vegetation is the water availability within the rooting zone of the plants (Groeneveld, 1986; Sorenson and others, 1991). Cycling pumpage from one well field to another can enable the water table near the wells to recover and soil moisture in the overlying unsaturated zone to be replenished via capillarity. Although recovery of the water table occurs fairly rapidly, replenishment of soil moisture is much slower (Groeneveld and others, 1986a, 1986b). Field data and modeling results suggest that a few weeks or months are needed to replenish soil moisture (Groeneveld and others, 1986a, p. 86; Welch, 1988). Although the valleywide model can give some semi-quantitative guidance, water management using rotational pumpage needs to rely on monitoring of multiple-depth wells and soil-moisture sites in the vicinity of well fields, and possibly on results from unsaturated-saturated flow models.

Seal upper perforations of existing wells.—Sealing of perforations adjacent to the unconfined zone in existing production wells was investigated during this study and was found to be marginally successful. Continuation of this effort will limit the immediate effect of production wells on the unconfined zone and the related adverse effects on nearby native vegetation (fig. 25). Sealing of abandoned wells limits the short-circuiting of flow that occurs through a casing that is open to multiple strata. Installation of new production wells with perforations only in the lower zones (hydrogeologic unit 3) of the aquifer system will reduce the effects of pumping on the water table and native vegetation. Adverse effects on native vegetation, however, still will occur if a large quantity of water is pumped for an extended period of time, possibly 1 to 3 years (fig. 25; Sorenson and others, 1991, p. G35).

Utilize other ground-water basins.—Additional recharge and extraction facilities in other basins along the route of the dual-aqueduct system might provide additional flexibility in the water management of the Owens Valley (Danskin, 1990). For example, the Indian Wells Valley, just south of the Owens Valley, is having ground-water storage depletion and related ground-water-quality problems (Berenbrock and Martin, 1991; Berenbrock and Schroeder, 1994) that might be mitigated by additional recharge. During periods of above-average runoff in the Sierra Nevada or during a period of lesser demand in Los Angeles for water from the Owens Valley, surplus water could be conveyed via the Los Angeles Aqueduct to the Indian Wells Valley, and recharged there. Conversely, during drier periods, ground-water production from the Indian Wells Valley could be increased to augment flow in the Los Angeles Aqueduct, thereby reducing the quantity of water needed from the Owens Valley. Other desert basins between the Owens Valley and Los Angeles, such as in the Mojave Desert, the Antelope Valley, and the Coachella Valley, have a large potential for ground-water storage (California Department of Water Resources, 1964, 1967a; the Antelope Valley–East Kern Water Agency, 1965; Reichard and Meadows, 1992). These basins, which are connected to the extensive system of water delivery in southern California (California Department of Water Resources, 1987), could provide additional water-banking opportunities.

NEED FOR FURTHER STUDIES

This evaluation of the hydrologic system in the Owens Valley has resulted in the following suggestions for further studies. The items are listed in their approximate order of importance within each topic.

Aquifer System

Improved understanding of the aquifer system west of Bishop.—Conceptual understanding and simulation of the area west of Bishop need improvement. The geologic structure, aquifer materials, and effect of faulting on ground-water movement in that area are unclear.

Detailed mapping of the Bishop Tuff.—The Bishop Tuff includes both permeable layers that enhance horizontal flow and nearly impermeable layers that restrict vertical flow. Detailed mapping of individual layers throughout the Bishop Basin will permit an improved conceptualization and simulation of the aquifer system in that area.

Improved understanding of the aquifer system near Lone Pine.—A better understanding of ground-water flow near Lone Pine is needed. This area is difficult to simulate because of the several en echelon faults, the abrupt change in ground-water gradient near Lone Pine, and the unknown rate of underflow from the aquifer system to the Owens Lake. Installing monitoring wells east of Lone Pine and north of the Owens Lake to confirm lithology, aquifer characteristics, and ground-water gradients will aid in a needed reevaluation of data and concepts.

Aquifer characteristics east of the Owens River.—Aquifer characteristics have been defined for most parts of the valley, except east of the Owens River. Additional wells and aquifer tests in this area will be helpful in confirming assumptions made in this study and in the related study by Hollett and others (1991).

Numerical model of the depositional evolution of the Owens Valley.—The general depositional character of the basin is well documented, but mapping of individual deposits is limited by the sparse lithologic data and by the complexity of the depositional environment. Linking lithologic data to depositional concepts and numerically extrapolating them throughout the basin in the manner of Koltermann and Gorelick (1992) will aid in being able to predict the three-dimensional location of different types of deposits within the aquifer system and their hydraulic importance in controlling ground-water flow.

Ground-Water Flow

Survey of ground-water quality.—A survey of ground-water quality from different locations and depths throughout the Owens Valley ground-water system will aid in confirming concepts and results of this study and related work by Hollett and others (1991). In particular, isotopic analyses of ground water from different depths in the aquifer system will aid in defining ground-water flow paths and rates of movement (Alley, 1993).

Detailed mapping of volcanic deposits in the Big Pine volcanic field.—A more detailed spatial definition of basalt flows, particularly ones deeper than 300 ft below land surface, will help to identify important ground-water flow paths in the area extending from Big Pine to Oak Creek.

Discharge measurements of the Owens River.—Additional discharge measurements are needed along the Owens River, especially near the Laws and the Big Pine well fields, to better identify gaining and losing reaches of the river. The temporal variability of flow in each reach also is important.

Improved understanding of underflow from the Chalfant Valley.—A difference between simulated heads and measured ground-water levels was noted near the boundary of the aquifer system north of Laws. An improved understanding and simulation of underflow in this area will lend additional credibility to results from the valleywide model in the vicinity of Laws.

Surface-Water Flow

Use of a streamflow-routing simulator.—Use of a streamflow-routing simulator, such as that by Prudic (1989), in conjunction with the ground-water flow model will enhance simulation of extremely wet or extremely dry conditions and will aid in developing an integrated surface-water and ground-water budget.

Water Budgets

Set of consistent water budgets.—A set of consistent and interrelated water budgets is needed, including a surface-water budget, a ground-water budget, and a budget for the entire valley. Ideally, the same components would be used in each budget to ensure consistency and facilitate comparisons with numerical models of either the surface-water or ground-water system. The valleywide budget will need to include all precipitation falling on, and all evapotranspiration from, the valley-fill deposits. As part of the present study, a detailed ground-water budget has been provided along with descriptions of key hydrologic processes and some of the relations needed to develop the related water budgets. This information needs to be expanded to include surface-water and valleywide water budgets.

Improved estimates of ungaged runoff and recharge.—Items with a high degree of uncertainty in the present study are ungaged mountain-front runoff between tributary streams and related ground-water recharge. Additional verification of ungaged drainage areas north of Taboose Creek, likely runoff, and resulting ground-water recharge will help to confirm water-budget estimates in the Bishop area.

Measurements of recharge from direct precipitation on alluvial fans.—The quantity of ground-water recharge from direct precipitation on the alluvial fans is virtually unknown. Some field measurements of precipitation, evapotranspiration, and soil-moisture content, such as those made on the valley floor, will help to verify the assumption used in this study that nearly all precipitation on alluvial fans is evaporated or transpired.

Native Vegetation

Precipitation measurements.—Although some predictive relations have been developed from past precipitation measurements (figs. 7 and 8), the great variability of precipitation on the valley floor and its importance in the health of native vegetation requires that precipitation measurements be continued. Additional precipitation measurements near established vegetation study sites (table 1 and fig. 2) will continue to be useful in determining the response of native vegetation to changes in water availability and in understanding the role that other factors play in the health of native vegetation (tables 3 and 5).

Valleywide evapotranspiration measurements.—Valleywide measurements of evapotranspiration will aid in detecting changes in native vegetation and in correlating field data with model results. The detailed mapping of native vegetation done by the Los Angeles Department of Water and Power during 1984–88 provides an excellent basis for analysis. However, continued valleywide data collection is needed to aid in evaluating the 1984–88 data set and to detect temporal changes. Remote-sensing techniques may provide a reasonably accurate method of correlating valleywide coverage to site-specific measurements of evapotranspiration and plant density (Jackson, 1985; Reginato and others, 1985).

Further understanding of native vegetation.—Continued investigation is needed of the physiology of native vegetation, in particular how water availability and biochemical factors affect plant growth, vegetative stress, and recovery from stress.

Water Management

Monitoring of native vegetation near production wells.—Monitoring of native vegetation, soil moisture, and ground-water levels near production wells and in areas of the valley most susceptible to hydrologic stress (figs. 26, 31, 32, and 33) is needed to aid in making water-management decisions that are based on actual field data.

Investigation of the ground-water system in the Owens Lake area.—Future water-management issues, such as rotational ground-water pumpage, probably will involve the Owens Lake area (E.L. Coufal, Los Angeles Department of Water and Water, oral commun., 1992). Prior to additional pumping near the Owens Lake, the area needs to be studied to determine the feasibility of pumping freshwater near a saline lake and the effects of such pumping on native vegetation and on desiccation of the lakebed. The investigation will need to include installation of new wells, logging of lithology and ground-water quality, testing of aquifer characteristics, and monitoring of ground-water levels in different zones of the ground-water system.

Use of site-specific ground-water flow models.—Site-specific ground-water flow models, when used in conjunction with information from the valley-wide ground-water flow model, can be extremely useful in efficient testing of hydrologic concepts and possible water-management options. Suggested areas for site-specific models include west of Bishop, near Big Pine, east of Lone Pine, and near Cottonwood Creek. Some site-specific models could take advantage of additional model layers to more accurately represent the hydrogeologic units in the aquifer system.

Include Round Valley in the water-management analysis.—As knowledge about the area west of Bishop is improved, it may be advantageous to include Round Valley in future simulations of the Owens Valley ground-water system. Inclusion of Round Valley in the valleywide model will help to confirm underflow rates from Round Valley and the Bishop Tuff and will aid in evaluating any water-management options that include Round Valley.

More detailed valleywide ground-water flow model.—Detailed simulations of ground-water flow in complicated areas, such as the Big Pine volcanic and massive lacustrine deposits, may require additional layers in the valleywide model or development of a site-specific model. Updating the valleywide model with improvements in concepts and inevitable changes in recharge and discharge will be necessary at some point after water year 1988 in order to evaluate other water-management alternatives.

SUMMARY AND CONCLUSIONS

The Owens Valley, a long, narrow valley along the east side of the Sierra Nevada in east-central California, is the main source of water for the city of Los Angeles. The city diverts most of the surface water in the valley into the Owens River–Los Angeles Aqueduct system, which transports the water more than 200 mi south to areas of distribution and use. Additionally, ground water is pumped or flows from wells to supplement the surface-water diversions to the river–aqueduct system. Pumpage from wells used to supplement water export has increased since 1970, when a second aqueduct from the Owens Valley was put into service, and local residents have expressed concerns that the increased pumping may have a