III. Introduction to Water Resources and Contamination

INTRODUCTION

"Water is, in a sense, both artery and vein to urban life."

—Schneider, Rickert, and Spieker, 1973

"It seems apparent that water will become much more expensive in the future . . . "

—Keller, 2000

Lack of concern for some geological resources is frequently based on faith in economics and an option of substitution. Water is the one geological resource for which there is no substitute. Shortages of high-quality water degrade human health, reduce biological productivity of a region, lower the quality of life, and ultimately may produce conflict between individuals and countries.

SOURCES OF WATER

Fortunately the Earth's water cycles (it is a renewable resource) through evaporation, precipitation, surface runoff, and groundwater flow. We depend on our disruption of the hydrologic cycle (Figure III.1) to support our society. With increasing population in the United States and globally, we need increased efficiency of use, improved adaptation to seasonality of precipitation and runoff, options for responding to local climate changes

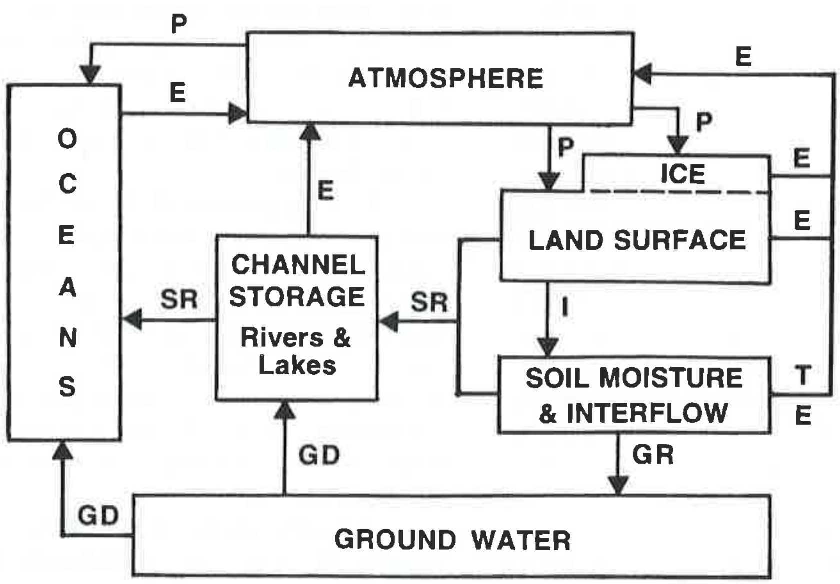

FIGURE III.1 The Earth's hydrologic cycle. (See Question 1 for explanation of abbreviations.)

due to global environmental change, and increased consideration of the environmental benefits and needs of other components of the hydrologic cycle such as wetlands. We also must remember that there is a connection between surface water and groundwater in this cycle; most rivers flow because of groundwater discharging into them.

Society's sources of water include rivers, lakes, groundwater (fresh and saline), and the oceans. Some cultures collect precipitation directly; precipitation also is used directly by agriculture. Most of the water that is withdrawn for use is freshwater (<1000 mg/L of dissolved solids) obtained from surface water (75%) and groundwater (25%). Some saline water (>1000 mg/L dissolved solids) is also withdrawn. Treated water released from wastewater treatment facilities is a source for irrigation of parks and golf courses and groundwater replenishment in a growing number of aquifer storage and recovery systems. In regions where water supply is a problem because of climate and/or increasing population, pollution, environmental concern, and capital shortages, the traditional "supply management" approach to managing water resources is changing to "water-demand management," which includes conservation programs.

AVAILABILITY OF WATER

On a global scale water abundance is not a problem. It is the availability of water in the right form in the right place at the right time that is a problem. Thus, the water available for human use is the key. Although more than 97 percent of the total water on Earth is in the oceans, this water is too salty for most uses. Less than 1 percent of the Earth's water is available for human use. The other 99 percent is unavailable or unsuitable because of its salinity (oceans and deeper groundwater) or its location and form (glaciers).

The annual runoff (surface and groundwater) per person has been used as a measure of the availability of water resources for a region or country. Although there may be local shortages and excesses of freshwater, the annual *water yield or runoff* from rivers and groundwater on a per capita basis is the critical figure in determining the water status in a region. According to Falkenmark and Widstrand (1992), when annual runoff is less than 1600 m^3 per person water stress begins, and when it reaches 1000 m^3 per person, chronic shortages occur. At less than 500 m^3/person, there is extreme scarcity. As population increases or runoff decreases in countries and regions, more areas with some level of water stress are to be expected.

In 2000, the global total offstream use of water was about 6000 km^3/yr. This figure is significant in comparison to the average annual global runoff of 47,000 km^3, which includes water that cannot be diverted for human use because of location or environmental needs or lack of storage. When we realize the importance of total freshwater runoff and how much there is, we begin to focus on our options for water management. Do we increase conservation and wastewater reuse, increase desalination (with associated increases in costs), move people to environments with surplus water, increase interbasin water transfers, increase domestic precipitation collection and storage systems, or all of these? Maybe we will also begin to reflect on a possible planetary capacity for humans. On a global basis currently the per capita use of water is about 700 m^3 per year; for the United States it is about 1800 m^3 per year.

HUMAN USE

Humans only require a gallon of water a day for drinking, but domestic use in most developed areas of the world includes drinking, cooking, bathing (30% of household use), washing dishes, laundry (10%), flushing toilets (40%), watering lawns and gardens, and sometimes washing cars and filling swimming pools. In the United States, this household total averages about 80 gallons per person per day. Water delivered by public water supply systems, which includes household (about 60%), commercial, and industrial deliveries, and supplier uses and losses in delivery is 180 gallons per person per day (Solley et al., 1993). However, per capita public-supply use varies with region. For example, when measured in gallons per day (gpd), Nevada uses 344 gpd/person and Utah 308 gpd/person, while Massachusetts uses 130 gpd/person and Vermont 116 gpd/person. Groundwater accounts for about 40 percent and surface water 60 percent of water in public supply systems.

Private water supply systems also withdraw water from surface and groundwater sources for commercial, industrial, irrigation, livestock, mining, and thermoelectric plant cooling uses. Most is freshwater, but for some industrial, mining, and thermoelectric needs it is saline. Irrigation is the largest category of freshwater use.

If we apportion all the freshwater withdrawals (not just for public water supply) to individuals in the nation, then the United States withdraws about 1,340 gpd/person for all these uses. (If we include both fresh and saline water it is 1,620 gpd/person.) The range of use by state or district is as low as 256 gpd/person in Washington, DC, where use is primarily domestic and commercial, to 19,600 gpd/person in Idaho, where large quantities are used for irrigation and there is a small population.

All of the above uses are known as *offstream* use because the water was withdrawn or diverted from the river (or lake, reservoir, or groundwater reservoir!) to a place of use. *Instream* use of water refers to uses within the channel. This includes hydroelectric generation and such difficult to quantify uses as navigation, pollution abatement, recreation, and fish and wildlife habitat. All of these uses provide benefits to humans in the Earth system.

Water use is considered to be *consumptive* when it is withdrawn and does not go directly back to the immediate water supply system. It includes water that is evaporated, transpired, incorporated in products and crops, and consumed by humans and livestock.

Although we don't use all of our share of the nation's water supply directly in our homes, we consume goods that require water to produce. When we buy a car, each pound of steel in it required 60,000 gallons of water; production of a pound of beef may have required more than 2,000 gallons of water. Shortages of water for irrigation of crops can translate to a shortage of food, forcing up food prices globally (Brown, 2006). In this way a water shortage on the other side of the world may impact you here in North America; a local drought can become a "global drought."

WATER QUALITY

Natural water is not necessarily "pure" or distilled; even water from glacier ice has ions precipitated from the atmosphere. Natural water contains minerals and elements from the atmosphere and the enclosing river channel or groundwater aquifer (calcite, silica, calcium, sodium, nitrates, iron, etc.), dissolved gases (oxygen, CO_2, etc.), organic wastes from plants and animals, and microbes (viruses, bacteria, and parasites such as *Giardia* and *Cryptosporidium*). A quick measure of the inorganic content of water is the total dissolved solids (TDS) which can be obtained using a conductivity meter. Evaporation of seawater provides a good demonstration of the mineral matter than can be dissolved in clear water.

The content of dissolved organic and inorganic material in water is usually given as ppm or even ppb (parts per billion). One ppm is 1 drop in 13 gallons of water. A ppb is a very small quantity. It is equal to: 1 inch in 16,000 miles; 1 second in 32 years; and 1 square foot in 36 square miles. Yet these ppb and ppm quantities are important in water quality as contaminants in water at these levels can cause health problems.

In discussions of water quality criteria, one must specify the use of the water. Water that is good for irrigation, may not be good for other uses such as drinking, boiler feed, bathing, or food processing. For swimming the important factor is not dissolved solids but fecal coliform bacteria, which indicate sewage pollution—a health hazard—and closure of beaches. For fish habitat, the dissolved oxygen level is important. For public water supplies in the United States, the USEPA has Primary Regulations for Human Health and Secondary Regulations based on aesthetics. For example, the Secondary Maximum Contaminant Level (SMCL) for Total Dissolved Solids (TDS) is 500 mg/L.

Waterborne diseases in the developed world are much reduced because of water treatment systems and public understanding of contamination. Still 20% of U.S. community drinking water systems violate some public safety requirement and in 1995 fish advisories for consumption covered all of the Great Lakes, (Great Lakes Information Network, 2005) and many rivers and smaller lakes. About half the population in 45 least developed countries lack access to safe drinking water. Understanding water contamination and remediation is essential in improving the quality of life for hundreds of millions of humans.

CONTAMINATION OF GROUND AND SURFACE WATERS

Contamination of water occurs from domestic, industrial, and agriculture wastes produced by society. Some contamination is from systems designed to place waste on the land or in the water: septic tanks with drain fields (nitrates might be the world's number one contaminant), land disposal of sludge, and disposal wells. Some contamination occurs because the wastes are accidentally discharged: animal feedlots, acid mine drainage, and landfills. In addition, sometimes non-wastes contaminate water: accidental spills from truck and train accidents, highway salt, fertilizers and pesticides, and leaky underground storage tanks (USTs). The types of pollutants include inorganic solids, minerals, metal ions, salts, bacteria and viruses, undecomposed organic matter such as grease, volatile organic compounds (VOC), radioactive waste, and silt. Of the VOC, the chlorinated solvents (TCE, PCE, and TCA)[1] are widespread as they were used as cleaning agents at many sites and have produced plumes of contaminated water far from the source.

Contamination of slow-moving groundwater may last for centuries and be difficult to clean up. Pulses of recontamination of a groundwater aquifer occur from contaminated soils above the water table during recharge events. We need proper waste handling systems to prevent groundwater and surface water contamination, and we need to protect the zones of groundwater recharge from contamination.

Addressing past contamination is a more difficult job. How do we clean up sites? Options include removal and reburial or decontamination of the fluid or the soils; on-site destruction of the hazardous material by biological, mechanical, and chemical techniques; or sealing off the site from further use and letting natural long-term remediation occur. These and other options are topics of research on clean-up of contaminated groundwater aquifers.

Finally, in discussions of potential pollution by human activity, we must always consider *background or baseline levels* in a watershed. Simply finding high levels of dissolved solids, for example, in a basin does not mean that humans are responsible. Some bodies of

[1] TCE, Trichloroethelyne; PCE, Tetrachloroethylene; and TCA, Trichloroethane.

water are naturally unfit for human consumption. While distilled water has 0 ppm of dissolved solids, the value for rainwater is 10 ppm, Lake Michigan is 170 ppm, the Missouri River is 360 ppm, the Pecos River is 2600 ppm, the ocean is 35,000 ppm (35 kg, or 77 pounds, of salt per cubic meter), and the Dead Sea is 250,000 ppm. Nonetheless, these environments provide useful habitats for certain organisms and in some cases mineral resources for humans.

In this section on Water Resources and Contamination, we focus on groundwater, how it moves, its quantity, and its quality. We also look at contamination of surface water and groundwater, groundwater overdraft, and saltwater intrusion of aquifers.

QUESTIONS III

1. The Earth's hydrologic or water cycle consists of several reservoirs for H_2O connected by flows of water or water vapor. The typical textbook representation of the hydrologic cycle usually is a cross-section diagram of a small part of the Earth's surface with an ocean, landmass, and clouds. A box model (Figure III.1) is another representation of the cycle that emphasizes the connections (arrows) and the importance of both groundwater and the cryosphere (ice). List and identify by name the different symbols in Figure III.1. One, the letter P, is provided as an example below.

P—Precipitation

2. Determine how many gallons of water you use in a day. Consider a rainy and cold Saturday, when you spend most of the day in your house or dormitory. To determine this amount, go to the USGS website that has a calculator for determining water usage on a per-capita basis: http://ga.water.usgs.gov/edu/sq3.html. Record your answers in Table III.1 below and be ready to explain in class why your "Saturday per-capita value" is higher or lower than the average of the class.

3. List any other water uses or factors that might increase or decrease the amount of water used in a single-family home.

4. According to SIWI–IWMI (2004), between 300 and 3,000 liters of water are needed to produce a kilogram of grain. Each one of us, depending on our diet, is responsible for the 2,000–5,000 liters of water used to produce the food we consume each day. This water is "hidden"; it does not show up in our household water calculations. If we are seeking to understand water use in a region, this agricultural use must be taken into consideration.

a. Given that 1 gallon (U.S.) of water equals 3.78 liters and assuming the food in your daily diet required 4,000 liters of water to produce, how many "food gallons" of water per day are you using?

b. How many times greater is the quantity of "food gallons" than the value of your standard household gallons calculated in Question 2 (above)?

5. Table III.2 provides average water requirements for production of food items. Use it in answering this question.

In Table 2, the water requirement given for cereals is up to 3 m^3 per kilogram. Below, in a *conversion example*, this quantity (3 m^3/kg) is converted to gallons (U.S.) per pound.

water used in growing a pound of cereal:

$$\frac{3\ \cancel{m^3} \times 264.2\ \text{gallons}/1\ \cancel{m^3}}{1\ \cancel{kg} \times 2.2\ \text{pounds}/1\ \cancel{kg}} = 792.6/2.2 = 360\ \text{gallons/pound}$$

a. From data in Table III.2 and the example above, how many gallons of water are used to produce a pound of grain-fed beef? (Hint: Simply consider how many times greater is the use of water for beef than the upper limit of water for cereal.)

TABLE III.1 Determining Your Daily Water Use from USGS (2004) Website*

Number of	Number of	Number of
Baths:	Showers: (Length =)	Clothes wash loads:
Brushings (teeth):	Hand/face wash:	Shaves (face/legs):
Dishwasher:	Dishes (hand):	
Flushes:	Drinks (8oz):	
Your water use =	**gallons**	

* http://ga.water.usgs.gov/edu/sq3.html

TABLE III.2 Water Required to Produce Selected Foods

Selected Food Items	Water Required		My estimated weekly intake of selected foods in kg *or* lbs	Estimated weekly water use in food production
	m^3/kg	gal/lb		
Citrus fruits	1	120		
Cereals	0.4–3	48–360		
Poultry	6			
Roots and tubers	11			
Grain-fed beef	15			
My total water use for food production				

(Modified from Table 2 of 2004 Stockholm International Water Institute report, Water—More Nutrition per Drop*)
* http://www.siwi.org/downloads/More_Nutrition_Per_Drop.pdf

b. Complete column 2 in Table III.2 with the equivalent number of gallons per pound.

c. Estimate your weekly intake of selected foods in pounds (or kilograms) and record in Table III.2.

d. Determine your weekly "food gallons" *or* "food liters" of water per week and record in column 4 (1 m^3 = 1000 liters).

6. As human population increases and changes in diet (more protein) continue, more food will be needed. At the same time, groundwater depletion due to irrigation threatens the needed increase in food production. What options would you suggest for addressing this problem?

Bibliography

Brown, L. R., 2006, *Plan B 2.0: Rescuing a planet under stress and a civilization in trouble:* New York, W. W. Norton.

Falkenmark, M., and Widstrand, C., 1992, Population pressure on water resources: *Population Bulletin*, v. 47 (3), p. 19–27.

Gleick, P. H., ed., 1993, *Water in crisis: A guide to the world's fresh water resources*: New York, Oxford University Press, 497 p.

Great Lakes Information Network, 2005, Fish Consumption in the Great Lakes. Retrieved May 27, 2008, from http://www.glin.net/humanhealth/fish/index.html

Keller, E. A., 2000, Environmental geology, 8th edition: Upper Saddle River, NJ, Prentice-Hall, 562 p.

Schneider, R. A., Rickert, D. A., and Spieker, A. M., 1973, *Role of water in urban planning and management*: U.S. Geological Survey Circular 601H, 10 p.

SIWI–IWMI, 2004, *Water—More nutrition per drop*: Stockholm International Water Institute, Stockholm, 36 p. Retrieved August 17, 2007, from http://www.siwi.org/downloads/More_Nutrition_Per_Drop.pdf

Solley, W.B., Pierce, R. R., and Perlman, H.A., 1993, *Estimated use of water in the United States in 1990*: U. S. Geological Survey Circular 1081, 76 p.

USGS, 2004, *Water Science for Schools Questionnaire #3.* Retrieved August 17, 2007, from http://ga.water.usgs.gov/edu/sq3.html