CALIFORNIA GEOGRAPHICAL SOCIETY
Volume XXIX, 1989

# Comparison and Evaluation of Ground Water Quality in Surprise Valley and Alturas Basin Using Thornthwaite's Evapotranspiration Model

*Sheryl Luzzadder Beach**

A quarter of a century ago, the California Department of Water Resources undertook an investigation of ground water basins in northeastern California. For more than two decades, California Department of Water Resources Bulletin 98, *Northeastern Counties Ground Water Investigation,*[1] was the major source of information on the area. At the same time, ground water quality studies[2] were also completed for both the Surprise Valley and Alturas Basin in Modoc County, California (Figure 1).

Twenty years later three investigations of northeastern California's ground water were conducted by the Department of Water Resources to update and supplement the original reports. These were *Northeast Counties Ground Water Update*, 1982,[3] *Alturas Basin Ground Water Quality Study*, 1986,[4] and *Surprise Valley Ground Water Quality Study*, 1986.[5] These reports were spawned from concern over then-recent increases in ground water pumping in the areas, declining water levels in wells, and possible impacts on water quality.[6]

Conducting the latter two studies initiated my interest in the comparability of conditions within the respective

**Sheryl Luzzadder Beach is a Ph.D. candidate in geography at the University of Minnesota in Minneapolis.*

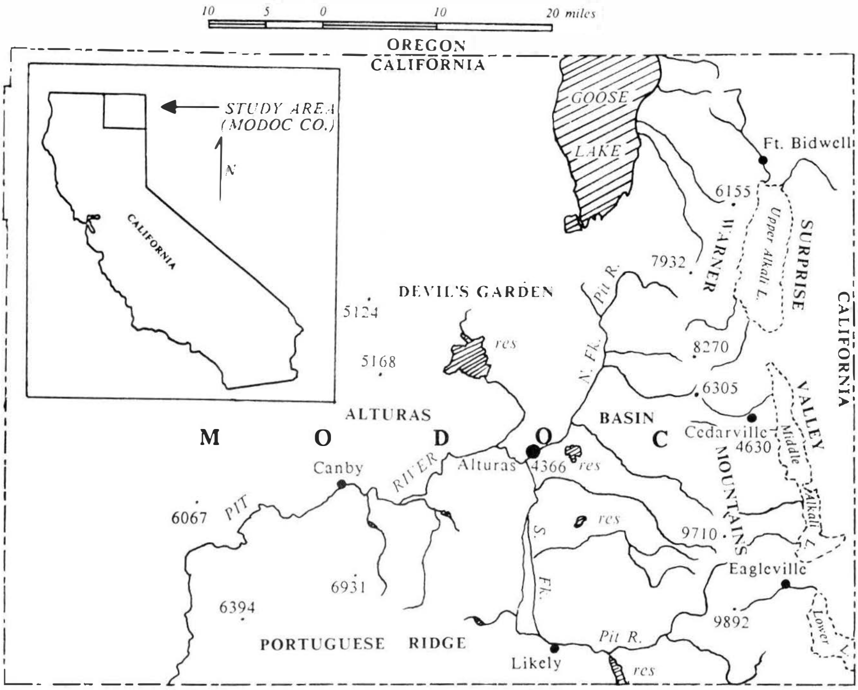


Figure 1. Location map: the Alturas Basin and Surprise Valley portions of Modoc County, California.

ground water basins. While comparing ground water qualities in the two basins, it was initially expected that Surprise Valley would have poorer ground water quality than the Alturas Basin. This assumption was based on the knowledge that Surprise Valley has a drier, hotter climate, is structurally closed, is located in the rainshadow of the 8,000-foot Warner Mountains, and has three alkali lakes gracing its floor. In contrast, Alturas Basin has a milder, more moist climate, has both ground water throughflow and surface water outflow, is on the windward side of the Warners, and has no alkali lakes.

Initial expectations could not be confirmed, however, for comparison of the two ground water basins revealed no significant difference in their respective ground water qualities. In this paper, therefore, it is hypothesized that a ground water flow equilibrium, or balance, exists in the closed basin (Surprise Valley) because of evapotranspiration losses, thus allowing its ground water to exhibit a similar quality to the open basin (Alturas). In an attempt to substantiate this hypothesis, the geographic differences and similarities of the two basins are explored, their relationship to ground water quality is examined, and an explanation is offered for their seemingly similar conditions of ground water quality.

**Study Area: The Alturas Basin and Surprise Valley**

The Alturas Basin is located in south-central Modoc County, northeastern California (Figure 1). The basin is on the windward side of the Warner Mountain Range, and is north and east of the Cascade Range. The Devil's Garden, a major ground water recharge area composed of Plio-Pleistocene Basalt flows,[7] is located north of Alturas Basin (Figure 2). The total area of the Alturas ground water basin is 134 square miles, and the area of its contributing watershed is about 1,430 square miles. The major water bearing formation in the Alturas Basin is the Alturas Formation, which consists of Plio-Pleistocene lake deposits of "tuff, ashy sandstone, gravel and diatomite" up to 1,450 feet thick.[8]

Surprise Valley is situated in eastern Modoc County, as shown in Figure 1. The valley lies in the rainshadow of the Warner Mountain Range, a complex fault block[9] composed of Pliocene and Miocene basaltics and pyroclastics.[10]

Along the fault zone which traces the eastern scarp of the Warners, alluvial fans have developed wherever intermittent streams lose their velocity as they enter the valley (Figure 3). The alluvial fans (up to 1,000 feet thick) and volcanic flows (1,500 feet thick) are the main water bearing formations for the basin.[11] The area of this ground water basin and its contributing watershed is about 350 square miles.

**Climate**

Temperature and precipitation regimes play important rôles in the hydrologic cycles of both basins; but they are

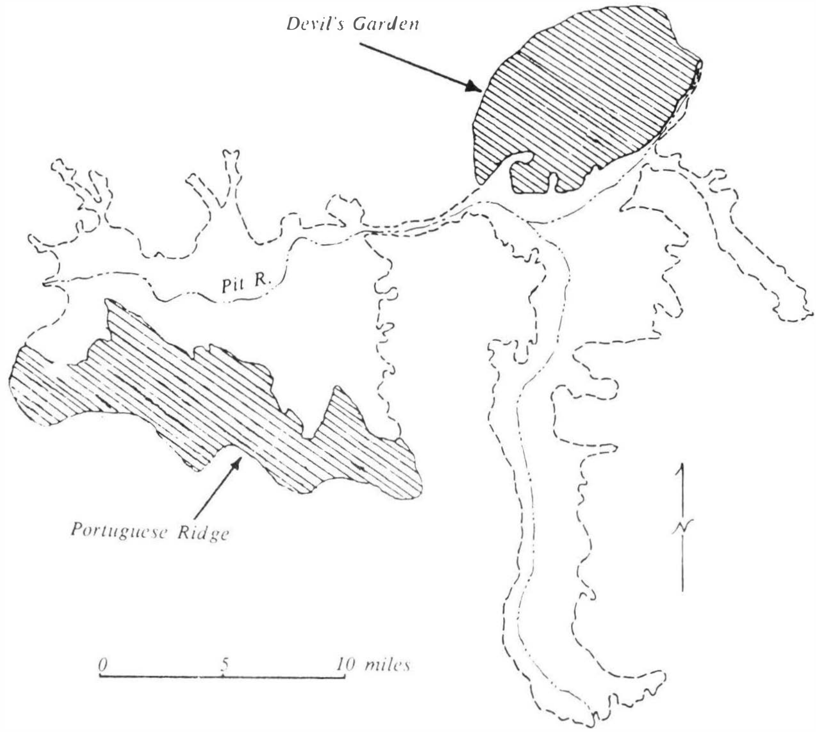


Figure 2. General location of ground water recharge areas in Alturas Basin, California.

especially significant in Surprise Valley, where their effects upon evapotranspiration rates,[11] and, accordingly, on the ground water balance, are extremely important in maintaining ground water quality in Surprise Valley.

Major factors modifying northeastern California's climate are its inland situation and the west to east orographic rainfall pattern of California.[13] In the process of transiting mountainous Northern California, from the Coast Ranges to the Klamath/Siskiyou Mountains and then on to the Cascades, moist Pacific air masses release precipitation. As they rise again and pass over the windward side of the Warners, most of their remaining moisture is lost, leaving essentially dry air to flow down the leeward side into Surprise Valley.[14] At Cedarville-Hanson climatological station in the middle of the valley,[15] mean

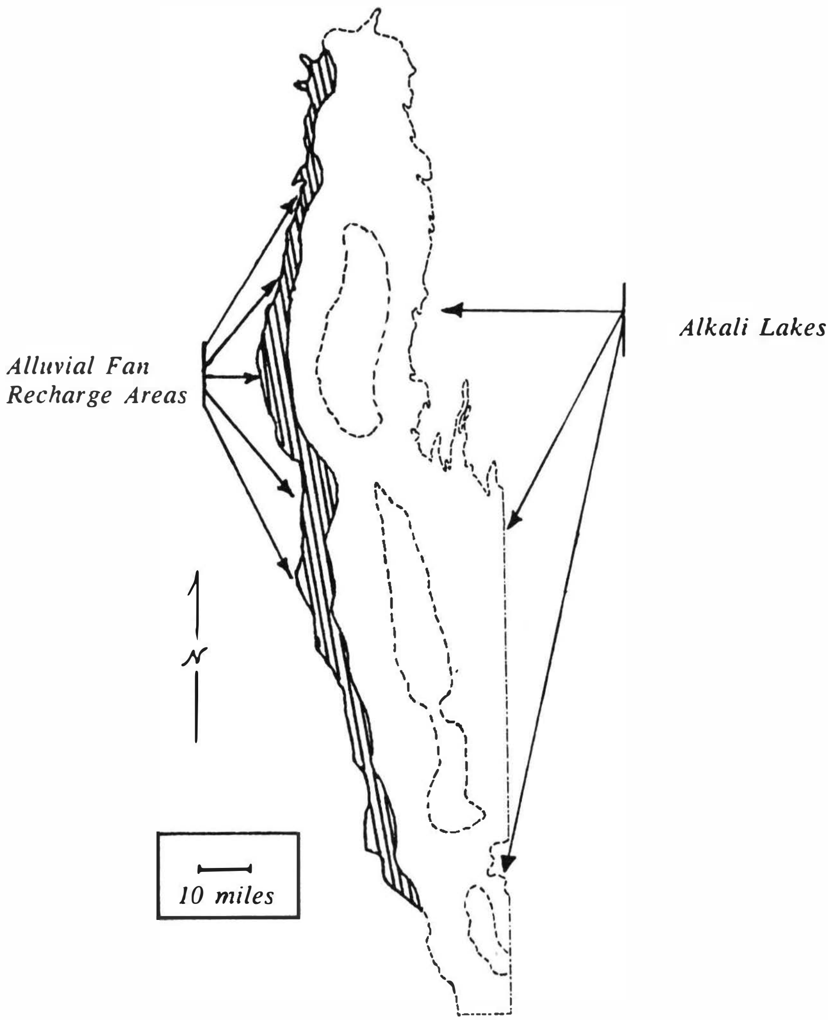


Figure 3. General location of ground water recharge areas in the Surprise Valley, California.

annual total precipitation is about 5.6 inches. Since Surprise Valley's low rainfall period coincides with its summer high temperature period, evapotranspiration may account for considerable water loss from this closed basin.

Because the Alturas Basin is not as dry as Surprise Valley, evapotranspiration is not as great a stress factor upon its water budget. Mean annual precipitation in the Alturas Basin amounts to about 13.4 inches.[16]

The temperature regime of Surprise Valley includes hot summers and cold winters. More extreme summer temperatures combine with the dry conditions to contribute to a greater water loss through evapotranspiration than occurs in the Alturas Basin. The Alturas Basin has a milder temperature regime than does Surprise Valley, with cold winters and warm summers. The January mean monthly temperatures for both basins are quite similar, with Cedarville in Surprise Valley recording 29.8° F as the average, and Alturas 28.6° F. However, Surprise Valley's highest mean monthly temperature is 73° F, higher than Alturas' warmest monthly mean of 66.2° F[17]; both high means occur in July.

**Water Supply**

Snow melt runoff provides the bulk of surface water supply for both basins.[18] Temperature and precipitation regimes determine not only when and where runoff water is released, but also how much of it enters the basins' water budgets. Springtime, therefore, as temperatures rise, is the peak runoff time for both basins. Mean annual runoff in the Alturas Basin has been estimated to be 238,000 acre-feet.[19] Though some water infiltrates to the ground water supply from the Pit River and its tributaries, the main ground water recharge source is the Devil's Garden upland recharge area, immediately north of the basin (Figure 2). Devil's Garden is an area of exposed volcanics. Other upland recharge areas include the western slope of the Warner Range, east of the basin, and the Portuguese Ridge area south of Warm Springs Valley (Figure 2). In 1979, total ground water pumpage in the Alturas Basin was 4,400 acre-feet.[20]

Surprise Valley's mean annual unimpaired runoff is about 174,000 acre-feet.[21] Since the water supply is derived almost entirely from snow melt runoff, minor spring-fed discharges supply the only flow in the latter part of the season. Surface drainage, which ends up in the three alkali lakes, comes from runoff of intermittent streams which drain into the valley from the mountains. Total ground water pumpage for 1980 in Surprise Valley was 52,700 acre-feet.[22] This amount, nearly twelve times that extracted in the Alturas Basin, serves to emphasize Surprise Valley's dependence upon ground water during the dry season, and Alturas' use of ground water to supplement diversion of surface waters for dry season agricultural application.

**Ground Water Quality Study Results**

To facilitate comparison and obtain a general picture of water characteristics for Surprise Valley and the Alturas Basin, historic and current ground water quality data for the two basins were combined. Data were obtained from the California Department of Water Resources' Water Data Information System.[23]

Major water quality elements and measures used in this study include electrical conductivity (E.C.), boron, chloride, sodium, adjusted sodium adsorption ratio, and fluoride. These variables were selected as good indicators of ground water's suitability for beneficial use. Beneficial uses are defined as domestic (human consumption and household use) and agricultural (crop application and animal consumption).

Comparison of these six major water quality parameters showed that median levels in Alturas Basin actually exceed those for Surprise Valley in four cases (Figure 4). This is despite the finding that in five out of six cases the range of levels (including anomalies) was greater for Surprise Valley. The median levels of all parameters for both basins were well below limits set for domestic and agricultural uses.

Ground waters in both basins are similarly bicarbonate in nature.[24] Except for a few specific wells,[25] neither basin showed severe water quality limitations for beneficial uses. Given the physical and geographical differences between the two basins, these unanticipated similarities posed a somewhat more challenging question: How does

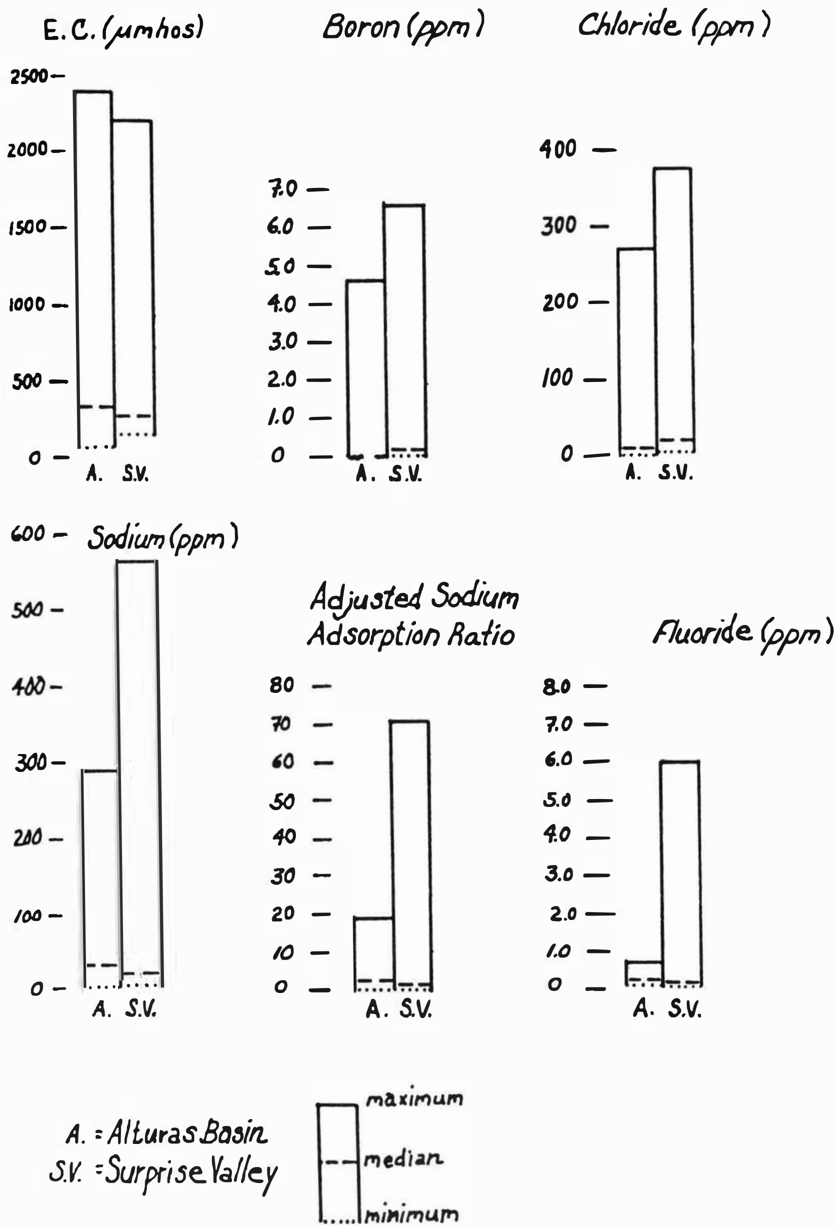


Figure 4. Mineral quality indicators.

one account for good ground water quality in a basin (Surprise Valley) seemingly destined to harbor water of unsatisfactory quality?

**Analysis**

The key to the good mineral quality of ground water in Surprise Valley is linked to relative residence time and also to the quality of waters which recharge the basin. The amount of time ground water spends in an aquifer often defines its character or quality. For example, dissolved gases present in meteoric water which enters the ground can dissolve minerals from the materials and rocks it contacts.[26] Accordingly, it follows that the less time ground water has in residence the smaller chance it has to pick up minerals from its aquifer.

A dilemma arises in this theory when the structure of Surprise Valley is compared to that of the Alturas Basin. Initially, one assumes a shorter relative residence time for the open Alturas Basin, where ground water actually exits the basin. In Surprise Valley, a closed basin in which ground water flows to its center and where there is no apparent outflow, one expects residence time to be longer.

For Surprise Valley, however, there is one major means of exit for ground water that does not involve physical outflow of water from the basin, namely lake surface evapotranspiration. If it can be shown that evapotranspiration from the surface of the three alkali lakes (the accumulation point for ground water in the basin) and ground water withdrawals for irrigation use are roughly equal to the mean annual unimpaired runoff into the basin (within about 10 percent), then one can make some basic assumptions about the flow system, residence time, and resultant quality of Surprise Valley ground water. These assumptions would be:

(1) a steady-state, or equilibrium ground water flow;
(2) shorter residence time due to steady-state throughflow; and
(3) fairly low concentration of dissolved minerals and, therefore, good mineral quality water.

The adjusted potential evapotranspiration for Surprise Valley was calculated using the Thornthwaite Equation (Table 1).[27] Thornthwaite's equation was adopted as an adequate and simple means of estimating the water budget for the basin. More elaborate equations exist, but their use would lend a false precision beyond the scale or

**Table 1. CALCULATION OF POTENTIAL EVAPOTRANSPIRATION FOR SURPRISE VALLEY USING THE THORNTHWAITE EQUATION**

**1931-1960 30-Year Normals for Cedarville Station, Calif.**

| Month | °F | °C | $H_i$ | UPE mm/mo | L | APE mm/mo | APE inches |
|---|---|---|---|---|---|---|---|
| January | 29.1 | −1.6 | — | — | 0.80 | — | — |
| February | 33.6 | 0.9 | 0.075 | 2.63 | 0.81 | 2.13 | 0.08 |
| March | 39.8 | 4.3 | 0.804 | 16.35 | 1.01 | 16.51 | 0.65 |
| April | 48.4 | 9.1 | 2.480 | 38.85 | 1.10 | 42.74 | 1.68 |
| May | 55.3 | 12.9 | 4.199 | 58.23 | 1.24 | 72.21 | 2.84 |
| June | 62.3 | 16.9 | 6.321 | 79.72 | 1.25 | 99.65 | 3.92 |
| July | 73.0 | 22.8 | 9.947 | 112.93 | 1.27 | 142.84 | 5.62 |
| August | 70.4 | 21.3 | 8.973 | 104.34 | 1.17 | 122.08 | 4.81 |
| September | 62.2 | 16.8 | 6.264 | 79.17 | 1.02 | 80.75 | 3.18 |
| October | 50.8 | 10.4 | 3.466 | 43.32 | 0.93 | 42.28 | 1.66 |
| November | 39.0 | 3.0 | 0.686 | 14.48 | 0.80 | 11.58 | 0.46 |
| December | 32.2 | 0.1 | 0.003 | 0.23 | 0.77 | 0.18 | 0.01 |
| Annual Avg. | 49.7 | 9.8 | | | | | |
| Totals | | | 42.9 | | | 632.96 | 24.92 = (2.077 ft.) |

Total Area of Lake Surfaces = 53,654 acres

Lake Surface APE = (53,654 acres x 2.077 ft.) = 111,439 acre feet

KEY TO SYMBOLS: °F = Degrees Farenheit; °C = Degrees Centigrade; $H_i$ = multiplication factor; UPE mm/mo = Unadjusted Potential Evapotranspiration in millimeters/month; L = adjustment factor for latitude and day length; APE = Adjusted Potential Evapotranspiration, in millimeters/month and in inches/month.

scope of data sources for this study. A graphic example of the relationship of rainfall income versus adjusted potential evaporation in Surprise Valley emphasizes the importance of evapotranspiration in the water budget for the valley (Figure 5).

Surprise Valley adjusted potential evapotranspiration totalled 24.9 inches per unit of area. The total area of lake surfaces was determined to be 53,654 acres. This means that a total of 111,439 acre-feet of adjusted potential evapotranspiration is possible from valley lake surfaces. When combined with 1980 ground water withdrawals of 52,700 acre-feet[28] for irrigation, this amounts to an estimated total loss of 164,139 acre-feet of ground water (Table 2).

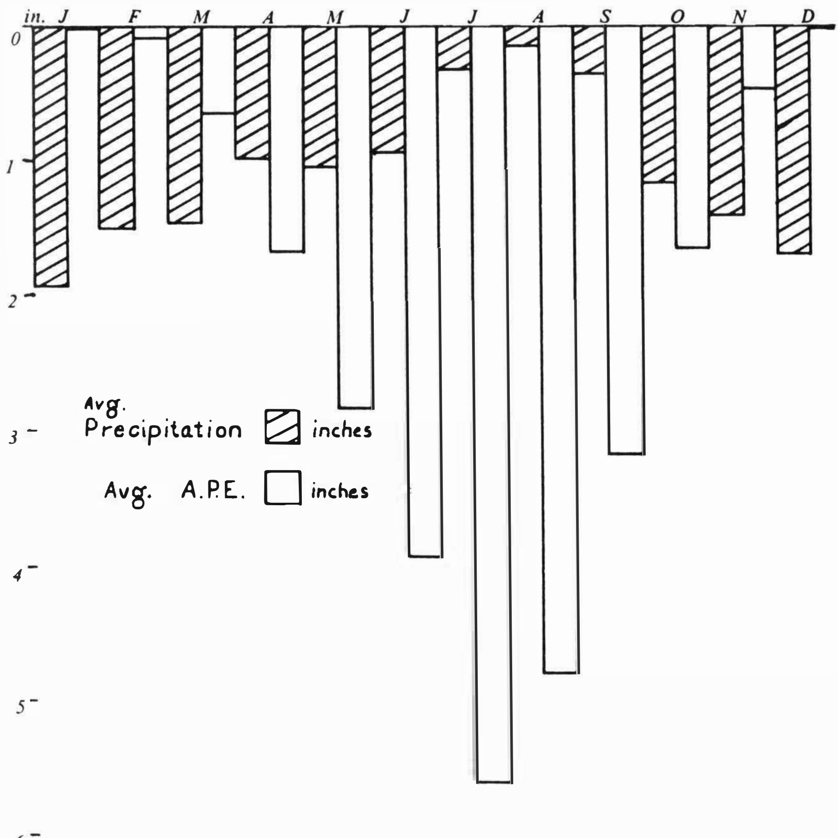


Figure 5. Surprise Valley average water budget in inches.

**Table 2. WATER BALANCE IN THE SURPRISE VALLEY GROUND WATER BASIN**

**Mean Annual Unimpaired Runoff = 174,300 acre feet[1]**

| | |
|---|---|
| Total Ground Withdrawal for Irrigation[2] | – 52,700 acre feet |
| APE from Surface of Lakes | – 111,439 acre feet |
| Estimated Total Losses | + 164,139 acre feet |
| Inflow | + 174,300 acre feet |
| Outflow | – 164,139 acre feet |
| Difference | + 10,161 acre feet |

[1]CDWR, 1986b

[2]For the year 1980, from CDWR, 1982

The mean annual unimpaired runoff for Surprise Valley is 174,300 acre-feet[29]; deducting estimated total loss from that figure yields a surplus of 10,161 acre-feet, or a difference between inflow and outflow of slightly less than 6 percent. Assuming a margin of error of plus or minus 10 percent, no closer estimate of this flow relation-ship can be made using Thornthwaite's model.[30]

Other basin water losses beyond the scope of Thornthwaite's equation include evapotranspiration from soil, native vegetation, and stream surfaces, as well as surface water diversions for irrigation. These losses are in addition to calculated losses and contribute to the margin of error.

## Conclusions and Recommendations

On the basis of this analysis, it can be concluded that ground water quality in Surprise Valley is maintained by virtue of a water balance sufficient to allow the lakes, rather than the aquifers, to serve as the prime areas of accumulation. Additionally, since much of the basin's recharge water infiltrates through the well-sorted structure of the west-side alluvial fans, it enters the system already well-filtered.

Development of the ground water resources of Surprise Valley may be approaching its reasonable limits, as the current flow state appears to be near equilibrium. Though the ground water quality of Surprise Valley is comparable to that of the Alturas Basin, further development could upset the flow balance, in the process changing not only ground water quality, but also depleting the quantity available for beneficial use. Further, any mining of water from alluvial fan recharge areas will decrease the amount of excellent, low-mineral content water available for recharging the ground water basin, as well as for diluting waters with higher potential mineral content which reside near the center of the basin.

Any further development of either Alturas or Surprise Valley ground water resources (whether to supplement limited surface water supplies or to increase pumpage) should be preceded by a careful study of impacts upon the resource. In the case of the Alturas Basin, downstream ground water basins which are recharged by it must have their needs and possible impacts considered whenever Alturas ground water use or distribution plans are developed. Indeed, in order to preserve their rates of recharge and qualities, the recharge areas in both basins must be protected from extensive development.

Though the general quality of ground water in both basins is good, problem wells do exist.[31] They should be taken into consideration in any planning or development ventures in the areas. Further modelling of their respective hydrologic budgets would provide information on how future development will affect the ground water qualities of the two basins. Regular monitoring of the quality and quantity of ground waters in both basins is essential for developing a firm data base for future studies.

## NOTES

1. California Department of Water Resources, *Northeastern Counties Ground Water Investigation*, Bulletin 98, Vol. I (Sacramento: California State Printing Plant, 1963).

2. California Department of Water Resources, "Surprise Valley Water Quality Investigation," Office Report (unpublished, 1960), and California Department of Water Resources, "Water Quality Investigation: Alturas and Warm Springs Valley Basins," Office Report (unpublished, 1960).
3. California Department of Water Resources, *Northeast Counties Ground Water Update*, Report (Sacramento: California State Printing Plant, 1982).
4. California Department of Water Resources, *Alturas Basin Ground Water Quality Study*, Report (Sacramento: California State Printing Plant, January, 1986).
5. California Department of Water Resources, *Surprise Valley Ground Water Quality Study*, Report (Sacramento: California State Printing Plant, January, 1986).
6. Op. cit., note 4, p. 1; and note 5, p. 1.
7. Sheryl Luzzadder Beach, "Comparative Geographic Evaluation of Water Quality in the Surprise Valley and Alturas Ground Water Basins, 1982-83" (University of Minnesota: unpublished M.A. Thesis, 1984), pp. 5, 9.
8. Op. cit., note 4, p. 2.
9. David W. Lantis, Rodney Steiner, and Arthur Karinen, *California: Land of Contrast*, Third Edition (Dubuque, Iowa: Kendall/Hunt Publishing Company, 1977), p. 20.
10. Op. cit., note 5, pp. 2-3.
11. Op. cit., note 5, pp. 7-8.
12. C. W. Fetter, *Applied Hydrogeology* (Columbus, Ohio: Charles E. Merrill Publishing Co., 1980), pp. 18-19.
13. Op cit., note 4, p. 2; and note 5, p. 4.
14. Op. cit., note 5, p. 4.
15. Op. cit., note 7, p. 11.
16. Op. cit., note 4, p. 2.
17. Op. cit., note 4, pp. 2, 4; and note 5, p. 4.
18. Op. cit., note 4, p. 5; and note 5, p. 5.
19. Op. cit., note 4, p. 5.
20. Op. cit., note 4, p. 4.
21. Op. cit., note 7, p. 4.
22. Op. cit., note 5, p. 5.
23. California Department of Water Resources, *Water Data Information System* (Sacramento, California: CDWR Computer sec-

tion, 1984). W.D.I.S. is California's water resources computer Geographic Information System, the contents of which are published biannually on microfiche, mainly for State Agency use.

24. Op. cit., note 4, p. 20; and note 5, p. 18.
25. Op. cit., note 4, pp. 21-22; and note 5, pp. 19-20.
26. Op. cit., note 4, p. 11; and note 5, p. 9.
27. Op. cit., note 7, p. 64.
28. Op. cit., note 7, p. 63.
29. Op. cit., note 7, p. 16.
30. Op. cit., note 12, p. 19.
31. Op. cit., note 4, pp. 20-24; and note 5, pp. 18-20.