an acid medium. The resulting antimony-phospho-molybdate complex turns blue when reduced by ascorbic acid. The intensity of the blue color is proportional to the concentration of orthophosphates. A variation of this method uses the reaction between the molybdate complex and malachite green in an acidic medium to form a green color. This reaction is often used in automated phosphate analyzers.

Ion chromatography is also widely used for the determination of orthophosphate concentration in water. The sample preparation steps determine the type of phosphorous that is measured in a chemical analysis. Passing the water sample through a 0.45-micron filter will remove all of the particulate phosphates. If the filtrate is tested without additional treatment, only the orthophosphate concentration will be determined. The result is usually reported as "dissolved reactive phosphorus." Persulfate digestion of the filtrate before analysis will convert the organic phosphorus to orthophosphate. The result is usually reported as "total dissolved phosphorus." If the filtrate is treated with sulfuric acid prior to analysis the polyphosphates will be converted to orthophosphates and the results are usually reported as "dissolved acid-hydrolyzable phosphorus."

For the determination of total phosphorus, the process of analysis is identical except that the sample is not filtered prior to analysis. In this situation, the untreated sample is tested for "total reactive phosphorus." The result for the acid-hydrolyzed sample is reported as "total acid-hydrolyzable phosphorus," and the result for the digested sample is reported as "total phosphorus." By adding and subtracting the various results, it is possible to determine parameters including "total organic phosphorus," "total suspended phosphorus," "suspended reactive phosphorus," and "suspended organic phosphorus."

—Kevin Olsen

See also: *Agriculture; Aquaculture; Fertilizers*

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Population Trends and Water Demand

In 1840, before the beginning of large-scale immigration to the West, there was a strong causal link between precipitation and population density in the United States—people lived where it rained. By 1990, this relationship had been broken (Beeson et al. 2001). People moved from wet places to dry places (e.g. from the Midwest to the Southwest) because massive projects made it possible to live somewhere dry and consume water from somewhere wet. Although some claim that water followed the people, it is more accurate to argue that people followed the water. This causal pattern is problematic because water is priced below cost, which subsidizes population growth and sprawl to unsustainable levels.

Water as a Necessary Condition for Settlement

People cannot live without water, but the presence of water does not mean that people will live nearby. Put differently, water is necessary but not sufficient for human settlement. This observation matches a stylized view of history. The earliest human settlements were next to lakes and rivers. As these settlements grew and demand for water exceeded local supplies, water was imported from elsewhere. Eventually, growth would end or slow—either because it was too expensive to bring more water or because other factors (e.g., limited land area) began to bind.

Throughout history, civilizations that depended on water for prosperity and growth (e.g., Rome, Egypt, Angkor) have overextended and crashed when water supplies fell short of demand (Diamond 2005). Is the United States on that path?

Early settlements in the eastern United States had abundant water, so cities grew in different places for different reasons. When people moved west, water scarcity played a larger role in their settlement decisions. Settlement patterns began to change when technology and political will facilitated large-scale water projects.

In 1900, the populations of San Francisco and Los Angeles counties were, respectively, 340,000 and 170,000. In 1990—after many years of importing water to Los Angeles—they were 750,000 and 8.8 million (Forstall 1995a). The case in Nevada is similarly striking: in 1900, water-rich Washoe County (where Reno is located) had a population of 6,000 while arid Clark County (where Las Vegas lies) had so few people that it was included in Lincoln County, where the population was 3,000. By 1990, Washoe had 250,000 people, but Clark had grown to 750,000 (Forstall 1995b). Today, after the growth of Las Vegas into a modern metropolis and tourist destination, not to mention the large-scale development of water resources such as the construction of Hoover Dam, over 2 million people live in Clark County.

Early water importation projects were large but simple. The Los Angeles (1913) and Hetch Hetchy (1934) aqueducts used gravity to move water hundreds of miles from the Sierra Nevada mountains to southern and northern California, respectively. Later projects pumped water between basins over greater distances. The Colorado River Aqueduct (1942) and California Aqueduct of the State Water Project (1971) brought water to southern California from the Colorado River and northern California, respectively. Recent projects to desalinate brackish water and seawater and recycle wastewater have much higher energy, environmental, and monetary costs. Although some claim that these technologies can meet demand "forever," others worry that their environmental impacts and energy consumption are unsustainable.

Urban versus Agricultural Water

To know whether the American West—and the rest of the United States—is on an unsustainable path, one needs to understand water management in the western part of the country. Over 130 years ago, Powell et al. (1879) noted that water in the arid Southwest was concentrated in rivers fed by seasonal snowmelt. Although some areas had groundwater, other areas were far from any water. The 1902 Reclamation Act sought to change this situation. It established and tasked the Bureau of Reclamation with reclaiming land for settlement and farming. (The U.S. Army Corps of Engineers—founded 1802—did similar work.) Reclamation changed landscape and population patterns, but it also resulted in environmental costs that have grown more controversial (Reisner 1993).

Large-scale irrigated agriculture is now common throughout the Southwest, and farmers control most water rights. As urban and environmental demand has grown, the tension between "highest and best use" of available water and existing property rights has increased. Although some say that "water flows towards money" (i.e., cities), money loses power when it conflicts with traditional farming or environmental values. Others contend that the public trust doctrine justifies forcible reallocation of water from agricultural to urban or environmental uses, but this view contradicts established property rights. The bottom line is that negotiations over water are slow, contentious, and disorganized—whether they take place in bureaucracies, legislatures, courts, or markets.

Although it is clear that water's "value in use" is greater in urban than in agricultural areas, it is not clear whether urban demand per acre is greater than agricultural demand. Using 2004 data, I calculated water demand per acre for two cities in Southern California—wealthy Beverly Hills (average assessed value of $4.2 million/acre) and poor Compton (average assessed value of $0.4 million/acre). Beverly Hills uses an average of 4.4 acre-feet (af) of water per acre; Compton uses 1.5 af/acre. With agricultural water use averaging 2.5 to 5.5 af/acre, there is little evidence that water use rises when farms are paved over.

Water and Sprawl

Many antigrowth activists argue that increases in water supply lead to increases in population and sprawl. Water managers facilitate this result by "building ahead of demand." They estimate future demand based on historic growth rates and per capita water use. Then they build infrastructure and secure supplies to meet that demand. This professional norm has created financial or environmental problems in some places (Los Angeles) but continues in others (Las Vegas).

Building ahead of demand drives population increases because large water projects take five to twenty years to bring online, are designed to meet *projected* growth, and are paid for by existing customers. Because expansion creates surplus capacity, extra water is sold at the cost of delivery (existing customers cover the new system's capital costs) to new customers who buy cheap houses on land that previously had no water.

Is their assumption of constant per capita demand wrong? Lifestyle water use (for pools, power showers, lawns, etc.) and settlement in hotter areas are increasing demand, but a growing awareness of conservation is decreasing it.

Does the price of water matter? Current prices are too cheap to affect demand—averaging about $3 per unit of 748 gallons—but water managers have responded to shortages with command-and-control regulations instead of "conservation pricing." Higher prices would lower the quantity of water demanded, but politicians and water managers resist raising them to avoid "hurting the poor." This problem can be avoided by selling some water cheaply—a "human right" allocation of perhaps 75 gallons/capita/day—and then selling additional water at prices high enough to choke demand down to supply. Revenue in excess of costs could be rebated per capita.

A cycle of subsidy and growth drives urban sprawl. To some, building ahead of supply seems natural and efficient, but it is neither if one is concerned about full cost allocation, sustainability, and/or undistorted resettlement decisions.

Resources for the Future

Founded in 1952, Resources for the Future (RFF) is a nonprofit and politically independent think tank headquartered in Washington, D.C., that employs more than forty research specialists, most of whom hold advanced degrees. The organization's research interests fall into the areas of climate, energy, transportation, urban areas, human health, and ecology. Its employees utilize the methodologies of the social sciences, with a particular emphasis on economic analysis, for their research. The RFF endeavors to share its research with the general public, academics, policy makers, environmental groups, and business interests around the world so that each respective group of decision makers can make informed choices on issues related to the environment. Much of the research is disseminated by the organization through the Internet and RFF Press. Among its publications are numerous monographs and *Resources Magazine,* which is published quarterly.

—John R. Burch Jr.

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Politics and Development

Step back a moment from the facts and mechanisms of population growth and sprawl to consider the forces that support it. On the one hand, we have citizens' demand for living in cheap and sunny places. On the other, we have politicians and real estate developers who supply this living space to increase, respectively, their power and profits. All players favor expanding water systems to previously dry areas.

The movie *Chinatown* (1974) famously portrayed the connections among water, politics, and development in southern California, and its plot is more or less accurate. In reality, William Mulholland oversaw the construction of the Los Angeles Aqueduct from Owens Valley to Los Angeles. The city used the imported water to expand, exchanging water for political control over neighboring cities and areas. The Aqueduct went into service in 1913. In 1915, Los Angeles annexed the mainly agricultural San Fernando Valley and grew by 170 square miles. Between 1910 and 1932, Los Angeles grew from 90 to 450 square miles. Although political opposition to Los Angeles's growth slowed further expansion, a pattern of using water to increase area and population density was set.

This pattern has been repeated in many places—San Diego, Las Vegas, and Phoenix, to name a few. It is popular because it turns financial assets (money for infrastructure) into "liquid" assets ("water") and these, in turn, into political and financial assets (valuable land). The pattern has slowed, however, as financial and environmental costs have increased. In some cases, cities have been forced to stop all development. The California town of Bolinas has refused new water connections since 1971. This policy is famous mostly because it is so rare in the growth culture of the western

United States. At the other extreme is fast-growing Las Vegas, where Pat Mulroy (general manager of the Southern Nevada Water Authority) promotes growth as "inevitable." Vegas residents pay far less per month and per unit than people in other U.S. cities. They also use a lot more water—250 gallons per capita per day (Southern Nevada Water Authority 2009).

Sustainability and Climate Change

Climate change stresses water supplies by increasing the variation of precipitation. Since less reliable supplies require expensive mitigation measures (more dams, bigger reservoirs, etc.), maintaining current supplies is expensive. Some cities are reacting by spending millions of dollars on plants to desalinate brackish water or seawater and/or recycle wastewater, but these plants take years to bring online, do not slow demand growth, and use massive amounts of energy.

Can demand be reduced? The conventional wisdom is that "hardened" demand—demand that is unresponsive to price—cannot be reduced, but timid price increases and lackluster conservation campaigns ("Take a shower with a friend," or "Turn in your neighbor for overwatering.") do not really put "hard" to the test. Growing public awareness of decreasing water reliability can perhaps be combined with substantial price restructuring to change expectations of "lifestyle" water use and permanently lower demand. Australia offers a useful example: demand in large Australian cities is down to about 40 gallons per capita per day—about half the amount used in conservation-minded San Francisco.

By definition, sustainable water use can continue indefinitely. With much of the Southwest—and, increasingly, other parts of the country—experiencing shortages, it seems that we have moved away from sustainable water use. A simple solution would bring demand in line with supply, but there does not appear to be very much institutional, professional, or political support for this solution. It seems, indeed, that unsustainable use may continue until crisis forces change.

A Sustainable Future?

Water has affected population and growth patterns throughout history, but growing environmental consciousness and an unstable climate are disrupting these patterns. In the past, politicians directed allocation, engineers built projects, and real estate developers made money. Can these interest groups change their professional habits and institutions and no longer build ahead of demand? Not unless intense outside pressure forces them to think differently, use economic tools, and step off an unsustainable path.

—David Zetland

See also: *Agriculture; Climate Change; Groundwater Recharge and Water Reuse; Urbanization; Urban Rivers*

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Poverty and Water

The link between water and poverty is found in the lack of access to safe and clean water in poor and minority areas, especially those located near waterways that carry large commercial shipping traffic and near large industrial or commercial agricultural sites. These areas experience higher than usual water and air pollution from industrial activity, higher rates of disease, and a poor quality of life largely because the areas' inhabitants have no political voice and cannot protect themselves. Both in the United States and worldwide, the willingness of government and private commercial interests to take advantage of the poor and minorities to get around restrictions imposed by legislation or treaties has triggered accusations of environmental racism