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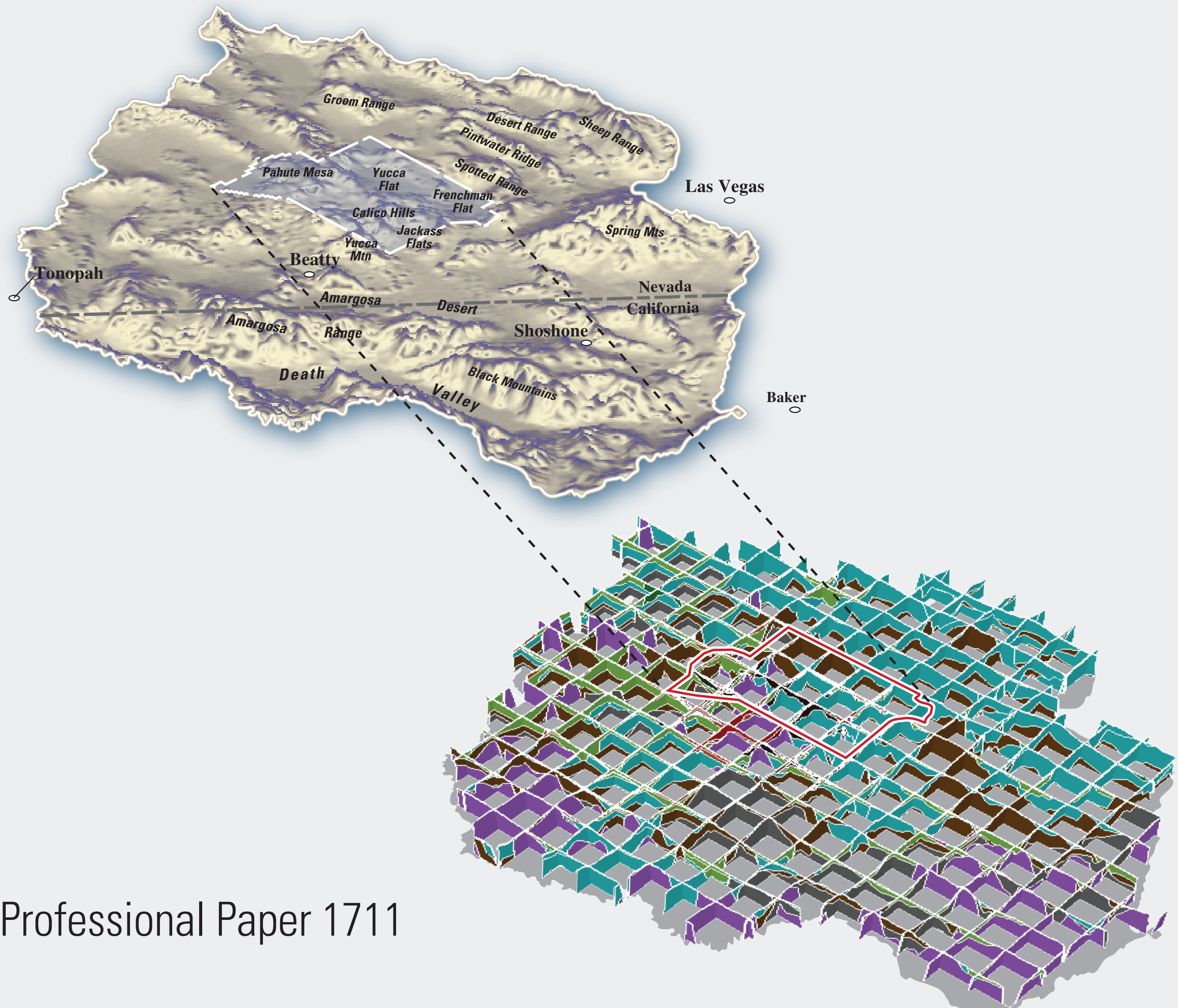
Death Valley Regional Groundwater Flow System, Nevada and California—Hydrogeologic Framework and Transient Groundwater Flow Model



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

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KEN SALAZAR, Secretary

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This Professional Paper updates and formalizes the geologic and hydrologic conceptualization and numerical modeling of the Death Valley regional groundwater flow system originally released in 2004 as U.S. Geological Survey Scientific Investigations Report 2004–5205 (SIR 2004–5205). The Scientific Investigations Report was released at the time to meet project deadlines and funding limitations and to meet the needs of cooperators. However, at the time, all authors felt that the work was of sufficient scope and lasting impact as to merit release as a U.S. Geological Survey Professional Paper.

This Professional Paper formalizes the material originally presented in SIR 2004–5025. We have corrected a number of minor errors and inconsistencies within and between chapters and have improved the clarity and accuracy of a number of the figures. Otherwise, the report remains essentially unchanged from that documented within SIR 2004–5025. This report reflects the scientific rationale and programmatic direction for constructing a regional-scale groundwater flow model current in 2004; we have not updated the language in the original report to reflect changes in Federal priorities related to the Nevada Test Site or the Yucca Mountain site. Although the numerical model continues to serve as an archive of regional geologic and hydrologic observations and continues (as of 2010) to be used by and meet the needs of Federal cooperators, we present in this report the calibration of the numerical model as it existed in 2004. Future plans call for published updates of the regional numerical model; this Professional Paper presents the numerical model as the natural outgrowth of comprehensive geologic and hydrologic characterization of this complex region.

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Conversion Factors, Datums, and Abbreviations

Multiply	By	To obtain
millimeter (mm)	0.03937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
square kilometer (km^2)	0.3861	square mile
cubic meter (m^3)	35.31	cubic foot
million cubic meters (Mm^3)	35.31	million cubic feet
meter per day (m/d)	3.281	foot per day
millimeter per year (mm/yr)	0.03937	inch per year
meter per year (m/yr)	3.281	foot per year
meter squared per day (m^2/d)	10.76	square foot per day
cubic meter per day (m^3/d)	35.31	cubic foot per day
cubic meter per day (m^3/d)	264.2	gallon per day
cubic meter per year (m^3/yr)	35.31	cubic foot per year
meter per day per meter (m/d/m)	1	foot per day per foot

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27). Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations and Acronyms

2D	Two-dimensional
3D	Three-dimensional
AA	Alluvial aquifer
ACU	Alluvial confining unit
BRU	Belted Range unit
CAU	Corrective Action Unit
CFBCU	Crater Flat–Bullfrog confining unit
CFPPA	Crater Flat–Prow Pass aquifer
CFTA	Crater Flat–Tram aquifer
CHVU	Calico Hills volcanic-rock unit
CSS	Composite scaled sensitivity
CV	Coefficient of variation
DEM	Digital elevation model
DOE	U.S. Department of Energy
DOE/NV	U.S. Department of Energy, Nevada Operations Office
DRN	Drain
DSS	Dimensionless scaled sensitivity
DVRFS	Death Valley regional groundwater flow system
ECU	Eleana confining unit
EM	Office of Environmental Management
ERD	Environmental Restoration Division

ET	Evapotranspiration
EWDP	Early Warning Drilling Program
FWS	U.S. Fish and Wildlife Service
Ga	Giga-annum (billion years ago)
GFM	Geologic framework model
GIS	Geographic information system
GPS	Global positioning system
GWSI	Ground Water Site Inventory
HFB	Horizontal flow barrier
HFM	Hydrogeologic framework model
HG	Hydrograph
HGU	Hydrogeologic unit
HRMP	Hydrologic Resource Management Program
HUF	Hydrogeologic-unit flow
ICU	Intrusive-rock confining unit
K	Hydraulic conductivity
ka	Kilo-annum thousand years ago
K-Ar	Potassium-argon
LA	Limestone aquifer
LCA	Lower carbonate-rock aquifer
LCA_T1	Lower carbonate-rock thrust
LCCU	Lower clastic-rock confining unit
LCCU_T1	Lower clastic-rock confining unit thrust
LFU	Lava-flow unit
LOTR	Line of transient regression
LVVSZ	Las Vegas Valley shear zone
LVVWD	Las Vegas Valley Water District
Ma	Mega-annum (million years ago)
MNW	Multi-node well
MGE	Intergraph Modular GIS Environment®
Mvs	Mesozoic volcanics and sedimentary rock unit
NAD 27	North American Datum of 1927
NAVD 88	North American Vertical Datum of 1988
NDWR	Nevada Division of Water Resources
NNSA	National Nuclear Security Administration
Nobs	Number of observations
NPS	National Park Service
NSO	Nevada Site Office
NTS	Nevada Test Site
NWIS	National Water Information System
OAA	Older alluvial aquifer
OACU	Older alluvial confining unit
OCRWM	Office of Civilian Radioactive Waste Management
ORD	Office of Repository Development
OVU	Older volcanic-rock unit

P1	Lower clastic confining unit
P2	Regional carbonate aquifer
PCC	Parameter correlation coefficient
PMOV	Pahute Mesa–Oasis Valley
PVA	Paintbrush volcanic-rock aquifer
SCCC	Silent Canyon caldera complex
SCU	Sedimentary-rock confining unit
sd	Standard deviation
SOSWR	Sum of squared weighted residuals
SWNVF	Southwestern Nevada volcanic field
TBA	Belted Range aquifer
TBCU	Basal confining unit
TBQ	Basal aquifer
TC	Paintbrush/Calico Hills tuff cone unit
TCB	Bullfrog confining unit
TMA	Timber Mountain aquifer
TMCC	Timber Mountain caldera complex
TMVA	Thirsty Canyon–Timber Mountain volcanic-rock aquifer
TSDVS	Tertiary sediments–Death Valley sediments
TV	Tertiary volcanic-rock unit
UCA	Upper carbonate-rock aquifer
UCCU	Upper clastic-rock confining unit
UGTA	Underground Test Area
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VA	Volcanic-rock aquifer
VCU	Volcanic-rock confining unit
VSU	Volcanic- and sedimentary-rock unit
VU	Volcanic rocks undifferentiated
WVU	Wahmonie volcanic-rock confining unit
XCU	Crystalline-rock confining unit
YAA	Younger alluvial aquifer
YACU	Younger alluvial confining unit
YMP	Yucca Mountain Project
YVU	Younger volcanic-rock unit

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Abstract

A numerical three-dimensional (3D) transient groundwater flow model of the Death Valley region was developed by the U.S. Geological Survey for the U.S. Department of Energy programs at the Nevada Test Site and at Yucca Mountain, Nevada. Decades of study of aspects of the groundwater flow system and previous less extensive groundwater flow models were incorporated and reevaluated together with new data to provide greater detail for the complex, digital model.

A 3D digital hydrogeologic framework model (HFM) was developed from digital elevation models, geologic maps, borehole information, geologic and hydrogeologic cross sections, and other 3D models to represent the geometry of the hydrogeologic units (HGUs). Structural features, such as faults and fractures, that affect groundwater flow also were added. The HFM represents Precambrian and Paleozoic crystalline and sedimentary rocks, Mesozoic sedimentary rocks, Mesozoic to Cenozoic intrusive rocks, Cenozoic volcanic tuffs and lavas, and late Cenozoic sedimentary deposits of the Death Valley regional groundwater flow system (DVRFS) region in 27 HGUs.

Information from a series of investigations was compiled to conceptualize and quantify hydrologic components of the groundwater flow system within the DVRFS model domain and to provide hydraulic-property and head-observation data used in the calibration of the transient-flow model. These studies reevaluated natural groundwater discharge occurring through evapotranspiration (ET) and spring flow; the history of groundwater pumping from 1913 through 1998; groundwater recharge simulated as net infiltration; model boundary inflows and outflows based on regional hydraulic gradients and water budgets of surrounding areas; hydraulic conductivity and its relation to depth; and water levels appropriate for regional simulation of prepumped and pumped conditions within the DVRFS model domain. Simulation results appropriate for the regional extent and scale of the model were provided by acquiring additional data, by reevaluating existing data using current technology and concepts, and by refining earlier interpretations to reflect the current understanding of the regional groundwater flow system.

Groundwater flow in the Death Valley region is composed of several interconnected, complex groundwater flow systems. Groundwater flow occurs in three subregions in relatively shallow and localized flow paths that are superimposed on deeper, regional flow paths. Regional groundwater flow is predominantly through a thick Paleozoic carbonate rock sequence affected by complex geologic structures from regional faulting and fracturing that can enhance or impede flow. Spring flow and ET are the dominant natural groundwater discharge processes. Groundwater also is withdrawn for agricultural, commercial, and domestic uses.

Groundwater flow in the DVRFS was simulated using MODFLOW-2000, the U.S. Geological Survey 3D finite-difference modular groundwater flow modeling code that incorporates a nonlinear least-squares regression technique to estimate aquifer parameters. The DVRFS model has 16 layers of defined thickness, a finite-difference grid consisting of 194 rows and 160 columns, and uniform cells 1,500 meters (m) on each side.

Prepumping conditions (before 1913) were used as the initial conditions for the transient-state calibration. The model uses annual stress periods with discrete recharge and discharge components. Recharge occurs mostly from infiltration of precipitation and runoff on high mountain ranges and from a small amount of underflow from adjacent basins. Discharge occurs primarily through ET and spring discharge (both simulated as drains) and water withdrawal by pumping and, to a lesser amount, by underflow to adjacent basins simulated by constant-head boundaries. All parameter values estimated by the regression are reasonable and within the range of expected values. The simulated hydraulic heads of the final calibrated transient model generally fit observed heads reasonably well (residuals with absolute values less than 10 meters) with two exceptions: in most areas of nearly flat hydraulic gradient the fit is considered moderate (residuals with absolute values of 10 to 20 meters), and in areas of steep hydraulic gradient along the Eleana Range and western part of Yucca Flat, southern part of the Owlshead Mountains, southern part of the Bullfrog Hills, and the north-northwestern part of the model domain (residuals with absolute values greater than 20 meters).

Groundwater discharge residuals are fairly random, with as many areas where simulated flows are less than observed flows as areas where simulated flows are greater. The highest unweighted groundwater discharge residuals occur at Death Valley, Sarcobatus Flat (northeastern area), Tecopa, and early observations at Manse Spring in Pahrump Valley. High weighted-discharge residuals were computed in Indian Springs Valley and parts of Death Valley. Most of these inaccuracies in head and discharge can be attributed to insufficient representation of the hydrogeology in the HFM and(or) discharge estimates, misrepresentation of water levels, and(or) model error associated with grid-cell size.

The model represents the large and complex groundwater flow system of the Death Valley region at a greater degree of refinement and accuracy than has been possible previously. The representation of detail provided by the 3D digital hydrogeologic framework model and the numerical groundwater flow model enabled greater spatial accuracy in every model parameter. The lithostratigraphy and structural effects of the hydrogeologic framework; recharge estimates from simulated net infiltration; discharge estimates from ET, spring flow, and pumping; and boundary inflow and outflow estimates all were reevaluated, some additional data were collected, and accuracy was improved. Uncertainty in the results of the flow model simulations can be reduced by improving on the quality, interpretation, and representation of the water-level and discharge observations used to calibrate the model and improving on the representation of the HGU geometries, the spatial variability of HGU material properties, the flow model physical framework, and the hydrologic conditions.

View from Mount Stirling (2,506 m) in the Spring Mountains to the northeast toward the Pintwater, Desert, and Sheep Ranges. The Las Vegas Valley shear zone runs across the middle of the photograph between the Spring Mountains and the mountain ranges to the north. Playas are visible in Indian Springs Valley (toward the west or left side of the photograph) and in Three Lakes Valley (to the east or the right side of the photograph). Creech Air Force Base is visible in the center foreground, at the base of the Pintwater Range. Photograph by Nancy A. Damar, U.S. Geological Survey.