CONCEPTUAL EVALUATION OF REGIONAL GROUND-WATER FLOW IN THE CARBONATE-ROCK PROVINCE OF THE GREAT BASIN, NEVADA, UTAH, AND ADJACENT STATES

REGIONAL AQUIFER-SYSTEM ANALYSIS

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1409-D

770,000 in 1990. As the number of people in the province increases and surface-water supplies become less available, additional sources of water will be needed. One such source that has been proposed (Hess and Mifflin, 1978) is the water stored in the carbonate rocks beneath much of western Utah and eastern Nevada.

In most other RASA studies, enough information exists for comprehensive model simulations and evaluations of ground-water flow in regional aquifer systems. Although numerous wells have been drilled within the carbonate-rock province, most have been drilled into unconsolidated deposits in the valleys and usually to shallow depths, except at the Nevada Test Site. Thus, little is known about the deeper and more regional ground-water flow in the carbonate rocks. However, because of the greatly increased demand for water and because of the potential for contamination of ground water from underground testing of nuclear weapons at the Nevada Test Site (fig. 2) and from the possible storage and disposal of nuclear and hazardous wastes, an improved understanding of ground-water flow in the province is needed.

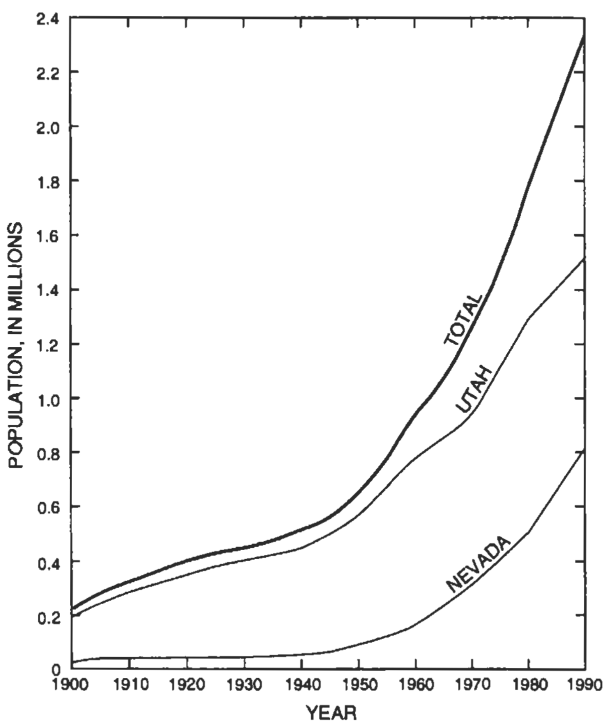

FIGURE 3.—Population growth in study area between 1900 and 1990. Data from U.S. Bureau of Census (1913, 1921, 1952, 1983, 1991a, b).

PURPOSE AND SCOPE

The purpose of this report is to present a conceptual evaluation of ground-water flow in the carbonate-rock province, mainly in Nevada and Utah. The evaluation is based on simulation results using the three-dimensional ground-water flow model of McDonald and Harbaugh (1988). The basic conceptual model for the province includes relatively shallow flow from recharge areas in the mountains to discharge areas in the adjacent valley lowlands, superimposed over deeper, more regional flow through carbonate rocks. The concept is based on theoretical analyses of regional flow by Freeze and Witherspoon (1967, p. 623–634) where, in regions of hummocky terrain, numerous relatively shallow flow systems are superimposed over fewer deeper flow systems. Results of the model analysis include: transmissivity distributions, identification of shallow and deep flow systems, and comparisons of simulated flow and discharge to estimates presented in previous reports.

The original version of this report was published in January 1991 as a U.S. Geological Survey interim Open-File Report and in September 1991 as a U.S. Geological Survey Professional Paper. In November 1991, an error that resulted from an inadvertent coding transposition of the cell-dimension variables DELR and DELC (McDonald and Harbaugh, 1988, chap. 5, p. 8) was discovered. This error produced an unintended regional anisotropy in the model transmissivities (Stillwater and others, 1992). As a result, the model grid cell dimensions have been corrected and the model recalibrated. David E. Prudic did the recalibration and, along with James R. Harrill, has revised the report to reflect changes resulting therefrom. In addition, Donald H. Schaefer and James R. Harrill assisted in checking information used in the model.

PREVIOUS INVESTIGATIONS

Surveys of geologic features in the Great Basin began in the late 1860's under the leadership of Clarence King, J.W. Powell, G.K. Gilbert, A.R. Morvine, and E.E. Howell. Nolan (1943) summarized available geologic information pertaining to the entire Great Basin. Between 1938 and the late 1970's, numerous geologic investigations were completed in the Great Basin region. The results of all these studies and studies before 1938 are summarized on a map of Nevada by Stewart and Carlson (1978), a publication about Nevada by Stewart (1980), and a map of Utah by Hintze (1973). Since 1980, numerous articles have been published that pertain generally to metamorphic core complexes, geophysics, and geologic structure. The hydrogeologic framework of the Great Basin has been described by Plume (1995) as another part of the Great Basin RASA project.

Ground-water investigations within the carbonate-rock province began in the early 1900's. Mendenhall (1909, p. 13) suggested that many of the desert springs in southern Nevada are not dependent on rainfall in the area immediately surrounding the springs but that their source is from distant mountains. Carpenter (1915, p. 18) noted that rocks exposed in the mountains in southeastern Nevada generally act to close the adjacent valleys by making the sides and bottoms of the valleys practically impervious. He did, however, state that several topographically closed valleys higher in altitude than adjacent valleys lose water through fissures in the rocks because water levels in the higher valleys are far below land surface. Meinzer (1917, p. 150) reported that water from a valley near Tonopah, Nev. (fig. 1), leaks through a mountain range into an adjacent valley. These are some of the earliest reports that suggest the possibility of interbasin flow of ground water within the carbonate-rock province.

Few additional ground-water investigations were done until after World War II, when several studies of selected basins commenced. These studies generally focused on recharge and discharge of ground water in individual basins. In the early 1960's, the State of Nevada and the U.S. Geological Survey began systematic reconnaissance studies of all unstudied basins in Nevada to determine potential ground-water supplies. A similar series of investigations began in Utah in 1964. The results of these investigations have been published by the Nevada Department of Conservation and Natural Resources and the Utah Department of Natural Resources, and most are summarized in Eakin and others (1976). These reports provide the basic estimates of recharge and discharge used in this report.

Detailed discussion of interbasin flow also began in the 1960's. Hunt and Robinson (1960) discussed the possibility of interbasin flow into the Death Valley (fig. 1) area on the basis of chemical analysis of water samples from springs and wells. Loeltz (1960) discussed the source of water issuing from springs at Ash Meadows in the Amargosa Desert near Death Valley (fig. 1). Winograd (1962) discussed interbasin movement of ground water at the Nevada Test Site. Winograd (1963) also summarized ground-water flow between Las Vegas Valley and the Amargosa Desert and presented evidence for fault compartmentalization of the aquifers in the region. Eakin and Moore (1964) presented information about the uniformity of discharge at Muddy River Springs in southeastern Nevada (fig. 1) and related it to interbasin movement of ground water. Winograd and Eakin (1965) and Eakin and Winograd (1965) presented evidence and some economic implications of interbasin flow of ground water in south-central Nevada. Hood and Rush (1965) discussed the possibility of interbasin flow of water to and from Snake Valley in western Utah (fig. 1). Eakin (1966) presented information that described interbasin flow in an area in southeastern Nevada that he named the White River area. Shortly afterward, Mifflin (1968) delineated ground-water basins for all Nevada and concluded that interbasin flow of ground water occurs wherever the consolidated rocks in the mountains and beneath the valleys are permeable or wherever the basins are connected by unconsolidated deposits. The area of interbasin flow through permeable consolidated rocks is primarily within the carbonate-rock province. Mifflin and Hess (1979) discussed regional carbonate flow systems in Nevada. Gates and Kruer (1981) discussed regional flow in west-central Utah, and Gates (1984, 1987) discussed regional flow in northwestern Utah and adjacent parts of Idaho and Nevada.

The U.S. Geological Survey began a study in 1981 to evaluate potential hydrogeologic environments for isolation of high-level radioactive waste in the Basin and Range physiographic province of the southwestern United States. The study includes a much larger area than is described in this report. Bedinger and others (1989, 1990) characterized the geology and hydrology of the Death Valley region and the Bonneville region; both areas are included in this study.

The most detailed information regarding ground-water flow in carbonate rocks is at the Nevada Test Site (fig. 2). Detailed studies began in 1957 and included the drilling of several deep test holes into carbonate rocks beneath the unconsolidated and volcanic deposits in the vicinity of the Test Site during 1962–64. Numerous reports have been written about the area. Most of the work from 1957–64 is summarized by Winograd and Thordarson (1975), which is the

Locally, the model results might be improved by increasing transmissivities in northern Kawich Valley to simulate southward flow from southern Railroad Valley. This might reduce simulated evapotranspiration in Penoyer Valley and increase subsurface flow to the Death Valley region. However, locally changing transmissivities during model calibration did not always result in expected changes in simulated discharge. Observations made during the model calibration indicate that increasing the transmissivities in southern Railroad Valley results in a northward shift of the subregion boundary, with an accompanying increase in simulated flow to the south.

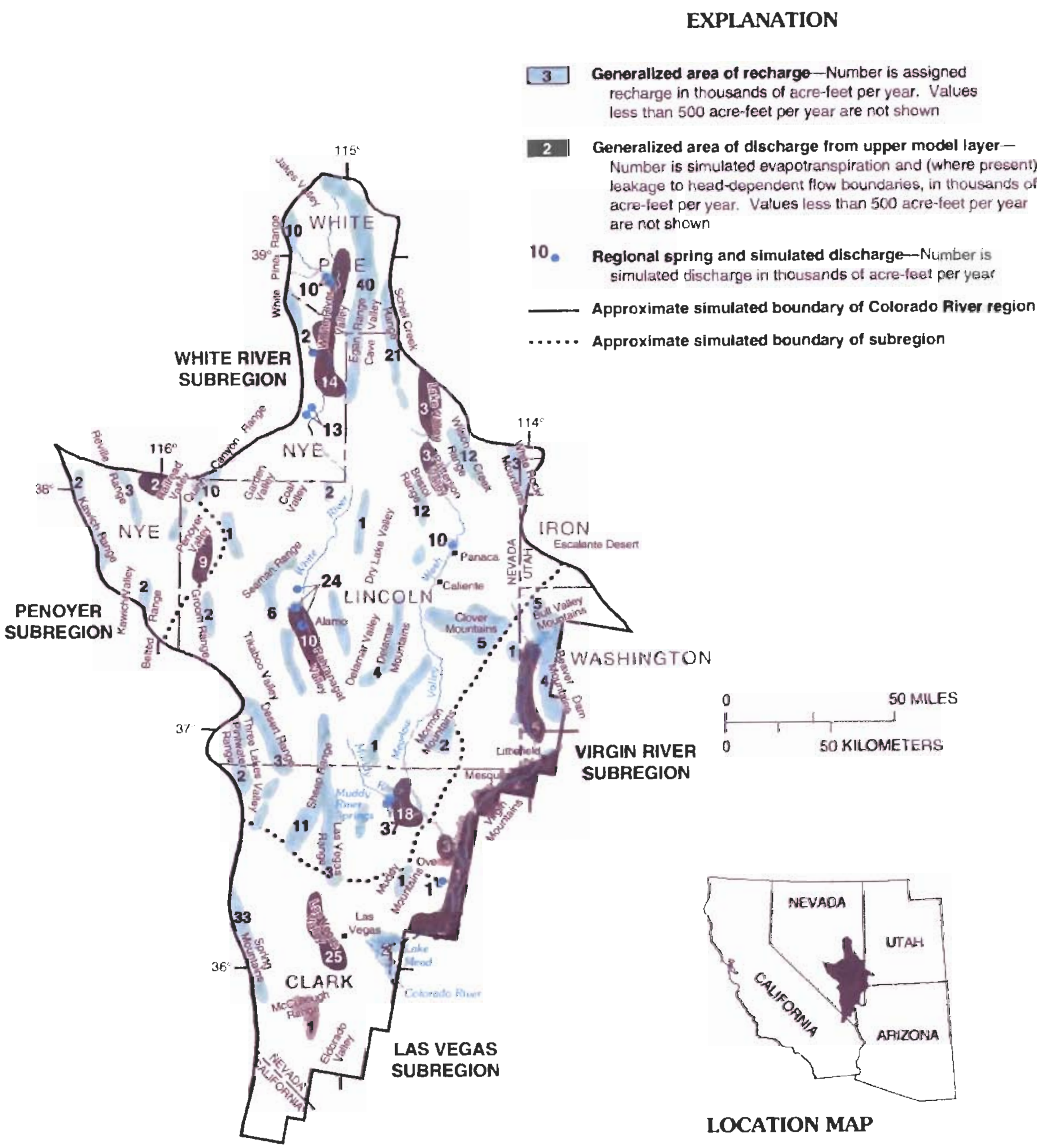

FIGURE 30.—Areas of assigned recharge, simulated discharge from upper model layer, and simulated discharge from regional springs in Colorado River region.

gion, and 1,000 acre-ft/yr from the Las Vegas subregion (table 5).

Outflow from the subregion is primarily discharge to regional springs in the lower model layer, which totals 96,000 acre-ft/yr. Discharge as evapotranspiration from the upper layer is only 47,000 acre-ft/yr. Discharge is simulated in three general areas of the subregion that correspond to mapped areas of ground-water evapotranspiration and to regional spring discharge (Harrill and others, 1988). The three areas are: Patterson and southern Lake Valleys and Panaca Warm Spring in the upper Meadow Valley Wash drainage, White River and Pahranagat Valleys in the White River drainage, and Muddy River Springs (fig. 30). Subsurface outflow to the Bonneville region simulated through the upper layer from the Egan, Schell Creek, and Wilson Creek Ranges (fig. 31) totals about 2,000 acre-ft/yr (table 5). An additional 3,000 acre-ft/yr is simulated as outflow to the Virgin River subregion, and 1,000 acre-ft/yr flows to the Death Valley region near the Pintwater Range (table 5; fig. 31).

Ground-water flow in the subregion is generally from north to south in both model layers (fig. 31), paralleling the Meadow Valley Wash and White River drainages. Simulated flow is west to east near the Sheep Range. More ground-water flow is simulated in the lower layer in the White River subregion than in any other in the study area. Ground-water flow in most other subregions is generally in the upper layer from recharge areas in the mountain ranges to discharge areas in adjacent valleys. In contrast, about 69 percent of the total inflow to the subregion is simulated as inflow to the lower layer. Downward flow from the upper layer to the lower layer totals 113,000 acre-ft/yr. Discussion of flow and comparison of simulated to estimated discharge is separated into three areas—flow along the Meadow Valley Wash and White River drainages, and flow to Muddy River Springs.

Ground-water flow in the lower model layer is simulated from southern Lake Valley into Patterson Valley, then southward to Panaca (fig. 31). Recharge areas contributing flow to Panaca Warm Spring are primarily the Bristol and Wilson Creek Ranges. Overall, simulated discharge in Patterson Valley and at Panaca Warm Spring is about 13,000 acre-ft/yr, which is greater than the 8,500 acre-ft/yr estimated by Rush (1964, p. 19, 22). Minor quantities of evapotranspiration (totaling about 3,000 acre-ft/yr), which have been estimated elsewhere along the axis of Meadow Valley Wash, are not simulated in the model. Simulated evapotranspiration in southern Lake Valley is 3,000 acre-ft/yr. Not all of the simulated discharge in Lake Valley is included in the White River subregion because the valley is bisected by the boundary between the Colorado River and Bonneville regions. When the additional 6,000 acre-ft/yr of evapotranspiration simulated in northern Lake Valley is added to that in southern Lake Valley, total simulated discharge in Lake Valley is approximately the same as the 8,500 acre-ft/yr estimated by Rush and Eakin (1963, p. 13).

South of Panaca, flow is toward Muddy River Springs (fig. 31). Additional flow is added from recharge areas in the Clover, Delamar, and Mormon Mountains (fig. 30). A total of 13,000 acre-ft/yr of underflow is simulated from lower Meadow Valley Wash to the area near Muddy River Springs, of which 9,000 acre-ft/yr is simulated in the upper layer. Estimated shallow underflow from Meadow Valley Wash into the Muddy River drainage just downstream from Muddy River Springs is 7,000 acre-ft/yr (Rush, 1968b, p. 26, 27).

Simulated ground-water flow along the White River is generally southward in both model layers from White River Valley to Pahranagat Valley, then southeast to Muddy River Springs. This flow is consistent with water levels in the area (Eakin, 1966, p. 258; Thomas and others, 1986). Less ground-water flow is simulated through Jakes Valley into White River Valley than was estimated by Eakin (1966, p. 265). He estimated that about 25,000 acre-ft/yr may enter the White River Valley from as far north as Long Valley (location shown on figure 34). Although recharge in mountains adjacent to Jakes Valley is included herein, only 7,000 acre-ft/yr is simulated as underflow from the Jakes Valley drainage basin into the upper end of White River Valley, and no flow is simulated from Long Valley. Simulated flow to White River Valley is from the White Pine and Egan Ranges. Discharge along the White River includes about 25,000 acre-ft/yr from three groups of regional springs simulated in the lower layer near the axis of the valley and 14,000 acre-ft/yr from evapotranspiration simulated in the upper layer (fig. 30). Evapotranspiration from the upper layer includes the flow of small springs not considered part of the regional group in the lower layer. Simulated flow to the northern group of springs and to Mormon Hot Spring is from the Egan Range, whereas flow to the southern group is from both the White Pine and Egan Ranges. Estimated discharge in White River Valley is ground-water budgets indicate interbasin flow. These zones of higher transmissivity may be related to places in the province where thick sequences of Paleozoic carbonate rocks are still present. The highest transmissivities are simulated in narrow bands associated with regional springs in the White River Valley in eastern Nevada, the Muddy River Springs in southern Nevada, and Fish Springs in west-central Utah. Transmissivities less than 0.006 ft^2/s are simulated throughout much of the province. Lowest transmissivities are simulated for the Great Salt Lake Desert, for Death Valley, and for the extreme southern end of the province.

Only one of several extensive east-west-trending lineaments could be correlated with a marked change in the simulated and measured water-level trends. This lineament, called the transverse crustal boundary, extends across southern Nevada. It generally corresponds to the southern extent of Cenozoic volcanism in the province, to a considerable southward decline in the altitude of the valley floor, to a change in gravity, and to the location of left-lateral shears. Except for a narrow zone of high transmissivities in eastern Nevada, assigned values in the lower model layer are less than 0.006 ft^2/s along the lineament.

The lack of correlation of marked changes in simulated water levels and transmissivities, as well as observed water-level trends, across other lineaments north of the transverse crustal boundary might be due to disruption of the lineaments by younger faulting. However, several regional springs are near the lineaments, which suggests that segments along some of the lineaments may restrict regional ground-water flow.

The model simulates the concept of numerous shallow-flow regions superimposed upon fewer deep-flow regions. A total of 45 shallow-flow regions are identified in the upper model layer on the basis of horizontal flow between cells. In the lower layer, flow is grouped into deep-flow regions and subregions. A total of 17 deep-flow subregions are delineated, also on the basis of horizontal flow between cells. The subregions are, in turn, grouped into five deep-flow regions on the basis of areas having simulated water levels that generally decline toward one of five regional discharge areas. These are named the Death Valley, Colorado River, Bonneville, Railroad Valley, and upper Humboldt River regions. Simulated water levels are generally highest in southwestern Utah and east-central Nevada, where altitudes of the valleys floors are highest. From this area, water levels generally decrease northward toward discharge areas in the upper Humboldt River and Bonneville regions and southward toward discharge areas in the Colorado River and Death Valley regions. Within the area of high water levels in east-central Nevada, some of the ground water flows to a terminal sink in Railroad Valley.

Water budgets for each of the deep-flow regions are summarized in table 9. The budgets include flow within the overlying shallow-flow regions. The budgets list cross-boundary flow between regions because cells that straddle a flow-region boundary are assigned to only one of the two regions and because simulated flow in the shallow-flow regions is not everywhere in the same direction as that in the underlying deep-flow regions.

Most of the simulated flow is in the upper model layer. Total simulated inflow is about 1.5 million acre-ft/yr (about 3 percent of the total precipitation), with all but 3,000 acre-ft/yr assigned as recharge to the mountains (table 9). This inflow does not include recharge that is discharged locally—that is, within the same 37.5-mi^2 model cell. If this recharge were included, the estimated total inflow would be considerably more. Simulated outflow is mostly from the upper layer as evapotranspiration (about 1.2 million acre-ft/yr) and as leakage to surface-water bodies and to the Death Valley playa (about 100,000 acre-ft/yr). Most of the simulated flow in the lower layer is in areas of high transmissivities. Flow is downward in recharge areas, then lateral to regional springs or to areas of discharge from the upper layer. Total simulated flow in the lower layer is 428,000 acre-ft/yr, or only 28 percent of total inflow. About half the flow through the lower layer (211,000 acre-ft/yr) is simulated as discharge to regional springs. This simulated total is only 0.5 percent more than the estimated total for the regional springs.

Simulated regional-spring flow is extremely sensitive to changes in transmissivities in both layers and to changes in vertical leakance between layers. For example, increasing transmissivities in the lower layer between Ash Meadows in Amargosa Desert and Death Valley results in less spring flow at Ash Meadows and greater flow to Death Valley. Similar results are simulated at Muddy River Springs in southern Nevada and Fish Springs in west-central Utah when transmissivities are increased downgradient from the springs. Even minor changes to the assigned hydraulic properties can result in changes to the discharge at regional springs. The final assigned distribution