*Journal of Hydrology*, 119 (1990) 357–388
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands



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# A DEUTERIUM-CALIBRATED GROUNDWATER FLOW MODEL OF A REGIONAL CARBONATE–ALLUVIAL SYSTEM

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(Received March 22, 1989; accepted after revision December 16, 1989)

## ABSTRACT

Kirk, S.T. and Campana, M.E., 1990. A deuterium-calibrated groundwater flow model of a regional carbonate–alluvial system. J. Hydrol., 119: 357–388.

The White River Flow System (WRFS), a regional carbonate–alluvial groundwater system in southeastern Nevada, U.S.A., contains large amounts of water in storage, especially in the underlying carbonate reservoir. As the population of Nevada grows, it may become necessary to tap the resources of this and other regional carbonate systems. Because of the depth to the carbonate reservoir and, until now, lack of motivation to collect detailed hydrogeological data on it, the state of knowledge of flow in the carbonate system is poor. However, a simple mixing-cell flow model of the WRFS can be constructed and calibrated with the spatial distribution of the stable isotope deuterium. This type of model subdivides the system into carbonate and alluvial cells and routes water and deuterium through the entire cell network. It provides estimates of recharge rates, groundwater ages and volumes of water in storage. Transience in recharge rates and their deuterium signatures are unaccounted for by the model.

The lack of constraints on the system mandates the calibration of three different flow scenarios, each of which differs slightly from the other. Despite these differences, some consistent quantitative results are obtained. Foremost among these are: (1) the carbonate aquifer may contain as much as 752 $km^3$ of water in storage; (2) recharge from the Sheep Range to Coyote Spring Valley is at least 90% greater than previously believed; (3) Lower Meadow Valley is part of the WRFS and contributes underflow to Upper Moapa Valley; (4) underflow with an average value of 0.163 $m^3 s^{-1}$ flows westward out of the system along the Pahranagat Shear Zone; (5) recharge to the alluvial system is greater than that to the carbonate system; (6) groundwater mean ages range from 1600 to 34 000 years, with the oldest waters exceeding 100 000 years old. The results also demonstrate that deuterium can be used to calibrate simple flow models and provide groundwater ages.

Despite the uncertainties and lack of constraints in mixing-cell models, they provide first approximations to information which, until now, has been difficult, if not impossible, to obtain. These models are especially useful for analyzing sparse-data systems, testing different flow hypotheses with minimal effort, providing ranges in parameter estimates, guiding future data collection and serving as precursors for the development of more sophisticated models.

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small (20%) relative to the total volume of recharge estimated for Long Valley. Eakin's (1966) original model of the WRFS included Long Valley in the system. Although recent potentiometric mapping in the alluvial aquifer by Thomas et al. (1985) concluded that Long Valley is not part of the system, this does not preclude the possibility that the carbonate aquifer of Long Valley contributes to regional flow in the WRFS. Other than inclusion of Long Valley, scenario 3 is similar to scenario 1.

*Cell volumes*

Thicknesses of the Paleozoic carbonates exceed 9000 m locally in the WRFS. Estimates of the thicknesses of the carbonate and alluvial aquifers are difficult because of lack of deep borehole data, although some geophysical data were available. We assumed thicknesses of 3050 m for the carbonate cells and 610 m for the alluvial cells. Effective porosities for the carbonate and alluvial aquifers were assumed to be 3 and 15%, respectively. These cell volumes (area × thickness × porosity) for all scenarios are listed in Table 1; carbonate

TABLE 1

Cell volumes for Scenarios 1, 2 and 3

| Cell no. | Scenario 1 ($10^9 m^3$) | Scenario 2 ($10^9 m^3$) | Scenario 3 ($10^9 m^3$) |
|---|---|---|---|
| 1 | 38.297 | 38.297 | 58.839* |
| 2 | 38.297* | 38.297* | 38.297 |
| 3 | 63.931* | 136.468 | 38.297* |
| 4 | 63.931* | 136.468* | 63.931 |
| 5 | 19.198 | 19.198 | 63.931* |
| 6 | 72.550* | 24.044 | 19.198 |
| 7 | 72.550 | 107.912 | 72.550* |
| 8 | 24.044 | 107.912* | 72.550 |
| 9 | 107.912 | 49.937 | 24.044 |
| 10 | 107.912* | 49.937* | 107.912 |
| 11 | 49.937 | 52.452* | 107.912* |
| 12 | 49.937* | 97.160 | 49.937 |
| 13 | 52.452* | 18.865* | 49.937* |
| 14 | 97.160 | 47.421 | 52.452* |
| 15 | 18.865* | 18.865* | 97.160 |
| 16 | 47.421 | 54.807* | 18.865* |
| 17 | 18.865* | 66.261* | 47.421 |
| 18 | 54.807* | 97.160* | 18.865* |
| 19 | 66.261* | 47.421* | 54.807* |
| 20 | 97.160* | 0.543* | 66.261* |
| 21 | 47.421* | | 97.160* |
| 22 | 0.543* | | 47.421* |
| 23 | | | 0.543* |
| Totals | 1209.451 | 1209.302 | 1268.288 |

* Carbonate cell.

cells are designated by an asterisk, a convention that will be used throughout this paper. We feel that these cell volumes are reasonable given the few data, and represent 'average' values. Should more detailed information become available, it can be easily incorporated into the model. It should be noted that the cell volume equals the volume of water in a given cell.

*System boundary recharge volumes*

The SBRV estimate for each boundary cell was based initially on recharge estimates calculated by the Maxey–Eakin method of recharge estimation. Table 2 shows the calibrated SBRV for each cell used in the three scenarios; Table 3 shows the recharge estimates on a hydrographic basin basis for each scenario and the corresponding estimate from Eakin (1966). The amount of recharge assigned to the carbonate cells is speculative, as virtually no quantitative estimates of mountain block recharge have been reported in the literature.

*System boundary recharge concentrations*

Each SBRV in the model is assigned a characteristic isotopic signature or system boundary recharge concentration. Table 4 shows the estimated SBRC

TABLE 2

Calibrated system boundary recharge volumes for Scenarios 1, 2 and 3

| Cell no. | Scenario 1 ($m^3 s^{-1}$) | Scenario 2 ($m^3 s^{-1}$) | Scenario 3 ($m^3 s^{-1}$) |
|---|---|---|---|
| 1 | 0.626 | 0.430 | 0.196* |
| 2 | 0.274* | 0.391* | 0.430 |
| 3 | 0.196 | 0.235 | 0.274* |
| 4 | 0.196* | 0.430* | 0.196 |
| 5 | 0.391 | 0.391 | 0.196* |
| 6 | 0.156* | 0.313 | 0.391 |
| 7 | 0.117 | 0.274 | 0.156* |
| 8 | 0.313 | 0.156* | 0.117 |
| 9 | 0.274 | 0.313 | 0.313 |
| 10 | 0.156* | 0.235* | 0.274 |
| 11 | 0.274 | 0.078* | 0.156* |
| 12 | 0.156* | 0.196 | 0.274 |
| 13 | 0.078* | 0.039* | 0.156* |
| 14 | 0.293 | 0.059 | 0.078* |
| 15 | 0.039* | 0.313* | 0.293 |
| 16 | 0.078 | 0.059* | 0.039* |
| 17 | 0.176* | 0.235* | 0.078 |
| 18 | 0.059* | — | 0.176* |
| 19 | 0.196* | — | 0.059* |
| 20 | — | — | 0.196* |

* Carbonate cell.

TABLE 3

Recharge to WRFS hydrographic basins

| Hydrographic basin | Eakin (1966) ($m^3 s^{-1}$) | Scenario 1 ($m^3 s^{-1}$) | Scenario 2 ($m^3 s^{-1}$) | Scenario 3 ($m^3 s^{-1}$) |
|---|---|---|---|---|
| Long Valley | 0.391 | — | — | 0.196 |
| Jakes Valley | 0.665 | 0.900 | 0.822 | 0.704 |
| White River Valley | 1.448 | 1.369 | 1.369 | 1.369 |
| Coal/Garden Valleys | 0.391 | 0.430 | 0.430 | 0.430 |
| Cave Valley | 0.548 | 0.430 | 0.548 | 0.430 |
| Pahroc Valley | 0.086 | 0.078 | 0.078 | 0.078 |
| Dry Lake Valley | 0.196 | 0.293 | 0.196 | 0.293 |
| Kane Springs Valley | — | 0.039 | 0.039 | 0.039 |
| Delamar Valley | 0.039 | 0.078 | 0.059 | 0.078 |
| Pahranagat Valley | 0.078 | 0.059 | 0.059 | 0.059 |
| Coyote Spring Valley | 0.102 | 0.196 | 0.235 | 0.196 |
| Lower Meadow Valley | 0.313* | 0.176 | 0.313 | 0.176 |
| Totals | 4.257 | 4.049 | 4.147 | 4.049 |

* From Rush (1964).

TABLE 4

System boundary recharge concentrations

| Cell | Scenario 1 (‰ $\delta D$) | Scenario 2 (‰ $\delta D$) | Scenario 3 (‰ $\delta D$) |
|---|---|---|---|
| 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.