USGS
science for a changing world

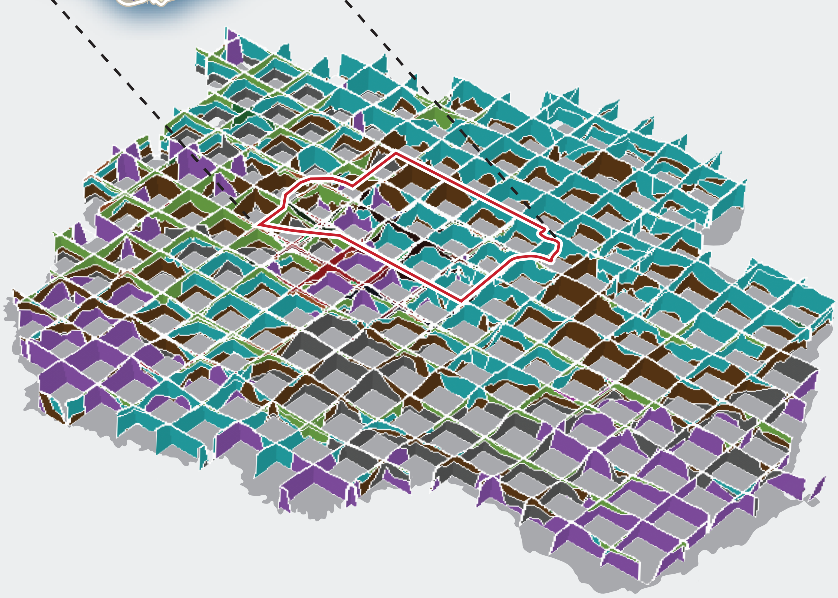
Prepared in cooperation with U.S. Department of Energy

Office of Environmental Management, National Nuclear Security Administration, Nevada Site Office, under Interagency Agreement DE–AI52–01NV13944,

Office of Civilian Radioactive Waste Management, under Interagency Agreement DE–AI28–02RW12167, and

Department of the Interior, National Park Service

Death Valley Regional Groundwater Flow System, Nevada and California—Hydrogeologic Framework and Transient Groundwater Flow Model



Professional Paper 1711

U.S. Department of the Interior
U.S. Geological Survey

Death Valley Regional Groundwater Flow System, Nevada and California—Hydrogeologic Framework and Transient Groundwater Flow Model

Edited by Wayne R. Belcher and Donald S. Sweetkind

Prepared in cooperation with the
U.S. Department of Energy

Office of Environmental Management, National Nuclear Security Administration, Nevada Site Office,
under Interagency Agreement DE–AI52–01NV13944,

Office of Civilian Radioactive Waste Management,
under Interagency Agreement DE–AI28–02RW12167, and

Department of the Interior, National Park Service

Professional Paper 1711

U.S. Department of the Interior
U.S. Geological Survey

by an HFB at the location of the fault. Although some pumping has occurred periodically for water supply and tests associated with the hydrogeologic characterization of Yucca Mountain, little drawdown is observed at a regional scale.

Model Evaluation Summary

The evaluation of the DVRFS transient model described on the preceding pages indicates that the model simulates observed values reasonably well. The three-dimensional aspects of the flow system are simulated with downward hydraulic gradients in recharge areas and upward hydraulic gradients in discharge areas. Most wells are in discharge areas and as a result, observations and hydrographs are biased to show upward hydraulic gradients.

Pumping from both shallow and deeper layers of the model is imposed early in the transient simulation. Simulation of increased pumping, mostly from the shallow layers for stress periods corresponding to the 1950s and 1980s, resulted in local drawdown cones and reversals of hydraulic gradients. Most of the pumpage has come from groundwater storage in the system (fig. F–39). A small amount of flow comes from a decrease in discharge at ET areas and springs (mostly in Pahrump Valley). The model underestimates this decrease in natural discharge in Pahrump Valley (fig. F–40).

Generally, the simulated boundary flows matched the estimated boundary flows well within their estimated error. Changes in flow across the model boundary segments with time are negligible, indicating that the effects of pumping have not reached the model boundary.

Evaluation of model fit on the basis of weighted residuals of heads and discharges reveals one or more types of model error: (1) Large positive weighted residuals for some head observations in steep hydraulic-gradient areas indicate that simulated heads in these areas are significantly lower than the observations, (2) large negative weighted residuals for groundwater discharge rates in Death Valley indicate that the simulated discharge rate is greater than the observations, (3) large positive weighted residuals for groundwater discharge rates at Sarcobatus Flat indicate that the simulated discharge is smaller than the observations, and (4) positive weighted residuals for groundwater discharge rates in Pahrump Valley in the transient simulations indicate that the simulated discharge rates are greater than the observations.

Model Improvements

The transient model is based on up-to-date geologic and hydrogeologic framework models of the regional flow system. The models represent an intensive integration and synthesis of the available hydrogeologic data and interpretations for the DVRFS.

Data and Data Analysis

The DVRFS groundwater flow model described in this report reflects the current representation of hydrogeologic and hydrologic data for the region. This current understanding affects nearly every aspect of the flow system and improves the constraints on the conceptual and numerical flow models. Improvements in data and data analysis include:

- More detailed description and delineation of the basin-fill units over the entire DVRFS model domain, particularly in the Amargosa Desert,
- Increased understanding of the volcanic-rock stratigraphy at the NTS and Yucca Mountain based on recent drilling,
- Evaluation of recharge using surface-process modeling,
- More accurate and comprehensive measurement of natural groundwater discharge (ET and spring flow),
- More complete compilation and analysis of hydraulic-head and pumpage data, especially in areas not included in previous models, and
- Evaluation of boundary inflows and outflows, resulting in a more realistic depiction of the flow system than in previous conceptual models.

Model Construction and Calibration

In addition to advances in data collection, compilation, and analysis, the ways in which these data were applied in the modeling process also represent significant advances in simulating hydrogeologic systems. For example:

- The DVRFS model simulates transient, long-term regional-scale changes in hydraulic heads and discharges that result from pumpage.
- Using the HUF package allowed the HGUs to be defined independently of model layers, linking the HFM and the flow models more directly. This linkage facilitated testing many different conceptual models.

Model Limitations

All models are based on a limited amount of data and thus are necessarily simplifications of actual systems. Model limitations are a consequence of uncertainty in three basic aspects of the model, including inadequacies or inaccuracies in (1) observations used in the model, (2) representation of geologic complexity in the HFM, and (3) representation of the groundwater flow system in the flow model. It is important to understand how these characteristics limit the use of the model.

Observation Limitations

Observations of hydraulic-head and groundwater discharge, and estimates of boundary flows, constrain model calibration through parameter estimation. Uncertainty in these observations introduces uncertainty in the results of flow-model simulations. Although head and discharge observations were thoroughly analyzed prior to and throughout calibration, there was uncertainty regarding (1) the quality of the observation data, (2) appropriateness of the hydrogeologic interpretation, and (3) the representation of observations in the flow model.

Quality of Observations

The clustering of head observations limits the flow model because it results in the overemphasis of many observations in isolated areas, thus biasing those parts of the model. Outside the Yucca Mountain, NTS, Amargosa Desert, and Pahrump Valley areas, water-level data are sparse, both spatially and temporally. A method of better distributing weights for these situations would reduce model uncertainty.

Some hydraulic-head observations used in the steady-state calibration likely are affected by pumping. Many observations in agricultural areas represent measurements made in pumping wells. Because many of the wells in the Amargosa Desert and Pahrump Valley were drilled at the start of, or after, groundwater development, it is difficult to assess which of these observations best represents prepumping conditions.

The errors in estimates of the model boundary flow also affect the accuracy of the model. Any unknown, and thus unsimulated, flow diminishes model accuracy, and improving the boundary-flow estimates can reduce model uncertainty.

Interpretation of the Observations

It is difficult to assess whether certain head observations represent the regional saturated-zone or local perched-water conditions. Areas of steep hydraulic gradient, which are important features in the regional groundwater flow system, also may be an artifact of perched water levels. The uncertainty used to weight head observations in recharge areas commonly was increased because large head residuals indicated the possibility of perched water. Decreasing the number of observations, or reducing observation weights, increased model uncertainty. Further evaluation of potentially perched water levels in these areas may help to reduce model uncertainty.

Most discharge observations were computed on the basis of vegetated areas, and it is assumed that these areas are similar to their size prior to groundwater development. In some areas, such as Pahrump Valley, this assumption may not be entirely valid because local pumping already had lowered water levels and decreased the size of the discharge areas. The uncertainty in the discharge observations increases uncertainty in the flow model.

Representation of Observations

Because of the small distance affected and comparably large grid-cell size, simulating drawdowns near wells with small pumpage rates (less than 700 m^3/d) was difficult because the cones of depression are small relative to the size of the model grid. This limitation may be resolved by creating a higher resolution model, lowering the weights on the observations, or by removing these head-change observations from the model.

The altitude assigned to drains affected the ability of the model to simulate groundwater conditions accurately. The altitude of drains used to simulate discharge through ET and spring flow likely approximates the extinction depth for all discharge areas, particularly in areas with highly variable root depth of plants and discontinuous areas of capillary fringe. Penoyer Valley is an example of a discharge area that may have a zone of fairly extensive capillary effects contributing to ET. The observed heads are lower than the drain altitudes, and the Penoyer Valley drain, or any drain with similar relative heads, will not discharge if the heads are simulated accurately.

Incised drainages and other focused discharge areas are difficult to simulate accurately at a grid resolution of 1,500 m because in many cases, the hydraulic conductivity of the HGUs at the land surface controls the simulated discharge. In situations where this methodology does not control flow, a consistent method for assigning drain conductance needs to be used.

Hydrogeologic Framework Limitations

The accuracy of the groundwater flow model depends on the accuracy of the hydrogeologic conceptual model. Limitations exist in the groundwater flow model because of the difficulties inherent in the interpretation and representation of the complex geometry and spatial variability of hydrogeologic materials and structures in both the HFM and the flow model.

Complex Geometry

Geometric complexity of hydrogeologic materials and structures is apparent throughout the model domain. One notable example is the LVVSZ (fig. F–47). Simulation of heads in this area is limited by the current understanding of fault-system geometry and the accuracy and resolution of its representation in the HFM and in the groundwater flow model.

Similarly, the steep hydraulic gradient that extends from the Groom Range through the Belted and Eleana Ranges to Yucca Mountain and the Bullfrog Hills (figs. F–46 and F–47) is inadequately simulated because of an incomplete understanding of the complex geometries in this area. However, the steep hydraulic gradient also is simulated inadequately because of simplifications inherent in the HFM and groundwater flow model construction and discretization.

Complex Spatial Variability

The spatial variability of material properties of the HGUs and structures is represented to some degree in the model (Chapter B, this volume). Incorporating these features in the flow model substantially improved the simulation; however, the model remains a significantly simplified version of reality, resulting in imperfect matching of hydraulic gradients and heads affected by detailed stratigraphy not represented in the HFM. In the groundwater flow model, the assumption of homogeneity within a given HGU or hydraulic-conductivity zone removes the potential effects of smaller scale variability. A particularly noteworthy area where poor model fit exists is in the vicinity of Oasis Valley and the Bullfrog Hills. In this area, the observed effects of hydrothermal alteration are characterized incompletely by data and inadequately represented in the HFM and the groundwater flow model. Many of the inadequacies in the simulation of heads within the SWNVF are caused in part by the underrepresentation of local-scale hydrogeologic complexities in the HFM and the groundwater flow model.

Flow Model Limitations

Three basic limitations of the flow model are inherent in its construction. These inaccuracies are in (1) representation of the physical framework, (2) representation of the hydrologic conditions, and (3) representation of time.

Representation of Physical Framework

While the 1,500-m resolution of the flow model grid is appropriate to represent regional-scale conditions, higher resolution would improve simulation accuracy, particularly in areas of geologic complexity. The large grid cells tend to generalize important local-scale complexities that affect regional hydrologic conditions. To represent more local dynamics, smaller grid cells throughout the model (or local refinement around selected features or in critical areas in the model domain) would be required.

Representation of Hydrologic Conditions

The hydrologic conditions represented by the model are expressed as boundary conditions and include recharge, lateral boundary flows, discharge from ET and springs, and pumpage. Of these boundary conditions, the most significant is recharge. The main limitation in the representation of recharge is the inaccurate estimation of net infiltration that likely is owing in large part to the assumption that net infiltration results in regional recharge. The net-infiltration model (Hevesi and others, 2003; Chapter C, this volume) likely overestimates recharge in many parts of the model domain because it is assumed that all infiltrating water that passes the root zone ultimately reaches the water table. This assumption ignores the possibility that infiltrating water could be intercepted and either diverted or perched by a lower permeability layer in the unsaturated zone, or the possibility of deep evaporation from the unsaturated zone. This limitation may be resolved by including in the flow model a means to account for deep, unsaturated-zone processes that may act to reduce or redistribute infiltrating water.

Limitations in the definition of lateral boundary flow are the result of incomplete understanding of natural conditions. Because very little data exist in the areas defined as lateral flow-system boundary segments, all aspects of the assigned boundary conditions are poorly known. Despite these uncertainties, the data used to characterize these boundary flows have been thoroughly analyzed for this model. The model does not simulate the complex process of ET but accounts for the groundwater discharge attributed to ET through use of the Drain package for MODFLOW-2000. Future revisions of the DVRFS model might be improved by using a more complex ET package instead of the Drain package. This package could incorporate spatially varying parameters to simulate direct recharge, soil moisture, and vegetative growth.

Representation of Time

The year-long stress periods simulated in the model limit its temporal applicability to dynamics that change over at least several years. Simulation of seasonal dynamics using shorter stress periods could be advantageous to account for the seasonal nature of irrigation pumpage. Such a simulation would require seasonal definition of hydrologic conditions.

Appropriate Uses of the Model

Because the DVRFS model was constructed to simulate regional-scale groundwater flow, it can be used to answer questions regarding groundwater flow issues at that scale. For example, interactions can be considered between hydraulic heads, discharge, pumping, and flow direction and magnitude on a regional scale.

The model can provide boundary conditions for the development of local-scale models, such as those being developed by the Department of Energy for both the NNSA/NSO and OCRWM programs. Consistency between regional and local models must be ensured. Advances in linking regional- and local-scale models may allow for simultaneous calibration and uncertainty analysis. Although regional scale by design, the DVRFS model includes many local-scale features and site-specific data. Local features include facies changes and pumpage from one or a few wells. In some circumstances the model could be used to evaluate the regional consequences of such local features. Yet, some regional consequences and all local consequences would be evaluated most effectively using local-scale models in combination with simulations from the regional model.