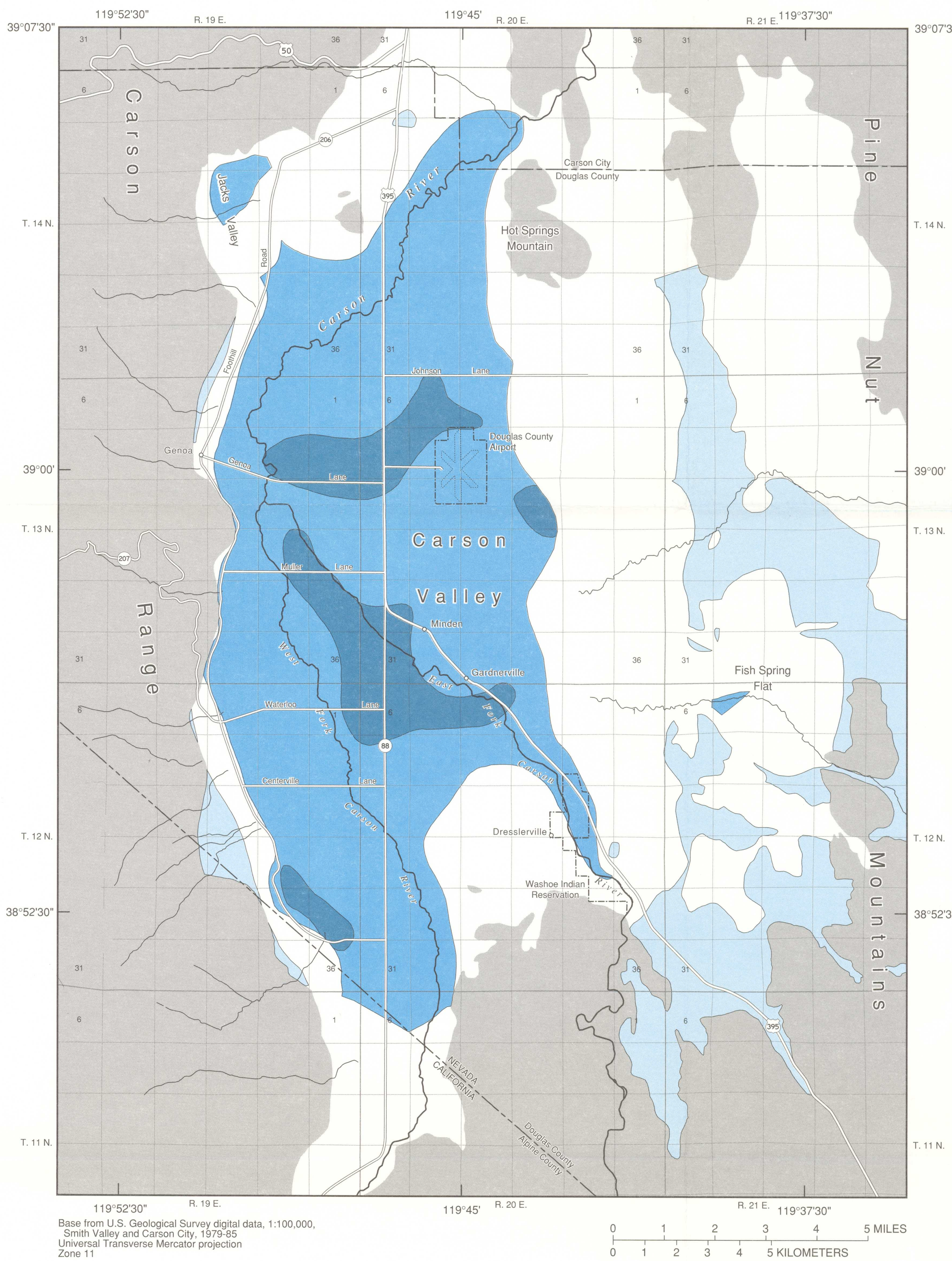
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with
DOUGLAS COUNTY UTILITY DIVISION

WATER-RESOURCES INVESTIGATIONS REPORT 94-4126
Potential for recharge by injection and possible effects of artificial recharge—SHEET 4 OF 4
Maurer, D.K. and Peltz, L.A., 1994, Potential for, and possible effects of, artificial recharge in Carson Valley, Douglas County, Nevada



EXPLANATION
[<, less than; >, greater than]

POTENTIAL FOR RECHARGE THROUGH INJECTION WELLS	DEPTH TO WATER (feet below land surface)	SPECIFIC YIELD (percent)
High	<20	>20
Moderate	<20	10 to 20
Unknown	>200	unknown
BASIN-FILL DEPOSITS NOT CLASSIFIED IN THIS FIGURE AS TO RECHARGE POTENTIAL		
CONSOLIDATED ROCK		

Figure 8. Distribution of areas with high, moderate, and unknown potential for artificial recharge through injection wells. Selection criteria are depth to water, specific yield, and exposure of unconsolidated sediments on the eastern side of the valley.

Recharge by Injection

For recharge by injection, areas totaling 7,800 acres have high potential, 43,500 acres have moderate potential, and 23,000 acres have unknown potential (fig. 8). Areas where depth to water is less than 20 ft below land surface and specific yield is greater than 20 percent have high potential; areas where depth to water is less than 20 ft below land surface and specific yield is from 10 to 20 percent have moderate potential. Recharge through infiltration is not practical in these areas because of the shallow depth to water.

Large-scale urban development could reduce irrigation diversions that maintain the high water table beneath the valley floor. This change in land use and an accompanying increase in ground-water withdrawals could increase the depth to water to more than 20 ft below land surface. Artificial recharge by infiltration would then be feasible over much of the valley floor.

In areas where depth to water is greater than 200 ft and unconsolidated sediments are exposed, potential for recharge through injection is unknown. Recharge by infiltration would probably not be efficient in these areas because water could be lost to perched and partly saturated zones. The potential for artificial recharge in these areas cannot be estimated without subsurface data.

POSSIBLE EFFECTS OF ARTIFICIAL RECHARGE

Hydrogeologic factors discussed previously–such as the thickness of water-bearing units, type of aquifer, capacity for storage, rate of horizontal movement of water, and location of recharge and discharge–all control the efficiency of artificial recharge. Not all of these factors were included directly in the criteria used to assess the potential for artificial recharge. However, all of these factors can be combined in a ground-water flow model that can be used to assess the regional effects and overall efficiency of artificial recharge at different locations. Because ground-water flow models use average values of aquifer properties in individual model cells, model simulations might not represent the actual aquifer response at a specific site, but they can show the general response of the hydrologic system expected from artificial recharge. A ground-water flow model developed by Maurer (1986) is used to simulate taking surface water from the Carson River and using it to artificially recharge ground water in two distinct hydrologic settings in Carson Valley. Because aquifers are not closed systems, some of the water added as artificial recharge does not remain in storage but is discharged to streams or to the atmosphere by evapotranspiration. The simulations show the possible effects of recharged water on ground-water storage, streamflow, and evapotranspiration rates. Volumetric water budgets calculated by the model provide estimates of changes in budget components after 1 year and 5 years of artificial recharge.

The three-dimensional flow model consists of a two-layer grid of 14 rows and 19 columns superimposed on the Carson Valley ground-water basin (figs. 9A and 9B). The grid cells each cover 1 mi^2; the upper layer (layer 1) represents the unconfined aquifer, and the lower layer (layer 2) represents the semiconfined aquifer. The eastern boundary of the model is specified as a constant-flux boundary where flow from semiconsolidated sediments enters the ground-water reservoir; no-flow boundaries are specified around the rest of the model grid near the impermeable bedrock (Maurer, 1986, p. 52). The model includes a streamflow-routing package that simulates ground-water/surface-water interactions between the system of irrigation ditches and the unconfined aquifer. Streamflow is routed across the entire valley floor and through most cells within the boundary of layer 2 (fig.9A; Maurer, 1986, p. 56). The model, including the assumptions and limitations, is discussed in detail by Maurer (1986). Input data for the model are documented by Maurer (1992).

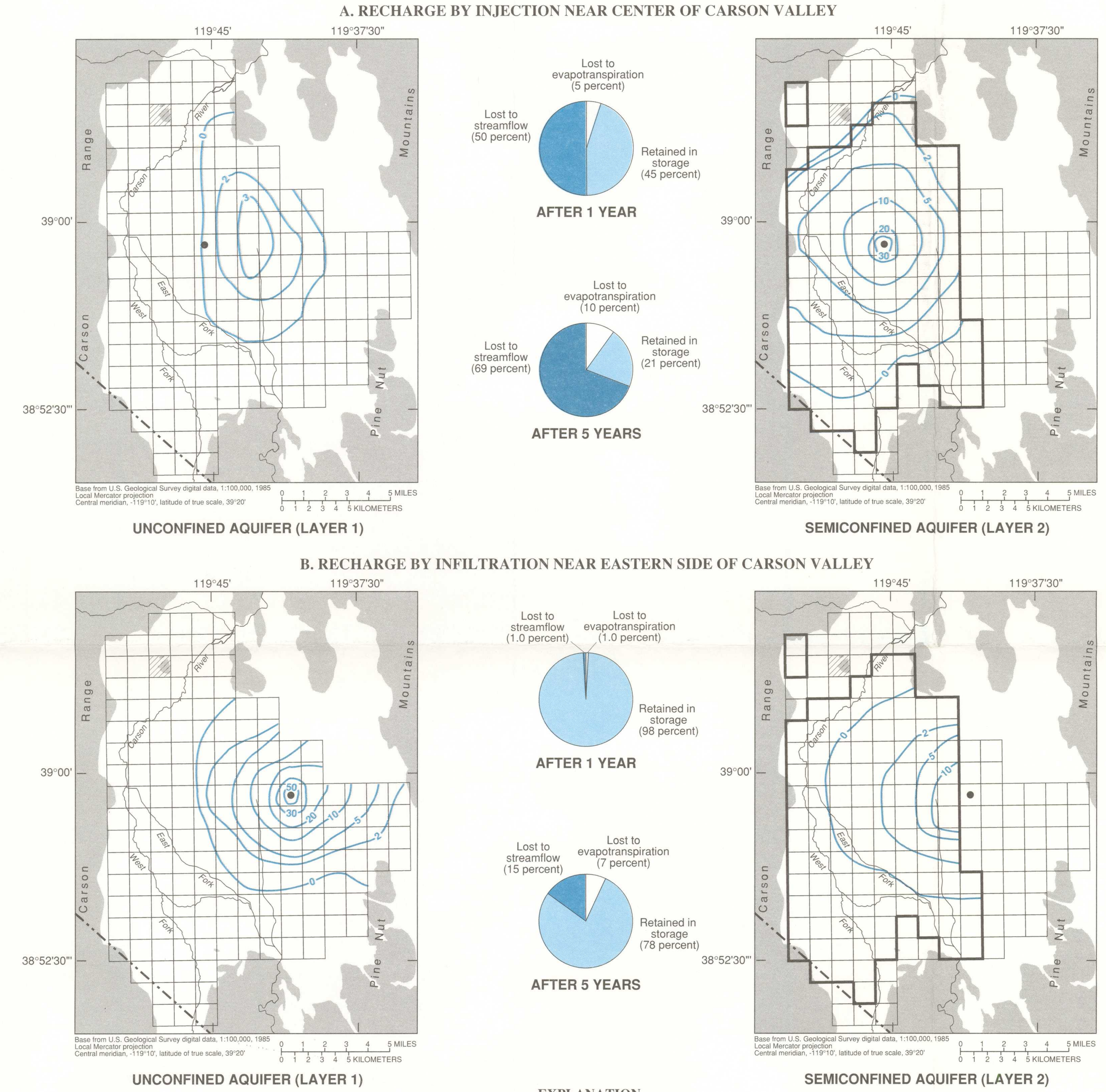
The ground-water flow model simulates average conditions for each square-mile area, and calculations are made at the center of each cell in the grid. The model simulates average annual conditions; it is not designed to simulate long-term seasonal variations in recharge, pumping, and streamflow near an operational recharge site. Also, the model does not simulate flow through unsaturated sediments beneath an infiltration bed. In simulating recharge, water is added directly to the unconfined or semiconfined aquifer; infiltration, percolation, and recharge are assumed to be instantaneous with no water lost during the process. Withdrawal of recharged water is not simulated, because recharge and withdrawal would probably take place within the same square-mile-grid cell. If the withdrawal rate were equal to the recharge rate, the net effect would be nil. For these reasons, the model cannot be used to simulate site-specific conditions for an artificial recharge site and nearby withdrawal wells. The simulations are intended to give a general indication of average changes in water levels within grid cells near the point of recharge and show how much recharge would be retained in ground-water storage and how much would be lost by discharge through the ground-water flow system over time.

Artificial recharge is simulated at two locations: near the valley floor where ground-water discharge takes place (fig. 9A), and on the eastern side of the valley at a point distant from ground-water discharge (fig. 9B). At both locations, recharge is simulated for periods of 1 year and 5 years to show the cumulative effects of recharge on the ground-water system. To simulate recharge using flow of the Carson River, 10,000 acre-ft/yr is removed from the river and added at a constant rate at locations shown in figures 9A and 9B. Near the valley floor, water is added directly to the semiconfined aquifer (layer 2 of the model); at the eastern site, water is added directly to the unconfined aquifer (layer 1).

Near the center of the valley, average yields of large-bore irrigation wells indicate that three to four wells might be required to inject 10,000 acre-ft/yr. The same wells could be used later to withdraw the water. On the eastern side of the valley, the average infiltration rate reported by the U.S. Soil Conservation Service is about 4 in/h–requiring a bed of about 400 ft by 400 ft to infiltrate 10,000 acre-ft/yr. If the rate of percolation to the water table is less than 4 in/h, a larger infiltration bed would be required. Well yields around the perimeter of the valley floor are much lower than on the valley floor; as a result, more than 20 wells might be required at some locations for withdrawal of 10,000 acre-ft/yr.

Near the center of the valley, after 5 years of recharge, head in the semiconfined aquifer (layer 2) rises as much as 35 ft in the recharge cell, more than 10 ft in cells surrounding the recharge cell, and more than 1 ft across most of the valley floor (fig. 9A). Head in layer 1 increased as much as 3 ft about 2 mi east of the recharge cell, and more than 1 ft over most of the northeastern part of the model grid. On the valley floor, west of the recharge cell, heads in layer 1 did not increase because discharge to the surface-water system and discharge by evapotranspiration effectively drain the unconfined aquifer. Changes in water-budget components after 1 year of recharge are shown in the pie diagrams (fig. 9A): 50 percent of the recharged water discharges to streams, 5 percent discharges by evapotranspiration, and 45 percent is retained in storage. After 5 years and 50,000 acre-ft of total recharge, only 21 percent is retained in storage, 69 percent discharges to streamflow, and 10 percent discharges by evapotranspiration.

On the eastern side of the valley, after 5 years of recharge to the unconfined aquifer (layer 1), head rises as much as 55 ft in the recharge cell, more than 20 ft in cells surrounding the recharge cell, and more than 1 ft over most of the northeastern part of the model grid (fig. 9B). The changes in head near the eastern boundary of the model would change the gradient across the boundary by 1 to 2 percent. This change is not sufficient to greatly affect the assumption of constant flux along the boundary. In the semiconfined aquifer (layer 2), heads increase more than 10 ft adjacent to the recharge cell, and more than 1 ft over much of the eastern part of the valley floor. Because the point of recharge is distant from areas of ground-water discharge, after 1 year most of the recharged water is retained in ground-water storage. After 5 years and 50,000 acre-ft of total recharge, 78 percent is retained in storage, 15 percent discharges to streams, and 7 percent discharges by evapotranspiration.



EXPLANATION

BASIN-FILL DEPOSITS

CONSOLIDATED ROCK

BOUNDARY OF LAYER 2

LINE OF EQUAL SIMULATED WATER-LEVEL RISE
Interval, in feet, is variable. Datum is water-level altitude at 119°40' at start of simulation

ACTIVE CELL

ACTIVE CELL WITH ASSIGNED RECHARGE

INACTIVE CELL SURROUNDED BY ACTIVE CELLS

Figure 9. Simulated rise in water levels for model layers 1 and 2, illustrated by lines of equal water-level rise, after 5 years of recharge near the center (**A**) and near the eastern side (**B**) of Carson Valley. Pie charts show percentages of recharge retained in storage, lost to evapotranspiration, and lost to streamflow after 1 year and 5 years.

Both simulations indicate that, if ground-water withdrawal accompanies recharge, much if not all of the water otherwise discharged to streams and by evapotranspiration could be pumped. Thus, management plans for an operational artificial recharge site would include a determination of the most efficient schedule for recharge and withdrawal to minimize loss of storage by discharge from the ground-water system.

The simulations show that artificial recharge near the center of the valley could increase heads in the semiconfined aquifer over much of the valley floor; much of the water added, however, would be quickly discharged. On the eastern side of the valley, artificial recharge could increase heads in the unconfined aquifer over an area of many square miles, and more of the water would be retained in ground-water storage. In both simulations, when artificial recharge is applied for longer periods, a greater percentage of the recharged water moves downgradient to discharge areas. Loss of recharged ground water to streamflow could benefit downstream surface-water users by increasing the base flow of the Carson River and provide further opportunity for conjunctive use of the ground-water and surface-water systems.

SUMMARY

Population growth in Carson Valley is causing changes in land and water use that require increases in ground-water storage. Artificial recharge could be used to supplement the normal recharge to the basin by flooding infiltration beds or injecting water through wells to increase storage in aquifers underlying the valley. Advantages of underground storage compared with storage in surface reservoirs include lower construction costs, smaller evaporation losses, and a more dependable, year-round supply, as well as the potential for using storm runoff or reclaimed wastewater. Disadvantages of underground storage include the costs of site-specific investigations prior to construction of operational sites, installation of withdrawal wells, and possible pretreatment of recharge water. Other disadvantages include clogging of infiltration beds or aquifer pore space, potential effects on ground-water quality, and water lost by uncontrolled ground-water discharge. Full consideration of the specific hydrogeology of each site in project design and operation can minimize some of the disadvantages.

Hydrogeologic factors that control the efficiency of artificial recharge include the rate that water moves to the water table and within the aquifer, the capacity of the aquifer for storage, whether the aquifer is confined or unconfined, and the location of natural recharge and discharge within the hydrologic system. In this study, criteria used to estimate the potential for artificial recharge in Carson Valley were developed from qualitative guidelines and values for aquifer properties indicative of efficient recharge as reported in the literature. The mapped geology of Carson Valley was used to delineate areas where artificial recharge is feasible. Depth to water was used to delineate aquifer type, areas of natural recharge and discharge, and areas where aquifers could be recharged by infiltration or injection. Infiltration rate was used to delineate areas with high, moderate, and low potential for recharge by infiltration, and specific yield was used to delineate areas with high and moderate potential for recharge by injection.

For recharge by infiltration, analysis of existing data for Carson Valley shows that about 5,100 acres have high potential, 17,000 acres have moderate potential, and 3,700 acres have low potential. In addition, for recharge by injection about 7,800 acres have high potential, 43,500 acres have moderate potential, and 23,000 acres have unknown potential. These criteria are arbitrary and provide only a preliminary indication of recharge potential. Site-specific investigations would allow a more precise assessment of recharge potential before construction of a recharge site.

Simulations of artificial recharge by use of an existing ground-water-flow model indicate that recharge to the semiconfined aquifer near the center of the valley could increase heads in that aquifer across most of the valley floor; much of the water added, however, would quickly discharge either to streams or by evapotranspiration. Near the eastern side of the valley, recharge to the unconfined aquifer could increase heads in that aquifer over many square miles and more of the water would be retained in storage. In both areas, when recharge is applied for long periods without accompanying withdrawal, recharged water moves downgradient to discharge areas.

ACKNOWLEDGMENTS

The authors thank Jim Doty of the U.S. Soil Conservation Service for providing the digital data on soils, and private well owners in Carson Valley for allowing access to measure depth to water.

REFERENCES CITED

Asano, Takashi, ed., 1985, Artificial recharge of groundwater: Boston, Mass., Butterworth, 767 p.

Bianchi, W.C., Nightingale, H.I., and McCormick, R.L., 1978, A case history to evaluate the performance of water-spreading projects: Journal of the American Water Works Association, v. 70, no. 2, p. 176-180.

Bouwer, Herman, 1988, Design and management of infiltration basins for artificial recharge of ground water, Proceedings, 32d. Annual New Mexico Water Conference, Ground Water Management: New Mexico Water Resources Research Institute Report 229, p. 111-123.

Dillingham, H.L., 1980, Carson Valley, Nevada, ground-water geology and resources, definite plan appendix: Sacramento, Calif., Bureau of Reclamation, 82 p.

Espina, J.M., 1980, The case for artificial recharge: Johnson Drillers Journal, v. 52, no. 1, p. 7-11.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Hamlin, S.N., 1987, Evaluation of the potential for artificial ground-water recharge in eastern San Joaquin County, California–Phase 3: U.S. Geological Survey Water-Resources Investigations Report 87-4164, 17 p.

Huisman, L., and Olsthoorn, T.N., 1983, Artificial groundwater recharge: Boston, Mass., Pitman Advanced Publishing Program, 294 p.

Lichtler, W.F., Stannard, D.I., and Kouma, Edwin, 1980, Investigation of artificial recharge of aquifers in Nebraska: U.S. Geological Survey Water-Resources Investigations 80-93, 112 p.

Maurer, D.K., 1986, Geohydrology and simulated response to ground-water pumpage in Carson Valley, a river-dominated basin in Douglas County, Nevada, and Alpine County, California: U.S. Geological Survey Water-Resources Investigations Report 86-4328, 109 p.

——1992, Documentation of model input and output values for simulation of ground-water flow in Carson Valley, Douglas County, Nevada, and Alpine County, California: U.S. Geological Survey Open-File Report 91-537, 5 p. and diskette.

Maurer, D.K., and Fischer, J.M., 1988, Recharge to the Eagle Valley ground-water basin by streamflow in Vicee Canyon, west-central Nevada: U.S. Geological Survey Water-Resources Investigations Report 88-4158, 66 p.

Mitten, H.T., 1982, Preliminary evaluation of the potential for artificial ground-water recharge in eastern San Joaquin County, California: U.S. Geological Survey Open-File Report 82-123, 46 p.

O'Hare, M.P., 1985, Site selection criteria for artificial recharge projects, *in* Proceedings of the Association of Ground Water Scientists and Engineers, San Antonio, Tex., Sept. 18-19, 1985: Worthington, Ohio, National Water Well Association, p. 251-265.

Stewart, J.H., 1980, Geology of Nevada–A discussion to accompany the geologic map of Nevada: Nevada Bureau of Mines and Geology Special Publication 4, 136 p.

Todd, D.K., 1980, Ground water hydrology (2d ed.): New York, John Wiley & Sons, 535 p.

U.S. Soil Conservation Service, 1983, Soil survey of Douglas County area, Nevada: U.S. Government Printing Office, 575 p.

Welch, A.H., (in press), Chemistry and quality of ground water in Carson and Eagle Valleys, western Nevada and eastern California: U.S. Geological Survey Open-File Report 93-33.

Welch, A.H., Plume, R.W., Frick, E.A., and Hughes, J.L., 1989, Ground-water-quality assessment of the Carson River basin, Nevada and California–Analysis of available water-quality data through 1987: U.S. Geological Survey Open-File Report 89-382, 115 p.

SELECTED READING

Johnson, A.I., and Finlayson, D.J., eds., 1989, Artificial recharge of ground water–Proceedings of the International Symposium, August 23-27, 1988, Anaheim, Calif.: New York, American Society of Civil Engineers, 638 p.

O'Hare, M.P., Fairchild, D.M., Hajali, P.A., and Canter, L.W., 1986, Artificial recharge of ground water, status and potential in the contiguous United States: Chelsea, Mich., Lewis Publishers, 419 p.

Schneider, B.J., and Oaksford, E.T., 1986, Design, operation, and monitoring capability of an experimental artificial-recharge facility at East Meadow, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 84-4321, 46 p.

Signor, D.C., Growitz, D.J., and Kam, William, 1970, Annotated bibliography on artificial recharge of ground water, 1955-67: U.S. Geological Survey Water-Supply Paper 1990, 141 p.

Todd, D.K., 1959, Annotated bibliography on artificial recharge of ground water through 1954: U.S. Geological Survey Water-Supply Paper 1477, 115 p.

Zomorodi, K., 1988, Optimization of design and operation of artificial groundwater recharge facilities: Logan, Utah, Utah State University, unpublished Ph.D. dissertation, 210 p.

POTENTIAL FOR, AND POSSIBLE EFFECTS OF, ARTIFICIAL RECHARGE IN CARSON VALLEY, DOUGLAS COUNTY, NEVADA

By
Douglas K. Maurer and Lorri A. Peltz

1994

U.S. GOVERNMENT PRINTING OFFICE: 1995—683-993