Simulating Regional Groundwater Flow in the Vicinity of the Nevada National Security Site, Nye County, Nevada – 16104

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ABSTRACT

The Death Valley Regional Groundwater Flow System (DVRFS) occupies an area of about 70,000 km^2 in south-central Nevada and southeastern California. Interest in this system stems from the need to (1) understand the groundwater flow paths and travel times associated with potential migration of radioactive material from the Nevada National Security Site (NNSS) where underground nuclear testing was conducted from 1956 to 1992; (2) characterize the groundwater system in the vicinity of the proposed high-level radioactive waste repository at Yucca Mountain, Nev.; and (3) address a variety of potential effects from NNSS activities on users down gradient from the NNSS and Yucca Mountain. A single groundwater flow model of the DVRFS has been developed that integrates data and results of two previous regional-scale models and supports Department of Energy (DOE) programs at the NNSS. The numerical model was constrained by organizing hydrogeologic data and interpretations in three-dimensional (3D) geographic information systems and constructing a digital three-dimensional (3D) hydrogeologic framework model (HFM) to represent 27 hydrogeologic units (HGUs) and major structures in the DVRFS region. The 3D hydrogeologic data sets were discretized to 1,500 meters (m) grid cell resolution for input arrays required for the model. The DVRFS was simulated using the USGS 3D groundwater-flow modeling code MODFLOW-2000. Two examples showing how the DVRFS regional model is used by the DOE as part of waste management activities at the NNSS: (1) use of the regional model to provide the boundary conditions for site-scale models, and

(2) use of the regional model to assess changes in hydraulic gradient and flow paths in the regional flow system resulting from changes in pumping in various areas of interest.

INTRODUCTION

The Death Valley Regional Groundwater Flow System (DVRFS) occupies an area of about 70,000 km^2 in south-central Nevada and southeastern California (Fig. 1). Interest in this system stems from the need to (1) understand the groundwater flow paths and travel times associated with potential migration of radioactive material from the Nevada National Security Site (NNSS; formerly known as the Nevada Test Site), where underground nuclear testing was conducted from 1956 to 1992 [1]; (2) characterize the groundwater system in the vicinity of the proposed high-level nuclear waste repository at Yucca Mountain, Nev. [2]; and (3) address a variety of potential effects on users down gradient from the NNSS and Yucca Mountain, including the agricultural communities in the Amargosa Desert, Death Valley National Park, and Tribal interests [3].

More than 20 years of groundwater flow modeling of the DVRFS has produced a succession of numerical models that are increasingly more complex and detailed representations of the hydrogeologic framework and groundwater flow system [3]. Groundwater models for the DVRFS were built to (1) characterize regional three-dimensional (3D) groundwater flow paths, and define recharge and discharge locations, (2) estimate the volume of subsurface flow, (3) provide a regional evaluation of the effects of pumpage, (4) provide boundary conditions for site-scale models at selected sites, and (5) provide information about regional-scale transport [3]. The longevity of the DVRFS models and their regional scale are unusual in a waste management scenario and are a result of long-term evaluation and monitoring activities by the U.S. Department of Energy (DOE) and the regional scale of the groundwater flow system.

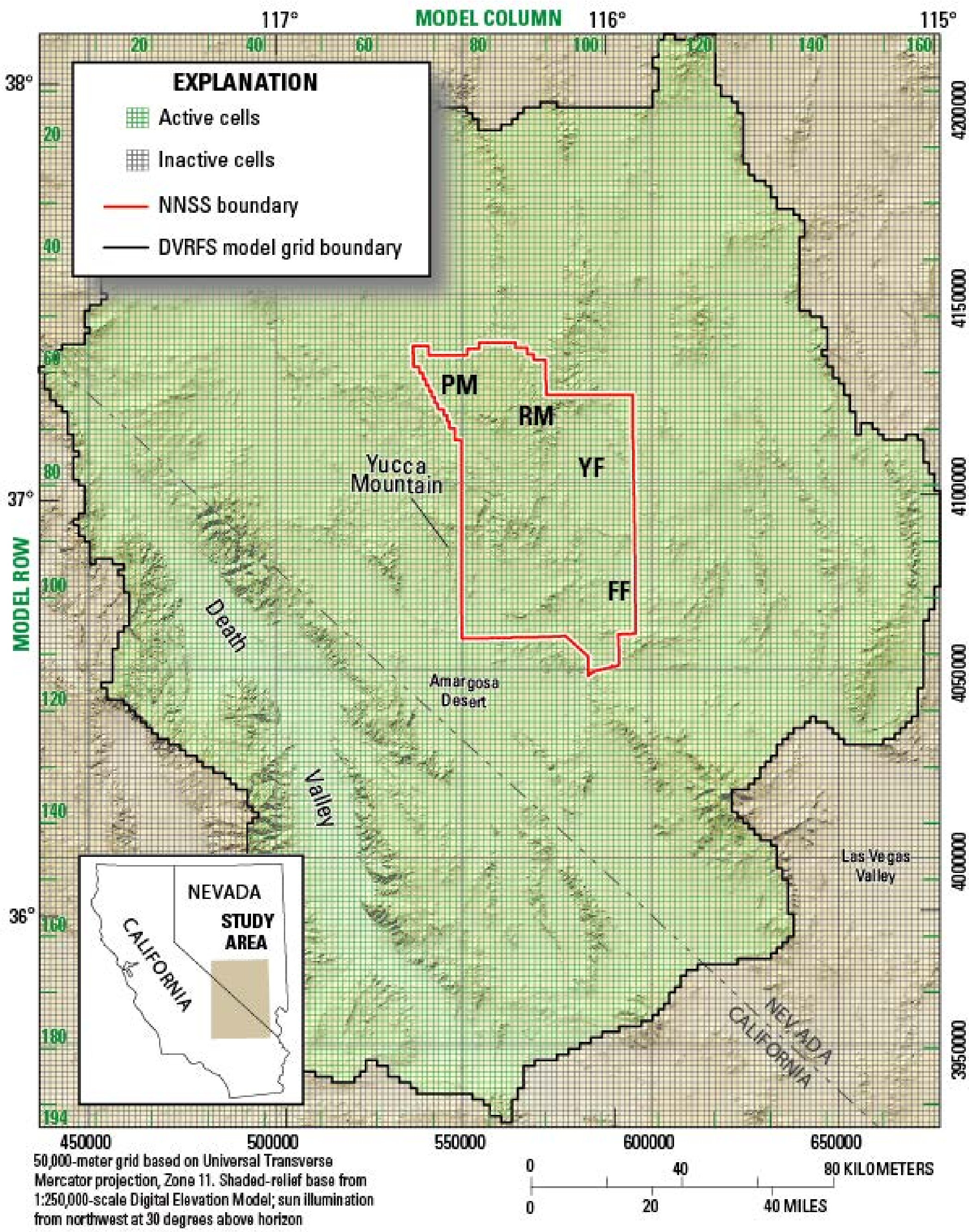


Figure 1. Geographic features and 1,500-m numerical model grid of the Death Valley regional groundwater flow system region, Nevada and California. General locations for Corrective Action Units at the Nevada National Security Site are shown as: FF, Frenchman Flat; YF, Yucca Flat; RM, Rainier Mesa; PM, Pahute Mesa.

HISTORY OF THE DVRFS MODEL

In the mid-1990's, two regional groundwater flow models that simulated the area in and around the NNSS were developed for DOE. One model evaluated the transport of radionuclides from underground nuclear test sites on the NNSS [4]; a second model characterized the regional groundwater flow system with respect to the potential release of radionuclides from the proposed geologic high-level radioactive waste repository at Yucca Mountain, Nev [5]. In 1998, the DOE requested that the U.S. Geological Survey (USGS) develop a single groundwater flow model of the DVRFS that would integrate the data and results of the previous two regional-scale models to support groundwater-focused aspects of waste management DOE programs at the NNSS. During this effort, the USGS incorporated new geologic, geophysical, and hydrologic data, used newly available modeling tools, and cooperated with other Federal, State, and local entities in the region in order to address stakeholder interests [3].

REGIONAL GEOLOGIC AND HYDROLOGIC SETTING

The DVRFS is a major regional groundwater flow system located in the southern Great Basin, a subprovince of the Basin and Range physiographic province [8,9]. Groundwater flows between recharge areas in the mountains of central and southern Nevada and discharge areas south and west of the NNSS and in Death Valley, Calif. [8,9]. Regional groundwater flow generally follows the regional topographic gradient as water moves toward Death Valley, Calif.; however regional groundwater flow patterns do not necessarily coincide with local topographic basins. Groundwater flow in the DVRFS is dominated by interbasin flow between several relatively shallow and local flow systems that are superimposed on deeper intermediate and regional flow systems [9]. The regional scale of the numerical model and the large size of the study area is a function of the regional scale of the groundwater systems and the large distance between recharge areas and discharge areas.

Groundwater flow in the DVRFS is strongly influenced by the geologic framework of the DVRFS region. Stratigraphic units in the DVRFS region are disrupted by largemagnitude offset thrust, strike-slip, and normal faults that have resulted in a complex distribution of rocks, creating variable and complex subsurface conditions [3]. Consolidated pre-Cenozoic rocks and Cenozoic volcanic rocks and basin fill form a complexly-layered system of aquifers and confining units [10, 11, 12, 13, 14]. Numerical modeling of the regional groundwater flow system must incorporate the 3D distribution of the principal aquifers and confining units, as well as the principal geologic structures that may affect subsurface flow.

NUMERICAL FLOW MODEL

The DVRFS groundwater flow model consists of: input hydrologic data sets representing recharge [15], natural groundwater discharge [16] and pumpage [17], a complex 3D hydrogeologic framework model (HFM) [18], and a numerical model that merges hydrologic data, estimates hydraulic conductivity for the regional model cells, and estimates parameter uncertainty [19]. Hydrologic components of the DVRFS were compiled to conceptualize groundwater flow through the DVRFS, to support development of a groundwater flow model, and to develop discharge and hydraulic-head observations for model calibration. Hydrologic components evaluated were those affecting water budget, including the distribution and volume of natural groundwater discharge, groundwater pumpage, groundwater recharge, lateral groundwater inflow and outflow, hydraulic conductivity values of the major hydrogeologic units (HGUs), and water levels [3].

The model design was based on a digital 3D HFM that defines the physical geometry and composition of the surface and subsurface materials of 27 hydrogeologic units (HGUs) through which ground water flows [18]. The geometries (horizons and thicknesses) of the HGUs were exported from the HFM and incorporated into the numerical flow model using the Hydrogeologic-Unit Flow (HUF) package [20, 21], which resamples the HGUs into the flow-model grid, calculating which HGUs are in each flow-model layer.

The DVRFS was simulated using the USGS 3D groundwater flow modeling code MODFLOW-2000 and related packages [20, 21, 22, 23, 24]. The transient regional flow model has 16 layers, a north-south oriented finite-difference grid consisting of

194 rows and 160 columns, and uniform cells that are 1,500 m on each side (Fig. 1). The groundwater flow model simulates a steady-state head distribution representing pre-pumping conditions and transient conditions from 1913 through 1998. Transient stresses imposed on the regional groundwater flow system include groundwater pumpage that occurred from 1913 through 1998. Estimated areal recharge was held constant at average annual values [3]. Calibration of parameter values primarily relied on parameter-estimation techniques [23]. Model calibration was achieved by first calibrating to pre-pumped (steady-state) flow conditions. Once calibrated, this model formed the initial conditions for the transient-flow model. The model was calibrated again to simulate transient-flow conditions for 1913–98 [19].

USES OF THE REGIONAL MODEL IN WASTE MANAGEMENT ACTIVITIES

Two examples are given below showing how the DVRFS regional model is used by the DOE as part of waste management activities at the NNSS: (1) use of the regional model to provide the boundary conditions for site-scale models, and (2) use of the regional model to assess changes in flow paths in the regional flow system from changes in pumping in various areas of interest.

Site-Scale Model Boundary Flows

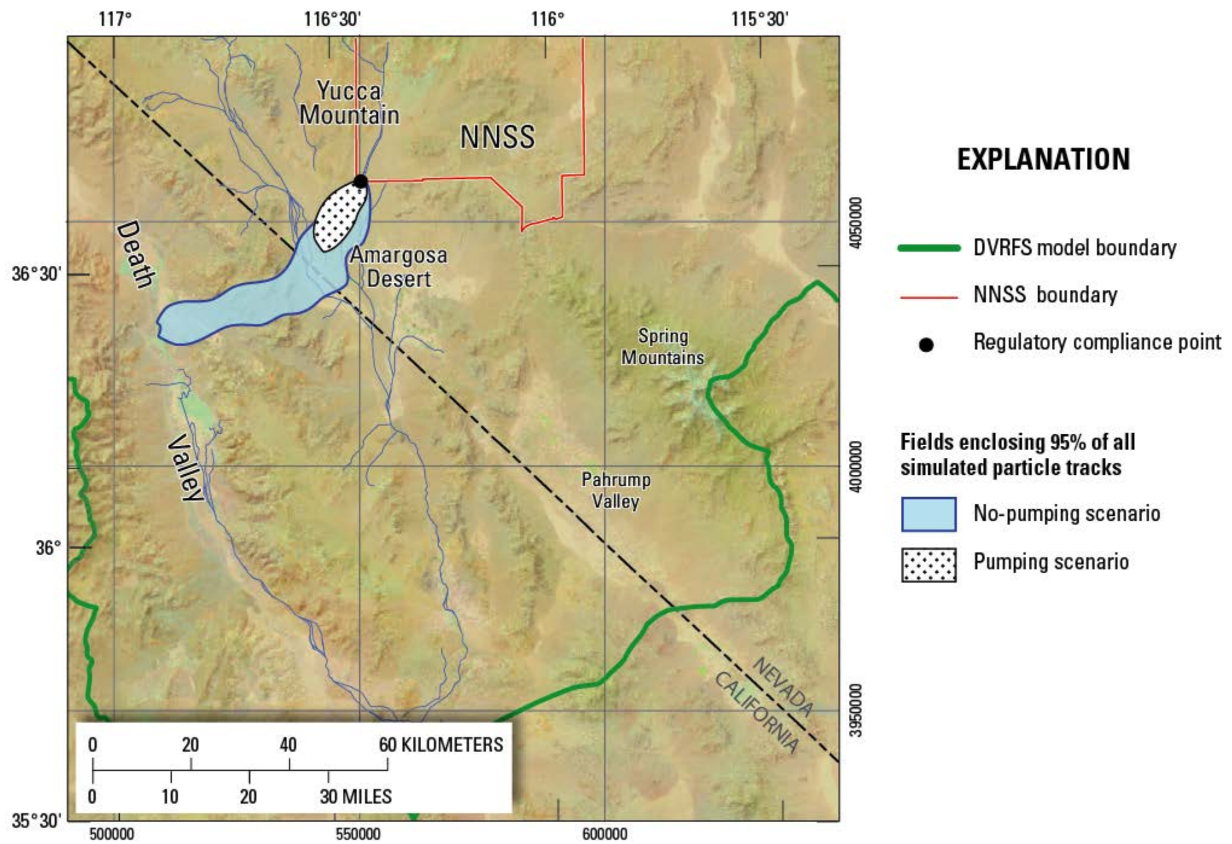
At the Yucca Mountain site, DOE designed site-scale saturated-zone hydrogeologic framework and flow models [25] to nest within the DVRFS regional model to take advantage of the great amount of regional hydrogeologic information. The Yucca Mountain site-scale models were constructed to: (1) estimate groundwater flow directions and magnitudes, (2) characterize the complex 3D behavior of flow through heterogeneous and fractured media, (3) identify the potential role of faults as barriers or conduits to groundwater flow, (4) provide a simulation of the flow system for use in subsequent modeling of contaminant transport, and (5) assess conceptual model and parameter uncertainties with respect to their influence on total system performance of the proposed repository at Yucca Mountain [26]. The vertical extents of the regional- and site-scale models match, both extending from the land surface down to a depth of 4,000 meters below sea level and both models incorporate the same hydrogeologic units. The site-scale flow model incorporated data from the regional groundwater flow model by incorporating volumetric and mass flow rates at the lateral boundaries of the site-scale model and by using recharge as defined in the regional model [25, 26].

Continued DOE activities at the NNSS have resulted in the development of detailed, site-scale geologic framework and numerical flow and transport simulations for five Corrective Action Units (CAUs) where sites of detonations at the NNSS are grouped by proximity, geography, contaminant source, geology, and hydrogeologic characteristics (e.g., [6,7]). At the NNSS, numerical models of the groundwater flow and transport are a critical part of assessing the migration of contaminants within a CAU to the NNSS boundary over the regulatory time frame. The DVRFS regional model was used directly to establish the boundary conditions for site-scale groundwater flow models in Yucca Flat. The model was used indirectly in the Pahute Mesa site-scale model (e.g., [6,7]).

Pumping Scenarios

Groundwater pumping can lead to changes in the hydraulic gradients and therefore alter the direction and rate of groundwater flow in the region, potentially affecting contaminant migration and water availability at water-dependent eco-systems. Pumping scenarios using the DVRFS regional model have been used to assess post-closure performance for the proposed Yucca Mountain repository and to simulate the potential effects of increased municipal pumping in areas to the east of the NNSS.

The DVRFS regional model was used in conjunction with the Yucca Mountain site-scale saturated-zone model to assess the effects of groundwater pumping in Amargosa Desert, an agricultural area 35 km south of Yucca Mountain, on flow



paths from the proposed repository (Fig. 2) [26].

Figure 2. Simulated particle tracks from the south end of the Yucca Mountain site-scale model for no-pumping and pumping scenarios (after [26]).

The groundwater flow and advective contaminant transport simulation used particle tracking to assess contaminant flow paths assuming no adsorption, filtering, or decay that would inhibit the particles from moving with the water. A no-pumping scenario simulated conditions of the regional flow system before any significant groundwater pumping had started (or the equilibrium conditions if all pumping were to cease). A pumping scenario was run to steady-state conditions using 2003 groundwater pumping locations and rates [27]. Under the no-pumping scenario, the simulated particles initially travel south from a regulatory compliance point (approximately 18 km south of the proposed repository footprint) at the southern boundary of the site-scale model, after which essentially all of the particles track to the west to exit the groundwater flow system at the floor of Death Valley (Fig. 2). Under the pumping scenario, no particles travel farther than the agricultural regions of the Amargosa Desert, indicating that groundwater pumping in this area effectively draws in all of the particles (Fig. 2).

The combined effects of increased urban growth in the Las Vegas area and an on-going regional drought in the southwestern United States have led to filing of applications to drill municipal water-supply wells in valleys to the east of the NNSS (Fig. 3). The effects of potential increased withdrawals on the ground-water flow system in the area surrounding the NNSS were simulated by using the DVRFS regional model in an analysis by the USGS (Claudia Faunt, 2006, U.S. Geological Survey, written commun.). The regional model was first recalibrated, adjusting parameters, such as depth decay in consolidated carbonate-rock aquifers, that showed high sensitivity to extra pumping stresses for long time periods. The baseline simulation included continued pumping at 1998 rates throughout the regional model domain plus additional withdrawals from the proposed municipal water-supply wells. The regional flow model was calibrated using these added stresses, focusing on greater pumping rates and the area of the pumped wells. Changes in the regional potentiometric surface were simulated for time periods of 50, 100, 500, and 1000 years (Fig. 3).

Simulated regional water levels at the eastern edge of the NNSS were up to 10 meters lower after 500 years of simulated pumping, with much greater declines in model cells containing the pumping wells (Fig. 3). However, the additional drawdown at the NNSS resulting from these additional municipal withdrawals is relatively minor compared to the amount of drawdown caused by 1998 pumping at from existing wells in surrounding valleys [Fig. 3; AD, IS, PV, and PyV]. Even long-term pumping of the proposed municipal water-supply wells does not vastly affect ground-water levels in the vicinity of the NNSS in the model.

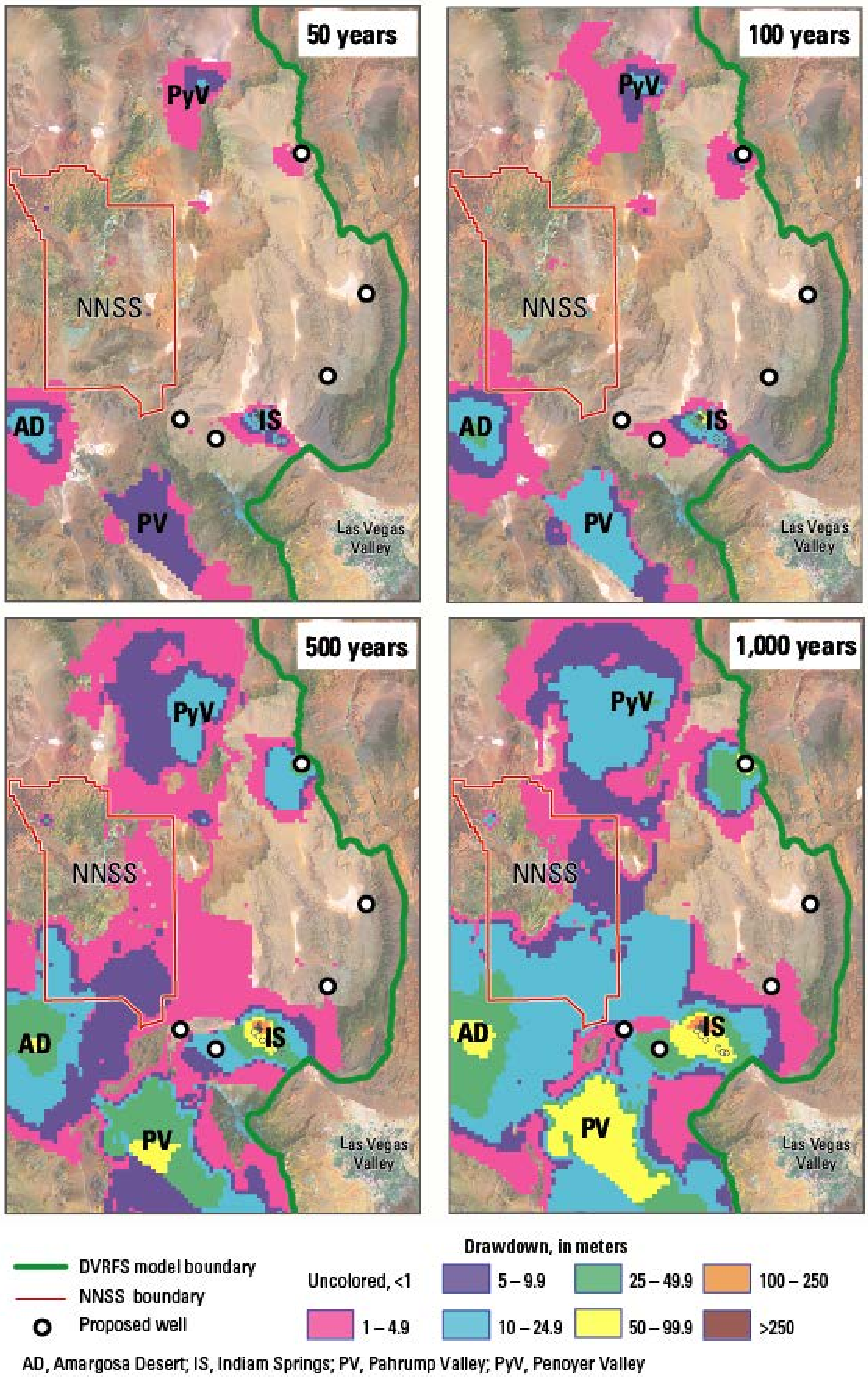


Figure 3. Map showing distribution of drawdown in relation to the water levels simulated in 1998 for continued pumping at 1998 rates with additional pumping at

proposed municpal-supply wells at 50, 100, 500, and 1,000 years (after Claudia Faunt, 2006, U.S. Geological Survey, written commun.).

CONCLUSIONS

The DVRFS model represents a large and complex groundwater flow system with a greater degree of detail and accuracy than previous regional studies. The model is appropriately used for evaluation of regional-scale processes, such as the evaluation of alternative conceptual models, the approximation of aspects of regional-scale advective transport of contaminants, and the analysis of the potential effects from changes to system stresses, such as increased pumpage. Water availability, water-dependent eco-systems, and contaminant migration may be affected by pumping. The regional model may also serve to provide boundary conditions for site-scale models. The regional model can be a tool for resource managers and decision makers to simulate the future effects of different amounts or locations of pumping on groundwater levels, spring flows, and groundwater flow paths in the region. The model can be a valuable tool for managing the scarce water resources in the region and for addressing complex socioeconomic and political issues about water uses in the region.

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