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SIMULATION OF GROUNDWATER FLOW IN A REGIONAL CARBONATE-ALLUVIAL SYSTEM WITH SPARSE DATA: THE WHITE RIVER FLOW SYSTEM, SOUTHEASTERN NEVADA

by

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TABLE 4. ESTIMATED RECHARGE.

Basin	Eakin (1966) (a-f/yr)	Scenario 1 (a-f/yr)	Scenario 2 (a-f/yr)	Scenario 3 (a-f/yr)
Long Valley	10,000	-	-	5,000
Jakes Valley	17,000	23,000	21,000	18,000
White River Valley	37,000	35,000	35,000	35,000
Coal/Garden Valleys	10,000	11,000	11,000	11,000
Cave Valley	14,000	11,000	14,000	11,000
Pahroc Valley	2,200	2,000	2,000	2,000
Dry Lake Valley	5,000	7,500	5,000	7,500
Kane Springs Valley	-	1,000	1,000	1,000
Delamar Valley	1,000	2,000	1,500	2,000
Pahranagat Valley	2,000	1,500	1,500	1,500
Coyote Spring Valley	2,600	5,000	6,000	5,000
Lower Meadow Valley	8,000*	4,500	8,000	4,500
Total	108,800	103,500	106,000	103,500

* = from Rush (1964), since Eakin (1966) excluded this valley from his White River system.

TABLE 5. SYSTEM BOUNDARY RECHARGE CONCENTRATIONS.

Cell	Scenario 1 (permil δD)	Scenario 2 (permil δD)	Scenario 3 (permil δD)
1	-124.0	-124.0	-126.0*
2	-124.0*	-124.0*	-124.0
3	-113.0	-112.0	-124.0*
4	-113.0*	-112.0*	-113.0
5	-113.0	-113.0	-113.0*
6	-110.5*	-104.0	-113.0
7	-110.5	-104.0	-110.5*
8	-104.0	-104.0*	-110.5
9	-103.0	-102.0	-104.0
10	-103.0*	-102.0*	-103.0
11	-102.0	-100.0*	-103.0*
12	-102.0*	-97.0	-102.0
13	-100.0*	-87.0*	-97.0*
14	-96.0	-87.0	-100.0*
15	-87.0*	-89.0*	-97.0
16	-87.0	-89.0*	87.0*
17	-89.0*	-93.0*	-87.0
18	-89.0*	-	-89.0*
19	-93.0*	-	-89.0*
20	-	-	-93.0*

* = carbonate cell

TABLE 6. FLOW DISTRIBUTIONS - SCENARIO 1.

Outflow Cell	Fraction of Cell's Outflow (%)	Volumetric Outflow (a–f/yr)	Inflow Cell
1	99	15,840	2*
1	1	160	3
5	1	100	3
2*	100	22,840	4*
4*	25	6,960	3
3	100	12,220	7
4*	34	9,470	6*
5	48	4,800	8
8	1	130	7
7	81	12,430	6*
7	19	2,920	9
6*	19	4,920	10*
9	80	7,930	10*
6*	38	9,840	13*
8	31	3,970	13*
11	100	7,000	12*
12*	100	11,000	13*
13*	100	26,800	18*
10*	100	16,850	18*
14	100	7,500	20*
20*	3	225	18*
20*	97	7,275	21*
16	100	2,000	21*
21*	5	460	18*
18*	36	16,500	19*
21*	95	8,810	19*
15*	100	1,000	19*
19*	100	31,320	22*
17*	100	4,500	22*

* = carbonate cell

NOTES:
Outflow/Inflow Cell 11 = Cave Valley
Outflow/Inflow Cell 20 = Dry Lake Valley
Outflow/Inflow Cell 21 = Delamar Valley

TABLE 7. FLOW DISTRIBUTIONS - SCENARIO 2.

Outflow Cell	Fraction of Cell's Outflow (%)	Volumetric Outflow (a-f/yr)	Inflow Cell
1	80	8,800	2*
1	15	1,650	3
1	5	550	5
2*	100	18,800	4*
5	1	110	3
5	51	5,380	6
6	1	130	3
4*	21	6,260	3
3	3	425	7
3	70	9,900	11*
3	27	3,820	13*
4*	4	1,190	8*
7	82	6,090	8*
4*	1	300	11*
6	35	4,680	11*
9	100	8,000	10*
10*	100	14,000	11*
11*	100	30,900	16*
8*	100	11,280	16*
12	100	5,000	18*
18*	10	500	16*
18*	90	4,500	19*
14	100	1,500	19*
19*	20	1,200	16*
16*	40	18,150	17*
19*	80	4,800	17*
13*	100	4,820	17*
17*	100	33,770	20*
15	100	8,000	20*

* = carbonate cell

NOTES:
Outflow/Inflow Cell 9 = Cave Valley
Outflow/Inflow Cell 18 = Dry Lake Valley
Outflow/Inflow Cell 19 = Delamar Valley

TABLE 8. FLOW DISTRIBUTIONS - SCENARIO 3.

Outflow Cell	Fraction of Cell's Outflow (%)	Volumetric Outflow (a-f/yr)	Inflow Cell
1*	100	5,000	2
2	99	15,840	3*
2	1	160	4
6	1	100	4
3	100	22,940	5*
5*	25	6,990	4
4	100	12,250	8
5*	34	9,500	7*
6	48	4,800	9
9	1	130	8
8	81	12,450	7*
8	19	2,920	10
7*	19	4,930	11*
10	80	7,940	11*
7*	38	9,860	14*
9	31	3,970	14*
12	100	7,000	13*
13*	100	11,000	14*
14*	100	26,830	19*
11*	100	16,870	19*
15	100	7,500	21*
21*	3	225	19*
21*	97	7,275	22*
17	100	2,000	22*
22*	5	460	19*
19*	37	16,980	20*
22*	95	8,810	23*
16*	100	1,000	20*
20*	100	22,980	23*
18*	100	4,500	23*

* = carbonate cell

NOTES:
Outflow/Inflow Cell 12 = Cave Valley
Outflow/Inflow Cell 21 = Dry Lake Valley
Outflow/Inflow Cell 22 = Delamar Valley

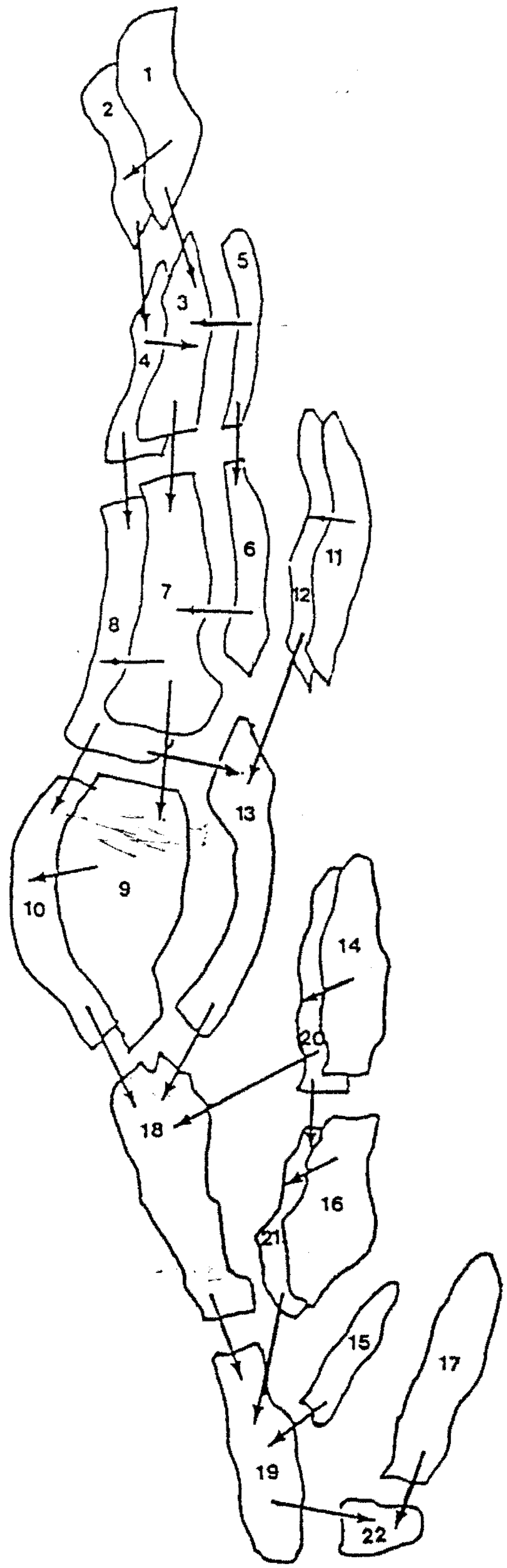

FIGURE 11. Flow Distributions for WRFS Scenario 1.

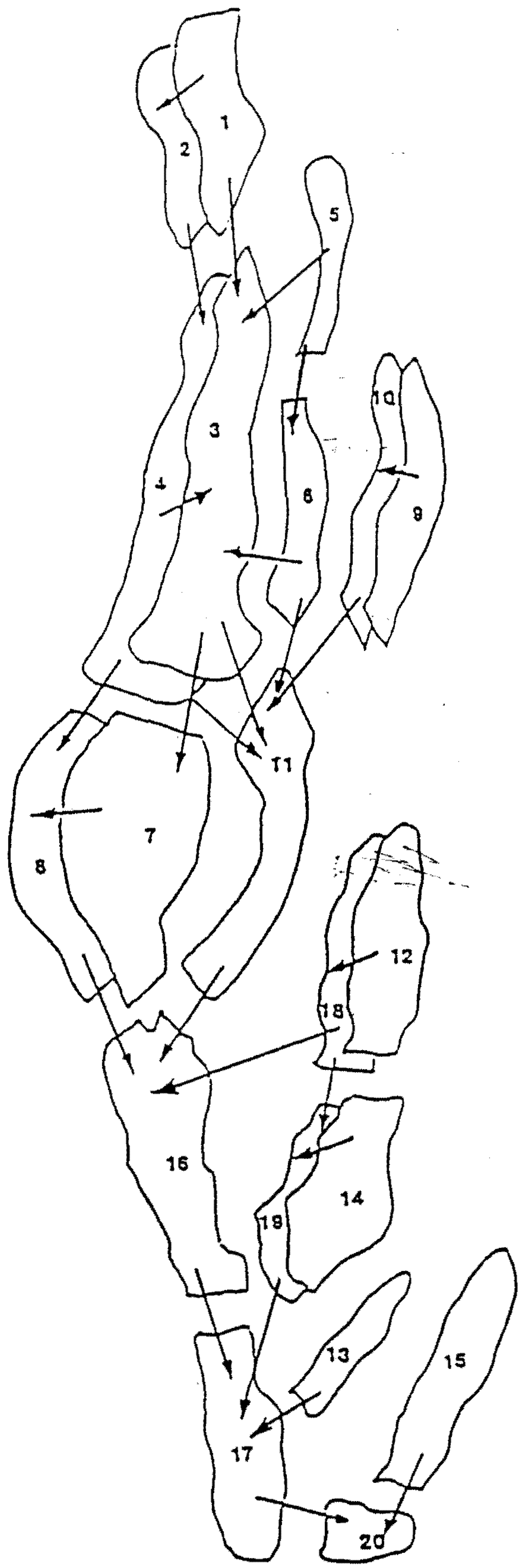

FIGURE 12. Flow Distributions for WRFS Scenario 2.

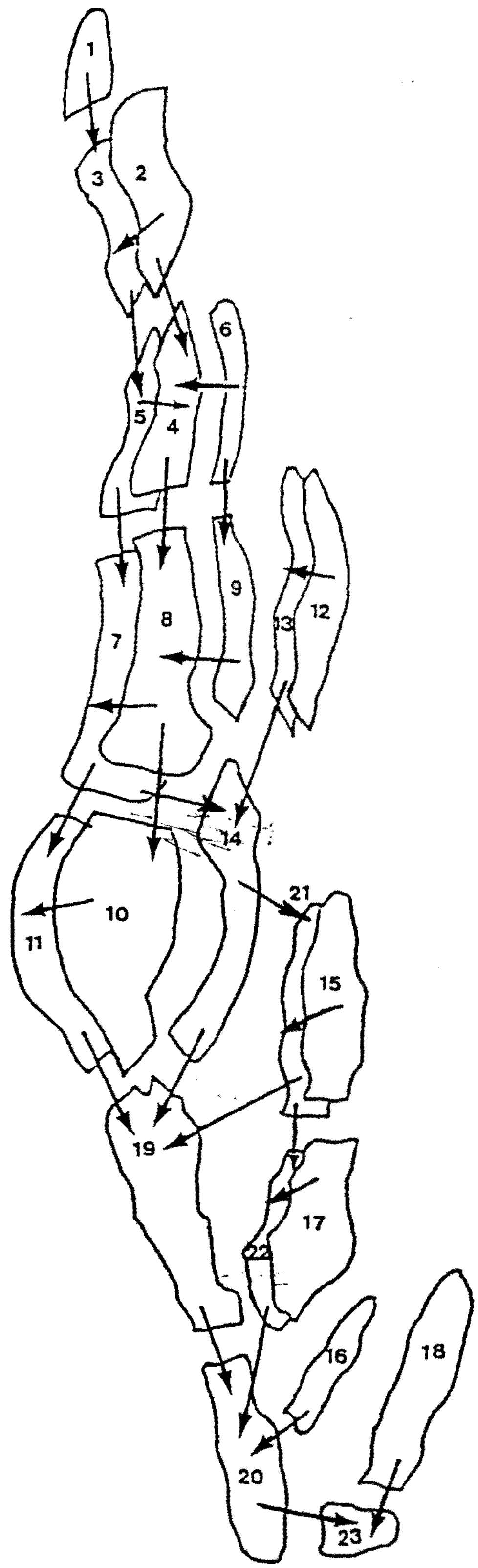

FIGURE 13. Flow Distributions for WRFS Scenario 3.

RESULTS

STEADY INPUT ASSUMPTION

For the first set of calibrations, the SBRC and SBRV values were assumed to be time invariant (steady input). Results of these calibrations are given in Table 10. Steady-state was reached after 8,000 iterations with an iteration interval of 20 years. Calibration was achieved when the model-derived deuterium values agreed to within 2 permil of the observed deuterium values which had been assigned to each cell, since the analytical error in deuterium determinations is ±1 permil. Figure 14 shows the locations of observed deuterium values in the system and Appendix 3 lists those springs and wells used for determining the observed deuterium values. In some instances there was a trade-off and calibration within 2.5 permil was the best fit attained.

Following calibration of the three scenarios with maximum estimated cell volumes, minimum cell volumes were used with the calibrated input files for the three scenarios. Results were identical to Table 10 with the exception of those cells listed in Table 11. These results indicate that an overall reduction in cell volumes does not significantly alter the calibration.

DISCUSSION OF STEADY INPUT RESULTS

After numerous trial and error computer runs, scenario 1 was calibrated by: 1) diverting 4,400 a-f/yr from the system along the Pahranagat Shear Zone, as hypothesized by Winograd and Friedman (1972); 2) specifying 5,000 a-f/yr of recharge from the Sheep Range to Coyote Spring Valley (cell 19*); 3) including 4,500 a-f/yr of underflow from Lower Meadow Valley (cell 17*) into Upper Moapa Valley (cell 22*); 4) increasing recharge to Dry Lake Valley to 7,500 a-f/yr, 50 percent more than the Maxey-Eakin estimate; 5) increasing the recharge to Delamar Valley from 1,000 to 2,000 a-f/yr; and 6) allowing most (8,810 a-f/yr) of the combined groundwater flow from Dry Lake and Delamar Valleys to discharge at Coyote Spring (cell 19*).

The following were required to calibrate scenario two: 1) dividing the western half of White River Valley into two cells, 3 and 4*, with an upward vertical hydraulic gradients from cell 4* to 3; 2) allowing discharge from alluvial cell 3 to the carbonate cell of Pahroc Valley (13*); 3) specifying that underflow from cell 4* to cell 8* of Coal/Garden Valleys is about 24 percent of the corresponding flow distribution in scenario 1 (1,200 and 4,920 a-f/yr, respectively); 4) discharging 3,700 a-f/yr from the system along the Pahranagat Shear Zone; 5) permitting groundwater flow of 4,800 a-f/yr from Delamar Valley to Coyote Spring Valley (as opposed to the 8,810 a-f/yr adopted in scenario 1; 6) specifying 6,000 a-f/yr of recharge from the Sheep Range to Coyote Spring Valley (cell 17*); 7) allowing 8,000 a-f/yr of groundwater to flow from Lower Meadow Valley (cell 15*) into Upper Moapa Valley (cell 20*); and 8) diverting about 3,000 a-f/yr from the system as underflow from Upper Moapa Valley into Moapa Valley. Scenario 2 represents the maximum amounts of recharge from the Sheep Range and underflow from Lower Meadow Valley.

Scenario 3 used the calibrated inputs of scenario 1, along with the introduction of 5,000 a-f/yr of underflow from Long Valley (cell 1*) and a corresponding decrease in recharge assigned to Jakes Valley (cell 3*). Calibration was achieved by decreasing the SBRC of cell 15 (Dry Lake Valley) by 2 permil and diverting 38 percent of cell 7's BDV into cell 14* (Pahroc Valley).

In summary, results of the steady input assumption have shown that for both maximum and minimum cell volumes, calibration required: 1) the diversion of groundwater outside the WRFS from Pahranagat Valley; 2) an increase in recharge from the Sheep Range; and 3) the introduction of underflow from Lower Meadow Valley into Upper Moapa Valley. The greatly increased recharge from the Sheep Range is supported by a water budget of Las Vegas Valley by Harrill (1979), who estimated that 2,000 a-f/yr of recharge from the Sheep Range flows to Las Vegas Valley, leaving the remaining estimated 9,300 a-f/yr of recharge available to Coyote Spring Valley and Desert Valley, which is just west of the Sheep Range. The attribution of underflow from Lower Meadow Valley into Upper Moapa Valley is based upon reconnaissance work by Rush (1964), who estimated that 8,000 a-f/yr is discharged out of Lower Meadow Valley as underflow. Finally, it is feasible that a certain percentage of groundwater which enters Upper Moapa Valley is not discharged at Muddy River Springs, but subsequently flows into Moapa Valley.

MEAN AGES

Mean ages for scenarios 1, 2, and 3 are listed in Tables 12 (maximum cell volumes) and 13 (minimum cell volumes). Figures 15, 16, and 17 depict the mean ages for scenarios 1, 2, and 3 with maximum cell volumes; Figures 18, 19, and 20 present the mean ages for scenarios 1, 2, and 3 with minimum cell volumes.

SUMMARY AND CONCLUSIONS

SUMMARY

The WRFS has been delineated with a deuterium-calibrated DSC model. This study has addressed the following: 1) alternative system boundaries; 2) estimates of storage volumes in a two-aquifer system (alluvial/carbonate); 3) alternative flow distributions among cells; and 4) transient and steady input assumptions for system boundary recharge volumes (SBRV) and concentrations (SBRC).

Issues central to the calibration of the WRFS DSC model include: 1) the observed δD differences between Pahranagat Valley springs and carbonate wells in Coyote Spring Valley; 2) a 3 permil difference between carbonate wells in Coyote Spring Valley and Muddy River Springs in Upper Moapa Valley; and 3) existence of underflow from Long Valley to Jakes Valley. In order to resolve the observed deuterium values, it was necessary to: 1) introduce underflow out of the system along the Pahranagat Shear Zone; 2) greatly increase Eakin's (1966) estimate of recharge to Coyote Spring Valley from the Sheep Range; and 3) introduce underflow from Lower Meadow Valley into Upper Moapa Valley.

Three different cell configurations (composed of 22, 20, and 23 cells) were calibrated with the following assumptions: 1) maximum thicknesses of alluvial and carbonate cells of 2,000 and 10,000 feet, with effective porosities of 15 percent and 3 percent, respectively; 2) minimum estimated alluvial and carbonate cell thicknesses of 1,000 and 5,000 feet, with effective porosities of 15 percent and 1.5 percent, respectively; and 3) paleoclimatically-induced shifts of deuterium and recharge inputs of -8 permil and +35 percent, respectively.

The following points summarize the most important aspects of calibrating the three scenarios, assuming maximum cell volumes with steady inputs:

1. scenario 1 was calibrated by introducing a minimum of 5,000 a-f/yr of recharge from the Sheep Range, 4,500 a-f/yr of underflow from Lower Meadow Valley, and 4,400 a-f/yr of underflow out of the system via the Pahranagat Shear Zone;

2. scenario 2 was calibrated by adopting a maximum of 6,000 a-f/yr of recharge from the Sheep Range, 8,000 a-f/yr of underflow from Lower Meadow Valley, and 3,700 a-f/yr of underflow out of the system via the Pahranagat Shear Zone; and
3. scenario 3 was calibrated by using the calibrated input file of scenario 1 with the exception of inclusion of 5,000 a-f/yr of underflow from Long Valley into Jakes Valley and a corresponding decrease in recharge to Jakes Valley.

Following calibration of the three scenarios to maximum cell volumes, cell volumes were reduced to one-half and one-fourth of the maximum volumes of the alluvial and carbonate aquifers, respectively. Results indicated that calibration was maintained. The first round of calibrations demonstrated that even without an input of isotopically light paleowaters into the system, it was necessary to introduce isotopically heavy recharge waters from the Sheep Range and underflow from Lower Meadow Valley. The amount of additional recharge and underflow were dependent upon the volume of groundwater which was allowed to flow from Dry Lake and Delamar Valleys into Coyote Spring Valley.

Age information was also provided by the DSC model. Groundwater mean ages and median ages were quite different in the cases presented, and groundwater age distributions indicated that the oldest waters in the system exceed 100,000 years old. This number is not the "age" of the system, but merely indicates that some of the waters in the WRFS were recharged over 100,000 years ago, far older than the climatic changes considered even in the transient input cases.

The second round of calibrations assumed transient inputs (SBRC and SBRV) and maximum cell volumes. Initially, the calibrated steady inputs were used. The following summarize the changes made to achieve calibration:

1. scenario 1 was calibrated by introducing a minimum of 6,500 a-f/yr of recharge from the Sheep Range, 9,000 a-f/yr of underflow from Lower Meadow Valley, and and a reduction of recharge to Jakes Valley from 23,000 to 15,000 a-f/yr;
2. scenario 2 was calibrated by increasing the SBRC to the middle portion of the system and diverting 90 percent (9,300 a-f/yr) of the groundwater from Dry Lake and Delamar Valleys into Coyote Spring Valley; and
3. scenario 3 was calibrated by adopting the calibrated inputs of scenario 1 with the exception of the introduction of underflow from Long Valley and a 2 permil increase in the SBRC for Dry Lake Valley.

Thus, the second round of calibrations demonstrated that introducing isotopically light recharge waters for only 7 percent of the total iterations dramatically changed the model derived deuterium values for scenario 1 and only minimally altered model output for scenario 2. Calibration of scenario 1 required the adoption of the calibrated input parameters of steady input parameters of scenario 2. In other words, it was necessary to greatly increase the SBRV to Coyote Spring Valley and underflow from Lower Meadow Valley.

Although the transient input assumption did not consider recharge from or discharge to a perennial White River or pluvial lakes in Dry Lake, Cave, and Coal Valleys, it does lend further support to the fact that is is necessary to: 1) divert isotopically light waters from the middle portion of the system; 2) greatly increase recharge to Coyote Spring Valley; and 3) introduce underflow from Lower Meadow Valley to Upper Moapa Valley.

The third round of calibrations assumed minimum cell volumes and transient inputs (SBRV and SBRC). Initially, the calibrated input files for the second round of calibrations was used for scenarios 1 and 2. The following summarize some of the changes made to achieve calibration:

1. scenario 1 was calibrated by increasing the SBRV to Jakes Valley by 4,000 a-f/yr and reducing the SBRV to Cave Valley by 3,000 a-f/yr;

2. scenario 2 calibration was achieved by reducing the SBRC to Jakes Valley to -125.0 permil; and

3. scenario 3 was calibrated by adoption of calibrated scenario 1 with the exception of inclusion of 5,000 a-f/yr of underflow from Long Valley to Jakes Valley.

Since the volumes of carbonate cells were reduced by a factor of four and alluvial cells by a factor of two, isotopically light paleowaters had almost been flushed from the upper portion of the system.

The following points summarize the similarities which the three scenarios had in common:

1. recharge from the Egan Range to the White River Valley is to the alluvial aquifer only;

2. vertical hydraulic gradients are downward in the alluvial aquifers in all basins but the White River Valley;

3. groundwater flows out of the system along the Pahranagat Shear Zone;

4. recharge to Coyote Spring Valley is about 100 percent higher than Eakin's (1966) recharge estimate; and

5. underflow occurs from Lower Meadow Valley to Upper Moapa Valley.

Tables 16 and 17 review the ranges in the various parameters for the steady input case.

CONCLUSIONS

A great many results, not all of them consistent, have been presented in this report. What is the truth? The authors' knowledge of and experience with both the White River Flow System and DSC models lead them to the following conclusions.

1. The steady input simulations are more meaningful than the transient ones. In reality, the system is transient, but at this juncture, the paucity of data renders the transient results less reliable than the steady ones. Transient simulations require more information than steady ones, and without sufficient data, the number of degrees of freedom in a DSC model becomes

TABLE 16. RANGES IN PARAMETERS FOR CARBONATE CELLS.

Parameter	Scenario 1	Scenario 2	Scenario 3
Recharge Volumes (10^4 a-f/yr)	3.80	4.95	4.30
Storage Volumes (10^8 a-f)	1.4 to 5.6	1.4 to 5.6	1.5 to 6.1
Mean Ages (years)	1,100 to 25,000	1,100 to 34,000	1,600 to 24,800

TABLE 17. RANGES IN PARAMETERS FOR ALLUVIAL CELLS.

Parameter	Scenario 1	Scenario 2	Scenario 3
Recharge Volumes (10^4 a-f/yr)	6.55	5.65	6.05
Storage Volumes (10^8 a-f)	2.1 to 4.2	2.1 to 4.2	2.1 to 4.2
Mean Ages (years)	800 to 19,200	800 to 26,000	800 to 19,200

oppressive. The transient simulations have been included simply to indicate some possibilities for future work.

2. The maximum volume cases seem to be "closer to reality" than the minimum volume cases.

3. Each of the three scenarios seems equally plausible. The scenarios are not really all that different in gross characteristics. If one does not wish to believe that Long Valley belongs in the WRFS, then scenario 3 can be eliminated. The authors do not believe that Long Valley should be eliminated yet.

With the above previous information in mind, the following conclusions can be reached:

1. recharge from the Sheep Range to Coyote Spring Valley is about 100 percent greater than what Eakin (1966) calculated;

2. Lower Meadow Valley is part of the WRFS;

3. underflow on the order of 4,000 a-f/yr exits the system to the west along the Pahranagat Shear Zone;

4. total recharge to the system is slightly over 100,000 a-f/yr and in each scenario, the alluvial system receives more recharge than the carbonate system;

5. maximum storage in the carbonate system is 610 million acre-feet (maf) and minimum is about 140 maf;

6. maximum storage in the alluvial system is 420 maf and minimum is about 210 maf;

7. maximum storage figures are probably closer to reality than the minimum ones; and

8. the age of the oldest groundwater exceeds 100,000 years old.

The lack of certainty in the estimates exists not because of some flaw in the DSC model or the approach used, but the lack of data. Additional data, should it ever be collected, will greatly assist in constraining some of the estimates produced in this report; indeed, the model results have indicated what must be done in terms of data collection. Despite this uncertainty, the WRFS DSC model has demonstrated its usefulness in describing a complex regional flow system and more fully utilizing deuterium data than do most typical stable isotope studies.