

# Time Scales in the Sustainable Management of Water Resources

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For several decades, humans have become increasingly aware of the need for “sustainability” of water resources for human consumption, industry, irrigation, and viable natural ecosystems. Sustainability is an especially relevant topic in the Southwest because of limited water supplies and rapidly expanding populations. However, the term is not clearly understood by all; ecologists, economists, hydrologists, and others have offered various definitions. Alley and others (1999) define sustainability of groundwater as “development and use of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences.” Other definitions introduce the concept of not leaving future generations with fewer resources than the present. Regardless of the definition, sustainability is a concept that pertains to maintaining water resources for an indefinite time in the future. Furthermore, sustainability is not a purely scientific concept, but one that involves societal decisions about which consequences of human water use are acceptable or unacceptable (Alley and Leake, 2004). Many human activities, ranging from

land use to direct diversions of water, affect water-resources systems. The time scales over which activities ultimately cause consequences range from nearly immediate to decades or centuries. Thus, if we wish to try to manage water resources sustainably, we must consider the time scales of these consequences.

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## Surface Water

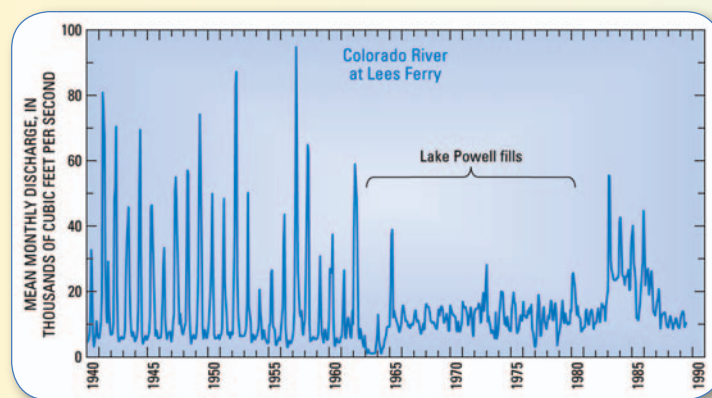
Surface-water diversion produces rapid, easily observed responses in water availability to streams, lakes, and wetlands. The graph below (left) illustrates how dam construction on the Colorado River caused immediate and unmistakable changes in downstream flow characteristics. However, time scales come

into play in other ways: climatic variations have both short- and long-term effects on surface-water resources. In a given week or year, an allocation may be affected by drought or flood. Yet a century of streamflow data was required to show that allocations in the lower Colorado River are based on a wetter-than-average period of time, and that the river is overallocated (Weatherford and Brown, 1986).

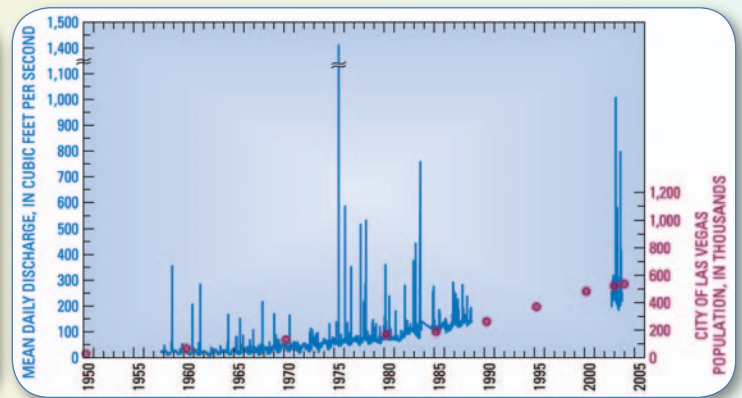
Human values also reflect a temporal aspect. During the dam-building era of the early- to mid-20th century, high value was placed on providing water for irrigation, public supply, power generation, and downstream flood control. These issues are still important, but recently the preservation and restoration of natural riverine ecosystems affected by dams have gained value.

## Land Use

Human activities affect surface-water runoff, groundwater recharge, and climate. The effects can be immediate or range over decades, but many, such as changes in recharge, might never be detected without careful, long-term monitoring. The cause and effect of land use activities is seen in the urbanization of the Las Vegas



Mean monthly discharge in the Colorado River at Lees Ferry, Arizona.



Average monthly and annual peak flow in Las Vegas Wash, 1957-2003, and population of the city of Las Vegas, Nevada.

Valley (see figure at right). The Las Vegas Wash, the major valley drainage, shows a trend in average monthly flow coincident with the trend in population (see graph, previous page, right). Furthermore, the series of annual peak flows shows a trend of increasing flows. These trends can be explained respectively by increased discharge of sewage effluent and higher runoff from an increasingly urbanized watershed during the period of record. Land-use practices also can affect water quality in terms of sediment concentration, salinity, and chemical composition over years to decades.

### Groundwater

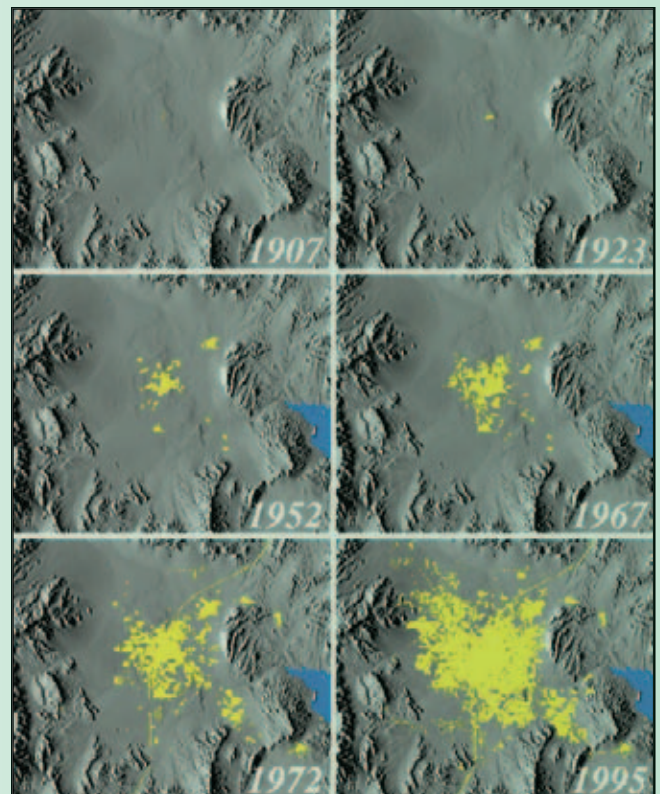
Groundwater has allowed human development in areas where surface-water supplies are unavailable or of poor quality. As of 2000, groundwater accounted for 35 percent of fresh water use in Arizona, California, Colorado, Nevada, New Mexico, and Utah (Hutson and others, 2004). When groundwater pumping begins, the rate of pumping is balanced by an equal rate of storage decline in the aquifer. If pumping continues long enough, cones of depression in many aquifers

stabilize, as the outflow to streams, springs and wetlands is “captured” by the pumping. If pumping continues indefinitely and sufficient outflow can be captured, a new stable condition will develop in which the rate of storage decline is zero and the rate of groundwater outflow to springs and streams is reduced by the rate of pumping. Consequences related to loss of storage in the aquifer include increased pumping lifts, land subsidence, and degraded water quality. These consequences can occur almost immediately near pumped wells and can spread to large distances in ensuing decades. Consequences related to capture of outflow include reduced availability of water to riparian and aquatic ecosystems and reduced availability of surface water for humans.

Timing of capture of surface water outflow is dependent on aquifer properties and the distance between pumping and outflow areas. A well that pumps 20 miles from a stream in an areally extensive aquifer that has a diffusivity of  $1.1 \times 10^5$  ft<sup>2</sup>/day could pump for more than 300 years before 50 percent of the pumping rate consisted of captured streamflow (see graph at left). A well located 5 miles from the stream would require just 20 years for the same level of capture.

### Management Strategies

Water-resources management and policy in states in the Southwest typically consider only short-term consequences of development, and tolerate or ignore long-term consequences. An exception might be Arizona’s Adequate and Assured Water Supply programs, which have 100-year management horizons. The Adequate

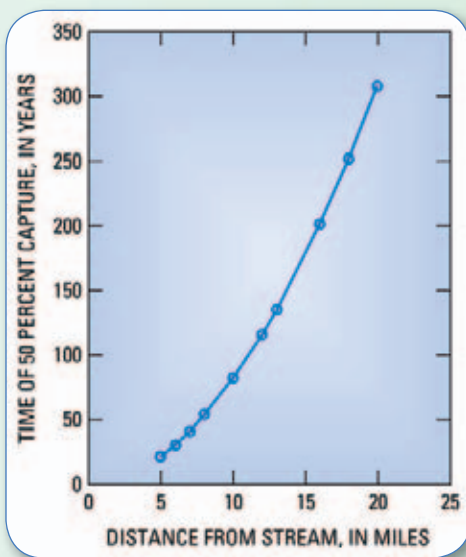


Urban land use in Las Vegas Valley (yellow), 1907-1995 (Acevedo and others, 2003).

Water Supply Program, initiated in 1973, stipulates that real-estate developments must have physical, legal, and continuous availability of water for 100 years. For developments with a central supply of groundwater, the main criterion is that depth to water cannot exceed 1,200 feet below land surface in 100 years. This program is a consumer-protection measure that does not consider consequences other than loss of water supply for homeowners.

Historically, groundwater and surface water in the Southwest have been managed separately, with little recognition that development of one resource could affect the other. But we’ve learned that groundwater withdrawals can affect surface-water resources over time scales from decades to centuries, and recently states have begun to consider management strategies that address this interconnection.

For future management of water resources, several points are noteworthy. First, it is not possible to develop water supplies without consequences to water-resource systems. Even small developments with



Relation between time of 50 percent capture of streamflow and the distance from a stream to a pumped well in an aquifer. Time of 50 percent capture is the number of years until 50 percent of the pumping rate is accounted for as reduced groundwater discharge to the stream. The relation is for a fully penetrating stream and pumped well in an aquifer having a diffusivity of 110,000 feet<sup>2</sup>/day.

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immeasurable effects can combine to result in significant consequences. The task of water scientists and engineers is to identify consequences of development, including timing and locations of effects. The task of society, on the other hand, is to determine which effects are tolerable. Second, long-term monitoring of key system components such as water levels and flow is important in understanding natural and human-induced variations. Such information can be used in adaptive management schemes in which action can be taken if conditions cross a prescribed threshold. This strategy works best for surface-water systems, in which response to change is rapid.

Groundwater systems, on the other hand, respond slowly and negative effects can persist long after withdrawals cease. Sound long-term management of water resources will require development and institutionalized use of decision tools that incorporate hydrologic data and analyses, climate variability, population and land-use trends, and societal values.

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