Conceptual Evaluation of Regional Ground-Water Flow in the Carbonate-Rock Province of the Great Basin, Nevada, Utah, and Adjacent States

By David E. Prudic, James R. Harrill, *and* Thomas J. Burbey

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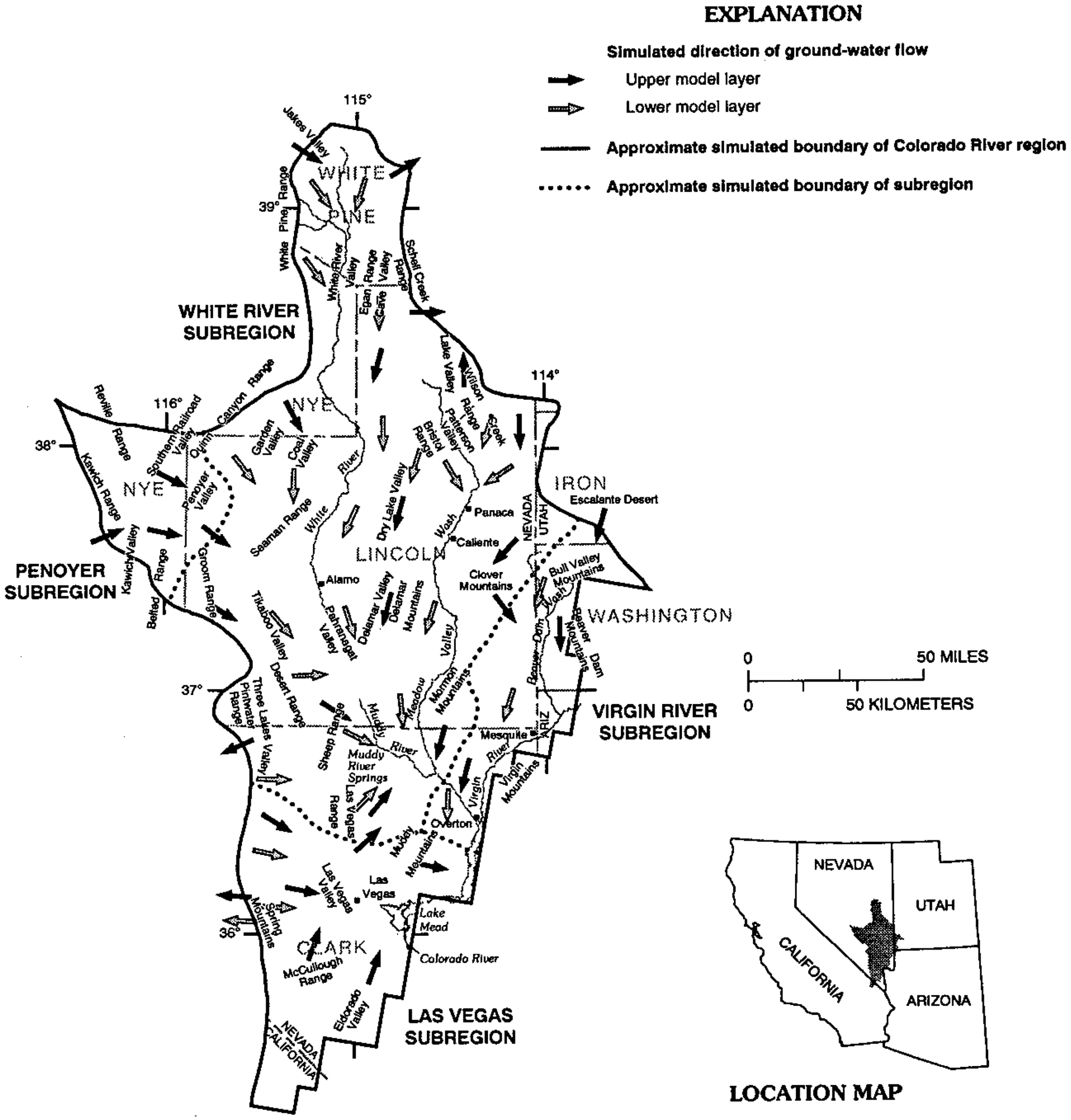

Figure 31. Simulated direction of ground-water flow for both upper and lower model layers in Colorado River region.

Simulated outflow from the subregion totals about 14,000 acre-ft/yr, of which 8,000 is evapotranspiration in the upper model layer, 5,000 is leakage to the Virgin River from the upper layer and 1,200 is discharge to Rogers and Blue Point Springs south of Overton in the lower layer (table 5--value in table differs slightly from table 1 due to rounding). Simulated evapotranspiration in Beaver Dam Wash is about 5,000 acre-ft/yr (fig. 30). An additional 1,200 acre-ft/yr is simulated as leakage at the head-dependent flow boundary cell corresponding to the confluence of Beaver Dam Wash and the Virgin River. Thus, total simulated discharge along Beaver Dam Wash is 6,200 acre-ft/yr. Estimated ground-water discharge in Beaver Dam Wash includes about 150 acre-ft/yr as evapotranspiration and 3,600 acre-ft/yr as leakage to the Virgin River for a total discharge of about 3,800 acre-ft/yr (Glancy and Van Denburgh, 1969, p. 36, 47). Evapotranspiration simulated along the lower Muddy River near Overton is about 3,000 acre-ft/yr--considerably less than the 11,000 acre-ft/yr estimated by Rush (1968b, p. 35; he refers to the area as lower Moapa Valley). Much of the ground-water recharge in this area is from downward seepage of streamflow in the Muddy River, and little is thought to enter the area either as direct recharge from precipitation or as underflow from adjacent areas (Rush, 1968b, p. 23-26). Secondary recharge to the upper model layer of spring flow from Muddy River Springs is not simulated in the model and may account for the difference between simulated and estimated evapotranspiration along the lower Muddy River.

The Virgin River below Beaver Dam Wash also is simulated as a discharge area for ground water flowing from recharge areas north of the river (fig. 31). Some ground water probably seeps into the Virgin River from recharge areas northwest and southeast of the river, but the location and magnitude of this seepage is unknown (Glancy and Van Denburgh, 1969, p. 36). The river reach from Beaver Dam Wash to Lake Mead is generally a losing stream that supplies water to underlying aquifers (Glancy and Van Denburgh, 1969, p. 37). Much of the seepage from the river in this reach is to the adjacent and underlying alluvium, where most of it is discharged by evapotranspiration. Shallow ground water not lost to evapotranspiration moves parallel to the river, and therefore is not included in the model because it is considered local flow.

The principal contribution of ground water to the Virgin River in or near the modeled area is about 50,000 acre-ft/yr of moderately saline water from springs in the channel of the river (Glancy and Van Denburgh, 1969, p. 33, 36). These springs were not specifically included in the model because they are at the model boundary. Discharge from these springs may be ground-water flow beneath the Virgin River as upstream from the springs, the river is a losing stream (Sandberg and Sultz, 1985, p. 25).

Transmissivities in both model layers generally range from 0.0006 to 0.006 ft^2/s. Because transmissivities are nearly the same for both layers, about half of the recharge is simulated as flow to the lower layer. Discharge from the lower layer is primarily to the upper layer along Beaver Dam Wash, the Muddy River, and the Virgin River. Transmissivities assigned to model cells in the vicinity of Beaver Dam Wash perhaps could be increased slightly to reduce the quantity of discharge as evapotranspiration along the wash and increase upward leakage to the Virgin River. Another alternative is to increase the vertical conductance in the head-dependent flow boundary used to simulate leakage to the river.

A zone of higher transmissivities is simulated along the western margin of the subregion, from Rogers and Blue Point Springs (fig. 11) northward to an area between the Mormon Mountains and Beaver Dam Wash (fig. 20). Transmissivities in this zone are based on calibration of spring discharge at Rogers and Blue Point Springs. During model calibration, transmissivities in the lower layer were increased in cells at and north of Rogers and Blue Point Springs. The springs issue from carbonate rocks near the contact with basin fill. Recharge in the adjacent Muddy Mountains (fig. 31) is insufficient to supply all the flow to the springs. Simulated flow to the springs is from the northern part of the subregion. Ground water could potentially flow from Muddy River Springs to Rogers and Blue Point Springs because land surface at the latter springs is about 200 feet less in altitude than that at Muddy River Springs (Thomas and others, 1986, pl. 2). However, differing isotope values for the two spring systems (Thomas and others, 1991, p. 14,19) and the presence of low-permeability rocks near land surface downgradient from Muddy River Springs (Michael D. Dettinger, U.S. Geological Survey, oral commun., 1987) suggest that underflow from those springs is an unlikely source.

White River Subregion

The White River subregion, the largest delineated in the Colorado River region, encompasses about 12,800 mi^2 (fig. 30). The subregion boundary generally corresponds to a shallow-flow-region boundary delineated in the upper model layer (compare figs. 23 and 24). The White River subregion extends farther east and west of the flow system defined by Eakin (1966). The subregion includes Tikaboo Valley and the Pintwater and Desert Ranges to the west, and southern Steptoe Valley, Lake and Patterson Valleys, Meadow Valley Wash, and western Escalante Desert to the east. The subregion, however, does not extend as far north. The subregion extends to southern Jakes Valley, whereas Eakin includes all of Jakes Valley as well as Long Valley (Long Valley is included in the Railroad Valley deep-flow region; figure 34). The northern part of the flow system delineated by Harrill and others (1988) is the same as Eakin's. Their flow system differs to the east and south because they extend their eastern boundary to the Virgin and Colorado Rivers, and extend their southern boundary to the boundary of the study area.

Inflow to the subregion totals 150,000 acre-ft/yr, of which recharge assigned to model cells in the upper model layer is 146,000 acre-ft/yr (table 5); the latter is more than 70 percent of the total for the entire Colorado River region. Principal areas of recharge include the White Pine, Egan, and Schell Creek Ranges in the northern part of the subregion; the Wilson Creek, Bristol, and Quinn Canyon Ranges in the central part; and the Sheep Range in the southern part (fig. 30). The remaining inflow is simulated subsurface flow from adjacent regions and subregions: about 1,000 acre-ft/yr from the Railroad Valley region; 2,000 acre-ft/yr from the Penoyer subregion; 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 basins. 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 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 and 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, and 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 37,000 acre-ft/yr (Eakin, 1966, p. 261), which is only 2,000 acre-ft/yr less than the total simulated discharge from regional springs and evapotranspiration.

Simulated underflow from White River Valley and adjacent Cave Valley (fig. 31) to the south is about 27,000 acre-ft/yr, which is 13,000 acre-ft/yr less than that estimated by Eakin (1966, p. 265). This underflow is toward Pahranagat Valley, where discharge from three regional springs in the lower layer is 24,000 acre-ft/yr and evapotranspiration in the upper layer is 10,000 acre-ft/yr. Estimated spring flow in Pahranagat Valley is about 25,000 acre-ft/yr (table 1 and Eakin, 1966, p. 261), nearly all of which is consumed by evapotranspiration in the valley. Although simulated discharge from springs is nearly the same as the reported spring flow, total discharge from Pahranagat Valley is 9,000 acre-ft/yr more than previously reported. Flow to the northern two springs in Pahranagat Valley is simulated from the White Pine, Egan, and Schell Creek Ranges. Flow to the southern spring (Hiko Spring of Thomas and others, 1986, pl. 2) is simulated from the Quinn Canyon, Seaman, and Schell Creek Ranges.

Simulated underflow from Pahranagat Valley and adjacent Tikaboo Valley (fig. 31) to Muddy River Springs is about 24,000 acre-ft/yr. This flow is about 11,000 acre-ft/yr less than the 35,000 acre-ft/yr estimated as underflow from Pahranagat Valley by Eakin (1966, p. 265). Tikaboo Valley was not included in his conceptualization of flow to Muddy River Springs. More recent studies based on geology, water levels, and deuterium concentrations of water from regional springs in Pahranagat Valley, at Muddy River Springs, and at Ash Meadows (location shown in figure 28) indicate that some ground water from within or near Pahranagat Valley may flow southwest through northern Tikaboo Valley to the regional springs in Ash Meadows (Winograd and Friedman, 1972; Thomas, 1988; Dettinger, 1989; and Kirk and Campana, 1990). Estimates of underflow to Ash Meadows range from about 4,000 acre-ft/yr (Kirk and Campana, 1990, p. 385) to 7,000 acre-ft/yr (Thomas, 1988). Perhaps flow in southern Tikaboo Valley is toward the Muddy River Springs, whereas flow in northern Tikaboo Valley is toward Ash Meadows. Such a possibility is suggested by Harrill and others (1988, pl. 2). Although no flow is simulated from Pahranagat Valley to Ash Meadows, such flow might be simulated by increasing transmissivities between the two places. However, to simulate the estimated spring flow at Ash Meadows, some of the flow from the Spring Mountains to Ash Meadows would need to be diverted either to Las Vegas Valley or Pahrump Valley by decreasing transmissivities in model cells at the north end of the Spring Mountains.

Ground-water flow in the subregion that is not discharged upgradient from the Muddy River Springs is discharged as regional spring flow in the lower layer or as evapotranspiration in the upper layer. Simulated spring flow at Muddy River Springs is 37,000 acre-ft/yr and evapotranspiration along the Muddy River from the springs to the confluence with Meadow Valley Wash is about 18,000 acre-ft/yr. The measured aggregate spring flow is about 36,000 acre-ft/yr (Eakin, 1966, p. 261). The reach of the Muddy River between its source at the springs and Lake Mead is perennial (fig. 31), but only part of the flow reaches Lake Mead. The average annual flow of the Muddy River near its confluence with Lake Mead is about 6,600 acre-ft/yr, which is based on a 12-year period; 1979-83 and 1985-91 (Garcia and others, 1992, p. 72). Much of the streamflow is consumed by evapotranspiration from phreatophytes and irrigated crops or is used for industrial and public supply. A small percentage of the streamflow may seep back into the ground.

Simulated ground-water discharge near Muddy River Springs is about 19,000 acre-ft/yr more than estimated. Perhaps some or all of extra discharge can be accounted for in the uncertainty of estimated evapotranspiration along the river. Another possibility is that some ground water flows through consolidated rocks beneath the river to discharge into Lake Mead. This does not seem likely, however, because low permeability rocks that are near land surface downstream from the springs probably inhibit significant underflow to the lake (Michael D. Dettinger, U.S. Geological Survey, oral commun., 1987).

Simulated upper-layer flow to the area of evapotranspiration at Muddy River Springs includes: 9,000 acre-ft/yr from Meadow Valley Wash; 5,000 acre-ft/yr from the southern Sheep Range; 3,000 acre-ft/yr from Pahranagat and Tikaboo Valleys and the northern Desert, Pintwater, and Sheep Ranges; and 1,000 acre-ft/yr from the Las Vegas subregion. Simulated flow in the lower layer to Muddy River Springs is mainly underflow from Pahranagat and Tikaboo Valleys, and the Sheep, Las Vegas, and southern Desert Ranges. Contributions to regional springs include: 23,000 acre-ft/yr from Pahranagat and Tikaboo Valleys; 8,000 acre-ft/yr from the Sheep, Las Vegas, and southern Desert Ranges; 4,000 acre-ft/yr from Meadow Valley Wash; and 2,000 acre-ft/yr from Delamar Valley.

The sources of water discharging at Muddy River Springs simulated in the model differs from the sources described by Eakin (1966, p. 265). Using imbalances in estimated water budgets for hydrographic areas north of the springs, he estimated only 2,000 acre-ft/yr of flow from the Sheep Range; the rest was ground-water flow through Pahranagat and Delamar Valleys from recharge areas to the north. A difference in concentrations of the deuterium isotope between spring water in Pahranagat Valley and at Muddy River Springs suggests that not all the discharge at Muddy River Springs is from Pahranagat Valley (Winograd and Friedman, 1972). Deuterium concentrations in water from Muddy River Springs are nearly the same as those in high-altitude springs in the Sheep Range and Spring Mountains, which led Winograd and Friedman (1972, p. 3705) to propose that the principal source of water to the Muddy River Springs is the Sheep Range, the Spring Mountains, or both. On the basis of chemical balances of ground water, Thomas (1988) proposed that nearly all recharge in the Sheep Range may discharge at Muddy River Springs, and that ground water beneath the southernmost reach of Meadow Valley Wash may also flow to the springs. Similar conclusions were reported by Kirk and Campana (1990), except they did not suggest as much flow from the Sheep Range to the Muddy River Springs. Because of (1) lack of knowledge regarding the extent of the carbonate-rock aquifers contributing flow to Muddy River Springs, (2) lack of hydraulic properties and water-level gradients in the aquifers, and (3) uncertainties in deuterium concentrations over time and at the different source areas, several areas remain candidate sources of flow to the Muddy River Springs.

Simulated flow to the regional springs is sensitive to the distribution of transmissivities in the lower layer. During model calibration, transmissivities in the lower layer were increased along an axis that generally corresponds to the location of springs in White River and Pahranagat Valleys, and at Muddy River Springs. Transmissivities for the lower layer generally range from 0.006 to 0.18 ft^2/s, but in White River Valley and near Muddy River Springs the values range from 0.18 to 0.66 ft^2/s (fig. 20*B*). The highest transmissivities are concentrated near regional springs; this may be related to locally high flow rates that enhance or maintain openings in the carbonate rocks (Dettinger, 1989, p. 16). Eakin (1966, p. 251) estimated a regional transmissivity value of 200,000 (gal/day)/ft (equivalent to about 0.3 ft^2/s) on the basis of estimated flow across three vertical sections. The zone of higher transmissivities in the lower layer (fig. 25), which acts as a drain for ground water from adjacent areas, generally corresponds to an area of thick carbonate rocks that may be considered the principal aquifers in central and southern Nevada (Dettinger, 1989, p. 13).

Bonneville Region

The Bonneville region, in the northeastern part of the study area (fig. 24), encompasses about 39,000 mi^2--largest of the five regions. It includes six deep-flow subregions in the lower model layer--Escalante, Spring-Steptoe, Ruby, Clover-Independence, Utah Lake, and Great Salt Lake Desert (fig. 32)--and all or part of 23 shallow-flow regions in the upper layer (fig. 23). Ground-water flow is from recharge areas in the mountains to topographically low parts of basins within each subregion. Little flow is simulated between adjacent subregions, even though water levels in most of the Bonneville region generally decline toward the Great Salt Lake Desert or Great Salt Lake.

Inflow

Inflow to the Bonneville region totals about 889,000 acre-ft/yr (table 6), which is considerably more than inflow to the other four deep-flow regions. Recharge assigned to cells in the upper model layer, which constitutes most of the inflow, totals about 855,000 acre-ft/yr. The eastern boundary of the flow region is along mountain ranges that supply large quantities of water to both the southeastern Great Salt Lake area and the Sevier Desert area (fig. 32). Other principal recharge areas include fault-block mountains in extreme eastern Nevada and western Utah. Subsurface flow in both layers from adjacent regions, which totals about 34,000 acre-ft/yr, accounts for only 4 percent of the inflow to the Bonneville region. Much of the subsurface inflow is from the upper Humboldt River region, where about 25,000 acre-ft/yr is simulated along the Ruby Mountains and East Humboldt Range; another 5,000 acre-ft/yr is simulated from the Colorado River region, and 4,000 acre-ft/yr is from the Railroad Valley region. Inflow from the upper Humboldt River region is simulated along the crest of the Ruby Mountains, where boundaries of both the shallow-flow and deep-flow regions are drawn across model cells. Because cells are not subdivided when