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Author(s): William S. Abruzzi
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# Water and Community Development in the Little Colorado River Basin

**William S. Abruzzi**[1]

*Water has historically been a critical limiting factor affecting community development throughout the American West. Within the Little Colorado River Basin of northeastern Arizona, abundant groundwater resources enabled local agricultural communities to overcome the limitations of unstable surface-water sources. However, industrialization has led to sharp increases in groundwater consumption in the basin and to a decline in groundwater levels and/or quality at several locations. This paper examines the broader historical and regional implications of recent groundwater changes in the basin. Emphasis is placed upon the relationship between local developments and the rapid expansion of metropolitan centers in southern Arizona.*

**KEY WORDS:** ecology; water; community development; Arizona.

## INTRODUCTION

The Little Colorado River Basin is a relatively isolated, arid region in northeastern Arizona. Most of the approximately two dozen towns in the basin were founded during the late nineteenth century by Mormon pioneers struggling to establish viable, self-sufficient agricultural settlements removed from the non-Mormon influences around them (see Peterson, 1973; Leone, 1979; Abruzzi, 1981). While agriculture remained the regional economic base throughout the first half of the twentieth century, its prominence in the local economy has declined sharply in recent years. Today, agriculture accounts for less than 2% of total employment, compared with 50% as recently as 1940 (U.S. Bureau of Census).

[1]Department of Anthropology, The Pennsylvania State University, Ogontz Campus, Abington, Pennsylvania.



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The relative decline of agriculture began with a sharp increase in tourism and summer-home development after 1950 and accelerated with the industrialization of the region since 1960. Population size has more than doubled during the past 20 years, with even sharper increases recorded in towns adjacent to newly constructed industrial facilities. In addition to the many other effects which have accompanied rapid economic development[2], communities in the basin have experienced sharp increases in groundwater exploitation. Increased groundwater consumption, most notably for agricultural and industrial use, is having a negative effect upon surface and subsurface water resources. The following paper examines the impact that current developments are having upon water resources in this arid basin in order to assess their implications for community development.

Water is a critical limiting factor in the development of all ecological systems, including human communities, and the overexploitation of groundwater resources has become a serious problem throughout the American West (Ballard et al., 1982; Weatherford et al., 1982). Declining groundwater availability has reached critical proportions in several areas of the Southwest and is rapidly approaching a crisis situation in southern Arizona (Arizona Water Commission, 1975; Briggs, 1976; Laney, 1976; Lansford and Ben-David, 1982). Water has likewise been a central factor determining historical community development within the Little Colorado River Basin. Given the traditional agricultural focus of towns in this region, variation in the availability of water for irrigation has been the primary cause of differences in local community development (Abruzzi, 1981). Consequently, declining groundwater quality and availability, with clear historical precedent, have direct implications for future community development in the region.

The present situation with regard to groundwater carries broader regional implications as well. Current developments are transforming these small, isolated rural communities into economic satellites of the expanding metropolitan centers of southern Arizona. Three coal-fired, electrical generating stations and a major pulp and paper mill have been constructed in the basin so far. The pulp mill and one of the generating stations have already completed expansion programs which more than doubled their initial productive capacities, and the remaining generating stations contain plans for future expansion, which would increase their productive capabilities as well. All three power plants are operated by utilities serving the Phoenix and Tuc-

[2]The labor required to construct and operate the newly established industrial facilities has far exceeded local supply, and substantial manpower has had to be imported into the region. Rapid population growth has resulted, and several local communities have exhibited so-called "boomtown" characteristics (see Cortese and Jones, 1976; Freudenberg, 1976; Weber and Howell, 1982 for general discussions of the effects of rapid economic development and population growth on small rural communities).

son metropolitan areas, and the pulp mill is the principal manufacturing facility of Southwest Forest Industries (SWFI), a *Fortune 500* industrial corporation located in Phoenix. In addition, much of the tourism and most of the summer-home development are products of the increasing recreational demand of residents in these two metropolitan areas.

This paper will examine current developments in the Little Colorado River Basin in light of the historical relationship between water and community development in this arid region, as well as in terms of their implications for the assimilation of local rural communities into the expanding, metropolitan-dominated regional economy of southern Arizona. The discussion will begin with a description of the physical features of the Little Colorado River Basin, with primary emphasis upon water availability, distribution, and quality. A brief account of current developments will then be presented, followed by a consideration of their impact upon local water resources. Because the most significant changes have occurred within Navajo County between the towns of Snowflake and Joseph City (see Fig. 1), where the initial industrial facilities have been located, the paper will concentrate primarily on the events that have taken place in this portion of the basin. Developments which have already occurred here will provide the basis for assessing the implications of subsequent developments elsewhere in the region.

## THE LITTLE COLORADO RIVER BASIN

The region under consideration encompasses the upper Little Colorado River Basin, and may be conveniently defined as the nonreservation portion of Navajo and Apache Counties in northeastern Arizona. The study area, which comprises over 5000 square miles, is bounded on the north and south by the Navajo and Apache Indian Reservations, respectively, on the east by the New Mexico border and on the west by the Coconino County (Arizona) line. Located on the southern periphery of the Colorado Plateau, the region appears as an undulating, saucer-like plain, sloping to the north and northeast. Rising from an elevation of less than 5000 feet in the valley of the Little Colorado River, average elevation in the basin increases southward to nearly 8000 feet along the Mogollon Rim, a steep escarpment defining the southern boundary for much of the area. Southern highlands within the basin include peaks exceeding 10,000 feet, with Baldy Peak, the highest of these, reaching an elevation of 11,403 feet.

Precipitation increases with elevation and ranges from less than 9 inches in the north to over 25 inches along the Mogollon Rim. The majority of the basin, however, receives less than 15 inches of precipitation annually (see U.S. Weather Bureau). Consequently, over 40% of the region is covered by

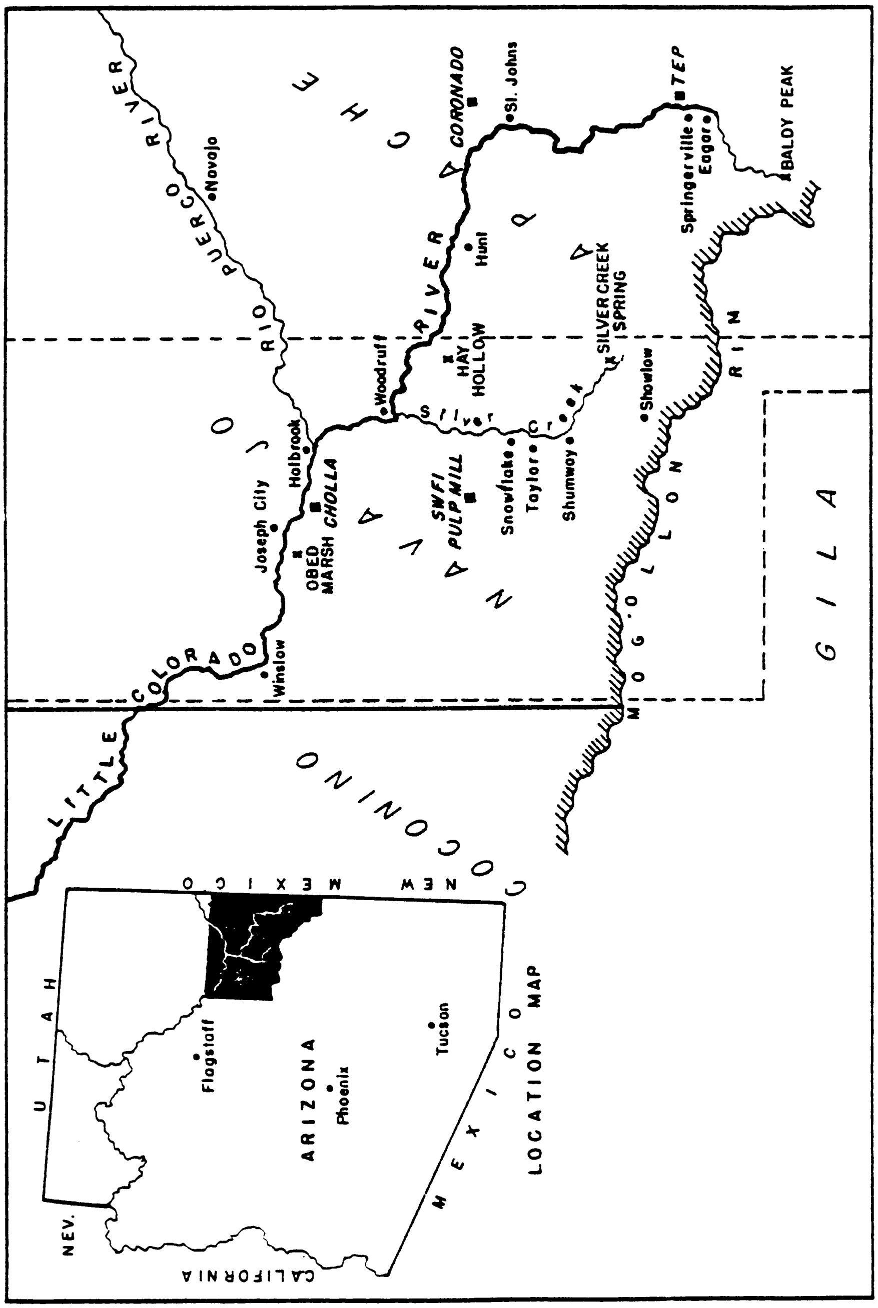


**Fig. 1.** Little Colorado River Basin.

grasslands, with juniper-pinon woodland, the second largest plant community, accounting for 38% of the total area.[3] Both the grassland and the juniper-pinon woodland communities have been exploited primarily for livestock grazing.[4] Proceeding southward, juniper and pinon give way to ponderosa pine as elevation approaches 6000 feet. The ponderosa pine community forms part of the largest continuous stand of ponderosa pine in the United States and has been the focus of an increasingly active lumber and wood-related industry[5], as well as of a growing tourist and summer-home development boom. Ponderosa pine is succeeded above 8000 feet by aspen and Englemann spruce, and alpine meadows occur over extensive areas above 9000 feet.

Because precipitation is both sparse and variable, all farming settlements in the region have necessarily been located in river valleys. Only two streams of any consequence exist in the region, however, the Little Colorado River and its principal tributary, Silver Creek. Most agricultural settlements were established along these two waterways, and the specific characteristics of each stream strongly determined differences in community development in the region (see Abruzzi, 1981).

## Surface Water

Originating from a series of springs about 10 miles southeast of Snowflake, Silver Creek is the only fully perennial stream in the basin. Silver Creek Spring, as these several springs are collectively known, is the largest spring in the region, having an annual discharge of 11,660 acre-feet (Salt River Project, 1974 Section 3, p. 283). Silver Creek Spring is noted for its stability and reliability, as well as for the quality of the water that it discharges. No report exists of this spring ever failing to discharge (Harrell and Eckel, 1939, p. 30; Bureau of Reclamation, 1947, p. 50), even during the most protracted drought in the region (Bureau of Reclamation, 1947, p. 87), and more than a century of irrigation with water from Silver Creek has produced no notice-

[3]Juniper and pinon are short, woody types of vegetation, which dominate in rough, broken country with shallow soils. Density of tree cover in this plant community increases with precipitation and ranges from ten trees per acre near St. Johns to 30 trees per acre near Snowflake (Salt River Project, 1974, Section 3, 79, 99). Mean annual precipitation is 11.19 inches at St. Johns and 12.62 inches at Snowflake (see Abruzzi, 1981, p. 115).

[4]Widespread bulldozing—"chaining," as it is called—of juniper and pinon has occurred in recent years in order to increase grazing capacity in this community.

[5]Access to nearby forests was a major consideration in SWFI's decision to locate its pulp mill in the basin. SWFI is the largest single private employer in the region and owns the lion's share of cutting leases in the Sitgreaves-Apache National Forest located in the southern highland portion of the basin.

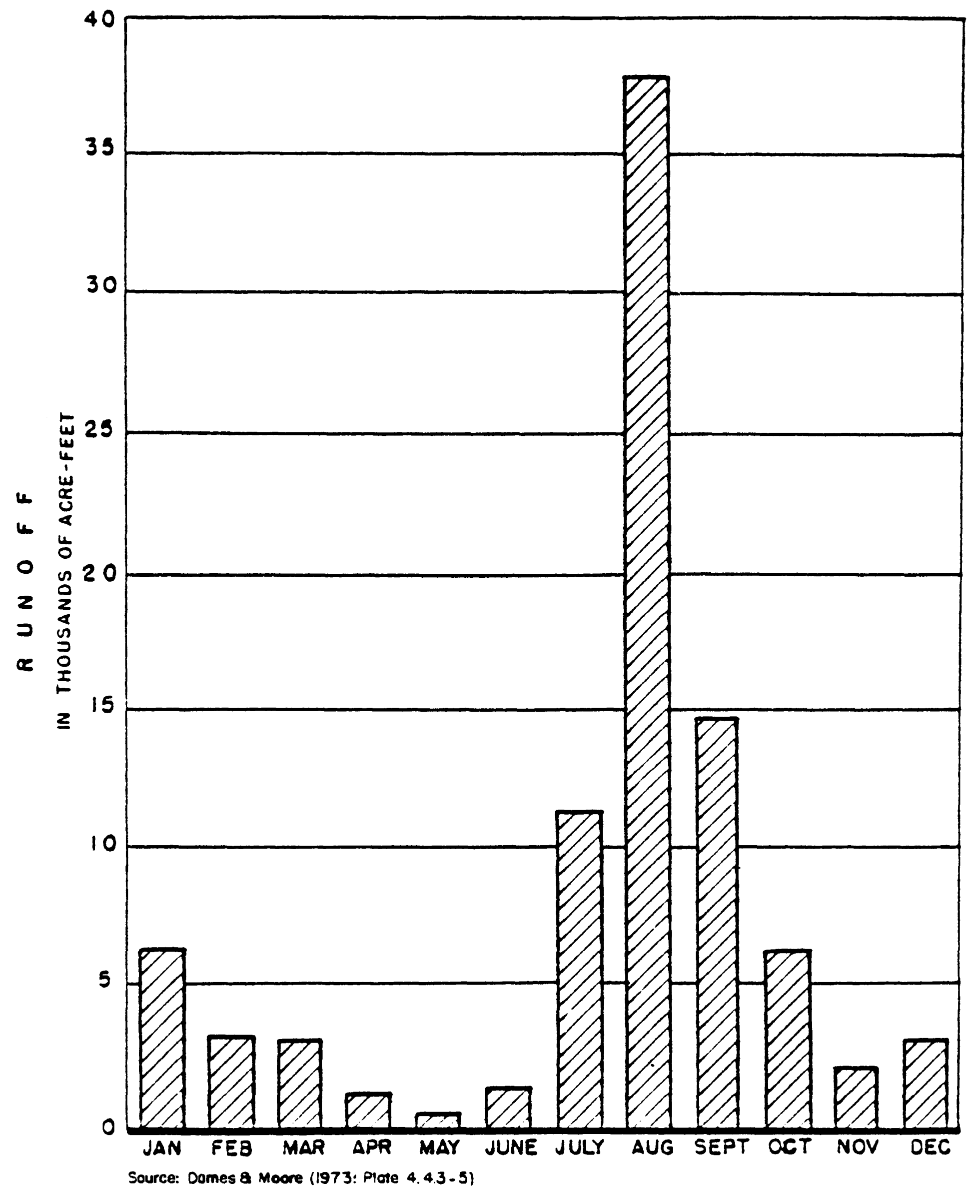


**Fig. 2.** Average monthly runoff—Little Colorado River at Holbrook.

able soil deterioration at either Snowflake or Taylor (Bureau of Reclamation, 1947, pp. 66-67; Salt River Project, 1974, Section 3, p. 78).

The Little Colorado River originates as snowmelt from Mount Baldy and is perennial south of St. Johns only, where it is fed by underground springs (Akers, 1964, p. 8). Surface flow in the Little Colorado becomes intermittent below St. Johns and is confined exclusively to subsurface channels during the dry months of April, May, and June. Although water quality in the Little Colorado is considered good south of St. Johns, its quality declines sharply below St. Johns as the river receives increasing amounts of water from tributaries that intersect highly saline geological strata to the north.

Most remaining streambeds in the basin are dry throughout the year and flow primarily in direct response to precipitation. Three characteristics of surface water in the basin constrained agricultural productivity historically and underscore the importance of groundwater resources for local community development.

First, because local streams flow primarily in direct response to precipitation, surface water availability follows a distinct annual cycle which is at variance with local agricultural requirements. Precipitation occurs primarily during the months of December–March and July–September, with the remaining months receiving little, if any, accumulation. Water levels and stream velocity are generally moderate from December–March due to the intermittent melting of snowpacks at higher elevations, and streamflow subsides during the spring as snowpacks become smaller and precipitation declines (see Fig. 2). With the onset of intense summer storms in July, both the volume and velocity of surface flow increases sharply. Stream flow generally remains high until the passing of summer storms in September and then subsides again until snow reaccumulates at higher elevations. Mean monthly stream flow in the Little Colorado River near Holbrook varies from less than 1000 acre-feet in May to over 37,000 acre-feet in August.

Nearly half the annual irrigation requirements must be applied to fields during the dry months of April, May, and June when streambeds throughout the basin are dry (see Bureau of Reclamation, 1947, p. 72; U.S. Geological Survey, 1975, pp. 40-43). Many towns were thus forced to build storage reservoirs in order to offset seasonal fluctuations in surface water availability. This option was available only to settlements at higher elevations, however, where suitable reservoir sites exist.

Pronounced seasonal stream-flow variation also placed an inordinate stress upon irrigation systems and caused the loss of numerous early dams. Although many dams were lost during spring thaws, particular devastation was caused by freshets attending summer storms, with the greatest destruction imposed upon irrigation systems in the lower valley. Joseph City and Woodruff, which suffered the highest incidences of dam failures in the region, lost 14 and 13 dams, respectively, between 1876 and 1923, compared with five at St. Johns, six at Snowflake and Taylor, and one each at Showlow and Eagar (see Abruzzi, 1981, pp. 165-196).

A second factor limiting surface water's contribution to community development in the region is its variable quality. Sediment concentrations, particularly sodium, increase in streams along a northward gradient and are especially high in the lower valley of the Little Colorado River. Total dis-

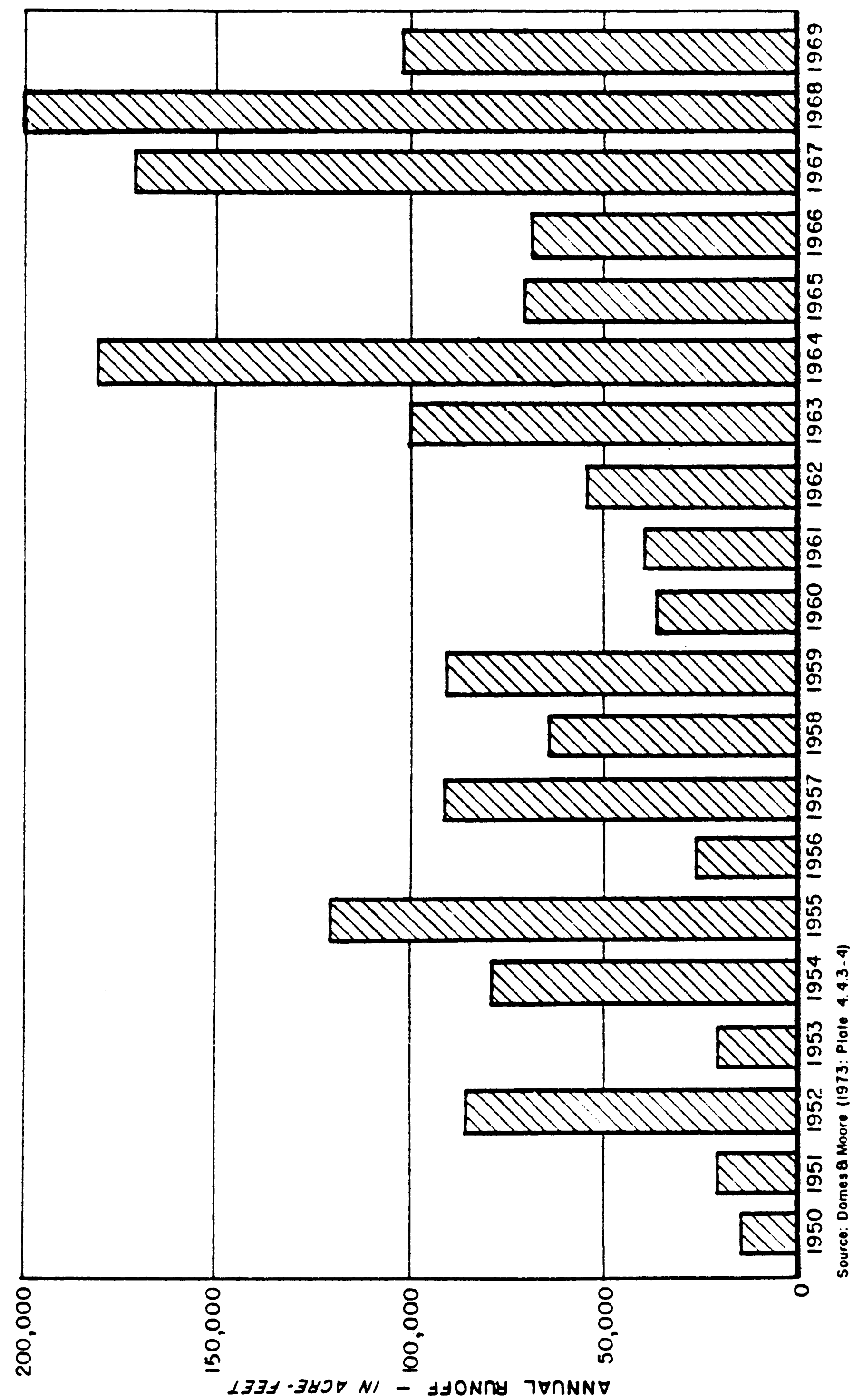


**Fig. 3.** Annual runoff – Little Colorado River at Holbrook.

solved solids in the Little Colorado near Holbrook and Joseph City exceed 500 mg/liter under average discharge conditions and surpass 1000 mg/liter during periods of high evaporation. Due to the extensive distribution of bare surface cover and alkaline soils throughout the grassland community, considerable sediment is deposited regularly in streams at lower elevations. Sediment load is particularly high during the heavy flow that accompanies summer storms and may account for as much as 20% of stream flow near Joseph City (Bureau of Reclamation, 1950, p. 3).[6] Several water samples were collected from the Little Colorado River below Joseph City by the Bureau of Reclamation (1950, pp. 9-10) during 1950. Although water quality varied widely from day to day, and even within the same day, total sodium content of the water obtained was consistently high and exceeded the permissible limit in all but two samples (7%). Owing to such high levels of sediment concentration, water in the Little Colorado River below St. Johns has been classified as unsuitable for domestic, agricultural, or industrial use.

Third, because stream flow is both unpredictable and highly variable, it offers an unreliable source of water for irrigation. Several streams, most notably the Little Colorado River at lower elevations, have been transformed within hours from sandy river beds to raging torrents destroying everyting in their path. While the average volume of water discharged in the Little Colorado River at Woodruff between 1940 and 1947 was 86,000 acre-feet, actual flow during this period ranged from 20,000 acre-feet in 1944 to 280,000 acre-feet in 1941 (Bureau of Reclamation, 1950, p. 7). Likewise, discharge in the Little Colorado between 1950–1969 ranged from less than 15,000 acre-feet to nearly 200,000 acre-feet (see Fig. 3). Average velocity of discharge in the Little Colorado near Holbrook between 1966–1970 ranged from 8.6 cubic feet per second during May to 874.6 cubic feet per second in August (U.S. Goeological Survey, 1975, pp. 72-74). In 1967 alone, average discharge varied from 3.93 cubic feet per second in May to 1446 cubic feet per second in August, yielding a flow of 242 acre-feet in May, compared with 88,940 acre-feet in August (U.S. Geological Survey, 1975, p. 73). Peak stream flow in the Little Colorado near Holbrook during the flood of September 19, 1923, has been estimated by the U.S. Corps of Engineers at about 60,000 cubic feet per second (see Dames and Moore, 1973, Section 4, p. 143).

Such extreme surface water variability limited agricultural productivity. It was not uncommon, for example, for farmers to suffer crop losses from flooding and drought during the same agricultural season (Abruzzi, 1981,

[6]A story frequently recounted by early pioneers illustrates the sediment level characteristic of the Little Colorado River at lower elevations:

> A 7-gallon kettle was filled when they camped for the night with water from this stream and set by for use the next morning after it had "settled"—there was about an inch at the top of the kettle of fairly "clear" water; but soluble matter in the water was still so much in solution that the water was of poor quality. (Porter, pp. 7-8)

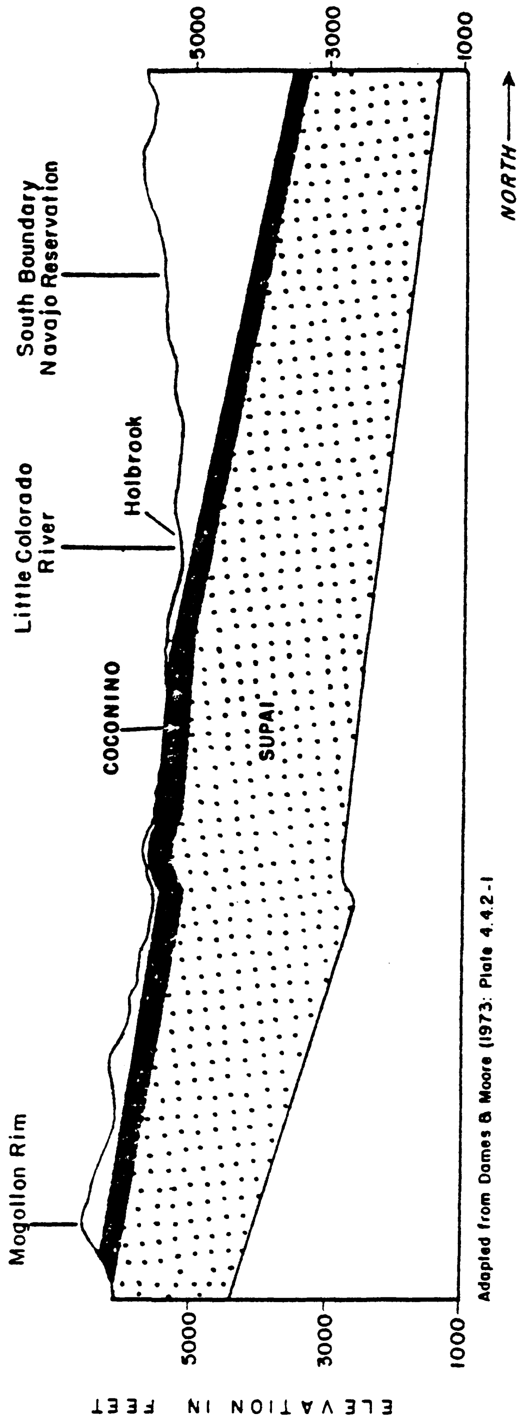


**Fig. 4.** Coconino sandstone.

pp. 76-77).[7] Inasmuch as community development depends upon the reliability of critical resources, development in the region ultimately depended upon the extent to which local communities could overcome reliance upon unstable surface-water sources. Two options presented themselves. The first alternative was the construction of storage reservoirs. In addition to the limited availability of suitable reservoir sites, storage reservoirs presented other problems. In the face of excessive stream flow, a recurring feature of the regional surface water cycle, dams impounding reservoirs frequently burst, adding to the destructive force of an already swollen river (Abruzzi, 1981, pp. 183-186, 300). On several occasions, settlements at lower elevations lost dams in chain reactions to dam failures upstream.

The second option has been the exploitation of groundwater resources. Readily available to settlements throughout the basin, this option has eventually been exploited by all. Pressure to escape dependence upon surface water was greatest in the lower valley, however, and the Joseph City Irrigation Company drilled the first permanent well in the region in 1924.[8] Following this initial success, groundwater exploitation increased at Joseph City and spread elsewhere. Although subsurface water resources were first exploited to supplement surface water supply, groundwater soon became the principal source of irrigation water for most communities in the basin. Today, surface water serves only as a supplement to groundwater at most locations.

Groundwater exploitation eventually allowed the spread of farming to new locations, such as Hay Hollow Wash, completely removed from major surface-water sources. More important, the discovery of abundant groundwater sources allowed entirely new forms of economic activity to enter the region. The current industrialization of the basin is fundamentally dependent upon the local availability of abundant, superior quality groundwater resources.

[7]The sequence of events which occurred at Joseph City (then called St. Joseph) during the first year of Mormon settlement in the basin clearly illustrates the drain that stream-flow variability imposed upon farmers and communities in the region. Arriving at their destination on March 23, 1876, farmers at Joseph City immediately began building a dam, constructing irrigation canals, and planting fields. The absence of rain for several months produced declining water levels in the Little Colorado and required the planting of additional crops to replace those which perished during the seasonal drought. On July 16, the first rains finally fell. On July 17, a torrential flood swept away St. Joseph's dam. A second flood occurred on August 25 which destroyed what the settlers at St. Joseph had constructed since the previous flood.

[8]Significantly, 1924 followed a devastating and expensive dam failure at Joseph City. During that year, a new dam was built at Joseph City. This final dam was constructed partially with cement. Cement had previously not been used in the basin because of its great expense. Its use this time had been made possible by a $3000 appropriation from the Mormon Church (Tanner and Richards, 1977, p. 50).

The increasing use of groundwater in agriculture, combined with its expanding exploitation for municipal and industrial purposes, has resulted in groundwater replacing surface water as the principal water resource of the region, especially in Navajo County (see Arizona Water Commission, 1975, p. 33). Groundwater now provides *the* major subsidy to community development in the basin, since industrialization could not be supported by surface water alone. This new potential has been quickly recognized and is being rapidly exploited. In order to appreciate the developmental opportunities presented by abundant groundwater resources, as well as the implications of their increasing exploitation, it is necessary first to understand the nature and distribution of groundwater in the basin.

## Groundwater

From the perspective of community development in this arid region, groundwater offers at least one distinct advantage over precipitation and surface flow: it is abundant thoughout the basin and during the entire year. While several major geological formations exist within the basin (Harrell and Eckel, 1939; Babcock and Snyder, 1947), only one, the Coconino sandstone, yields water in sufficient quantity for agricultural and industrial use and of acceptable quality for irrigation (see Babcock and Snyder, 1947, p. 7; Bureau of Reclamation, 1950, p. 3). This formation underlies most of the region under consideration and ranges from 1,100 feet thick along the Mogollon Rim to between 450 and 900 feet thick near Holbrook (Babcock and Snyder, 1947, p. 5; see Fig. 4). It is the principal water-bearing stratum in the basin, providing as much as 93% of the total withdrawal from active wells in Navajo County (Mann, 1976, p. 32). While other formations have occasionally been exploited for livestock wells and other uses, most contain sodium and other soluble minerals in quantities that limit their economic exploitability.

Water enters the Coconino through precipitation and stream flow, primarily at higher elevations to the south where the water table is below the surface. Water flows in the Coconino in the direction of the hydraulic gradient to points of natural discharge south of the Little Colorado River (Dames and Moore, 1973, Appendix A, Section 3.2, p. 23), and artesian conditions have created several perennial springs in the vicinity of Holbrook and Joseph City. These springs have created isolated marshes among the surrounding desert vegetation, the most notable of which is Obed Marsh. The flow of water from such springs prompted their exploitation and the digging of shallow wells by early Mormon pioneers.

Numerous springs originating in the Coconino also occur as seeps into the bed of Silver Creek between Snowflake and Woodruff where they maintain its perennial character at lower elevations. Springs from the Coconino exist in the Little Colorado as well. From the perspective of farmers in the lower valley, these springs have provided important sodium-free water to dilute the saline, silt-laden water entering the Little Colorado from northern tributaries.

Most wells drilled into the Coconino sandstone have provided potable water. In most cases where saline waters have been obtained from this stratum, the high salinity has been attributed to contamination by overlying formations (Harrell and Eckell, 1939, p. 42; Babcock and Snyder, 1947, p. 10). Chemical analysis indicates that a tongue of relatively dilute groundwater exists in the Coconino extending northwards from near the Mogollon Rim to between Woodruff and Hunt (Babcock and Snyder, 1947, p. 14).

Today, the largest discharge of groundwater in the basin is overwhelmingly through flowing and nonflowing wells, as opposed to natural springs, and this has been the case for several years (Babcock and Snyder, 1947, p. 8). Individual wells vary in the quantity and/or quality of the water they yield. The amount of water that wells produce varies from a few gallons per minute for domestic and livestock wells to 2800 gallons per minute (4500 acre-feet per year) for some irrigation wells (Mann, 1976, p. 41). Most irrigation and industrial wells yield 500–2000 gallons per minute.

The quality of water obtained from the Coconino is variable and, like that received through surface flow, deteriorates in a northerly direction. Water quality is also highly variable in individual wells from the same area, depending upon the stratum overlying the Coconino at a particular location. Total dissolved solids in groundwater sampled from the Snowflake region range from 130 to 3580 mg/liter,[9] although the most common range is 300–600 mg/liter (Salt River Project, 1974, Section 3, p. 288-289). This is generally characterized as good quality water. East of Snowflake near St. Johns, however, total dissolved solids in groundwater obtained from the Coconino sandstone generally range from 1500 to 2000 mg/liter (Salt River Project, 1974, p. 293). Subsurface water quality decreases sharply northeast of St. Johns, where water sampled in one well near Navajo contained 59,300 parts per million (p.p.m) dissolved solids (Akers, 1964, p. 10).

The poorest quality groundwater among local communities exists in the vicinity of Joseph City. The concentration of dissolved solids in wells near Joseph City is quite high, and soluble salts comprise a significant portion of these sediments. In general, water samples taken from wells within a few miles south of the Little Colorado River near Joseph City contain 400–850 p.p.m. dissolved solids, while concentrations in wells just north of

[9]Milligrams per liter (mg/liter) and parts per million (p.p.m.) are roughly equivalent measures of sediment concentration.

the river range 1600–4000 p.p.m. (Dames and Moore, 1973, Section 4, p. 156). An examination of the chemical content of 64 wells in the vicinity of Joseph City between 1933 and 1971 reveals an average concentration of 1185 p.p.m. dissolved solids and 352 p.p.m. sodium (see Dames and Moore, 1973, Appendix A, Table 5).

The Little Colorado River Basin is, thus, an arid to semi-arid region in which precipitation and surface-water flow are too sparse and variable to support substantial agriculturally-based community development. Although storage reservoirs offered an important subsidy to agriculture at selected locations, farmers and ranchers throughout the region increasingly turned to the exploitation of groundwater resources. Because farmers and ranchers in the lower valley were most negatively affected by the poor quality and uneven availability of surface water, they were the first to undertake groundwater exploitation. Others followed, and groundwater resources soon provided a major subsidy to community development throughout the basin. Groundwater resources subsidized community development not only by facilitating the expansion of agriculture, the traditional economic base of the region, but also by enabling the introduction of large-scale industrial projects into the area. Increased groundwater exploitation is having an effect upon subsurface water resources, however, with important implications for future community development in the region.

## Current Developments

The past 30 years have witnessed a dramatic increase in the withdrawal of water from the Coconino sandstone. In Navajo County, groundwater obtained from the Coconino aquifer increased from an estimated 11,000 acre-feet around 1950 to over 38,000 acre-feet in 1972 (see Mann, 1976),[10] and present withdrawal likely exceeds 50,000 acre-feet per year. Three factors have contributed to this sharp increase in groundwater consumption: (1) increased irrigation, (2) industrial development, and (3) population growth.

According to the U.S. Census, irrigated farmland in Navajo County increased from 7852 acres in 1940 to 11,390 acres in 1978. As recently as 1972, irrigation consumed 60% of the groundwater pumped in the county (Mann, 1976, p. 32). Two principal locations account for most irrigated acreage in Navajo County: (1) the Joseph City–Holbrook area, and (2) the Snowflake–Hay Hollow Wash area.

As late as 1946, only 600 acre-feet of groundwater was actively pumped in the Joseph City–Holbrook area (Babcock and Snyder, 1947, pp. 8-9). A

[10]According to Millsaps et al. (1980, p. 28), between 46,000 and 48,000 acre-feet of groundwater was pumped in Navajo County during 1975.

remaining 3700 acre-feet was received as uncontrolled discharge from flowing wells, most of which entered the Little Colorado River during the non-irrigation season. By 1972, however, 3800 acres were irrigated with groundwater obtained from the Coconino, consuming 7750 acre-feet of water (Dames and Moore, 1973, Appendix A, Section 3.2, pp. 13-14). Farmers and ranchers in the Joseph City–Holbrook area have increased their reliance upon groundwater, due in large part to the deteriorating quality of surface water in the Little Colorado. Prior appropriation of surface water upstream on both the Little Colorado River and Silver Creek caused an increasing proportion of water in the Little Colorado River at lower elevations to originate from northern tributaries. Because of the lower quality of this northern water, farmers and ranchers in the Joseph City area now rely upon surface water only during periods of low stream flow. Suspended sediment concentrations are lowest at this time due to the more tranquil movement of water.

Snowflake has been one of the most successful agricultural settlements in the entire river basin (see Abruzzi, 1981). Its relative prosperity has been largely based upon its location within a broad, fertile valley with access to the reliable and superior quality irrigation water provided by Silver Creek. Agricultural development in the Snowflake region was traditionally limited primarily by the total amount of water that this stream could supply. An attempt was made to expand the irrigable acreage at Snowflake and Taylor[11] by building a dam on Show Low Creek, a tributary to Silver Creek. The effort failed, however, because extensive faulting caused by ancient volcanic activity prevented water from being stored at the reservoir site (see LeVine, 1977, p. 16; Abruzzi, 1981, p. 302). Groundwater exploitation thus freed farmers and ranchers in Snowflake and Taylor from the existing limitations of their surface-water supply, and both the amount of irrigated farmland and the extent of groundwater exploitation has increased significantly at this location. In addition, farming spread to the Hay Hollow Wash, increasing the total irrigated acreage in the Snowfake–Hay hollow Wash area to over 4000 acres by 1962 (Johnson, 1962, p. 1). About 6000 acres is currently irrigated in this area, and groundwater consumption for irrigation has increased from 4500 acre-feet in 1953 to 13300 acre-feet in 1972 (Mann, 1976, p. 34). Farmers and ranchers in the Snowflake–Hay Hollow Wash area now rely primarily upon groundwater for irrigation. An agreement exists between the Show Low-Silver Creek Water Conservation and Power District and a real estate developer which guarantees that at least a minimum water level will be maintained in Daggs Reservoir, currently known as White Mountain Lake

[11]From very early in their settlement histories, irrigation proceeded jointly at Snowflake and Taylor. Formal integration occurred in 1893 with the incorporation of the Snowflake and Taylor Irrigation Company (see LeVine, 1977, p. 113; Abruzzi, 1981, pp. 301-302).

(Millsaps, Goertz, and Stipe, 1980, p. 41). Thus, water which was previously impounded exclusively for irrigation has now been set aside primarily for recreational purposes.

Large-scale groundwater exploitation in Navajo County began in 1960 with the construction and subsequent expansion of two major industrial facilities: the Cholla power generating station southeast of Joseph City, and the Southewest Forest Industries pulp and paper mill northwest of Snowflake.

Construction of the Cholla generating station was undertaken in 1960 by Arizona Public Service (APS), a utility serving the Phoenix metropolitan area. Initial plans called for the construction of a 115 megawatt power generating station consuming 3100 acre-feet of water per year. The construction of three additional units began in 1973, and has raised the generating capacity of the Cholla station to 850 megawatts (Gilmore et al., 1982). APS purchased land or water rights for a radius of 16.5 miles surrounding the plant (Dames and Moore, 1973, Section 3, pp. 19-20), including all but two wells of the Joseph City Irrigation Company, and had a "critical groundwater area" declared in the northern portion of Navajo County.[12] By this action, APS precluded future groundwater exploitation for irrigation which might compete for water with the Cholla generating station. The Joseph City region is the only declared critical groundwater area in the Little Colorado River Basin. As of 1980, with three units operating, Cholla consumed 7425 acre-feet of water (Evans, 1982).

Construction of the SWFI pulp and paper mill began in 1960 as well, and the mill commenced production late the following year. During its initial years of operation, the mill produced 75,000 tons of newsprint and 65,000 tons of lineboard annually. A two-phase expansion of the mill completed in 1976 raised the plant's productive capacity to 258,000 tons of lineboard (a 105% increase) and 154,000 tons of newsprint (a 297% increase), with an additional production of 9000 tons of crude tall oil and 300,000 gallons of turpentine per year (Southwest Forest Industries). As a consequence of this expansion, groundwater consumption at the mill increased from 9350 acre-feet in 1972 (Mann, 1976, p. 34) to 16,469 acre-feet in 1980 (Evans, 1982).

Industrialization has caused a dramatic increase in the size of the region's population. As Table I indicates, population more than doubled between 1960 and 1980. For some towns, population growth was even greater. The towns that experienced the largest population increase were specifically those at which a new industrial facility had been located. Snowflake and Taylor have clearly felt the effect of the pulp mill in their vicinity, and the construc-

[12]A critical groundwater area is defined in Arizona law as "any groundwater basin ... or any subdivision thereof, not having sufficient groundwater to provide a reasonably safe supply for irrigation of the cultivated lands in the basin at the then current rates of withdrawal" (quoted in Egbert, 1972, p. 169).

**Table I.** Population Growth in the Little Colorado River Basin (1950–1980)[a,b]

| | 1950 | 1960 | 1970 | 1980 | Percent change (1960–1980) |
|---|---|---|---|---|---|
| Apache County | 6,348 | 4,497 | 5,322 | 10,930 | 143 |
| St. Johns | 1,469 | 1,310 | 1,320 | 3,368 | 157 |
| Eagar | 637 | 873 | 1,279 | 2,791 | 220 |
| Springerville | 689 | 719 | 1,151 | 1,452 | 102 |
| Navajo County | 14,400[c] | 19,247 | 24,937 | 36,974 | 92 |
| Winslow | 6,518 | 8,862 | 8,066 | 7,921 | −11 |
| Holbrook | 2,336 | 3,438 | 4,579 | 5,785 | 68 |
| Joseph City[c] | 300 | 550 | 800 | 1,300 | 136 |
| Woodruff[c] | 138 | 140 | 200 | 300 | 114 |
| Snowflake | 929 | 982 | 1,977 | 3,510 | 257 |
| Taylor | n.a. | 400 | n.a. | 1,915 | 376 |
| Showlow | 822 | 1,625 | 2,129 | 4,298 | 164 |
| Total | ---- | 23,744 | 30,259 | 47,904 | 102 |

[a]Data from the U.S. Bureau of the Census and Gookin et al. (1972).
[b]Figures include only nonreservation population.
[c]These figures are estimates.

tion of Cholla has substantially increased population size at Joseph City. Likewise, in Apache County, population has increased sharply at St. Johns and Eagar, both of which are situated adjacent to newly constructed generating stations. The Coronado generating station at St. Johns was completed and in operation just prior to 1980, consuming 5597 acre-feet of water that year (Evans, 1982). The Tucson Electric and Power Company's (TEP) generating facility near Eagar is currently under construction and is expected to begin operation shortly. The particularly high population increase recorded at Eagar in 1980 reflects the substantial number of construction workers still at this site at the time.

The combined effect of expanded irrigation, industrial development, and population growth has been a dramatic increase in groundwater exploitation, particularly in Navajo County from the vicinity of Showflake north to the Little Colorado River (see Table II). Increased groundwater consumption in the Snowflake–Hay Hollow Wash area is of particular importance because of its implications for groundwater users downstream. This area experienced a 282% increase in groundwater consumption between 1946 and 1972.[13] Adding just the increased groundwater withdrawal by the pulp mill between 1972 and 1980 to the 1972 figures raises groundwater consumption in the Snowflake–Hay Hollow Wash area to almost 32,000 acre-feet. This represents an increase of nearly 400% since 1953. Likewise, if just the additional

[13]Millsaps et al. (1980, p. 28) record a total of 29,300 acre-feet of groundwater withdrawn just in the vicinity of Snowflake and Taylor during 1975.

**Table II.** Groundwater Consumption in Navajo County (in Acre-Feet)[a]

| Area | Previous (date) | 1972 | Percent change |
|---|---|---|---|
| Joseph City-Holbrook | 4,300 (1946) | 11,500 | 167 |
| Snowflake-Hay Hollow | 6,500 (1953) | 24,800 | 282 |
| Woodruff | – | 720 | – |
| Total | 10,800[b] | 36,020 | 234 |

[a]Data from the Bureau of Reclamation (1950), Johnson (1962), Arizona Water Commission (1975), and Mann (1976).
[b]Circa 1950.

1980 groundwater consumption at the Cholla generating station is added to the 1972 figures, then groundwater consumption in the Joseph City region has increased to nearly 16,000 acre-feet, or by almost 270% since 1946.

## Impact on Groundwater

Water levels in irrigation wells normally experience marked declines during the pumping season. Seasonal declines of 30 feet in irrigation wells near Joseph City are not uncommon (see Dames and Moore, 1973, Section 4, p. 154), and in the Hay Hollow Valley declines of 20–30 feet have been recorded during a single growing season (see Mann, 1976, p. 34). Recharge into the Coconino through precipitation and stream flow has generally been sufficient to restore groundwater to its pre-irrigation season level, however, and Babcock and Snyder (1947, pp. 9-10) reported no ostensible change in either water level or quality in the wells previously sampled by Harrell and Eckel (1939).

Because precipitation in the northern portion of the basin is sparse, insufficient recharge occurs where the Coconino sandstone is exposed to the surface at lower elevations. Consequently, subsurface water levels throughout this area depend upon the northward flow of water entering the Coconino at higher elevations to the south. Decreases are being reported, however, in the levels at which water is being obtained from wells in the basin. While the drawdowns do not compare to the major depletions currently taking place in southern Arizona, they do suggest that groundwater has begun to decline over a substantial portion of the basin, particularly since the advent of large-scale industrial pumping.

Arizona Public Service drilled several wells in conjunction with their construction of the Cholla power station. As already indicated, they also purchased water rights and wells previously owned in the Joseph City region. Two of the wells purchased from the Joseph City Irrigation Company provided 80–90% of the water consumed by the initial generating unit. Continu-

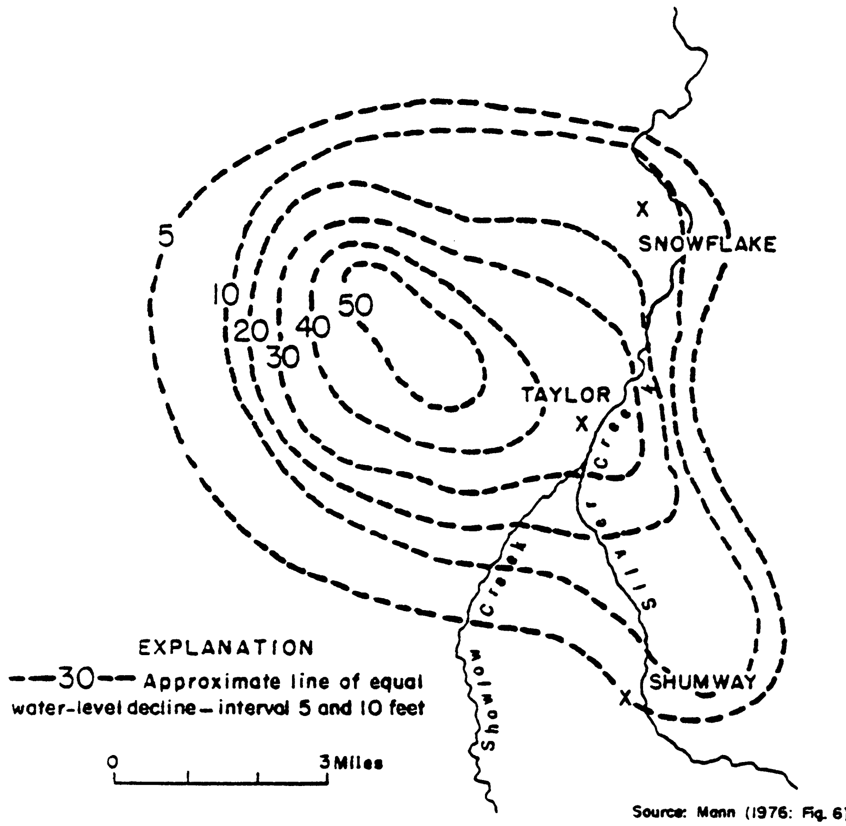


**Fig. 5.** Water level declines in the Snowflake-Taylor-Shumway area – 1951-1973.

ous pumping between 1962 and 1971 produced a decline of 18 feet and 16 feet, respectively, in these two wells (Dames and Moore, 1973, Appendix A, Section 3.2, p. 15).

Several reports of declining groundwater have been recorded for the Snowflake region as well. Drawdowns of 5-60 feet have been reported over a 60 square mile area surrounding the town of Snowflake between 1951 and 1973 (see Fig. 5), with decreases between 5 feet and 30 feet registered in the immediate vicinity of Snowlfake, Taylor, and Shumway (Mann, 1976, p. 34). The maximum recorded groundwater decline of 60 feet for the Snowflake area was at the SWFI well 3 miles southwest of that town (Salt River Project, 1974, Section 3, p. 288), although some ranchers in the vicinity have complained of even greater declines, around 70 feet, in their wells since the opening of the mill. In the Hay Hollow Valley, water declines of 10-20 feet have been recorded between 1955 and 1972 (Salt River Project, 1974; Mann, 1976, p. 34). Moreover, while numerous wells drilled in this valley prior to 1955 flowed to the surface for several years, only one well still flowed during the nongrowing season in 1972 (Mann, 1976, p. 34). A 20-foot decline in water levels has also been recorded for wells at Woodruff between 1960 and 1967 (see Woodruff Irrigation and Recreation Project), and in the vicinity of Hunt, where irrigated farming is also practiced, wells decreased in flow from 2000 to 1000 gallons per minute (Akers, 1964, pp. 81-82) between 1950 and 1964.

Insufficient data exist to determine the size of dependable groundwater supplies in either Apache or Navajo counties. At present, dependable groundwater supply is considered to exceed depletion, with groundwater overdraft recorded as nil (see Arizona Water Commission, 1975, p. 29). While water level declines have generally been viewed as localized, occurring within a few miles of heavily pumped wells (Dames and Moore, 1973, Appendix A, Section 3.2, p. 9), information exists which suggests that a broader, more extensive decline in groundwater levels is taking place. Of particular importance is the change experienced by Silver Creek. Formerly a perennial stream, Silver Creek experienced sharp fluctuations in discharge at lower elevations as early as 1950 due to the diversion and storage of irrigation water at Snowflake and Taylor. With the significant increase in groundwater exploitation by the pulp mill, however, Silver Creek is no longer perennial at lower elevations and dries up completely in the vicinity of Woodruff. Seeps in the Coconino, which feed Silver Creek and which formerly preserved its perennial status, have apparently ceased flowing since the intensification of groundwater exploitation upstream.

As previously indicated, artesian conditions in the Coconino produced numerous springs and marshes along the northern portion of the basin, the most notable of which was Obed Marsh. Due to increased groundwater exploitation, the spring that sustained this marsh and formerly discharged 400 gallons per minute ceased discharging as of 1973 (Dames and Moore, 1973, Section 4, p. 153).

Annual discharge from wells in the Joseph City–Holbrook area in 1972 was estimated at about 14,000 acre-feet per year (Dames and Moore, 1973, Section 4, p. 153). Of the total annual recharge to the Coconino aquifer, 9000 acre-feet per year is estimated to flow into this portion of the basin (Dames and Moore, 1973). Consequently, as of 1972, groundwater consumption near Joseph City already exceeded recharge by approximately 5000 acre-feet per year. While this excess discharge has been claimed to mine only local storage and not to be intercepting available recharge (Dames and Moore, 1973), widely distributed accounts of reduced water flow suggest that increased groundwater exploitation is, in fact, depressing water levels over a larger area.

Important changes have also occurred in the quality of groundwater available in the basin, particularly along the lower valley of the Little Colorado River. Subsurface water quality has deteriorated noticeably in wells near Joseph City since the advent of increased groundwater exploitation in the region (see Dames and Moore, 1973, Section 4, p. 156). Deteriorating groundwater quality prompted APS to cap certain wells it had otherwise planned to use to supply the Cholla generating station. Likewise, the residents of Woodruff have encountered problems with the quality of water available in their wells. Due to significant decreases in local groundwater quantity and quality, the residents of Woodruff have petitioned federal, state, and county assistance to recondition the irrigation ditches leading to their abandoned dam on Silver Creek (see Woodruff Irrigation and Recreation Project).[14]

The decline in groundwater quality in the lower valley has resulted from processes similar to those that caused the deterioration of surface water at the same location. The prior appropriation of superior quality groundwater to the south has led to an increase in the relative proportion of less desirable water migrating from inferior geological strata to the north. The chemical composition of subsurface water in the lower valley depends largely upon the relative pressure between northern and southern waters entering the underlying water-bearing stratum. Because significant increases have occurred in the quantity of water removed from the Coconino aquifer to the south, underground water pressure has shifted in favor of groundwater entering the area from the north. In addition, lowered groundwater levels have enhanced the vertical mobility of more saline waters to higher levels at specific locations within the Coconino. Although groundwater quality in the lower valley was already inferior to its quality elsewhere in the region, current developments are increasing this difference.[15]

## CONCLUSION

Although it has been determined that sufficient water exists in the Coconino sandstone to sustain substantial increases in groundwater exploitation (see Arizona Water Commission, 1975, p. 29), widespread reports of groundwater decline and indications of groundwater deterioration in wells along the lower valley suggest that increased groundwater exploitation is having a negative effect upon the water in this aquifer. Due to limited transmissibility rates and to the specific features of underground water pressure in

[14]The residents at Woodruff are caught in the middle by declining groundwater levels in their area. The increased groundwater pumping that has produced a negative effect upon the water in their wells has also contributed to the decline of Silver Creek.

[15]Declining groundwater quality along the lower valley of the Little Colorado River has already forced one of the few remaining full-time farmers in Joseph City to abandon farming. Sodium levels in his wells reached 2600 p.p.m., a level which prohibits healthy plant growth.

the Coconino, increased groundwater exploitation may significantly diminish local subsurface water quality and availability even though the entire aquifer is not in immediate danger of serious depletion. Moreover, because industrial pumping is not seasonal and thus allows no time for the recharge of exploited aquifers, a continued decline in groundwater levels and quality is likely. Significantly, many indications of groundwater decline had already occurred prior to the major expansion programs undertaken at either the Cholla generating station or the SWFI pulp mill.

The immediate costs of groundwater decline are economic and will most directly affect farmers and ranchers in the basin (see Willett and Hathorn, 1975). The average cost of groundwater pumped by irrigation districts in Arizona increased from $2.49 to $3.74 per acre-foot per 100 feet between 1963 and 1974 (Arizona Water Commission, 1975). As groundwater levels decline, the cost of pumping each unit of water increases further. Large industrial corporations can accommodate such increasing costs more readily than local farmers and ranchers, particularly when such corporations are public utilities that can pass increased costs on to consumers. According to Mann (1976, p. 42), groundwater is below 500 feet in 35% of the region, restricting its current economic exploitability. As groundwater levels decline and approach economically prohibitive depths over an increasing portion of the basin, fewer farmers and ranchers will be able to absorb the increasing costs. Domestic and municipal water-related costs will also escalate. For communities in the lower valley, the costs incurred by declining water levels will be compounded by those caused by groundwater deterioration.

The effects of increasing groundwater exploitation in Navajo County have important implications for future development elsewhere in the basin. The construction of generating stations near both St. Johns and Springerville-Eagar suggests that similar groundwater problems will occur in neighboring Apache County.[16] Because of its proximity to less desirable geological formations, St. Johns will likely witness groundwater problems comparable to those experienced at Joseph City, Woodruff, and other locations along the lower valley. St. Johns already imports groundwater because of its poor quality locally (Briggs, 1974, p. 25). Potential groundwater problems will likely intensify in Apache County if the two generating stations already construct-

[16]A recent article in the *White Mountain Independent* (2/12/1985, p. 1), a local newspaper, reported that the residents of Concho, a small, historically Hispanic community about 12 miles west of St. Johns, were left without water due to a substantial decline in local groundwater levels. The Coronado power plant near St. Johns exports groundwater from the Concho area, and this may be a factor in the groundwater decline. While the exact amount of groundwater currently withdrawn from the Concho area is unavailable, Millsaps et al. (1980, p. 35) state that by 1990, the Coronado generating station is expected to remove 4900 acre-feet of water annually from the Concho area.

ed follow existing plans for future expansion,[17] and such problems may spread to other locations if projections for additional generating stations in the region are fulfilled.

While proximity to coal reserves, limestone supplies, and railroad connections make the Little Colorado River Basin a promising location for expanded energy production, the industrialization of the region is in no small part prompted by the critical groundwater situation in southern Arizona. Groundwater depletion statewide is 1.7 times the annual replenishment rate (Arizona Water Commission, 1975, p. 29). The worst imbalance at the county level is in Pima County, the location of Tucson, where 1970 groundwater consumption was 4.7 times the dependable supply (Arizona Water Commission, 1975). Groundwater depletion in Maricopa County, where Phoenix is located, is 1.9 times the replenishment rate with the depletion rate in the Harlaquah Valley listed at 96 times annual recharge (Briggs, 1974, p. 25). Although agriculture has traditionally consumed about 90% of the groundwater withdrawn in the state (Arizona Water Commission, 1975, p. 18), this proportion is decreasing, particularly in the counties containing the Phoenix and Tucson metropolitan areas. If dependable groundwater supplies in Pima County were reserved exclusively for municipal and industrial uses, depletion would still approach twice the dependable supply (Briggs, 1976, p. 17), and one recent estimate suggests that by the year 2000, only 20% of the water distributed by the Salt River Project in Maricopa County will be allocated to agriculture (Mason, 1982, p. 18).[18]

Conflict over water has been one of the most sensitive and volatile issues in Arizona politics, and the history of groundwater litigation and legislation in the state clearly reflects the intensity of this struggle (Dunbar, 1977). It also demonstrates the increasing dominance of growing urban-industrial interests at the expense of those of agriculture (Goodman, 1978). The passing of legislation replacing proprietary rights with those favoring "reasonable and beneficial use" and establishing "critical groundwater areas" indicate

[17]During the summer of 1984, the Salt River Project (SRP) announced plans to construct an additional coal-fired power plant at the Coronado site. The new power plant will be the third generating unit at the Coronado site and is expected to be completed in 1991. The new unit will produce 350 megawatts, matching the capacity of each of the two units already on line. With completion of the third unit, groundwater consumption by the Coronado station should increase by about one-third.

[18]The Salt River Project (SRP) is a public utility in the Phoenix metropolitan area. It was established in 1903 to construct dams and provide water largely for agricultural use in the Salt River Valley. The SRP also produces and sells electricity within its boundaries, mostly to municipal and industrial users. While the overwhelming majority of water supplied by SRP is still consumed in agriculture, municipal and industrial uses are increasing rapidly. SRP occupies a unique position among utilities in that it has the legal status of a municipality. Its boundaries overlap but do not coincide with those of the city of Phoenix and adjacent towns (see Mason, 1982 for a discussion of the complex boundary relations between the SRP and the different municipalities in the Phoenix metropolitan area).

the growing power of metropolitan interests. Reasonable use legislation has enabled mining companies and urban areas such as Tucson to import water from neighboring groundwater basins without having to provide injunctive relief to farmers in the affected basin (see Clark, 1974, p. 809; Goodman, 1978), while the declaration of a "critical groundwater area" explicitly prohibits only the subsequent drilling of irrigation wells within delineated areas (see Kelso, 1948).[19] Approximately 80% of Arizona's population and the overwhelming majority of its industry are located in the southern half of the state. The Phoenix and Tucson standard metropolitan statistical areas account for about 75% of the state's population, with over 50% located in the Phoenix metropolitan area alone. Thus, groundwater legislation favoring urban-industrial interests enhances primarily the interests of these two metropolitan areas, and reflects their dominance in the region's political economy.

Groundwater cannot be economically transported over long distances. It can be obtained, however, by exporting high water-consuming industries, such as electrical generation and pulp and paper production, to basins with relatively abundant groundwater resources,[20] and the Little Colorado River Basin is one of the few regions outside of southern Arizona with sufficient groundwater to sustain large-scale industrial production (see Briggs, 1976, p. 17). Groundwater in the Coconino, thus, offers a powerful inducement

[19]In 1980, the Arizona Legislature passed the *1980 Groundwater Code,* the most comprehensive water law in Arizona history. Critical groundwater areas were eliminated by this law and replaced by a hierarchy of water management areas. Those areas where groundwater decline is most critical have been defined as "active management areas" (AMAs). The current AMAs are primarily located in the southern half of the state and largely coincide with the regions which prompted the original declaration of critical groundwater areas in 1948. The former critical groundwater area near Joseph City is defined under the new law as an "irrigation non-expansion area" (INEA). The intent of the new definition, as the name implies, remains unchanged. An INEA could become an AMA if deteriorating groundwater conditions warrant it.

[20]Industrialization is only part of the economic transformation taking place in the basin with implications for groundwater overexploitation. During the past two decades, economic development throughout the basin has become increasingly oriented to the Phoenix and Tucson metropolitan areas. Industrialization has occurred simultaneously with a dramatic increase in the transient-recreation industry, most of which is concentrated in the southern highlands communities. Thousands of acres of private land within and adjacent to the national forest have been sold and subdivided. Most of this property has been converted to summer-home development serving primarily non-native residents. In their study of one locale along the Mogollon Rim, for example, Boster, O'Connell, and Thompson (1974, p. 3) reported that 70% of lot owners listed the Phoenix metropolitan area as their primary residence, compared with only 13% who claimed local residence. Besides the economic problems created by the increasing specialization of local economies in those sectors most dependent upon external market forces and least likely to generate secondary economic development and the political problems presented by the increasing external ownership of local real estate, the rapid growth of tourism and summer-home development has already produced an increasing contamination of surface and subsurface water among highland communities. In at least one local community, groundwater pollution from summer-home development led to a conflict over incorporation and the raising of taxes to construct sewage disposal facilities. This conflict was at least partially between recent migrants and native residents.

for the future location of energy (and other industrial) production facilities, and the pressure to locate generating stations in the basin should increase as the critical groundwater situation in the Phoenix and Tucson metropolitan areas demands that future energy production take place outside their immediate groundwater basins. Consequently, energy development will likely increase in the Little Colorado River Basin as it has elsewhere on the Colorado Plateau (Wolff, 1972; Baldwin, 1973; Little, 1975).

The rapid exploitation of local resources is not a new phenomenon in this remote region. During the past 100 years, surface water, rangeland, and forest resources have all experienced periods of intensive exploitation with important implications for local community development. The impact that surface water and rangeland exploitation had nearly a century ago has direct implications for current developments in the region. As with present groundwater exploitation, earlier developments demonstrated the interrelationship of resource utilization in the basin and the potentially negative effect that resource exploitation at higher elevations has upon communities downstream. The lower valley settlements suffered from others' prior expropriation and overexploitation of resources upstream during this previous period as well.

During the 1880's, the speculative cattle ranching industry entered the Little Colorado River Basin. At this time, the Aztec Land and Cattle Company, a consortium of West Texas ranchers and eastern business interests, purchased one million acres of the Atlantic and Pacific Railroad's right-of-way through the basin.[21] Owning every other section for a depth of 50 miles south of the railroad line, the Aztec Co. monopolized rangeland throughout the entire portion of present-day Navajo County between Snowflake and Joseph City. Grazing as many as 60,000 head of cattle on this land, the Aztec Co. maintained animal densities far in excess of the range's sustainable carrying capacity.[22] Devastating droughts and depressed beef prices during the 1890's produced overstocked ranges and resulted in the death of tens of thousands of cattle. By 1900, the Aztec Co. was bankrupt, but not before it had caused widespread range deterioration with significant implications for communities in the lower valley.

Bare ground comprises 55–65% of total surface cover throughout the grassland community north of Snowflake (Dames and Moore, 1973, Section 4, p. 201), and rangeland in this vicinity is currently estimated to sup-

[21]For a discussion of the Aztec Land and Cattle Company and the ecological effects of its operations in the basin, see Abruzzi (1981, pp. 236-143, 152-158) and Kennedy (1968).

[22]Between six and seven animal units can be supported per section on rangeland in the Joseph City area (Dames and Moore, 1973, Section 4, p. 235). Only 3.5 animal units can be maintained per section near Snowflake (Salt River Project, 1974, Section 3, p. 85). One animal unit consists of a cow and its calf, and a section comprises 1 square mile or 640 acres. During its brief reign, the Aztec Co. maintained animal densities as high as 20 animal units per section (see Abruzzi, 1981, p. 295).

port only one-third to one-half the animal densities possible prior to the 1880's. The reduced plant cover caused by intense grazing pressure enhanced soil erosion and added substantially to the silt-bearing quality of the Little Colorado River and its tributaries. In a single year, the Little Colorado is estimated to transport "the equivalent of nine inches of topsoil from an entire township" (U.S. Department of the Interior 1946, p. 152). Much of this sediment was deposited behind dams, in irrigation canals, and upon fields in the lower valley. The costs imposed upon agriculture by the increasing sediment load of surface water in the lower valley contributed prominently to the pressure among settlements in this vicinity to develop groundwater resources.

Lower valley settlements also felt the negative effect of concurrent increases in surface water exploitation upstream in the basin. Colonization of the Little Colorado River Basin was largely a Mormon achievement; and consistent with Mormon colonization elsewhere, settlement in this region emphasized the founding of irrigated agricultural communities at every available location. Although residents at Joseph City and Woodruff had established prior use of water in the region, the subsequent location of agricultural settlements upstream on both the Little Colorado River and Silver Creek resulted in the increasing expropriation of surface water from these two streams. By 1930, 37 reservoirs impounded 72,795 acre-feet of water that had previously flowed past these two towns (U.S. Bureau of Census).

Irrigation and the impounding of surface waters upstream created substantial problems for communities in the lower valley. As previously discussed, the expropriation of superior quality water to the south relegated lower valley settlements increasingly dependent upon less desirable surface water entering from the north. It also accentuated stream-flow variation. Lower valley settlements received less water during dry years as an increasing proportion of dwindling supplies were appropriated upstream. They were also made increasingly susceptible to dam failures and flooded communities caused by the bursting of storage dams upstream.

Because they exist downstream from all other users, lower valley settlements have been highly vulnerable to the negative effects of changes in resource conditions elsewhere in the basin. Previously cited figures of dam failures clearly illustrate the greater drain imposed upon farmers and communities in the lower valley. They had to irrigate fields with water obtained from a river noted for its instability and unpredictability at the same time that the quality of this water deteriorated as events transpired upstream. Not surprisingly, the lower valley contained the greatest number of unsuccessful settlements in the basin, and those which have survived have been among the most marginal in the region developmentally. It was declining surface water quality and availability that prompted Joseph City to initiate groundwater exploitation. Today, communities in the lower valley find themselves in familiar circumstances. Prior expropriation of resources upstream is again having a negative effect upon the quantity and quality of critical water supplies in their vicinity. This time, however, no alternative water resources exist.

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