household, corporation, city, or country is an indicator of total impact on freshwater resources, including both direct and indirect uses of water. The water footprint of the average person on the planet is 1,056 gallons of water per day—enough to fill up 21 standard bathtubs.[15] The average water footprint of an American citizen is more than twice the global average, amounting to 2,220 gallons of water per day, which is equivalent to 44 full bathtubs of water. In the USA, the average water footprint per year per capita is as much as the water needed to fill an Olympic swimming pool (2,842 cubic meters).[16]

water footprint the total amount of water consumed by a human entity—individual, family, city, corporation, or country—whether directly or indirectly, calculated by summing all the virtual water embedded in the products, energy, and services used by this entity.

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[13] Concept and term coined by Allan, 2011, p. 9.
[14] Virtual water uses calculated based on data from World Policy Institute, 2011.
[15] Allan, 2011, p. 4.
[16] Water Footprint Network, 2016.

Table 2. *Virtual Water Embedded in a Selection of Products, per Unit of Product (in liters: 1 gallon = 3.78 liters)*

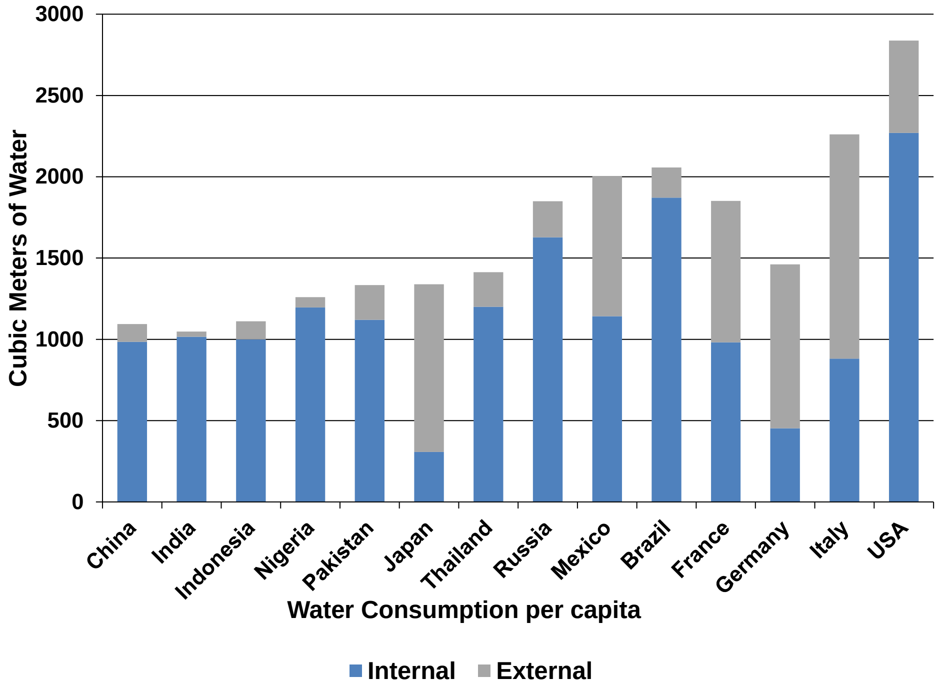
Product	**Virtual-Water Content (liters)**
1 sheet of paper (80 g/m2)	10
1 tomato (70 g)	13
1 slice of bread (30 g)	40
1 orange (100 g)	50
1 apple (100 g)	70
1 glass of beer (250 ml)	75
1 glass of wine (125 ml)	120
1 egg (40 g)	135
1 glass of orange juice (200 ml)	170
1 bag of potato crisps (200 g)	185
1 glass of milk (200 ml)	200
1 hamburger (150 g)	2,400
1 pair of shoes (bovine leather)	8,000

Source: Hoekstra and Chapagain, 2008, p. 15.

Figure 5 presents water footprints for a selection of countries, calculated in cubic meters per person per year. The water footprint of nations is not necessarily a function of their GDP, as the water footprint of low-income countries such as Nigeria and Pakistan are comparable to the water footprint of Japan. The U.S. footprint is the highest, almost three times that of China or India.

The figure displays two values for each nation:1) how much of that water footprint lies within the country's borders (internal footprint); 2) how much is related to water used for imported good (external footprint). The full water impact of an economy is a function of what is consumed, whether it is produced domestically or somewhere else in the world.

Figure 5. *National Water Footprint for Selected Countries, 1997–2001 (in Cubic Meters per Person per Year)*



Sources: Mekonnen & Hoekstra, 2011. National Water Footprint Accounts, UNESCO-IHE; also available at https://www.waterfootprintassessmenttool.org/national-explorer

1.2 Virtual Water Trade

Water footprints take into account all the water embedded in the goods and services consumed in a country, regardless of whether this water comes from the national resources inside the borders of the country or whether it comes from other parts of the world. An invisible circulation of water takes place between countries through trade: water-scarce countries can consume imported products that would have been too water-consuming to produce with their own water resources.

But trade does not necessarily follow a logical pattern in terms of water transfer. The cotton industry, for instance, is particularly water-intensive, and a single cotton T-shirt contains 2,700 liters of virtual water. Cotton is often produced in water-stressed or water-scarce countries, such as India, Pakistan, or Egypt. The water footprint of the exports of cotton from India to Europe represents more than 5 billion cubic meters of water per year,[17] while two-thirds of the population of India (769 million) lacks access to improved sanitation and 77 million lacks access to safe water.[18]

European countries, on the other hand, which are far from being water-scarce, have living styles that require massive imports of water-intensive goods. As a result, 40 percent of Europe's water

[17] Hoekstra and Chapagain, 2008, p. 85.
[18] Water.org (formerly WaterPartners International), http://water.org/country/india/.

footprint lies outside of its borders (69 percent in the case of Germany).[19] The difference in the water footprint profiles of countries, according to their reliance on water-intensive imports, can be seen in Figure 5. The water footprint of European countries (Germany, France and Italy) as well as of Japan show that these countries' water impacts derive in large proportion (and almost exclusively in the case of Japan) from the goods they import from the rest of the world. In contrast, the emerging economies of Brazil, Russia, India, China, and South Africa (BRIICS), most of their water footprint is internal, water consumption being mostly embedded in domestic production. The USA is a net water exporter (primarily due to agricultural exports).

Most of the countries that are water abundant tend to be net exporters of virtual water, while countries that are water-scarce tend to be net importers of virtual water. However, there are important exceptions to the rule, as many of the Asian countries that are experiencing water stress are virtual water exporters, including India, Pakistan, and China. On the other hand, countries that are relatively water-abundant, such as Italy or Japan, are nevertheless virtual water importers.

Hydrologists express concern that once water is removed from a watershed (through the export of virtual water), it is irreversibly removed from the local hydrological cycle as well, which in turn reduces evaporation, heating up the atmosphere.[20] Countries which are net virtual water exporters are therefore unknowingly trapping themselves in a vicious circle where the more virtual water they export, the drier their climate becomes, which is of particular concern for developing countries that are already water stressed or water scarce.

Perverse effects of virtual water transfers are observed within developed countries as well. In the U.S., virtual water trade is emptying the Colorado and Rio Grande Rivers and depleting the Ogallala Aquifer.[21] In Australia, which is a net exporter of 64 billion cubic meters of virtual water each year, shipping out more water than it takes in, "a country continually struggling with unreliable rainfall and severe drought allows more virtual water to be lost than any other nation on the planet."[22] And in water-abundant Canada, the province of Alberta is expected to become the first water "have-not" province under the pressure of intensive livestock operations in anticipation of large export demand for meat.

1.3 Water Footprint the Future of Water: Horizon 2050

Global water demand is projected to increase by 55 percent between 2000 and 2050, as shown in Figure 6. All the demand growth is expected to occur in developing countries, mainly China and India. While the global demand for irrigation water is actually projected to decline in the coming decades due to increased irrigation efficiency, significant growth is expected for manufacturing, domestic, and electricity needs. According to the Organization for Economic Cooperation and Development (OECD), "In the absence of major policy changes and much better water management the situation will deteriorate and water availability will become increasingly uncertain."[23]

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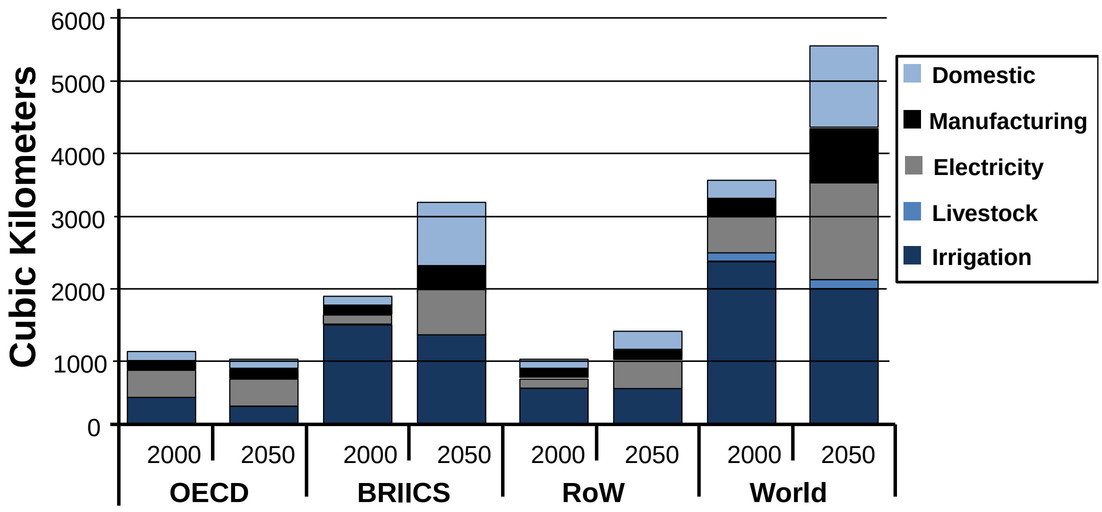
[19] Water Footprint Network, National Water Footprint Explorer. www.waterfootprint.org.
[20] Barlow, 2013 pp. 168–169.
[21] Fred Pearce, 2008.
[22] Ian Douglas, 2011, quoted in Barlow, 2013, p. 169.
[23] OECD, 2012, p. 1.

Figure 6. *Global Water Demand, 2000 and 2050*



Source: OECD, 2012.

Note: BRIICS = Brazil, Russia, India, Indonesia, China, South Africa; OECD = Organization for Economic Cooperation and Development; RoW = rest of world.

One of the Millennium Development Goals set by the United Nations in 2000 was to halve the proportion of the world's population without access to safe drinking water between 1990 and 2015. This goal was met ahead of schedule, in 2010, when an estimated 89 percent of the world's population had access to safe drinking water.[24] The UN has explicitly recognized that the right to water and sanitation is a human right.[25] But progress in expanding access to safe water has been uneven. About half the progress occurred in China and India, while in some African countries safe water access has declined since 1990. In 2020, some 2.2 billion people around the world still did not have safely managed drinking water services, 4.2 billion people did not have safely managed sanitation services, and 3 billion lacked basic handwashing facilities.[26]

2. ADDRESSING WATER SHORTAGES

Water shortages can be addressed using two basic approaches: from the supply side or the demand side. Given the extent of projected water shortages in some regions, a "magic bullet" solution is unlikely. A range of options will be needed.

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[24] Ford, 2012.
[25] United Nations, 2021.
[26] United Nations, 2020.

We have a menu of options, but the status quo is not one of them. In the United States, the usual response to water shortages is to divert more water from rivers, build more dams, and drill more groundwater wells. These traditional alternatives are not viable solutions. Other ideas—surreal ones—include towing icebergs from the Arctic, importing water from British Columbia, and seeding clouds. These ideas reflect a misguided hope that there is a new oasis out there, somewhere, that will obviate the need to examine carefully how and for what we use water. More sensible approaches include conservation, desalination, and reuse of treated municipal effluent. Yet even communities that have embraced these measures still face ominous water futures.[27]

BOX 2: WATER AND CONFLICT

Many conflicts have erupted throughout history between populations clashing over access to scarce water sources. The first archaeological signs of water conflicts date as far back as 2500 B.C. in Mesopotamia. In the conflicts of our times, water is one of the leading factors in some regional contexts. The civil war that devastated Syria starting in 2011 was strongly related to water shortage issues. A climatic event, a prolonged six-year drought from 2006 to 2011, caused the ruin of hundreds of thousands of small-scale farmers and forced them to migrate with their families to the outskirts of major cities such as Aleppo, Damascus, Hama, Homs, and Dara'a. This impoverished and destitute population formed the demographic basis for a popular revolution against the Assad regime in 2011, ushering in a period of extreme instability and civil war.

In one of the most protracted conflicts of our times, between the State of Israel and the Palestinian people, access to the water aquifers underneath the hills of the West Bank is an important factor. A World Bank report indicates that Israelis use four fifths of the West Bank groundwater resources, and the Palestinians only one fifth. Israelis use 240 cubic meters of water per person per year, compared with 75 cubic meters per person per year for West Bank Palestinians. In some areas of the West Bank, Palestinians are surviving on as little as 10 to 15 liters a person each day, which is at or below humanitarian disaster response levels recommended to avoid epidemics. The amount recommended by the World Health Organization is at least 100 liters per person per day.

For Palestinians in the Gaza Strip, water supply depends on the coastal aquifer (also shared with Israel) that has become increasingly saline and polluted. Because of the conflict, there has been little or no investment in water infrastructure in decades and only 5–10 percent of the available water is clean enough to drink. The issue of water resources has been an essential dimension of all the rounds of diplomatic talks between Israelis and Palestinians since the 1990s.

***Sources*: Gleick *et al.*, 2014, p. 147: "The Syrian Conflict and the Role of Water" and p. 174: "Water Conflict Chronology"; World Bank, 2009; B'Tselem, 2017.**

[27] Gleick, 2011, pp. xi–xii.

2.1 Increasing Water Supply: Aquifers, Dams, and Desalination

Past water management policies have generally focused on ways to increase the supply of water. In regions where freshwater supplies are insufficient to meet demand, additional water has often been obtained by extracting groundwater from aquifers. While underground aquifers are normally recharged by water seepage, in most cases withdrawal rates greatly exceed the rates of recharge.

Countries such as Saudi Arabia and Libya rely on “fossil” groundwater from ancient aquifers in desert areas, which now have practically no recharge and are likely to be depleted in the next 40 to 60 years. In the western United States, the Ogallala Aquifer is also severely depleted, and as a result irrigated area has started to shrink. Similar problems affect aquifers in North China and in India. (For more on the exploitation of aquifers around the world, see Box 3.)

Another way to increase water supplies is to construct dams. Dams can capture seasonal floodwater that would otherwise be unavailable for human use, as well as providing hydroelectric power and irrigation. Worldwide about 58,000 large dams are in operation, about 41% of them in China.[28] These dams provide 16 percent of the world’s electricity.[29] More dams are still being built, mainly in China, Iran, Japan, and Turkey, but the best sites are already in use.

Existing dams are often affected by problems of siltation, and new large dam proposals have been criticized for the environmental and social damage that results from the flooding of large areas.[30] For example, the Three Gorges Dam in China, the largest hydroelectric dam in the world, displaced 1.3 million people and disrupted the habitat of dozens of endangered species. The top reason invoked for its construction had been to control flooding, but recent episodes of mega floods caused by record summer rainfalls in the summer of 2020 confirmed its inability to perform this task; as many critics, including Chinese geologists, had warned: “it’s like using a small cup to deal with a big tub of water”. The storage capacity of the reservoir can handle only 9% of the amount of a “one-in-a-century” flood, but such destructive events are likely to happen at a higher frequency due to global climate change.[31]

The World Wildlife Fund reports that large dams (more than 15 meters high) built to provide hydroelectricity and flood irrigation are killing the ecosystems of the major rivers in the world. Only 21 (12 percent) of the world’s longest rivers run freely from source to sea. The world’s large dams have wiped out species, flooded huge areas of wetland, forest, and farmland, and displaced many millions of people. Dams reduce biodiversity, decrease fish populations, lower crop production, disrupt the flow of nutrients needed for water health, and contribute to global warming by trapping methane and rotting vegetation in their reservoirs. Canadian scientists have made a preliminary estimate that reservoirs worldwide release up to 70 million tons of methane and around a billion tons of carbon dioxide every year. Toxic algae blooms have rendered some reservoirs unfit to drink. And because they greatly increase the surface area of water, dams increase evaporation. About 170 cubic kilometers of water evaporate from the

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[28] International Commission on Large Dams, 2020. Large dams are those over 15 meters in height.
[29] Urpelainen *et al.* 2018.
[30] World Commission on Dams, 2000. Quoted in Schulz and Adams, 2019.
[31] Gan, 2020.

world's reservoirs every year, equal to more than 7 percent of the amount of fresh water consumed by all human activities.[32]

BOX 3: DEMAND FOR WATER OUTSTRIPS SUPPLY

According to an analysis of global groundwater supplies published in 2012, nearly one-quarter of the world's population lives in areas where groundwater is being withdrawn faster than it can be replenished. This includes many of the world's major agricultural regions, including the Central Valley in California, the Nile delta in Egypt, and the Upper Ganges in India. In addition to providing water for irrigation, water stored in underground aquifers for thousands of years supplies basic human needs, manufacturing demands, and water for wildlife habitat.

"This overuse can lead to decreased groundwater availability for both drinking water and growing food," says Tom Gleeson, a hydrogeologist at McGill University in Montreal, Quebec, and lead author of the study. Eventually, he adds, it "can lead to dried up streams and ecological impacts."

The study found that some aquifers are being depleted at an alarming rate. For example, the geographical area dependent upon the Upper Ganges aquifer is more than 50 times the size of the aquifer itself. Gleeson notes that "the rate of extraction is quite unsustainable there."

Gleeson also points out that remaining groundwater supplies, overall, are quite large. As much as 97 percent of the fresh, unfrozen water on the planet is groundwater. "It's this huge reservoir that we have the potential to manage sustainably," he says. "If we choose to."

***Source*: Mascarelli, 2012.**

Because of the vast amounts of seawater on the planet, **desalination** has appeal as a potential source of virtually unlimited supply. However, cost is a significant barrier to desalination. Removing salt from seawater requires large amounts of energy. While desalination costs have declined as technology has improved, it currently costs about $0.50 to $1.00 per cubic meter to desalinate seawater,[33]which is usually more expensive than obtaining water supplies from surface water or groundwater. For example, in an analysis of water supply options in San Diego, California, desalination costs were estimated to be $1,800–$2,800 per acre-foot (AF) while the supply costs were $400–$800 per AF for surface water and $375–$1,100 per AF for groundwater.[34] While desalination may make economic sense in some very dry regions, it is unlikely to supply a significant amount of the planet's water in the future:

> Despite major advancements in desalination technologies, seawater desalination is still more energy intensive compared to conventional technologies for the treatment of fresh water. There are also concerns about the potential environmental impacts of large-scale seawater desalination plants, which must

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[32] Barlow, 2013, pp. 142–143.
[33] WaterReuse Association, 2012.
[34] Equinox Center, 2010.

> dispose of large volumes of highly saline brine that is the byproduct of desalination.[35]

desalination the removal of salt from ocean water to make it usable for irrigation, industrial, or municipal water supplies.

2.2 Water Demand Management

One of the ways that we can alter the projected trend of increasing water demand in Figure 6 is to increase water use efficiency. The greatest efficiency gains can be made in agriculture. Whereas traditional irrigation by flooding or channeling water by gravity is inefficient (60 percent of the water is lost by evaporation or infiltration), new techniques of **micro-irrigation** by drip systems allow an efficiency of 95 percent.[36] Also, technologies that permit better monitoring of soil and weather conditions can more accurately determine appropriate irrigation needs.

micro-irrigation irrigation systems that increase the efficiency of water use by applying water in small quantities close to the plants.

For non-agricultural uses, recycling and reuse of wastewater can reduce water demand. For example, through a graywater system, water used for such purposes as laundry and bathing can also be used to irrigate landscaping. Water use standards for devices such as dishwashers, toilets, and showerheads can reduce domestic water needs. Leak detection and repair, especially in municipal water supply lines, can also help reduce water consumption.

Economic research shows that conservation is generally the cheapest way to address water shortages. In the San Diego study mentioned above, the cost of conservation was estimated at between $150 and $1,000 per AF, based on a range of conservation options. The study concluded:

> Conservation appears as the most attractive of the seven water solutions analyzed for San Diego County by a wide margin. These findings suggest that solving San Diego County's water challenge may rest significantly on the demand side.[37]

Water conservation can be realized using several approaches, including price-based and nonprice approaches. Nonprice approaches can be classified into four basic categories:[38]

1. *Required or voluntary adoption of water-conserving technologies*: This includes setting standards for appliance efficiency or offering water customers rebates or even free items such as low-flow showerheads.

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[35] Elimelech and Phillip, 2011, 712.
[36] Postel, 1992, chap. 8.
[37] Equinox Center, 2010, p. 18.
[38] Olmstead and Stavins, 2007.

2. *Mandatory water use restrictions*: These are often implemented in response to drought conditions and may include restrictions on watering lawns, washing cars, or filling swimming pools.
3. *Education and information*: These include mailing information to customers about ways to reduce water use, offering talks on water conservation, or airing public service messages on TV or the Internet.
4. *Innovative institutional design of common-property resources*: In some locations traditional patterns of communal water use can be promoted or recreated as an alternative to large-scale water supply (see Section 5).

While these nonprice methods are all useful to curb demand, economists tend to focus on **water pricing** as the most effective way to induce water conservation. Prices should serve as indicators of economic scarcity, reflecting physical limits and environmental externalities. For various social and political reasons, however, governments have maintained low water prices, particularly for agriculture. We now turn to a discussion of water pricing, in theory and in practice.

water pricing setting the price of water to influence the quantity consumed.

3. WATER PRICING

Our study of water pricing requires us to recall several of the concepts discussed earlier in the text. First we need to differentiate between value and price.[39] The value of water to consumers is reflected in willingness to pay for it. The difference between willingness to pay for water and its price is its net benefit, or consumer surplus. In theory, consumers will continue to purchase water as long as their willingness to pay for it exceeds the price. But this market analysis does not tell the whole story. While water has obvious use values, including for domestic uses and irrigation, it also has nonmarket and nonuse values, such as for recreation and wildlife habitat.

We must also differentiate between the average cost of supplying water and its marginal cost. The marginal cost is the cost of supplying one additional unit of water. The average cost is simply the total supply cost divided by the number of units supplied. The distinction is important because water utilities are normally **regulated monopolies**. A company seeking to maximize profits will produce as long as marginal revenue exceeds marginal supply costs (i.e., as long as it is making a profit on each unit). While an unregulated monopolist can set its price to maximize profits, a regulated monopolist, such as a water utility, is normally restricted in its ability to set prices.

regulated monopolies monopolies that are regulated by an external entity, for example through controls on price or profits.

[39] See Hanemann, 2005, for a discussion of the value and price of water.

Water utilities in the United States are either privately or publicly owned. Private water utilities are permitted to make a reasonable profit, while municipal utilities' prices are set to cover their total supply costs, considering both fixed and variable costs. In either case, regulatory bodies normally set water prices using **average-cost pricing**, without any consideration of marginal costs. For a municipal utility, setting price equal to average cost means that they will just break even.[40] A private utility would be allowed to charge a price somewhat above average cost in order to make a profit.

average-cost pricing a water pricing strategy in which price is set equal to the average cost of production (or equal to average cost plus a profit mark-up if the water utility is a for-profit entity).

But does average cost pricing result in an efficient level of water supply? We know that the socially efficient level of provision for a good occurs where marginal benefits equal marginal costs. Thus average-cost pricing is unlikely to result in an efficient level of water supply. Normally the marginal cost of water supply is quite low relative to its average cost because supplying water requires significant up-front capital costs, such as for pipes and treatment facilities. This might seem to imply that the efficient price for water should be lower than its average cost. But we also need to consider the externality costs of supplying water, which may include such impacts as the loss of wetlands and wildlife habitat. For a socially efficient price, any externality costs should be considered when calculating the average cost of supply. In this respect, failing to account for water's externality costs implies that average-cost pricing may result in a price that is too low. So it is unclear whether average-cost pricing results in a price that is too high or too low from the perspective of economic efficiency.

For the management and pricing of groundwater, a nonrenewable resource, we also need to consider the externality costs imposed on future generations if future supplies will be insufficient to meet their demands. In principle, these costs can be internalized by charging a fee or tax on the present so that more will be conserve for the future. This is rarely done in practice for groundwater, again suggesting an inefficient allocation of water.

Further complicating our analysis is the fact that water is often subsidized by the government, in particular for irrigation uses.

> Many authors have called for the elimination of irrigation subsidies, at times suggesting that water is a commodity and should be priced accordingly. They describe the potential gains in irrigation efficiency and the public value of communicating scarcity conditions through market-based prices. Other authors suggest that subsidies can be justified because irrigation projects provide both public and private goods, or that higher water prices will reduce agricultural net revenues without motivating notable reductions in irrigation diversions.[41]

In regions where irrigation has significant environmental impacts, it may be more appropriate to tax water rather than subsidize it. Consider some of the environmental damage caused by irrigation:

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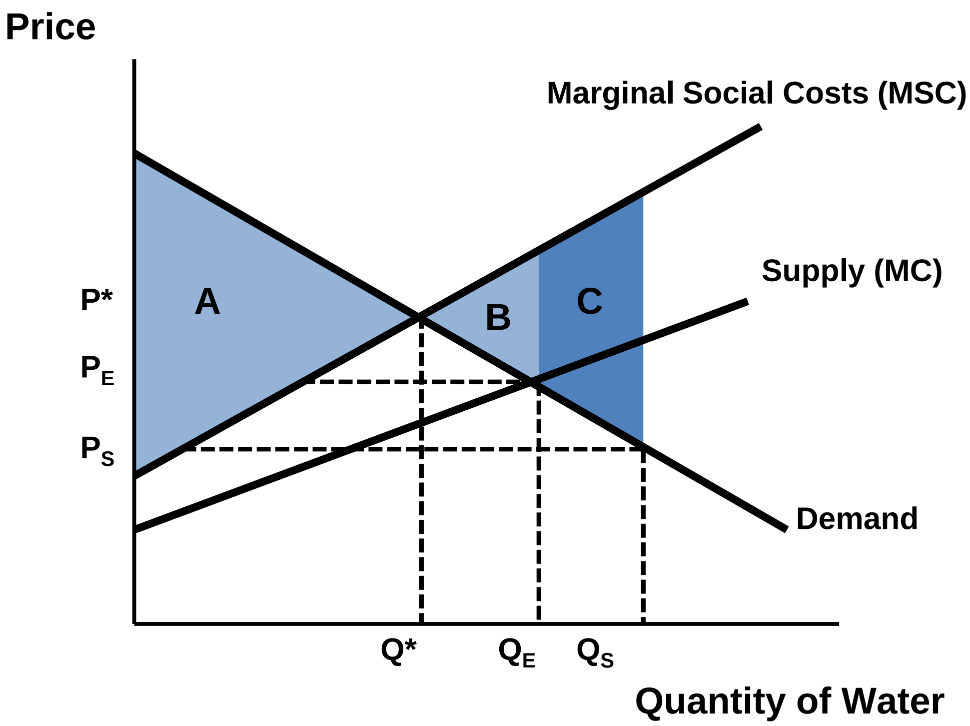
[40] Carter and Milton, 1999.
[41] Wichelns, 2010, p. 7.

> An excessive withdrawal of water for irrigation is clearly impacting the environment in some areas. For example, the Colorado River often contains essentially no water by the time it crosses the border into Mexico, owing to both urban and agricultural withdrawals. In fact, in most years, the Colorado River doesn't make it to the ocean. This has consequences for the river and its riparian ecosystems, as well as for the delta and estuary system at its mouth, which no longer receives the recharge of fresh water and nutrients that it normally did. The same is true for the Yellow River in China. The San Joaquin River in California is so permanently dewatered that trees are growing in its bed and developers have suggested building housing there. In the last 33 years, the Aral Sea has lost 50 percent of its surface area and 75 percent of its volume, with a concomitant tripling in its salinity, owing largely to diversion of water from its feeding rivers for irrigating cotton.[42]

A supply and demand graph helps to illustrate the inefficiency of subsidizing irrigation water even though its withdrawal and use have negative externalities. In Figure 7, the market equilibrium for irrigation water occurs where the marginal cost curve (MC) intersects the demand curve, resulting in a price of P_E and a quantity of Q_E. But suppose that irrigation is subsidized such that its price is P_S, below the equilibrium price. The quantity sold will increase from Q_E to Q_S.

Figure 7. *Effects of Subsidizing Irrigation Water*



[42] Strockel, 2001, pp. 4–5.

In order to analyze the welfare effects, we also need to account for the negative externalities. The true marginal social cost of irrigation water is represented by the curve MSC, which includes the externality costs. For every unit above Q^*, the marginal social cost exceeds the marginal benefit (recall that the demand curve indicates the marginal benefits).

Area A represents the amount of net benefits of irrigation water at a quantity of Q^*. In other words, it is economically efficient to supply irrigation water up to Q^*. At the market equilibrium, Q_E, the net social welfare would be (A − B). At the subsidized quantity, Q_S, the net social welfare would be (A − B − C), a lower level of social welfare than at the market equilibrium. B and C represent areas of net loss resulting from a failure to internalize negative externalities and from subsidizing the price of water. In this example, the maximum social welfare would be obtained at a quantity of Q^*. We could also obtain this level of welfare by taxing water instead of subsidizing it.

So far we have discussed water as if it has a single price. But the price of water varies in several respects. First, the price of water normally depends on its use. Specifically, water prices charged by utilities are different for domestic, agricultural, and industrial users. The cost of agricultural water in the United States is approximately \$5–\$100 per thousand cubic meters.[43] Meanwhile, a typical household monthly water bill is about \$20–\$120 per month, which equals a cost of about \$400–\$2,500 per thousand cubic meters.[44] While it may initially seem inefficient, and perhaps unfair, to charge different users different rates, there is some justification for charging agricultural and industrial users less than households. Household water requires a high degree of treatment because it must meet drinking water standards. Irrigation water is not required to meet the same quality standards and thus is cheaper to supply. After use, domestic water must also be removed for treatment. In many municipalities, households are charged a separate "sewer rate" for water disposal in addition to a charge for their water supply.

The price ranges presented above indicate that the price of water can vary regionally. Figure 8 shows the average monthly water bill in different American cities, presented in relation to average precipitation. We might expect that water prices would be highest where water is the scarcest (i.e., precipitation is the lowest). While some arid cities, such as Santa Fe and San Diego, do charge high water rates, other dry regions, such as Las Vegas and Fresno, charge very low rates. This reflects the kind of government subsidy for water discussed in the example above.

Water rates in relatively wet cities can also vary considerably. In fact, there seems to be no discernible relationship between water rates and precipitation. Of course, other factors can determine water availability besides precipitation. Water is relatively cheap near the Great Lakes because they provide a low-cost supply of water. Some cities may have access to sufficient groundwater while others may not. Some cities can store water in reservoirs to keep supplies relatively constant throughout the year.

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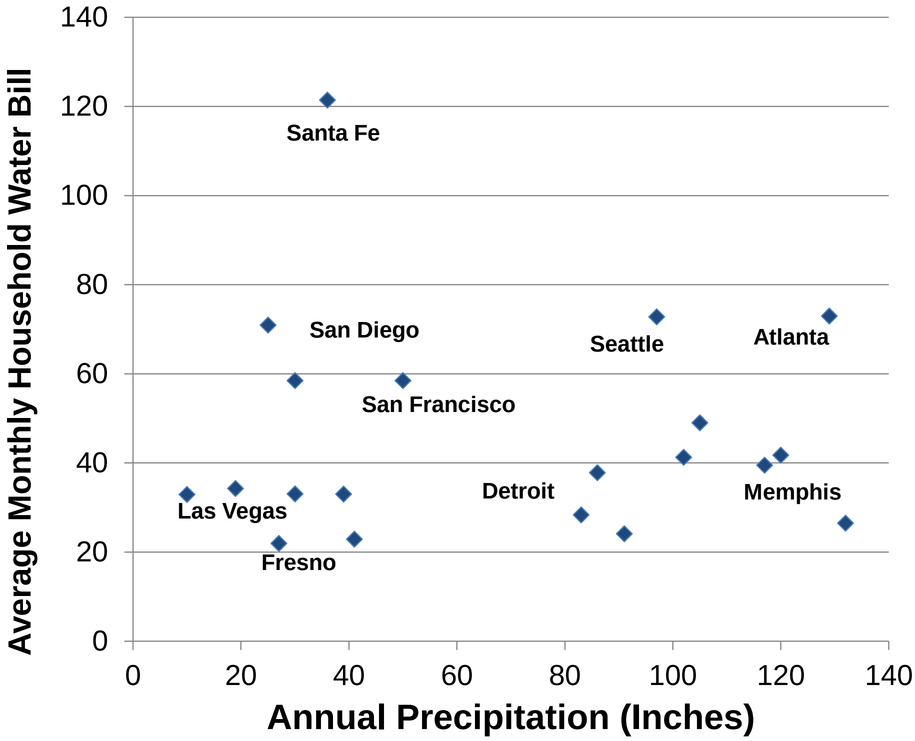
[43] Wichelns, 2010.
[44] Walton, 2010.

Figure 8. *Average Monthly Water Bill versus Precipitation in U.S. Cities*



Source: Walton, 2010.

Note: Water bill based on a family of four using 100 gallons per person per day. About 264,000 gallons is equivalent to a thousand cubic meters.

Water prices are generally rising, particularly in regions where supplies are scarce and population is increasing. Additional supplies can often be obtained only by relying upon relatively expensive sources such as desalination. As water levels in underground aquifers fall, pumping becomes more expensive. As mentioned earlier, the alternative to obtaining additional supplies is to manage demand. By raising prices, utilities send consumers a signal about the increasing scarcity of water.

Higher water prices will induce a behavioral response in households and other water users. Irrigators are more likely to invest in efficient irrigation methods. Households are more likely to purchase low-flow showerheads and wash cars less frequently. But how much will water users reduce their water consumption in response to higher rates? This depends on the **price elasticity of demand**. The elasticity of demand for water tends to be inelastic, meaning that the percent change in the quantity demanded tends to be smaller in absolute value than the percent change in price.

price elasticity of demand the responsiveness of the quantity demanded to price, equal to the percentage change in quantity demanded divided by the percentage change in price.

A significant amount of research has been conducted to estimate the elasticity of demand for water, particularly for residential users. A 2003 meta-analysis identified more than 300 elasticity estimates from 64 studies.[45] The mean elasticity was −0.41, with a median of −0.35. A meta-analysis of studies on irrigation water found a mean elasticity of −0.51 and a median of −0.22, based on 53 estimates.[46] A review of several studies on industrial water use finds that the elasticity varies considerably across different industries, ranging from about −0.10 to −0.97.[47] As expected, water demand also tends to be more elastic in the long run than in the short run.

Based on these estimates, water managers can determine how to adjust the price to meet conservation objectives. For example, suppose that a water utility is experiencing a potential water shortage and needs to lower water usage by 10 percent: If the elasticity of demand is −0.41, then the water utility would need to raise price by 41 percent to achieve a 10 percent reduction in quantity demanded.

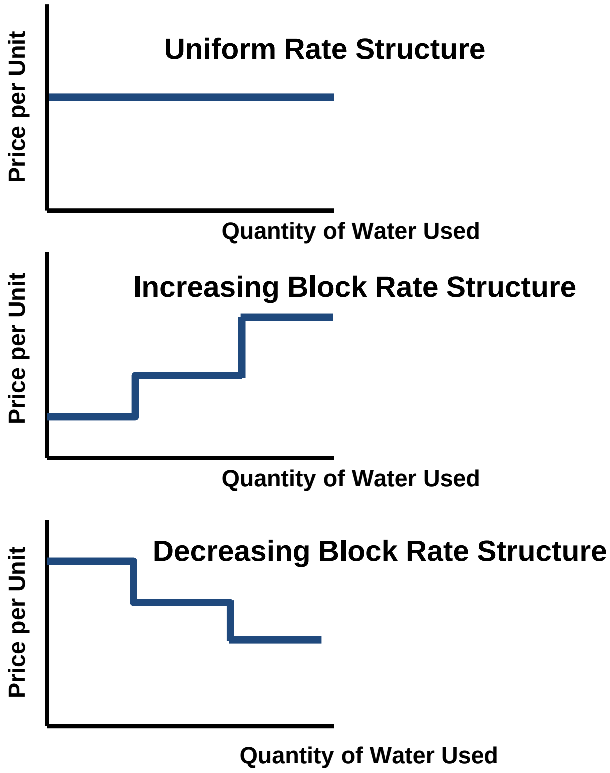
But the relationship between water demand and price is not as simple as this example. One reason is that elasticity is not constant across regions or seasons. In the meta-analysis of residential water mentioned above, water demand tends to be more elastic in arid Western states than in the eastern United States. Also, water demand tends to be less elastic in winter months than in summer months. In the summer, more water use is for relatively nonessential purposes, such as irrigating lawns and washing cars. In the winter, a higher percentage of total water use is for more essential tasks, such as bathing and washing dishes. So in the summer, households can more easily reduce water use in response to a price increase.

Another complication in pricing water is that water commonly is not sold at a constant price per unit. In some cases, water users simply pay a flat monthly fee and then are able to essentially consume all the water they wish with no marginal increase in cost. While water metering is standard in the United States, in some countries, including Canada, Mexico, Norway, and the United Kingdom, water is not normally metered.[48] Where water usage is metered, there are three basic pricing structures, as illustrated in Figure 9:

- **Uniform Rate Structure**: The price per unit of water is constant regardless of the amount of water used.
- **Increasing Block Structure**: The price per unit of water increases as the amount of water used increases. The price is constant within each block, but the price per unit is higher for successive blocks.
- **Decreasing Block Structure**: The price per unit of water decreases as the amount of water used increases.

[45] Dalhuisen *et al*., 2003.
[46] Scheierling *et al*., 2004.
[47] Olmstead and Stavins, 2007.
[48] OECD, 2009.

Figure 9. *Water Pricing Structures*

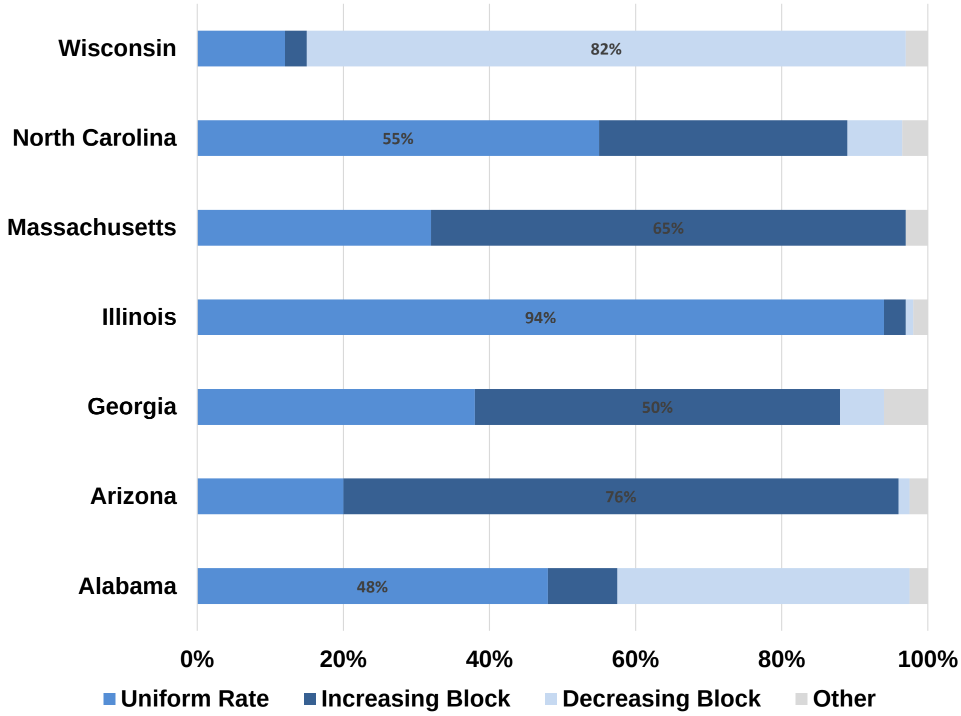


An increasing block structure encourages more water conservation, as water users will wish to avoid moving into the higher-priced blocks. The rationale behind a decreasing block structure is that it provides a price break for large water users, typically for commercial or industrial users. Water may also be priced differently by season, with rates normally higher during the summer season to discourage nonessential water consumption.

In the past, decreasing block rate structures used to be the most common pricing method for public water supplies in the United States.[49]As concerns about water conservation have grown, increasing rate block structures have now become the most common approach. There is a wide variety of approaches among the different states, as shown by Figure 10. In Wisconsin, 82% of public water pricing is decreasing block, whereas in Illinois 94% of pricing is uniform rate, and in Arizona 76% of pricing is increasing block.[50]

[49] Tietenberg and Lewis, 2012.
[50] Irvin, 2016.

Figure 10. *Rate Structures by State*



Source: https://efc.web.unc.edu/2016/10/12/water-system-rate-structures/
Note: In addition to the three main categories, "uniform", "increasing", "decreasing", a fourth category "other" includes hybrid structures such as increasing then decreasing or vice versa, flat fee, tiered flat fee, etc.

Internationally, rate structures vary widely. An international survey of water utilities found that in OECD countries (generally more advanced economies), 49 percent used increasing block pricing, 47 percent used uniform rates, and only 4 percent used decreasing block rates. In non-OECD countries, 63 percent of water utilities used uniform pricing, and nearly all others used increasing block pricing.[51] While an increasing block structure tends to promote higher rates of water conservation, other factors are also relevant when determining which rate structure and prices to adopt. Other considerations include:

- Utility rates are regulated; thus they cannot simply raise rates to induce a specific amount of conservation.
- Raising water rates disproportionately affects low-income households. Utilities may therefore try to take equity into consideration when setting water rates. In South Africa, the right to "sufficient water" is written into the constitution. This is operationalized by making the first block of water free (successive blocks are normally charged using an increasing block structure) so that even poor households can afford a baseline amount of water.
- Increasing block structures are somewhat more difficult to understand. Users should clearly understand when their usage moves into higher-priced blocks.

[51] OECD, 2009.

- Finally, raising water prices or changing the water rate structure may be politically difficult. While involving customers in rate discussions can increase support for conservation programs, utilities need to balance political feasibility with conservation objectives.

4. WATER RIGHTS, WATER MARKETS, AND PRIVATIZATION

An economically efficient distribution of water implies that water should be allocated toward uses that generate the highest marginal values (i.e., the highest willingness to pay). In theory, transferring water from low-valued uses to higher-valued uses increases overall social welfare. At the efficient allocation, the marginal value of water would be constant across different uses, such that further transfers would not clearly result in a net increase in overall welfare.

Table 3 provides estimates of the marginal value of water for several different uses, based on a review of existing studies from the mid-1990s in the United States. We see that the value of water can vary significantly among uses—highest for industrial and domestic uses, lowest for generating power and recreation/wildlife. The uses are not all mutually exclusive. For example, water could be used for recreation and then further downstream for irrigation.

Table 3. *Marginal Value per Acre-Foot of Water in Various Uses*

Water Use	Average Value per AF	Median Value per AF
Navigation	$146	$10
Recreation/Wildlife Habitat	$48	$5
Hydropower	$25	$21
Thermoelectric Power	$34	$29
Irrigation	$75	$40
Industrial	$282	$132
Domestic	$194	$97

Source: Frederick et al., 1996.

Note: A large difference between the average and median values indicates that a relatively small number of particularly large estimates shifts the average upward.

We also need to account for differences in water quality. The marginal WTP for residential water would not be equal to the marginal willingness to pay for irrigation water at the efficient allocation because the water quality needs of these users differ.

In general, the allocation of water in the United States and elsewhere is rarely determined by concerns about economic efficiency. Instead, water rights are usually allocated based on various historical and legal considerations. In the eastern United States, water rights are commonly allocated based on **riparian water rights**. Under this doctrine, the right to reasonable use of water is granted to those who own the land adjacent to a water source. Where demands exceed the available water supply, rights may be allocated based on the amount of water frontage of each owner. Riparian water rights generally do not allow for irrigation withdrawals or the transfer of water to lands nonadjacent to bodies of water.

riparian water rights a system of water rights allocation based on adjacent land ownership.

While riparian water rights were initially applied in the western United States, by the late 1800s the water demands of agriculture and mining necessitated a different water rights system. **Prior appropriation water rights** separate the right to water from land ownership. Under this system, a right to water is recognized when someone establishes a **beneficial use** for it, such as for irrigation or municipal use. This system is also called "first in time, first in right" because rights are assigned on the basis of when a beneficial use first occurs.

prior appropriation water rights a system of water rights allocation in which rights are not based on land ownership but on established beneficial uses.
beneficial use term used to refer to the use of water for productive purposes, such as irrigation or municipal supplies.

Say, for example, that a farmer begins to withdraw 1,000 AF of water per year from a river. Then suppose that several years later a factory wishes to withdraw 5,000 AF per year from the same river. The farmer would be recognized as the "senior appropriator," and the factory (the "junior appropriator") would only have access to water after the farmer takes 1,000 AF. Anyone else who starts to withdraw water after the factory has established its right could still establish a prior appropriation right, but only after both the farmer and factory have taken their full allotment. In the case of a drought, if only 3,000 AF were available from the river, the farmer could get his or her full allocation of 1,000 AF, the factory would get the remaining 2,000 AF, and any other more-junior water users would get nothing.

Obviously, the doctrine of prior appropriation does not allocate water in an economically efficient manner. In fact, it tends to discourage conservation because if senior water right holders start using less than their full allocation, over time the amount of water associated with their rights could be legally reduced. Also, prior appropriation rights tend to make no allowance for ecological needs. Thus in the case of water shortages, ecosystems may suffer significant damage.

The creation of **water markets** has been proposed as a way to increase the economic efficiency of water allocation in the presence of prior appropriation rights. In a water market, water rights holders can sell some of their water to willing buyers. One example is a farmer who sells some of his or her water to a municipality. The municipality might buy the water in a one-time purchase (referred to as a lease) or could buy the actual water rights, which would establish it as the senior appropriator for a given amount of water per year.

water markets mechanism to sell water or water rights to potential buyers.

As in any other market transaction, a water market in theory increases social welfare because both the buyers and sellers perceive that they will benefit from the transaction. But efficiency gains may need to be weighed against the impact of water markets on existing inequities. If poor people hold secure water rights, then water markets could provide an additional source of income. More likely, though, is that water could be directed away from the needs of the poor toward profitable uses by large-scale farmers, corporations, or other interests. For example, water markets were established in Chile in the early 1980s but led to higher water prices as a result of speculation and the monopolization of water rights. In 2005 the Chilean water market laws were revised to limit the potential for speculation and monopolization.

A water market does not necessarily require the direct transportation of water. An upstream water right holder could easily sell her rights to a downstream user. The upstream right holder would simply withdraw less water, allowing the downstream user to withdraw more. The sale of a water rights from a downstream user to an upstream user could also be conducted similarly. But in some cases a water sale may require water to be transported through canals or pipes. A fairly complex system for water transfers has already been established in the western United States. The California State Water Project and the Central Arizona Water Project are examples of engineering projects that transport water hundreds of miles to its final users.

The conditions necessary for a successful water market to form have been identified as:

- Water rights must be clearly defined.
- Water demand must exceed water supply. There must be some water users or potential users who are unable to obtain all water they seek at prevailing prices.
- Water supplies must be transferable to where water is desired for purchase and available when it is needed. Also, transaction costs must be relatively low.
- Water buyers must be confident that purchase contracts will be honored, with appropriate regulation and oversight.
- A system must be in place to resolve conflicts. This could involve both legal proceedings and less-formal resolution options.
- The cultural and social context must be considered. Some regions may resist water markets if most people believe that water is not a salable commodity.[52]

Water markets are in place in several countries, including Australia, Chile, South Africa, the United Kingdom, and the United States. An analysis of water markets in the United States identified about 1,400 water sales between 1990 and 2003.[53] Most of the water volume transferred involved short-term leases rather than outright purchases of water rights. Municipalities were the most common purchaser of water (normally from irrigators),but transfers between irrigators were also common.

About 17 percent of the water purchased was for environmental purposes, including purchases by municipalities and environmental organizations. The potential for water market transfers to meet environmental objectives, such as maintaining sufficient in-stream flows for wildlife

[52] Conditions adapted from Simpson and Ringskog, 1997.
[53] Brown, 2006.

habitat, is receiving increased attention. Some analysts see great potential for water markets to improve the environment:

> Overcoming [barriers to water market trades] is an increasingly important challenge as populations and western economies continue to grow. With this growth comes increasing demands for environmental and recreational amenities… Removing barriers to trade will reduce transaction costs, promote more efficient water allocation among offstream and instream uses, create incentives for improved water use, and improve environmental quality.[54]

Even where environmental values exceed the values of other water uses, the proper institutions must exist to obtain the necessary funding. Voluntary contributions to environmental organizations can raise some funds to purchase water rights, but the presence of free riders means that environmental water purchases will be undersupplied to society. Also, water markets can harm as well as help the environment. Water transfers can degrade water quality and excessively deplete aquifers.[55] And as in any market, negative externalities may require government intervention to internalize the externalities.

4.1 Water Privatization

A related issue is whether water should be supplied as a public good by government agencies or as a commodity by private companies. **Water privatization** has been promoted by international organizations such as the World Bank and International Monetary Fund on the grounds that private companies can provide more efficient and reliable service than public entities, particularly in developing countries. In theory, if a private company can provide water at a lower cost, then these cost savings can be passed on to customers, and perhaps more people can obtain access to water. But without appropriate regulation a private company may be able to charge excessive rates or fail to address the water needs of low-income households.

water privatization the management of water resources by a private for-profit entity as opposed to a public utility.

Water privatization has occurred, to some extent, in many countries, including Brazil, China, Colombia, France, Mexico, and the United States. The experience with water privatization has been mixed. According to the World Bank, water privatization in Manila, Philippines, has been successful in expanding water supplies to poor households:

> By expanding the provision of reliable and affordable services to customers, the program has benefited some 107,000 poor households since its inception in 1997. Near-to-regular access to potable/piped water supplies and increased community sanitation facilities has been achieved in low-income residential centers. Furthermore, the program established customer facilities to encourage communities to discuss and participate in the process of expanding services, and to resolve their concerns.[56]

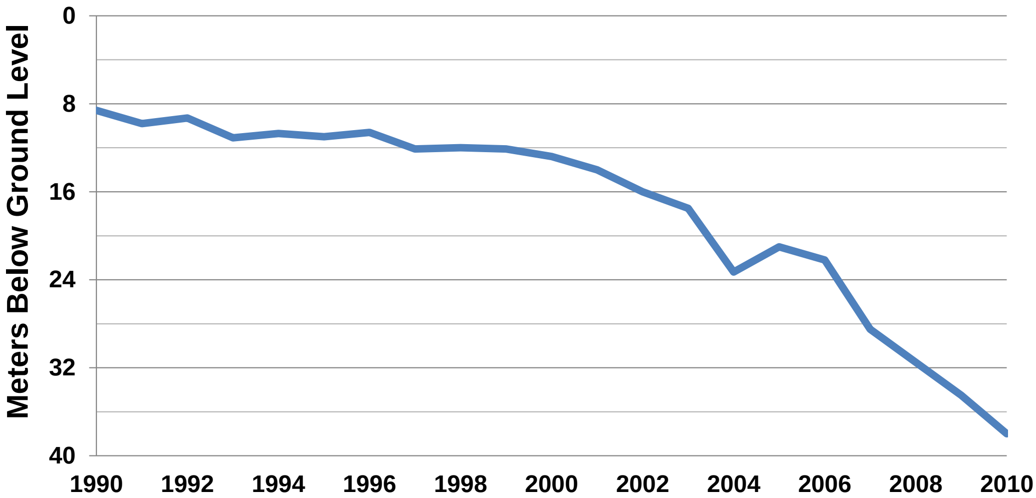
[54] Scarborough, 2010, p. 33.
[55] Chong and Sunding, 2006.
[56] World Bank, 2010, p. 2.

However, in other cases water privatization has failed to deliver on its promise. A dramatic example was the experience in Bolivia.

> In April 2000, after seven days of civil disobedience and angry protest in the streets, the president of Bolivia was forced to terminate the water privatization contract granted to Aguas del Tunari, subsidiary of the giant Bechtel corporation. The Bolivian government had granted a 40-year contract to Aguas del Tunari in 1999… Water rates increased immediately—by 100 to 200 percent in some cases. Small farmers and the self-employed were especially hard hit. In a country where the minimum wage is less than $100 per month, many families were paying water bills of $20 or higher.[57]

The privatization of water resources can also lead to their overexploitation. In many rural communities throughout the world, access rights to groundwater have been sold to soft drink producing companies such as Coca-Cola and Nestlé. These multinationals have often exploited the water resources in unsustainable ways, such as in the village of Plachimada, in the State of Kerala, India. Not long after Coca-Cola started its bottling plant, pumping out groundwater, farmers found that groundwater was contaminated and toxic waste released. Popular resistance eventually led to the shutdown of operations at the plant.[58] In another rural town in India, Kala Dera, scientists have measured a dramatic decline in the groundwater table after a Coca-Cola bottling plant started its operations in 2000, as seen in Figure 11.

Figure 11. *Groundwater Levels Before and After Coca-Cola Started Operations in 2000 in Kala Dera, India, 1990–2010*



Source: India Resource Center, 2011.

Note: A Coca-Cola bottling plant started operations in 2000, leading to a dramatic decline in groundwater levels.

[57] Public Citizen, 2003.

[58] Koonan, 2007.

The World Bank continues to promote privatization, noting that higher water prices are necessary to induce conservation. Public utilities rarely charge enough to reflect the true economic and social costs of water, which privatization advocates argue is the root cause of unsustainable water use. From the perspective of social welfare, even market prices are too low if they fail to account for externalities. But economic efficiency may conflict with the goal of equity. Privatization may work best when combined with policies ensuring that the poorest can afford enough water to meet their basic needs, as in the South African system that provides a basic supply of water for free, with increasing prices for larger quantities.

Water markets and privatization remain controversial. The challenge is to ensure that markets and privatization operate in a manner to meet broader social and environmental goals, rather than simply maximize profits. (For more on this debate, see Box 4.) A major problem with privatization is that it fails to recognize the nature of water as a common property resource, discussed further in the next section.

BOX 4: THE NEW OIL: SHOULD PRIVATE COMPANIES CONTROL OUR MOST PRECIOUS NATURAL RESOURCE?

There is wide agreement that global water supplies are being used unsustainably. Can privatization lead to more sustainable practices, with market prices motivating water conservation?

Privatization of water supplies has traditionally been implemented in developing countries. In the late 1990s the World Bank pushed scores of poor countries to privatize their water supplies as a condition for receiving desperately needed economic assistance. In several cases, most infamously Bolivia, private companies raised the price of water so much that poor families couldn't afford enough to meet basic needs.

But more recently emphasis has shifted to privatizing water in richer countries. "These are the countries that can afford to pay," says water rights attorney James Olson. "They've got huge infrastructure needs, shrinking water reserves, and money."

The need for better water management is especially acute in China. As groundwater demands increase in Beijing, wells dug around the city must reach ever-greater depths (nearly two-thirds of a mile or more, according to a recent World Bank report) to hit fresh water. With contracts to supply water becoming more lucrative, the number of private water utilities has skyrocketed. But in order to recover investment costs, companies have dramatically raised the price of water. "It's more than most families can afford to pay," says Ge Yun, an economist with the Xinjiang Conservation Fund. "So as more water goes private, fewer people have access to it."

***Source*: Interlandi, 2010.**

5. WATER AS A COMMON PROPERTY RESOURCE

Although the World Bank and other international financial institutions are still promoting privatization, community opposition has pushed policy in many areas in the opposite direction, of re-municipalization of water supplies:

> A report by the Transnational Institute (TNI), Public Services International Research Unit and the Multinational Observatory indicates that 180 cities and communities in 35 countries, including Buenos Aires, Johannesburg, Paris, Accra, Berlin, La Paz, Maputo and Kuala Lumpur, have all "re-municipalized" their water systems in the past decade. More than 100 of the "returnees" were in the U.S. and France, 14 in Africa and 12 in Latin America. Those in developing countries tended to be bigger cities than those in richer countries."[59]

Re-municipalization can improve access and quality of water services, as well as offering opportunities to build democratic governance by involving citizens into the collective decision-making processes, strengthening accountability and transparency. It pressures municipalities to be more responsive to the needs of the poorest of their inhabitants, in ensuring a basic right to water, which a purely market-based approach to water management may not.

Municipal control is one approach to the management of water as a common property resource. Another approach is traditional communal management. There is a long history of management of common property resources through communal institutions. This is true of water resources in many areas. Local collective systems of irrigation that have proved sustainable over centuries are found in numerous societies around the world (see Box 5).

In an effort to emulate the benefits of traditional communal water management systems, some hydrologists have proposed a new paradigm of water management, **watershed restoration**, based on small scale natural water cycles. Through the careful harvesting of rainwater, which is then used to recharge groundwater, and through the re-creation and protection of wetlands that purify water and retain it in the soils, natural water cycles can be restored.

watershed restoration restoring natural watershed functions through the management of small-scale water cycles.

Rethinking water cycles as part of the larger ecosystem picture implies a different approach to water management in the future. As part of this new paradigm, the role that water cycles play in mitigating climate change can be recognized and enhanced. Recreating local wet ecosystems and restoring small-scale water cycles can help combat some of the worst effects of climate change by increasing mist and moisture in the atmosphere, preventing drying and desertification.[60]

Watershed protection and restoration at a much larger scale is also the leading paradigm for water management of megapolises, such as New York City, whose water municipal system is

[59] Transnational Institute, 2015, p. 3.
[60] Kravčík *et al.*, 2007.

the largest in the US. Protection of the one million acres of watershed land surrounding the lakes and reservoirs in the rural Catskill mountains provides more than a million gallons of water flowing daily in networks of aqueducts and tunnels to the City. the provision of high-quality water thus does not need to rely on expensive filtration plants, providing a compelling example of what ecosystem services can provide when watershed ecosystems are protected.[61]

Exploring different approaches to water management reflects the dual nature of water as both private and public good. No single approach is likely to hold the answer, but a balance of considerations of ecological cycles, economic efficiency, and the social functions of water is clearly needed.

BOX 5: THE ACEQUIA WATER SYSTEM

The Acequia water management system evolved over 10,000 years in the deserts of the Middle East (the name derives from "as-saaqiya" which means "water conduit" in Classical Arabic) and was introduced into Southern Spain by the Moors. Spanish colonizers took acequias to the New World, where they found similar ancient indigenous systems of collective irrigation that Native Americans had developed for centuries. Acequia agroecosystems promote soil conservation and soil formation, provide terrestrial wildlife habitat and movement corridors, protect water quality and fish habitat, and support crop biodiversity. Acequias have been maintained through a carefully regulated and monitored collective management of common-property resources, reinforcing a strong land and water ethic.

The non-monetary services offered by traditional community-based systems of acequias in the Upper Rio Grande Bioregion include ecosystem services as well as social and cultural services, such as spiritual and religious values, educational values, and esthetic values, which greatly enhance the quality of life of the communities which take care of these agroecosystems. In recent times these traditional systems of common property resource management, which were based on bartering systems where irrigators/neighbors would exchange services with one another, are experiencing the pressures of the dominant monetary market economy in ways that disrupt ancient customs and communal practices. Market pressures have led some to sell their rights to bigger interests, such as the City of Las Vegas. But market mechanisms may not be the best way to allocate scarce water rights, since transfer of water rights to the highest bidder may be unfairly coercive for cash-poor people.

Sources: **Ostrom, 1990, p. 69–82; Raheem, 2014.**

6. SUMMARY

Water systems are under pressure from steadily growing agricultural, industrial, and urban demand. Many countries currently experience permanent water stress, defined as less than 1,700 cubic meters per capita available supply. Shortages will become more serious as

[61] Winnie Hu, 2018.

population grows and climate change affects precipitation patterns and glacial runoff. Human activity relies on water consumption as a fundamental input.

The concept of virtual water takes into account both direct and indirect uses of water to create goods and services. This concept can be used to calculate a "water footprint" for an individual, community, corporation, city, or country. Trade in virtual water allows water-scarce countries to import goods that are water-intensive, but some water scarce countries are depleting their scarce water resources through water-intensive exports.

Increasing supply by pumping from aquifers has led to groundwater overdraft in major water-scarce areas throughout the world. Construction of dams also increases available supply, but most major dam sites are already being exploited, and new dam construction often involves major environmental and social costs. Desalination offers the potential to tap into a virtually unlimited supply of ocean water, but it is energy intensive and expensive. Innovative methods of collecting rainwater and protecting watersheds and waterways offer a new paradigm of water management, which restores natural processes of replenishment of local water cycles.

Proper water pricing can promote conservation and encourage technologies for efficient water use. Government policies, however, often subsidize water, thereby encouraging overuse. Higher prices will reduce demand, but since water demand is inelastic, relatively large price increases are necessary to induce significant conservation. Well-designed price structures, such as increasing block pricing, can also promote conservation.

In theory, water markets can increase the economic efficiency of water allocation by allowing transfers from low-valued uses to higher-valued uses. Water markets can also be used to meet environmental objectives, although the results have been mixed. Privatization of water supplies has also produced mixed results, expanding affordable access in some situations while leading to dramatic price increases and reduced access in other cases. The evidence indicates that while both the private and public sectors have a role to play in meeting water challenges, appropriate regulation and institutions are needed to ensure that water is sustainably managed, including management of water both as a marketed and as a common-property resource.

7. DISCUSSION QUESTIONS

1. Suppose you were managing a public water utility facing a shortage due to drought conditions. What steps would you take in response to the drought?
2. Human demands for water can lead to an insufficient supply for maintaining natural resources such as wetlands and fish habitat. How would you balance the allocation of water between human and environmental demands?
3. Do you believe that access to safe drinking water is a fundamental human right? How should water be priced in developing countries, considering the potentially conflicting issues of affordability and conservation?

8. KEY TERMS AND CONCEPTS

Absolute water scarcity – term used for countries where freshwater supplies are less than 500 cubic meters per person per year.

Average-cost pricing – a water pricing strategy in which price is set equal to the average cost of production (or equal to average cost plus a profit mark-up if the water utility is a for-profit entity).

Beneficial use – term used to refer to the use of water for productive purposes, such as irrigation or municipal supplies.

Desalination – the removal of salt from ocean water to make it usable for irrigation, industrial, or municipal water supplies.

Flow – the quantity of a variable measured over a period of time, including physical flows, such as the flow of a river past a given point measured in cubic feet per second, or financial flows, such as income over a period of time.

Hydrologic cycle – the natural purification of water through evaporation and precipitation.

Micro-irrigation – irrigation systems that increase the efficiency of water use by applying water in small quantities close to the plants.

Price elasticity of demand – the responsiveness of the quantity demanded to price, equal to the percentage change in quantity demanded divided by the percentage change in price.

Prior appropriation water rights – a system of water rights allocation in which rights are not based on land ownership but on established beneficial uses.

Regulated monopolies – monopolies that are regulated by an external entity, for example through controls on price or profits.

Riparian water rights – a system of water rights allocation based on adjacent land ownership.

Stock – the quantity of a variable at a given point in time, such as the amount of water in a lake, or the amount of timber in a forest, at a given time.

Virtual water – water embedded in goods or services, based on water used as an input throughout the production process.

Water footprint – the total amount of water consumed by a human entity—individual, family, city, corporation, or country—whether directly or indirectly, calculated by summing all the virtual water embedded in the products, energy, and services used by this entity.

Water markets – mechanism to sell water or water rights to potential buyers.

Water pricing – setting the price of water to influence the quantity consumed.

Water privatization – the management of water resources by a private for-profit entity as opposed to a public utility.

Water scarce – term used for countries where freshwater supplies are less than 1,000 cubic meters per person per year.

Water stressed – term used for countries where freshwater supplies are between 1,700 and 1,000 cubic meters per person per year.

Watershed restoration – restoring natural watershed functions through the management of small-scale water cycles.

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