Water-management practices as of 1988 were defined and evaluted using the model. Simulation results indicate that increased ground-water pumpage since 1985 for enhancement and mitigation projects within the Owens Valley has further stressed the aquifer system and resulted in declines of the water table and reduced evapotranspiration. Most of the water-table declines are beneath the western alluvial fans and in the immediate vicinity of production wells. The water-table altitude beneath the valley floor has remained relatively constant over time because of hydrologic buffers, such as evapotranspiration, springs, and permanent surface-water features. These buffers adjust the quantity of water exchanged with the aquifer system and effectively minimize variations in water-table altitude. The widespread presence of hydrologic buffers is the primary reason the water-table altitude beneath the valley floor has remained relatively constant since 1970 despite major changes in the type and location of ground-water discharge.

Evaluation of selected water-management alternatives indicates that long-term variations in average runoff to the Owens Valley of as much as 10 percent will not have a significant effect on the water-table altitude. However, reductions in pumpage to an average annual value of about 75,000 acre-ft/yr are needed to maintain the water table at the same altitude as observed during water year 1984. A 9-year transient simulation of dry, average, and wet conditions indicates that the aquifer system takes several years to recover from increased pumping during a drought, even when followed by average and above-average runoff and recharge. Increasing recharge from selected tributary streams by additional diversion of high flows onto the alluvial fans, increasing artificial recharge near well fields, and allocating more pumpage to the Bishop area may be useful in mitigating the adverse effects on native vegetation caused by drought and short-term increases in pumpage.

Analysis of the optimal use of the existing well fields to minimize drawdown of the water table indicates no significant lessening of adverse effects on native vegetation at any of the well fields at the end of a 1-year simulation. Some improvement might result from pumping from a few high-capacity wells in a small area, such as the Thibaut–Sawmill well field; pumping from the upper elevations of alluvial fans, such as the Bishop well field; or pumping in an area surrounded by irrigated lands, such as the Big Pine well field. Use of these water-management techniques would provide some flexibility in management from one year to another, but would not solve the basic problem that increased ground-water pumpage causes decreases in evapotranspiration and in the biomass of native vegetation. Furthermore, the highly transmissive and narrow aquifer system will transmit the effects of pumping to other more sensitive areas of the valley within a couple of years.

Other possible changes in water management that might be useful in minimizing the short-term effects of pumping on native vegetation include sealing well perforations in the unconfined part of the aquifer system; rotating pumpage among well fields; continuing or renewing use of unlined surface-water features such as canals and ditches; developing recharge and extraction facilities in deeper volcanic deposits near Big Pine or in alluvial fan deposits along the east side of the valley; installing additional wells along the west side of the Owens Lake; and conjunctively using other ground-water basins between the Owens Valley and Los Angeles to store exported water for subsequent extraction and use during droughts.

INTRODUCTION

The Owens Valley, a long, narrow valley along the east flank of the Sierra Nevada in east-central California (fig. 1), is the main source of water for the city of Los Angeles. Precipitation in the Sierra Nevada and the Inyo and the White Mountains, which surround the valley, results in an abundance of water flowing into this high desert basin. Because the valley has no surface-water outlet, streams historically have flowed into the Owens Lake, a large saline body of water at the south end of the valley, and evaporated.

Figure 1. Drainage areas and physiographic and cultural features of the Owens Valley and the Mono Basin, California.

In 1913, the Los Angeles Department of Water and Power constructed a 233-mile-long aqueduct to divert surface water from the Owens River to the city of Los Angeles. This supply later was increased to an average export of 330,000 acre-ft/yr by adding diversions of surface water from the Mono Basin, which adjoins the northwestern side of the Owens Valley (fig. 1). The Owens River–Los Angeles Aqueduct system (subsequently referred to in this report as “the river–aqueduct system”) begins in the Mono Basin and extends southward through the Owens Valley.

In 1970, a second aqueduct to Los Angeles was completed, increasing the total maximum capacity to 565,000 acre-ft/yr. The average export subsequently increased to 482,000 acre-ft/yr. This additional supply was obtained by increasing surface-water diversions from the Owens Valley and the Mono Basin, by reducing the quantity of water supplied for irrigation on lands owned by the city of Los Angeles in Mono and Inyo Counties, and by pumping ground water from the Owens Valley into the river–aqueduct system. Ground-water pumpage in the Owens Valley for both export and local use has varied from year to year and is dependent on the availability of surface-water supplies.

Natural discharge of ground water also occurs in the Owens Valley. The principal mechanisms include transpiration by indigenous alkaline scrub and meadow plant communities (Sorenson and others, 1989, p. C2), evaporation from soil in shallow ground-water areas, including the Owens Lake playa, and discharge from springs. Approximately 73,000 acres of the valley floor is covered by alkaline plant communities that are dependent on ground water (Dileanis and Groeneveld, 1989, p. D2). These plant communities collectively are referred to in this report as “native vegetation.” Transpiration from native vegetation and evaporation from soil expend about 40 percent of the average annual recharge to the aquifer system (Hollett and others, 1991, p. B58). The “aquifer system” of the Owens Valley, as defined by Hollett and others (1991, fig. 17), includes nearly all the ground water flowing through the valley, except for lesser quantities flowing (1) beneath the Volcanic Tableland, (2) south of the Alabama Hills, and (3) at depths greater than 1,000 ft below land surface (fig. 1).

In the early 1970's, ground-water levels and the acreage covered by native vegetation were similar to the levels and acreage observed between 1912 and 1921 (Griepentrog and Groeneveld, 1981). Between 1970 and 1978, water levels in many wells declined, and in 1981, a loss of 20 to 100 percent of the plant cover on about 26,000 acres was noted (Griepentrog and Groeneveld, 1981). This reduction was postulated to be a response to increases in ground-water pumpage and changes in surface-water use. Residents of the valley and local businesses that depend on tourism became concerned that the additional export of water since 1970 by the Los Angeles Department of Water and Power was a cause of the degradation observed in the Owens Valley environment.

In addressing the concerns about water, officials of Inyo County filed a lawsuit claiming that the Los Angeles Department of Water and Power needed to prepare an Environmental Impact Report (EIR) on the effects of increased ground-water pumping. In 1970, the California Legislature had enacted the California Environmental Quality Act (CEQA), which required public decision-makers to document the environmental implications of their actions and to seek the reduction or avoidance of significant environmental damage. Although the second aqueduct was operational 6 months prior to the passage of CEQA, Inyo County argued for an injunction on water export until an EIR was prepared and approved. A sequence of litigation ensued (Los Angeles and Inyo County, 1990a, sec. 2.4), and litigation still is pending (1994).

The political impasse became more critical because of an impending reduction in one of the alternative sources of water available to Los Angeles. As a member of the Metropolitan Water District of Southern California, Los Angeles receives part of its water supply from the Colorado River. As a result of a U.S. Supreme Court decree, the allocation of water in the Colorado River was changed, effectively reducing the quantity of water available to Los Angeles. As the physical capability of the Central Arizona Water Project increases and the State of Arizona uses more of its allocation of the Colorado River, Los Angeles will be forced to rely more heavily on water imported from the Owens Valley and northern California (Los Angeles and Inyo County, 1990a, sec. 3.4).

The diversion of surface water from the Mono Basin to Los Angeles via the river–aqueduct system prompted a similar, but separate sequence of litigation. In 1979, the Audubon Society filed a lawsuit against Los Angeles, seeking to reduce the surface-water exports from the Mono Basin and contending that the exports, which had reduced water levels in Mono Lake, were harmful to the environment. This conflict resulted in hydrogeologic studies separate from those initiated in the Owens Valley (Los Angeles Department of Water and Power, 1984b, 1987).

The combination of increased demand for water, reduced regional supplies, and unresolved litigation emphasized the need to better understand the water resources of the Owens Valley. In 1982, the U.S. Geological Survey, in cooperation with Inyo County and the Los Angeles Department of Water and Power, began a series of comprehensive studies to evaluate the geology, water resources, and native vegetation of the Owens Valley. Extensive hydrologic field investigations and numerical ground-water flow modeling conducted over a 6-year period (1982–88) focused on determining the effect of ground-water withdrawals on native vegetation (fig. 2 and table 1). Results of these studies are being used by the Los Angeles Department of Water and Power and Inyo County in preparing the required EIR and in developing a joint ground-water-management plan for the valley (Los Angeles and Inyo County, 1990a, b, c). These studies and the related background materials are discussed more fully by Hollett (1987) and Danskin (1988).

Results of the studies, including a summary, are presented in a U.S. Geological Survey Water-Supply Paper series as the interpretive products become available. The series (Water-Supply Paper 2370), “Hydrology and Soil-Water-Plant Relations in Owens Valley, California,” consists of eight chapters as follows:

A. A summary of the hydrologic system and soil-water-plant relations in the Owens Valley, California, 1982–88, with an evaluation of management alternatives;

B. Geology and water resources of the Owens Valley, California;

C. Estimating soil matric potential in the Owens Valley, California;

D. Osmotic potential and projected drought tolerance of four phreatophytic shrub species in the Owens Valley, California;

E. Estimates of evapotranspiration in alkaline scrub and meadow communities of the Owens Valley, California, using the Bowen-ratio, eddy-correlation, and Penman-combination methods;

F. Influence of changes in soil water and depth to ground water on transpiration and canopy of alkaline scrub communities in the Owens Valley, California;

G. Soil water and vegetation responses to precipitation and changes in depth to ground water in the Owens Valley, California; and

H. Evaluation of the hydrologic system and selected water-management alternatives in the Owens Valley, California (this report).

During about the same period as the U.S. Geological Survey studies, Inyo County and the Los Angeles Department of Water and Power conducted a separate cooperative vegetation study that focused on mapping vegetation over most of the valley floor and quantifying the response of native vegetation to changes in water availability (Blevins and others, 1984; Groeneveld and others, 1985). Synthesis of the data obtained from that study, the U.S. Geological Survey studies, and several smaller studies conducted primarily by universities has resulted in an improved understanding of the native vegetation and its dependence on ground water, the geologic setting and its effect on ground-water movement, and the interaction of surface water and ground water.

Purpose and Scope

This report describes the results of an evaluation of the hydrologic system of the Owens Valley, with an emphasis on simulating ground-water flow and predicting the effects of pumping on native vegetation. The development and wise use of water resources are best achieved through a comprehensive understanding of the hydrologic system and its interaction with the geologic setting, native vegetation, and human water-supply needs. This report provides the necessary integration of geologic, hydrologic, and vegetation studies to more fully understand the hydrologic system of the Owens Valley and to evaluate selected water-management alternatives. As such, it relies heavily on findings presented in the companion reports (chapters B, C, D, E, F, and G). A primary purpose of this report is to communicate the specific methods used to evaluate the effects of ground-water pumping on native vegetation and to serve as a guide and technical reference to aid the management of the hydrologic system in the Owens Valley.

The scope of this report includes a thorough literature search and compilation of published and unpublished geologic, hydrologic, and vegetative information. Data collected through September 1988 and reports published through December 1992 were used in preparation of this report, which was approved for publication in March 1995. Much of the vegetative information was collected as a part of a separate study by Inyo County and the Los Angeles Department of

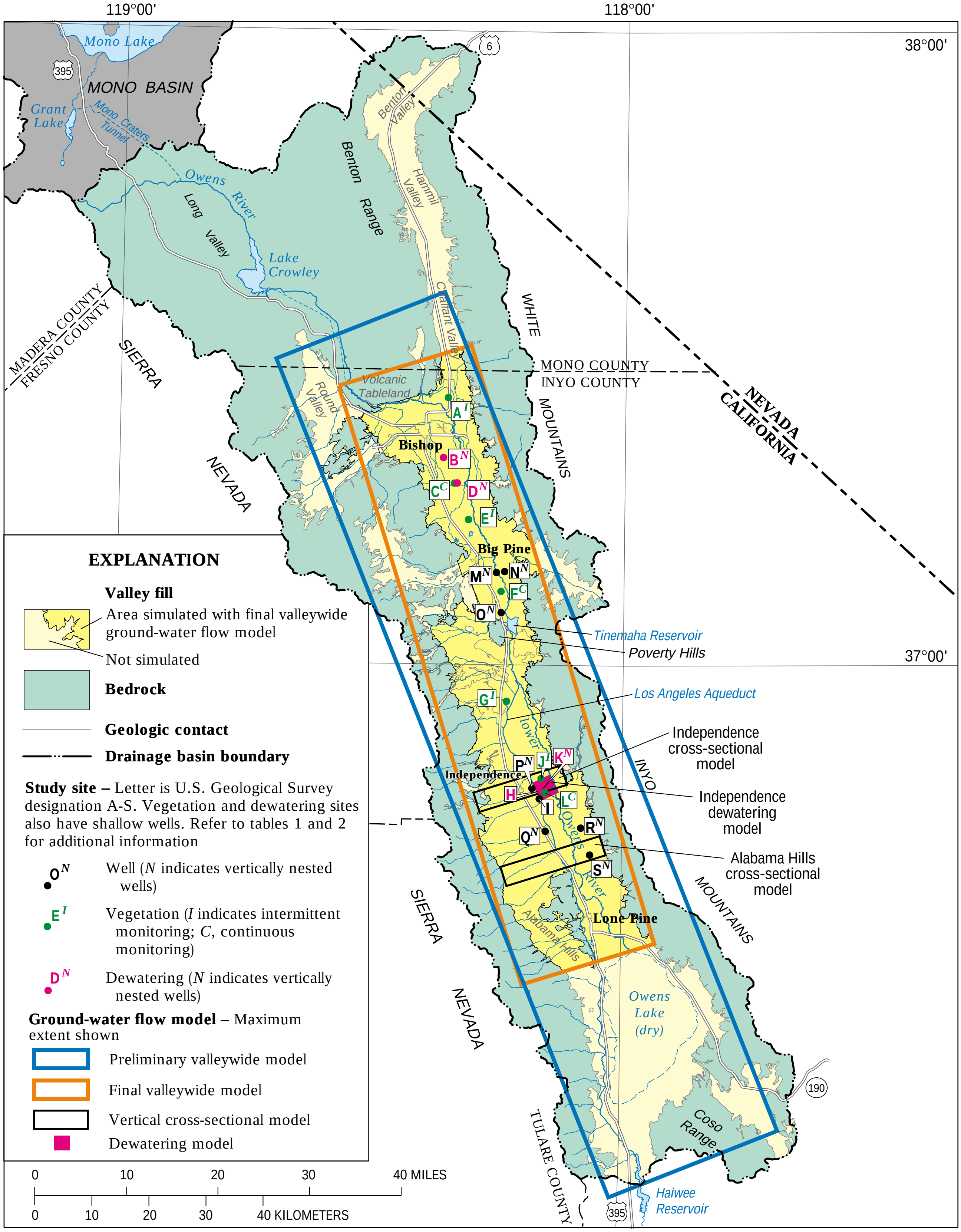

Figure 2. Location of detailed hydrologic investigations and ground-water flow models for the Owens Valley, California, 1982–88.

Table 1. Ground-water and vegetation study sites in the Owens Valley, California, 1982–88

[na, not applicable; nc, not collected; USGS, U.S. Geological Survey. Wells USGS 4 and USGS 11 dropped from study; USGS 9 selected for evapotranspiration monitoring, but used sparingly]

Site designation (figure 2)	Well number	Latitude (north)	Longitude (west)	Site name	Monitoring at site		
					Wells	Evapotrans-piration	Dewater-ing
A	USGS 1	37° 25' 06"	118° 21' 02"	Laws	Shallow	Intermittent	na.
B	USGS 12	37° 19' 25"	118° 21' 31"	Warm Springs slow site	Nested	nc	Slow.
C	USGS 2	37° 17' 02"	118° 20' 15"	Warm Springs weather site	Shallow	Continuous	na.
D	USGS 2A	37° 17' 00"	118° 20' 11"	Collins Road fast site	Nested	nc	Fast.
E	USGS 3	37° 25' 06"	118° 21' 02"	Klondike Lake site	Shallow	Intermittent	na.
F	USGS 5	37° 06' 48"	118° 14' 29"	Big Pine weather site	Shallow	Continuous	na.
G	USGS 6	36° 56' 23"	118° 13' 40"	Blackrock Spring site	Shallow	Intermittent	na.
H	USGS 13	36° 47' 57"	118° 09' 33"	Independence slow site	Shallow	nc	Slow.
I	USGS 9	36° 47' 11"	118° 09' 40"	South Independence site	Shallow	nc	na.
J	USGS 7	36° 49' 07"	118° 09' 28"	North Independence site	Shallow	Intermittent	na.
K	USGS 8	36° 48' 08"	118° 09' 11"	Independence fast site	Nested	nc	Fast.
L	USGS 10	36° 47' 45"	118° 09' 00"	Independence weather site	Shallow	Continuous	na.
M	USGS 14	37° 08' 35"	118° 15' 03"	Steward Lane west	Nested	nc	na.
N	USGS 16	37° 08' 41"	118° 14' 05"	Steward Lane east	Nested	nc	na.
O	USGS 17	37° 04' 47"	118° 14' 26"	Fish Springs	Nested	nc	na.
P	USGS 15	36° 48' 10"	118° 10' 32"	Independence spring field	Nested	nc	na.
Q	USGS 19	36° 44' 07"	118° 08' 55"	Manzanar airport	Nested	nc	na.
R	USGS 18	36° 44' 27"	118° 04' 44"	Reward Road east	Nested	nc	na.
S	USGS 20	36° 41' 54"	118° 03' 39"	Northeast of Alabama Gates	Nested	nc	na.

Water and Power. Additional background for the report included compilation and analysis of streamflow records, ground-water-level measurements, pumping and recharge data, aquifer-test data, drillers' logs, borehole geophysical logs, water-quality data, and reports from the cooperating agencies.

New field studies, which included test drilling, surface and borehole geophysical surveys, and reconnaissance geologic and hydrologic mapping, were used to refine the hydrogeologic knowledge of the valley. New ground-water-level data, particularly from multiple-depth wells, and pumping and aquifer-test data were used to improve the definition of the ground-water flow system. Preliminary ground-water flow models were used to evaluate the adequacy of background data, identify the most sensitive parts of the hydrologic system, and guide the design of the final, valleywide ground-water flow model. This detailed model, which is fully documented in this report, was used to confirm concepts of the surface-water and ground-water systems, identify historical changes in the systems, and evaluate selected water-management alternatives. Finally, this report identifies deficiencies in data and concepts that limit further improvements in the understanding and water management of the Owens Valley.

Previous Investigations

The geology and hydrology of the Owens Valley have been studied extensively since the late 1800's. Because of extensive faulting, glaciation, volcanism, and the occurrence of economic minerals and geothermal resources, the geologic history of the area has been a subject of continuing interest and debate.

Prior to 1900, investigations generally examined the geologic structure of the valley and proposed a geologic history for some of the major features (Walcott, 1897). At the turn of the century, the number of geologic investigations increased. These were related to quantification and understanding of mineral occurrence and to the regional geology (G.E. Bailey, 1902; Spurr, 1903; Trowbridge, 1911; Gale, 1915; Knopf, 1918; Hess and Larsen, 1921). As an economic resource, tungsten continued to be the subject of further geologic studies in the Bishop mining district from 1934 to 1950 (Lemmon, 1941; Bateman and others, 1950). During the late 1950's and early 1960's, there was a resurgence in both detailed and regional geologic investigations. These studies were aimed at further mineral assessment, understanding of crustal evolution and tectonics, and evaluation of geothermal resources along the eastern front of the Sierra Nevada. As a result of these numerous studies, geologic quadrangle maps were completed for nearly all parts of the Owens Valley drainage basin area. In addition, comprehensive regional structural and geophysical studies of the Owens Valley region (Pakiser and others, 1964) and the Bishop area and the Volcanic Tableland (Bateman, 1965) were conducted. Numerous small-scale, topical studies, primarily by universities, concerning geologic history and stratigraphy also have been completed. The geological investigations in the Owens Valley region generally have been supported by strong public interest in volcanic hazards and geothermal energy assessment, plate tectonic implications of the Sierra Nevada, recent volcanism, and seismicity. Selected discussions on regional tectonism in the Owens Valley region are given by Oliver (1977), Stewart (1978), Prodehl (1979), and Blakely and McKee (1985). A comprehensive review and compilation of previous geologic and geophysical studies are given by Hollett and others (1991, fig. 6).

Hydrologic investigations have paralleled geologic studies since the early 1900's because of the abundance of water in an otherwise arid region. Preliminary hydrologic investigations documented conditions in parts of the Owens Valley prior to the diversion of surface water to Los Angeles, which began in 1913 (W.T. Lee, 1906; C.H. Lee, 1912). On the basis of those investigations, the Owens Valley was divided into four ground-water regions: Long Valley, Bishop–Big Pine, Independence, and the Owens Lake (C.H. Lee, 1912, fig. 1). The exceptionally comprehensive and detailed study of the Independence area done by C.H. Lee (1912) included an analysis of both tributary streams and shallow ground water beneath the valley floor. Hydrologic investigations with comparable detail were not completed for other parts of the Owens Valley until after 1970. The availability and use of water in the Owens Valley and the Mono Basin to the north were summarized by Conkling (1921) as part of an evaluation of the potential export of water from the Mono Basin to the Owens Valley. Basic hydrogeologic concepts of the Owens Valley, including the hydrologic relation of ground-water flow from the alluvial fans to lacustrine deposits, the importance of buried members of the Bishop Tuff as water-bearing formations, and the differences in hydrogeologic character of the northern and southern parts of the Owens Valley, were described by Tolman (1937, p. 526).

As demand for water in Los Angeles increased, a more complete understanding of the hydrology of the Owens Valley was needed. Beginning during the drought of the early 1930’s and continuing through 1988, large quantities of data on streamflow and ground-water pumpage were collected throughout much of the valley by the Los Angeles Department of Water and Power. Although most of these data have not been published, four summaries are available (Los Angeles Department of Water and Power, 1972, 1976, 1978, 1979). Various technical reports associated with the construction and maintenance of the aqueduct also are available (Los Angeles Board of Public Service Commissioners, 1916; C.H. Lee, 1932; Los Angeles Department of Water and Power, written commun., 1913–87). The quantity of water in the valley that could be used for various recreational uses was calculated by the California Department of Water Resources (1960). As part of the planning and permitting for construction of the second aqueduct and the proposed increase in exported water from the Owens Valley, the California Department of Water Resources (1965, 1966) again evaluated the availability of local water supplies for recreation and local use, and concluded that although considerable surface-water data were available, scant information was available on the occurrence and movement of ground water. Nevertheless, the California Water Rights Board (1963) and the California Department of Water Resources (1967b) concluded that surplus surface water and ground water were available for export.

Litigation that resulted from the additional export of water in the second aqueduct prompted nearly 20 years of investigations related to water use and the effects of increased water exports. The Los Angeles Department of Water and Power (1974b, 1975, 1976, 1978, and 1979) submitted three drafts and two final versions of an EIR although neither final version was accepted by the California Court of Appeals that had jurisdiction in the litigation. Simple regression models were used with some success to quantify the relation between ground-water pumpage, precipitation, and ground-water levels (P.B. Williams, 1978). The state of knowledge as of 1980 about the multi-layer ground-water system was summarized and some of the unresolved hydrogeologic questions were answered by Hardt (1980). Also, in a related study, the additional data required to develop a water-management plan were identified (California Department of Water Resources, 1980). The hydrology of the valley and the effects of ground-water-level declines on native vegetation were the focus of a comprehensive report for Inyo County by Griepentrog and Groeneveld (1981). These results were integrated into a draft EIR by the Inyo County Water Department (1982) and a response by the Los Angeles Department of Water and Power (1982).

Shortly after litigation was halted and the U.S. Geological Survey studies began in 1982, the Los Angeles Department of Water and Power summarized the ongoing investigations of ground water and native vegetation (Blevins and others, 1984) and concluded from a cursory analysis of pumpage and ground-water levels that conditions in 1984 were similar to those in 1970 (Los Angeles Department of Water and Power, 1984a). The importance of the water table in determining the health of native vegetation and the key factors controlling water-table fluctuations were evaluated (An, 1985; Nork, 1987). In a series of reports, the Inyo County Water Department, using regression analysis, correlated pumpage with valleywide runoff; updated surface-water and ground-water budgets; and evaluated storage changes in the river–aqueduct system (Hutchison, 1986a, b, c). The depositional history of the ground-water system near Independence was recognized as important in controlling the effect of pumping on nearby ground-water levels and native vegetation (Walti, 1987). As part of the U.S. Geological Survey studies, prior geologic information was synthesized, hydrogeologic boundary conditions of the ground-water flow system were defined, and recent water-budget data were summarized (Hollett and others, 1991).

Ground-water modeling studies of the Owens Valley began about 1970 with D.E. Williams (1969), who investigated methods for increasing ground-water storage and developed a single-layer ground-water flow model for the Independence region using boundaries defined by C.H. Lee (1912). Later, a deterministic-probabilistic analysis coupled to a ground-water flow model of the Independence area was used to evaluate the effect of uncertainty in model parameters on computed hydraulic heads (Yen, 1985; Guymon and Yen, 1988). In the Bishop area, a ground-water flow model for the period 1938–68 was attempted by the Los Angeles Department of Water and Power (M.L. Blevins, written commun., 1985). Although the ground-water flow model was never successfully calibrated, it did identify important deficiencies in the understanding of the ground-water system. The first valleywide ground-water flow model of the Owens Valley was developed by Danskin (1988), who identified the key hydrogeologic concepts and data that would be required for a more accurate simulation of the ground-water system. A more complete discussion of previous hydrogeologic investigations, as well as a preliminary evaluation of the hydrogeologic system prior to the U.S. Geological Survey studies, is given by Danskin (1988).

These prior geologic and hydrologic studies provided the basis for development of the detailed, valleywide ground-water flow model documented in this report. During the process of developing the final valleywide model, several smaller ground-water flow models of selected areas of the Owens Valley were developed by the Inyo County Water Department (Hutchison, 1988; Hutchison and Radell, 1988a, b; Radell, 1989), and by the Los Angeles Department of Water and Power (1988). More recently, Hutchison (1990) proposed concepts and plans for simulating the entire Los Angeles aqueduct system from the Mono Basin to Los Angeles, including runoff and pumpage contributions to the aqueduct from the Owens Valley.

Investigations of water quality have been included as sections in other reports, but they have not been as prominent as studies of water quantity. This lack of attention probably results because both the surface water and ground water are generally of good quality. Although routine sampling of selected surface-water and ground-water sites is done by the Los Angeles Department of Water and Power, the sampling focuses on constituents related to public health, and results are not published. Discharge from the Tinemaha Reservoir was sampled extensively during water years 1975–85 for chemical and biological constituents, and results were published in annual data reports (U.S. Geological Survey, 1976–82; Bowers and others, 1984, 1985a, 1985b, 1987). In studying the effects of well-field pumpage near the Tinemaha Reservoir, the Los Angeles Department of Water and Power (Roland Triay, Jr., written commun., 1973) recognized the possibility of ground water having different water-quality characteristics on the east and west sides of the valley. Hollett and others (1991) summarized surface-water and ground-water quality throughout the valley and noted the few exceptions of water not suitable for drinking or agricultural uses.

Previous investigations of native vegetation generally were made in conjunction with hydrologic studies (C.H. Lee, 1912; Griepentrog and Groeneveld, 1981; Los Angeles Department of Water and Power, 1972, 1976, 1978, 1979). More recently, however, native vegetation has been a primary subject of study. Rooting characteristics, transpiration processes, and steady-state conditions for shrubs and grasses dependent on shallow ground water have been quantified for the period 1983–86 (Groeneveld, 1986; Groeneveld and others, 1986a, 1986b). Vegetation in most parts of the valley, particularly on the valley floor, has been mapped in great detail using aerial photographs and site visits (R.H. Rawson, Los Angeles Department of Water and Power, written commun., 1988). Also, vegetation in most parts of the valley, particularly on the alluvial fans, has been mapped using remotely sensed multispectral images (M.O. Smith and others, 1990a, b).

Detailed estimates of evapotranspiration from native vegetation during 1984–85 were made using Bowen-ratio, eddy-correlation, and Penman-combination methods (Duell, 1990). The response of native vegetation to changes in water-table elevation was investigated using specially designed dewatering sites (fig. 2) (Dileanis and Groeneveld, 1989). From detailed data collected at these sites, plant stress caused by drought was correlated to osmotic potential within the plant, and the osmotic potential within the plant was correlated to pressure within the soil matrix (Sorenson and others, 1989). The response of different plant species to changes in precipitation and depth to ground water was measured and summarized by Sorenson and others (1991). These detailed field investigations made major contributions to understanding the responses of native vegetation to changes in its environment and the type of monitoring system needed to observe plant stress caused by droughts or ground-water pumpage.

In addition to a lengthy list of scientific investigations—the geology, water resources, vegetation, and political controversies of the Owens Valley have resulted in an abundance of field guides, handbooks, novels, films, and historical accounts describing this unique area. Some of the most comprehensive of these include works by Nadeau (1974), G.S. Smith (1978), Hoffmann (1981), Kahrl (1982), and Reisner (1986).

Methods of Investigation

This evaluation of the hydrologic system of the Owens Valley consists of a comprehensive review of published and unpublished geologic and hydrologic information, a synthesis of water-budget data for the surface-water and ground-water systems, an incorporation of recently developed information about the survivability and water use of native vegetation, and the development and use of a detailed, valleywide ground-water flow model.

A companion report by Hollett and others (1991) presents much of the geologic and hydrologic information that formed the basis of this investigation. Over the 6-year period of investigation, the two studies were highly interdependent and thus minor differences between this report and the companion report reflect knowledge gained since the earlier work was completed. Nearly continuous interaction also was maintained with the technical representatives of Inyo County and the Los Angeles Department of Water and Power. This interaction is most evident in the presence of similar concepts, data, and findings by the several individuals and agencies.

The methods of investigation for this study differ from those of most prior hydrologic investigations of the Owens Valley. Nearly all previous investigations were either site-specific studies, such as aquifer tests, or general studies used to assess the average hydrologic characteristics of the entire valley. Site-specific studies, including those in the Owens Valley, provide necessary local information, but results from different studies may not be hydrologically compatible. For example, a ground-water budget compiled for one part of the valley may not be consistent with the values and boundary conditions assumed in compiling a ground-water budget for an adjacent part. Each budget when viewed separately might seem reasonable, although the budgets are hydrologically incompatible and one of them must be wrong. In contrast, general studies can give insight into the overall effects of water-management decisions, but local effects cannot be determined. For example, a valleywide ground-water budget may be useful for general planning, but it cannot be used to identify the effects of changing pumpage in a small part of the valley.

To help overcome these deficiencies, a valley-wide ground-water flow model was developed. This type of model integrates site-specific data with general valleywide concepts and ensures that both are compatible. The valleywide model played a critical role in simulating the aquifer system, defining many of the surface-water/ground-water relations, and providing a consistent basis to quantify the valleywide hydrologic system. Although detailed discussion of the ground-water flow model is included in a separate section, results of the modeling effort are pervasive throughout this report.

Development of the valleywide ground-water flow model was based on several preliminary models developed by the author (fig. 2; Danskin, 1988) and on models of parts of the Owens Valley developed by others (D.E. Williams, 1969; Yen, 1985; Los Angeles Department of Water and Power, 1988; Hutchison, 1988; Hutchison and Radell, 1988a, b). These other researchers, except for D.E. Williams (1969), worked in separate, but related environments. Their models were based on the general concepts of the ground-water system discussed by Danskin (1988) and Hollett and others (1991), but most used different mathematical formulations or simplifying assumptions. The similarity of results from all the different modeling exercises helped to validate the hydrologic concepts and particular approximations used in the valleywide model. The use of the various ground-water flow models developed as part of the U.S. Geological Survey studies is described in table 2.

Table 2. Characteristics and purpose of ground-water flow models developed for the Owens Valley, California

Model	Characteristics	Purpose	Reference
Half-valley models of Bishop and Independence areas.	Finite-element code; 5 layers; includes Round Valley and Owens Lake.	Identify computer codes, appropriate discretization, and boundaries of ground-water flow system.	Danskin (1988).
Half-valley model of Independence area.	Finite-element code; 2 layers.	Identify the effect of parameter uncertainty on model results.	Yen (1985).
Valleywide (preliminary).	Finite-difference code; 2 layers; includes Round Valley and Owens Lake.	Confirm initial hydrogeologic concepts and ground-water budget. Identify necessary data and concepts.	Danskin (1988); figure 2.
Dewatering.	Variable grid spacing with minimum 10-foot by 10-foot cell; 3 layers.	Determine vertical hydraulic conductivity and leakance.	Figure 2.
Cross-sectional (vertical slice).	Vertical section along parallel ground-water flowlines.	Determine ground-water flow characteristics from alluvial fans to valley floor and effect of depositional facies.	Figure 2.
Valleywide (final).	Finite-difference code; 2 layers; detailed hydrogeology, recharge, and discharge.	Verify regional hydrologic concepts and ground-water budget. Evaluate historical conditions. Predict valleywide effects of possible changes in water management. Provide boundary conditions for well-field models.	Figure 2.
Well field..........	Fine spatial discretization; each model uses 2 or 3 layers and covers from 1/4 to 1/2 of Owens Valley.	Testing and prediction of localized effects.	Hutchison (1988); Hutchison and Radell (1988a); Radell (1989); Los Angeles Department of Water and Power (1988).
Regression........	Statistical regression equations.	Prediction of effects at specific wells; no testing of concepts.	Hutchison (1986d, 1991).

Additional methods of investigation used to evaluate individual hydrologic features include semi-quantitative mapping (depositional patterns, hydrogeologic units, model parameter zones), quantitative areal interpolation (transpiration by native vegetation), linear regression (precipitation, tributary stream recharge, pumpage), and probability analysis (valleywide runoff).

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DESCRIPTION OF STUDY AREA

The Owens Valley is within the Owens Valley drainage basin area (fig. 1) and occupies the western part of the Great Basin section of the Basin and Range Province (Fenneman, 1931; Fenneman and Johnson, 1946). The Great Basin section typically consists of linear, roughly parallel, north–south mountain ranges separated by valleys, most of which are closed drainage basins (Hunt, 1974). The Owens Valley drainage area, about 3,300 mi^2, includes the mountain areas that extend from the crest of the Sierra Nevada on the west to the crest of the Inyo and the White Mountains on the east. Also included are part of the Haiwee Reservoir and the crest of the Coso Range on the south and the crest of the volcanic hills and mountains that separate the Mono Basin and the Adobe Valley from the Long and the Chalfant Valleys and the Volcanic Tableland (fig. 1). The drainage area includes the Long Valley, the headwaters of the Owens River (fig. 1). The Owens Valley ground-water basin extends northward from the Haiwee Reservoir in the south to include Round, Chalfant, Hammil, and Benton Valleys (fig. 1). The Owens Valley aquifer system, defined by Hollett and others (1991) and discussed extensively in this report, includes the main part of the Owens Valley ground-water basin and extends from the south side of the Alabama Hills to the Volcanic Tableland.

Physiography

Physiographically, the Owens Valley contrasts sharply with the prominent, jagged mountains that surround it (fig. 3). These mountains—the Sierra Nevada on the west and the Inyo and the White Mountains on the east—rise more than 9,000 ft above the valley floor and include Mount Whitney, the highest mountain in the conterminous United States. The valley, characterized as high desert rangeland, ranges in altitude from about 4,500 ft north of Bishop to about 3,500 ft above sea level at the Owens Lake (dry).

The valley floor is incised by one major trunk stream, the Owens River, which meanders southward through the valley. Numerous tributaries that drain the east face of the Sierra Nevada have formed extensive coalesced alluvial fans along the west side of the valley. These fans form prominent alluvial aprons that extend eastward nearly to the center of the valley (fig. 3). In contrast, the tributary streams and related alluvial fans on the east side of the valley are solitary forms with no continuous apron. Consequently, the Inyo and the White Mountains rise abruptly from the valley floor. As a result of this asymmetrical alluvial fan configuration, the Owens River flows on the east side of the valley.