The water-table decline simulated in alternative 4 can be reduced by focusing artificial-recharge efforts in areas of greatest decline and concentrated pumping (figs. 17 and 31). Localized recharge efforts may need to be continued for as long as 6 years after the end of a 3-year drought in order to compensate for the decline in water table. Areas of abundant water and lush vegetation induced by artificial recharge likely will become areas of stressed vegetation in future drought conditions (compare figs. 31 and 33).

Because of the limitations associated with the valleywide ground-water flow model and the unique characteristics of a particular drought, ongoing monitoring of the aquifer system, soil-moisture zone, and native vegetation needs to be continued, particularly in areas simulated in alternative 4 as having water-table declines greater than 10 ft (figs. 31, 32, and 33).

Optimal Operation of Well Fields

An extensive body of literature deals with the general topic of mathematical optimization of physical systems (Gorelick, 1983; Rogers and Fiering, 1986), and a few applications have been made to combined surface-water and ground-water systems (Young and Bredehoeft, 1972; Bredehoeft and Young, 1970, 1983; Danskin and Gorelick, 1985). Although use of these techniques was proposed initially as a promising method of evaluating water management in the Owens Valley, detailed appraisals during the 6-year study identified several numerical limitations. The mathematical dimensions ($m \times n$ matrix) required by a realistic optimization model for the Owens Valley are very large. There are more than 40 streams, 9 well fields, 200 production wells, 800 observation wells, and 600 surface-water gaging stations—as well as a multitude of decision points in the basin, such as whether or not to divert a stream. Also, the optimization problem is moderately nonlinear as a result of the piecewise-linear relations used to approximate some recharge and discharge components in the ground-water flow model (table 13). The large dimensionality and nonlinearities would require considerable computer time to solve even a relatively simple problem in a mathematically rigorous way. As computer capabilities increase and costs diminish, a basinwide optimization study may prove to be more tractable. The approach presented in this report uses the basics of the mathematical optimization techniques and could serve as the foundation of a simple optimization model.

The actual operation of individual well fields is a complex and iterative process, dependent on many factors—including those general concerns presented in the section entitled "General Water-Management Considerations," as well as day-to-day concerns of mechanical efficiency, repair and maintenance, and personnel requirements. Optimal operation probably involves meeting several different objectives, which makes the mathematical problem even more complex and makes a simple, instructive version of the water-management system difficult to define.

For this evaluation, however, optimal operation of well fields was defined in a semi-quantitative way to be the most pumpage for the least adverse effect on native vegetation. The ground-water flow model was used to determine the effect of pumpage from each well field. The model response, referred to in optimization literature as a "response function," is the change in head, recharge, and discharge in response to a defined increase in pumpage. A unit increase in pumpage produces a "unit response." Those well fields that produce the least adverse effects on native vegetation (least water-table decline under vegetation that relies on ground water) are considered the optimal well fields to use. Well fields with a greater water-table decline are less desirable, or less optimal.

Two similar analyses were done to determine the effect of pumpage from each well field. Each analysis involved simulating the response to pumpage at individual well fields. The simulation timeframe was 1 year with constant stresses. Initial conditions for each simulation were the 1988 steady-state conditions (alternative 1). To simplify the analysis, the Independence–Oak, the Symmes–Shepherd, and the Bairs–George well fields (fig. 17) were grouped together and are referred to as the "Independence south" well field. The Lone Pine well field was not included in the first analysis because of its limited capacity, the presence near the well field of relatively fine-grained and less transmissive aquifer materials (figs. 15 and 16), and the abundance of nearby en echelon faults that limit production (fig. 4).

The first analysis involved increasing pumpage at each well field (tables 11 and 15) by 10,000 acre-ft/yr more than the 1988 steady-state simulation (alternative 1). Pumpage for an individual well was increased in proportion to its 1988 steady-state value (table 11). After 1 year of simulation, the decline in water-table altitude was noted and is shown in figure 34. From this analysis, the well field having the greatest effect on native vegetation is readily discernible as the one producing the greatest water-table decline under the largest area of native vegetation

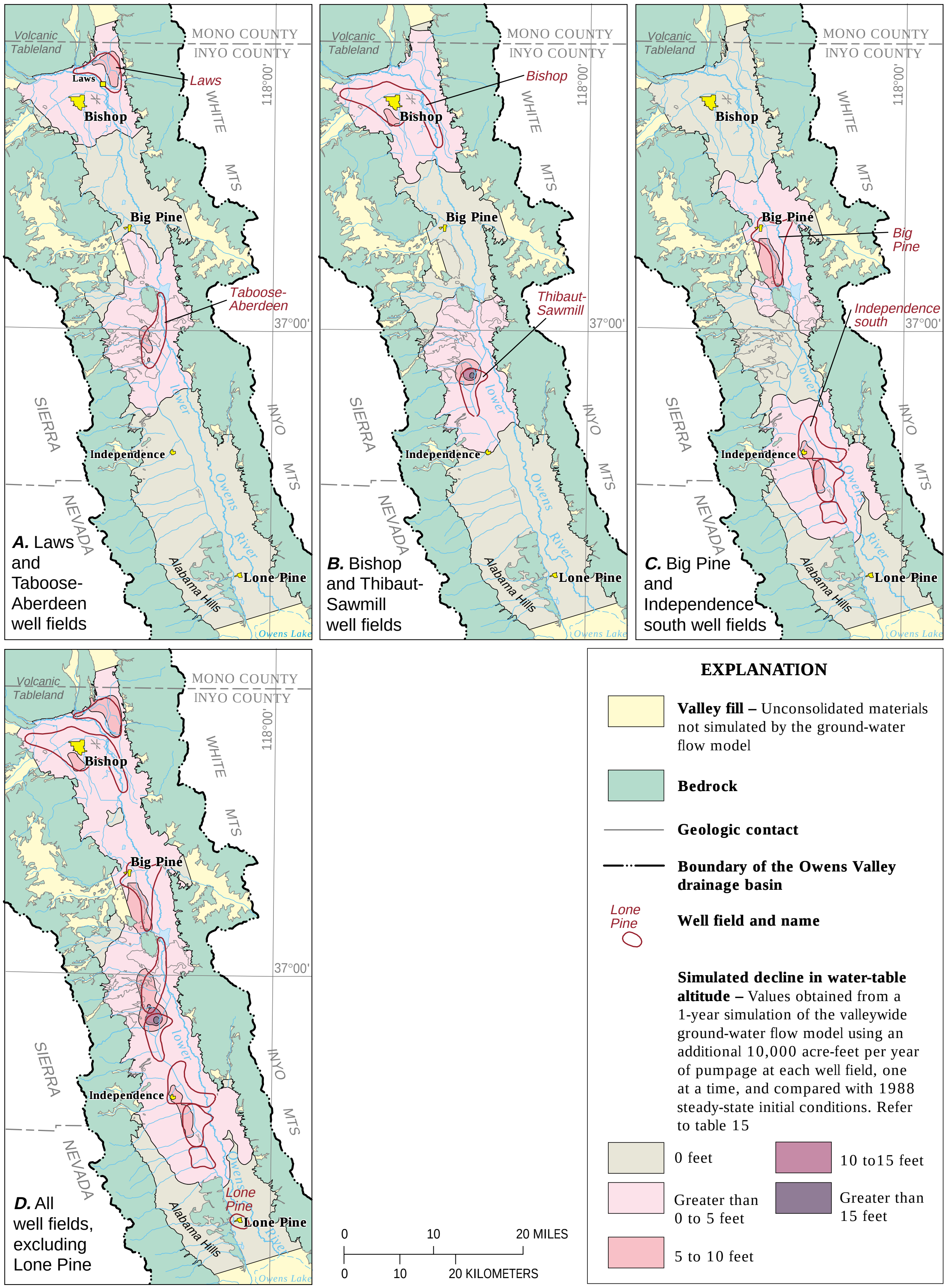

Figure 34. Simulated decline in water-table altitude in the Owens Valley, California, resulting from a unit increase in pumpage at each well field.

dependent on the water table. This technique of using a unit stress (10,000 acre-ft/yr of pumpage) to observe the “unit response” (drawdown surrounding each well field) is a dominant feature in most hydraulic optimization techniques (Gorelick, 1983). For comparison, the combined effect of 10,000 acre-ft of additional pumpage at each of the six well fields is shown in figure 34*D*.

The approximate area of native vegetation dependent on the water table is indicated by the boundary of alluvial fans (compare figs. 4 and 34). Detailed mapping by the Los Angeles Department of Water and Power (R.H. Rawson, written commun., 1988) identified a few isolated parts of the valley floor, primarily east of the lower Owens River, where native vegetation may not be dependent on ground water. Vegetation in these areas of the valley floor presumably is isolated from the effects of pumpage.

All well fields produce approximately the same areal effect (fig. 34). Cones of depression in the water table extend to the edge of the Owens Valley aquifer system, even within a single year. The cones of depression extend somewhat farther up and down the valley because of boundary effects along the edges of the valley and the linearity of hydrogeologic units (fig. 5). All well fields except the Bishop produce greater than 5 ft of drawdown beneath the valley floor, but the magnitude of drawdown is somewhat more concentrated in well fields that have fewer, higher production wells, such as the Big Pine and the Thibaut–Sawmill well fields. The combined pumpage of an additional 60,000 acre-ft/yr (fig. 34*D*) indicates that cones of depression from individual well fields merge and extend over most of the valley.

The most surprising result of this first “unit response” analysis is the similarity of response from each of the well fields. No obviously better place to extract water is evident despite the spatial differences in hydraulic properties of the aquifer system, the distribution of wells, the locations of surface-water features, or the presence of faults that retard ground-water movement. The Bishop well field probably produces the least effect on native vegetation, but water from this well field cannot be used for export, as stipulated by the Hillside Decree. The optimal management of well fields favors producing a large volume of water from a small area, such as from the Thibaut–Sawmill well field. The resulting drawdown is greater, but the area of significant drawdown is more localized.

Extraction of water from the large alluvial fan near Bishop in lieu of other areas of the valley is a favorable management alternative, as discussed in the preceding section (p. 122), except for the restrictions imposed by the Hillside Decree. Vegetation covering most of the fan is not dependent on ground water because the water table is tens or hundreds of feet beneath land surface. The present distribution of wells (fig. 17) indicates that the fan is not used extensively for production. Increasing production uniformly (fig. 34*B*) produces a small area with greater than 5 ft of drawdown near the edge of the fan. By distributing production farther up the fan, the area of greatest drawdown will be reduced in size, and any increased drawdown will occur beneath vegetation that does not subsist on ground water. An important caveat, however, is that sustained pumping from alluvial fan areas eventually decreases ground-water flow rates toward the valley floor area and will cause some change in native vegetation, even if the water table beneath the valley floor remains relatively unaffected. Although pumping from other alluvial fans will yield similar beneficial results, the benefits will be limited by problems of lesser recharge and technical difficulties in installing wells.

The second analysis involved increasing 1988 steady-state pumpage at each well field to the maximum annual value measured at each well during water years 1985–88 (tables 11 and 15). This analysis is designed to optimally distribute present pumping capacity in excess of the 1988 steady-state quantity (alternative 1). Water-table decline after the 1-year simulation is shown in figure 35. For some well fields, the increase is approximately 10,000 acre-ft/yr and the drawdown in figure 35 resembles that in figure 34.

Most of the pumpage from the Bishop and the Thibaut–Sawmill well fields is used for ongoing commitments of water (fig. 17 and table 11), and little pumping capacity above the 1988 steady-state values is available (table 15). Some flexibility exists in managing pumpage from Laws, Big Pine, Taboose, and Independence south well fields. None of these well fields, however, creates a pattern of drawdown that is markedly better with respect to native vegetation than the others (figs. 34 and 35). An ideal pattern from the simulation is zero drawdown beneath native vegetation on the valley floor. The area surrounding the Big Pine well field, because of the large area of irrigated lands and sparsely vegetated volcanic flows, is probably least affected and closest to the ideal. The Laws well field, because of its great distance from a large alluvial fan that acts as a storage reservoir, seems to affect the

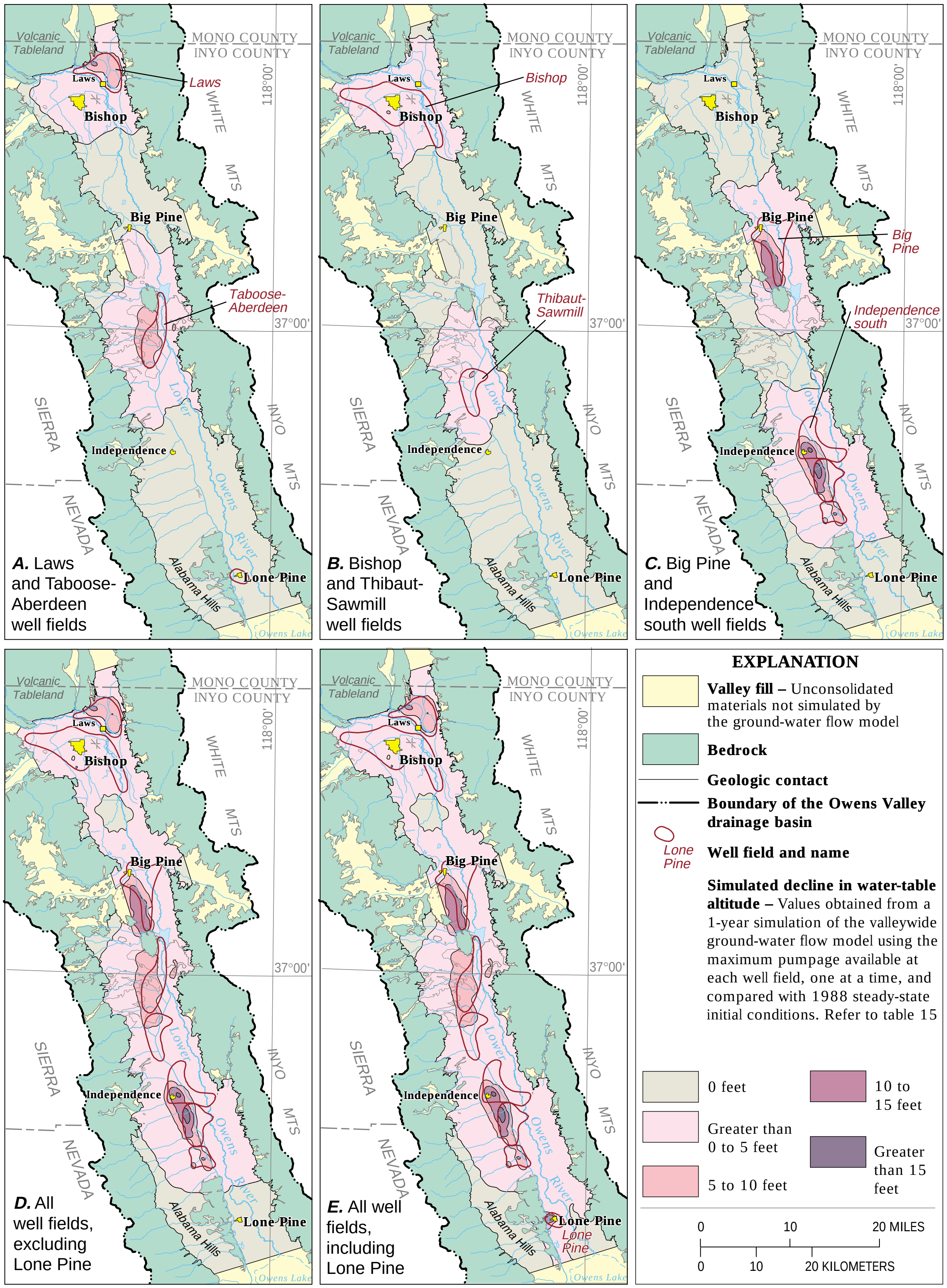

Figure 35. Simulated decline in water-table altitude in the Owens Valley, California, resulting from maximum pumpage at each well field.

largest area of the valley floor and is the poorest choice. Consequently, mitigation measures need to be more intensive in that area—as they have been in recent years—than in other parts of the valley.

The simulated water-table decline after 1 year of maximum pumpage at the six well fields, in comparison with 1988 steady-state conditions, is shown in figure 35*D*. As with the simulation of unit responses (fig. 34*D*), the cones of depression from the individual well fields overlap, but not to a significant degree. Pumping from the small Lone Pine well field, which has limited extra capacity (table 15), has a minimal effect on the rest of the valley (fig. 35*E*).

One feature that is interesting to note is an unaffected area south of Bishop. This area, near Collins Road and vegetation sites C and D (fig. 2), shows no decline in the simulated water table after 1 year of maximum pumpage (fig. 35*E*). Coincidentally, native vegetation in that area was observed to remain greener than in other parts of the valley during 1982–88, a period of wide variations in precipitation, recharge, and pumpage. This observation, paired with the simulated results presented in figures 34*D*, 35*D*, and 35*E*, helps to confirm the reasonableness of the ground-water flow model in that part of the valley. The primary reasons the area remains unaffected by changes elsewhere in the valley are the lack of nearby pumping (fig. 17) and the effectiveness of hydraulic buffering of the water table by native vegetation and the Owens River.

In summary, optimal water management of the well fields—with the objective of minimizing declines in the water table—is relatively insensitive to pumpage from a specific well field. The areal extent of greatest drawdown in the water table is similar for each of the six well fields, both from the standpoint of installing new production wells (fig. 34) and of using existing capacity (fig. 35). If pumpage can be increased at one or two well fields for only a single year or part of a year, then drawdown and any adverse effects on native vegetation will be restricted to a small, more manageable area. Rotating pumpage from one well field to another may facilitate this result, and may be an optimal way to manage the well fields during times of below-average runoff.

Reliability of Results

The reliability of this evaluation of water management in the Owens Valley depends on three critical assumptions: first, that the aquifer system and native vegetation are conceptualized correctly; second, that the aquifer system is numerically approximated with only minor, recognized errors; and third, that the selected water-management alternatives are a realistic representation of possible future conditions.

The conceptualization of the aquifer system and native vegetation was the focus of related studies by Groeneveld and others (1985, 1986a); Hutchison (1986b); Dileanis and Groeneveld (1989); Sorenson and others (1989, 1991), Duell (1990), and Hollett and others (1991). Although not all aspects of the aquifer system and native vegetation are well understood, the important role of the aquifer system in providing water for the long-term health of native vegetation on the valley floor is well documented. The primary difficulty in predicting the response of native vegetation to a change in water availability is that a decline in the water table does not always result in an immediate adverse effect on native vegetation (Sorenson and others, 1991, p. G35). For example, if precipitation on the valley floor is well above average, native vegetation can survive, even prosper, for 1 to 3 years with no water supplied via capillarity from hydrogeologic unit 1.

Because precipitation on the valley floor and valleywide runoff from the surrounding mountains are not well correlated, it is possible to have precipitation on the valley floor and thus an increase in soil moisture, which promotes additional plant growth, and at the same time have reduced runoff from the mountains, which prompts an increase in pumpage and results in a lowering of the water table. Under these conditions, the native vegetation remains healthy, but the water table declines. However, if the extra pumpage continues through a period of below-average precipitation on the valley floor, then plants will begin dropping leaves to conserve water and the overall health of native vegetation is jeopardized. During the evaluation of different water-management alternatives, this variability of response was recognized, but an assumption was made that the plants were not aided by a short-term increase in precipitation.

The numerical approximation of the aquifer system was made using a ground-water flow model that incorporates most of the major concepts of the aquifer system as well as the use of ground water by native vegetation. The limitations of ground-water flow models in general, and the valleywide model in particular, are discussed extensively in a previous section, entitled “Use, Limitations, and Future Revisions.” The reliability of the ground-water flow model is affected most by those limitations. For example, two areas of the basin—west of Bishop and near Lone Pine—are either poorly understood or poorly simulated. Results in these areas are less reliable than those in other parts of the basin. During development of the valleywide model, several other ground-water flow models of parts of the Owens Valley were developed by a number of different organizations and individual researchers (fig. 2; table 2). Each of the models tends to show similar results. Although it is possible that all the models are incorrect, this uniformity gives additional credibility to the modeling approach and results.

Use of the ground-water flow model to identify areas where native vegetation is likely to be affected adversely by pumping is based on the assumption that a hydraulic stress (decline in water-table altitude) equates to a vegetative stress (decrease in biomass). As discussed above, this is not always true. For longer periods of time, however, such as the period of steady-state conditions simulated in three of the four alternatives evaluated, the assumption becomes more reliable. The benefits of a short-term increase in precipitation on the valley floor are outweighed by long-term water requirements for transpiration. More reliable results might be produced by using another type of model that explicitly incorporates vegetative growth, precipitation, and use of ground water and is linked to a valleywide ground-water flow model. For the present study, however, such a model was deemed to be numerically too large and to have too many poorly quantified parameters.

Changes in simulated recharge and discharge in the valleywide ground-water flow model that were required to evaluate different water-management alternatives were well within the range of values used during calibration and verification of the model. This minimal modification of the model increases the reliability of results—particularly, if the results are viewed in a general, semi-quantitative way. In analyzing the different water-management alternatives, the simulated drawdown seems to be somewhat greater than what might actually occur. A simulated 30-ft decline might represent an actual decline of 20 ft; a simulated 10-ft decline, an actual decline of 6 ft; and so forth. The reason for the deviation is not known, but it may result from greater delayed drainage of hydrogeologic unit 1 or more effective action of hydraulic buffers, such as evapotranspiration. Because the ground-water flow model uses generalized model zones of aquifer properties and localized recharge and discharge, the spatial pattern and relative magnitude of drawdown probably are more reliable than the specific value of drawdown.

The selection of water-management alternatives was based on what was considered a realistic representation of possible future conditions. Because of the extremely wide-ranging nature of negotiations between Inyo County and the Los Angeles Department of Water and Power in designing a water-management plan for the Owens Valley, the definition of realistic is somewhat subjective. For example, the assumption that 1988 steady-state pumpage is the sum of average historical pumpage and new enhancement and mitigation pumpage was an arbitrary choice reflecting one possible agreement. The choice of some lesser quantity of pumpage would have been an equally valid assumption. Choice of a greater quantity of pumpage did not seem politically plausible. The use of 0, 25, 50, 75, 100, and 125 percent of 1988 steady-state pumpage for alternative 3 brackets the range of what was deemed realistic.

Many of the choices in defining future conditions were much less subjective. Several were based on long-term hydrologic conditions, such as runoff for water years 1935–84 or land use for water years 1970–88. Values of recharge and discharge based on past long-term conditions are probably reliable indicators of future long-term conditions.

Only a few choices were based on recent changes in water management, primarily the addition of enhancement and mitigation pumpage and related recharge. Both hydrologically and politically, the recently altered recharge and discharge are much less certain than long-term values. Additional changes in water management, such as reestablishing the lower Owens River as a perennial stream or establishing alfalfa fields near well fields, seem likely and will affect localized areas of the valley. The evolving water management of the Owens Valley prompted by the requirement of a court-accepted EIR and joint water-management plan for the valley creates the greatest uncertainty in future conditions and is probably the most important caveat in assessing the reliability of results presented in this report.

Potential Changes in Operation

The following is a summary of potential changes in water-management operations designed to protect native vegetation as well as to provide water for export to Los Angeles. The options involve changes in recharge, changes in pumpage, and changes in mitigation measures.

Increase tributary stream recharge.—An increase in recharge from tributary streams is limited by the timing and quantity of runoff from the Sierra Nevada. Some tributary streams have a lower loss rate (fig. 13 and table 9) than others, depending on characteristics of the surficial deposits and length of the stream channel. Estimates of evapotranspiration for vegetation along tributary stream channels indicate that most of the loss actually seeps into the ground and recharges the aquifer system. An increase in the recharge rate of selected streams, therefore, can compensate for an increase in ground-water pumpage, depending on the timing of recharge and pumping.

Most tributary streamflow that does not seep into the ground is exported out of the valley. Increasing the recharge rate in years of average or below-average runoff probably is not productive, as a reduction in streamflow means that additional ground water likely will be pumped from other parts of the valley to make up the difference. If the total quantity of water exported in average-runoff years could be reduced, then increasing recharge from some tributary streams, in particular Taboose and Bishop Creeks, can provide additional ground water in future years. A further increase in recharge for these or other tributary streams may be possible through modifications of the diversion operations near the base of the mountains or use of a different configuration of diversion channels on the alluvial fans. Increasing recharge during years of above-average runoff may be advantageous, but this general operating policy has been in effect since the early 1970's. Also, some of the recharge, particularly during wet periods, will be lost to increased evapotranspiration and gain of water by the river–aqueduct system.

Increase artificial recharge on the valley floor.—Artificial recharge of surface water on the valley floor is being done in the Bishop and the Laws areas, and to a lesser extent, in the Big Pine area (table 11 and pl. 3). The purpose of the recharge is to replenish ground-water storage that has been depleted by pumping and to enhance recovery of the water table in order to protect native vegetation. Expansion of these efforts may be possible to further reduce the adverse effects of pumping on native vegetation.

Artificial recharge in most parts of the valley floor is limited by the presence of fine-grained deposits and the horizontal layering of the aquifer system (figs. 5 and 14). Although unlined surface-water features are an important source of local recharge, direct irrigation of the native vegetation has been discounted as an option because of likely problems with salinity and disruption of the soil horizon (D.P. Groeneveld, Inyo County Water Department, oral commun., 1987). Direct recharge through wells, however, may be a water-management option—particularly, as new wells are installed with perforations only in the lower zones. Use of recharge wells can help repressurize the production zone after large extractions have been made, such as during a drought, or whenever extra surface water is available. Repressurizing a confined zone results in a moderate increase in ground-water storage—much less than if the zone is unconfined—and an important recovery of ground-water levels and gradients. Evaluation of the likely changes in ground-water quality resulting from direct recharge of surface water will require additional water-quality data.

Recharge surface water on the east side of the valley.—Artificial-recharge efforts on the east side of the valley during periods of above-average runoff will provide some additional storage of ground water. Because natural runoff on the east side of the valley is scant, recharge efforts probably will require diversion of surface water from the river–aqueduct system into those areas. As indicated by simulations using the valleywide ground-water flow model (figs. 34 and 35), drawdown cones from well fields reach to the bedrock sides of the valley. Recharge along the sides of the valley, even the east side, will help to reduce the effects of pumping. However, recharged water that is not captured by pumping may eventually seep into the river–aqueduct system or the lower Owens River, and may induce more growth of vegetation between the recharge and discharge points.

Recharge on the east side of the Bishop Basin, particularly east of the Big Pine well field, might help minimize the areal effects of pumping in the Big Pine area, as well as provide some additional ground-water storage, particularly beneath the blue-green clay. In contrast, recharge east of the Owens Valley Fault in the Owens Lake Basin has little effect on the western well fields. The Owens Valley Fault tends to channel recharge water down the east side of the basin, allowing only small quantities of flow westward across the fault.

Extract ground water from the Bishop Creek alluvial fan.—Extraction of water in the Owens Valley is a highly charged topic that does not lend itself to purely scientific assessments. Nevertheless, one of the premier places to extract water and have little effect on native vegetation seems to be near Bishop, particularly the Bishop Creek alluvial fan (Bishop Cone). The great depth to water over much of the fan, abundance of recharge, prevalence of urban land and irrigated vegetation, and large number of canals and ditches crisscrossing the fan make it an area with higher recharge and production potential and fewer adverse effects on native vegetation than most other areas of the valley. Uncertainties about the aquifer system west of Bishop do not alter this conclusion. However, additional understanding of how the Bishop Tuff, the Coyote Warp, and valley-fill faults (fig. 4) affect the aquifer system will be most helpful in planning any changes in water management.

Extract ground water from the Owens Lake area.—Additional extraction of ground water from the area south of the Alabama Hills and surrounding the Owens Lake may be possible. Although drilling and lithologic data are sparse for that part of the valley, depositional concepts indicate that the alluvial fan deposits along the western side of the basin probably grade into a narrow band of moderately transmissive transition-zone deposits. Extraction of a significant quantity of ground water near the Owens Lake probably will require additional recharge in order to minimize the migration of poorer quality (higher dissolved-solids concentration) ground water from beneath the lakebed toward the production wells. South of the valleywide model area, Cottonwood Creek (Hollett and others, 1991, fig. 16) has a greater discharge than any other tributary stream in the Owens Valley except Bishop and Big Pine Creeks. If recharge from Cottonwood Creek could be increased, especially by utilizing its large alluvial fan, then additional ground-water extractions from that area might increase water-management flexibility. Ground-water pumpage in that area likely will affect a narrow band of native vegetation near the springline and edge of the lakebed (figs. 1 and 3). Additional drilling, aquifer tests, water-level and water-quality monitoring, and possibly small-scale simulation studies will be required to further document and evaluate this option.

Extract ground water from the east side of the Owens Valley.—Extraction from the east side of the Owens Valley is not as efficient as extraction from the west side. Aquifer materials on the east side are finer and probably less transmissive. If the depositional models are correct for that side of the basin, then a narrow band of transition-zone deposits should be present as suggested on plate 2. The most transmissive deposits and greatest quantity of transition-zone deposits probably are near the alluvial fans of Waucoba and Mazourka Canyons (fig. 4). Because of the apparent symmetry of the basin and aquifer materials, the pattern and extent of drawdown from pumping on the east side of the valley probably will be similar to that of drawdown from pumping on the west side of the valley (fig. 34).

A major limitation of pumpage from the east side of the basin is the meager quantity of natural recharge. Without additional recharge near proposed wells, ground-water storage will be depleted rapidly. This depletion is accentuated by the restriction to ground-water flow caused by the Owens Valley Fault. Both the quality of ground water along the eastern side of the basin and the probable changes in ground-water quality resulting from recharge and extraction in that area are unknown. Despite these considerable limitations, extraction from the east side of the valley should be hydrogeologically feasible and might offer some flexibility in future water management.

Extract ground water from the Lone Pine area.—The Lone Pine area is characterized by finer-grained materials, lower transmissivities, more en echelon faulting, and possibly poorer water quality than in many other parts of the basin. These characteristics alone do not make it a particularly desirable place to develop additional well production. A more complete assessment requires a better understanding and simulation of ground-water flow in that part of the valley.

Pump from selected well fields.—A shift of pumping to selected well fields may provide protection for native vegetation in other areas. For example, the prevalence of irrigated lands near the Big Pine well field makes widespread, adverse effects on native vegetation less likely than at other well fields such as the Taboose–Aberdeen or the Independence–Oak (fig. 17). Also, localized pumping from highly transmissive volcanic deposits at the Thibaut–Sawmill well field restricts the areal extent of the adverse effects on native vegetation (fig. 34). Extraction from similar well fields or parts of the valley will require less mitigation for native vegetation than will extraction at other locations.

Rotate pumpage among well fields.—As indicated in figures 25, 34, and 35, rotational pumpage may have some advantage over continual extraction from a single well field. A key to the health of native 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.