Journal of Hydrology 373 (2009) 316–328

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

An unconfined groundwater model of the Death Valley Regional Flow System and a comparison to its confined predecessor

Rosemary W.H. Carroll *, Greg M. Pohll, Ronald L. Hershey

Division of Hydrologic Sciences, Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512, United States

ARTICLE INFO

Article history:
Received 12 November 2008
Received in revised form 21 April 2009
Accepted 4 May 2009

This manuscript was handled by P. Baveye, Editor-in-Chief, with the assistance of Hongbin Zhan, Associate Editor

Keywords:
Death Valley
Nevada Test Site
MODFLOW
SURFACT

SUMMARY

The MODFLOW version of the United States Geological Survey (USGS) Death Valley Regional Flow System (DVRFS) in California and Nevada is conceptually inaccurate in that it models an unconfined aquifer as a confined system and does not accurately simulate unconfined drawdown in transient pumping simulations. The transfer of geologic and hydrologic information from the confined MODFLOW DVRFS model to an unconfined MODFLOW–SURFACT (SURFACT) version was accomplished by maintaining cell structure between models and computing effective cell properties to translate the HUF2 package used in MODFLOW to the BCF4 package used by SURFACT. The confined version of the DVRFS was compared to the unconfined SURFACT version by examining head contour maps and the ability of the SURFACT model to match the 4900 observations of hydraulic head/drawdown, 49 observations of groundwater discharge, and 15 estimates of groundwater fluxes into/out of the model domain. Resultant weighted root mean squared error (ωRMSE) for the unconfined SURFACT model was lower than the USGS confined model. Despite a lower ωRMSE, unconfined conditions simulated with SURFACT did produce greater heads in mountainous regions compared to the confined MODFLOW with differences most pronounced in regions where cell thickness is large, horizontal conductivity small and recharge large. Difference in computed heads reflects computation schemes employed by both models to estimate interblock conductance. Specifically, interblock conductance for the unconfined SURFACT model is dependent on the relative saturation of a modeled cell while MODFLOW's confined system is not. Despite head differences, SURFACT simulates comparable flux estimates to MODFLOW (e.g. observed ET, groundwater spring flow, and groundwater flux across model boundaries), while significantly improving transient well drawdown estimates. SURFACT is also capable of producing more realistic estimates of water availability from proposed groundwater development and resultant potential impacts to the region.

Introduction

There have been numerous water rights applications submitted throughout southern Nevada to offset the needs of growth in Las Vegas. Several applications include groundwater withdrawals adjacent to the Nevada Test Site (NTS) where underground nuclear testing was conducted. If large quantities of groundwater are pumped adjacent to the NTS, the groundwater system could change dramatically. Potential impacts from groundwater pumping include decreasing water levels, reduction in groundwater resources on the NTS, reduction in spring flows adjacent to proposed pumping centers, and the alteration of groundwater flowpaths.

In 1998, the US Department of Energy (DOE) Nevada Site Office funded the United States Geological Survey (USGS) to improve upon two previous groundwater flow models of the Death Valley region with the initial intention of understanding groundwater flowpaths and travel times associated with potential movement of radioactive material from the NTS as well as to characterize the groundwater system in the vicinity of Yucca Mountain, and address effects on users down-gradient from the NTS and Yucca Mountain (Belcher, 2004). The first of these earlier models was developed by DOE for the National Nuclear Security Administration/Nevada Site Office (NNSA/NSO) Underground Test Area (UGTA) project (IT Corporation, 1996). The second was developed by the Office of Civilian Radioactive Waste Management's (OCRWM) Yucca Mountain Project (YMP) and the NNSA/NSO Hydrologic Resources Management Program (HRMP).

The resultant USGS Death Valley Regional Groundwater Flow System Model (DVRFSM) has improved upon the two previous models by using newly acquired data and modeling tools (Belcher, 2004). Studies compiled and used in the DVRFSM construction

* Corresponding author. Address: Division of Hydrologic Sciences, Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512 (P.O. Box 4196, Crested Butte, CO 81224), United States. Tel.: +1 970 349 0356; fax: +1 775 673 7363.
E-mail addresses: Rosemary.Carroll@dri.edu (R.W.H. Carroll), Greg.Pohll@dri.edu (G.M. Pohll), Ronald.Hershey@dri.edu (R.L. Hershey).

0022-1694/$ - see front matter
doi:10.1016/j.jhydrol.2009.05.006

include reassessing groundwater discharge via evapotranspiration (*ET*) (Laczniak et al., 1999, 2001; Reiner et al., 2002; DeMeo et al., 2003) and spring flow (refer to Table C-2, Belcher, 2004), cataloging historical groundwater pumping from 1913 through 1998 (Moreo et al., 2003), reinterpreting groundwater recharge as net infiltration (Hevesi et al., 2002, 2003), assessing model boundary inflows and outflows from regional hydraulic gradients, developing a water budget (Belcher, 2004), and finally incorporating hydraulic conductivity relationships as a function of depth (Belcher et al., 2001, 2002).

Carroll et al. (2006) used the DVRFSM to test the impacts of proposed groundwater development south of the NTS and found that, despite increased level of geologic detail and improved water budget accounting, the DVRFSM produced drawdowns on the order of thousands of meters after only a few decades of pumping. Such large drawdowns are not realistic and serve to highlight the most significant limitation of the DVRFSM: the model was built using the confined layer assumption to improve numeric stability. The use of a confined, rather than a "convertible" (i.e., unconfined), layer type within MODFLOW assumes that the saturated thickness remains constant throughout the entire simulation. Therefore, cells are not allowed to dry or become inactive as the water level decreases below the bottom of a cell. The confined approach was adopted by the USGS because the model was computationally unstable when cells were allowed to convert between confined and unconfined. Unfortunately the confined approach, while numerically stable, allows unrealistic estimates of drawdown to occur in transient simulations.

The primary objective of this study was to produce a numerically stable, unconfined version of the Death Valley Regional Flow System (DVRFS) for future use as a tool to more accurately address potential withdrawals in the NTS region and to determine the potential differences in the solution of the groundwater flow equation given confined and unconfined assumptions.

Numerical models

Death Valley Regional Flow System model: MODFLOW

The DVRFS and the associated USGS model domain (DVRFSM), with the NTS superimposed, are shown in Fig. 1. The DVRFS is approximately 100,000 km^2 in Nevada and California and is bounded by latitudes 35°00′N and 38°15′N and by longitudes 115°00′W and 118°00′W. This system encompasses flow between recharge areas in the mountains of central and southern Nevada and discharge areas of wet playas and springs south and west of the NTS and in Death Valley, California. The flow is strongly influenced by a complex geologic framework and the USGS DVRFSM incorporates the distribution of the flow system's principal aqui-

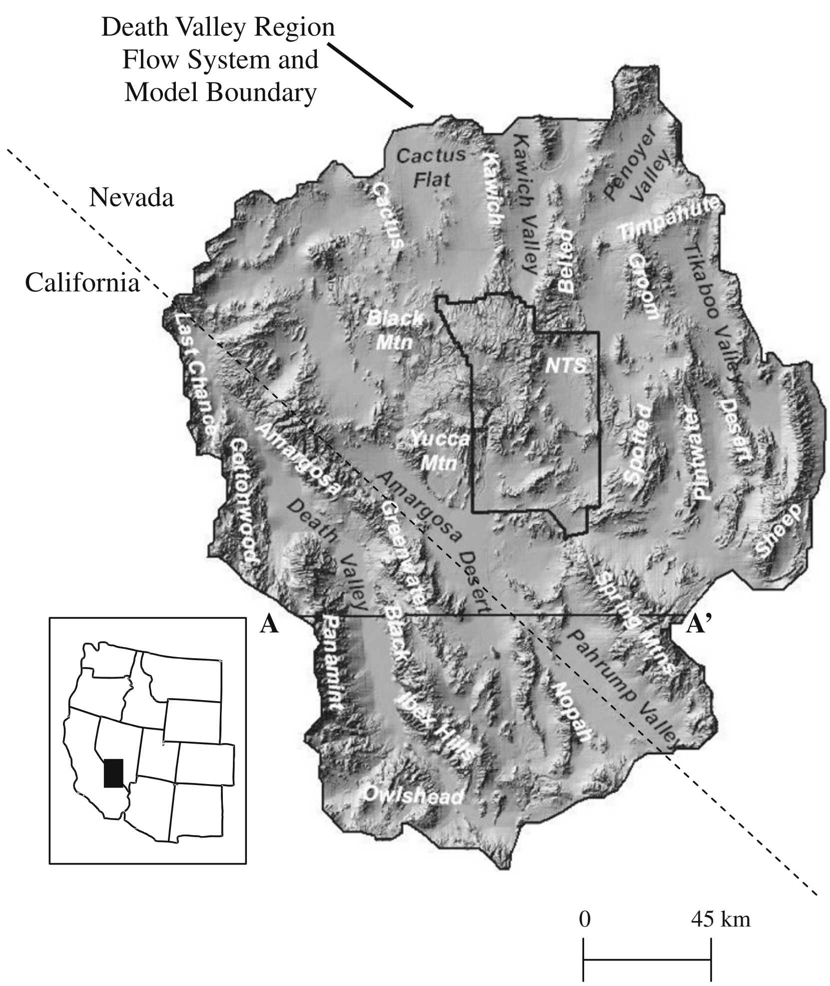

Fig. 1. Location of the Death Valley groundwater flow system with the Nevada Test Site (NTS), Death Valley, Spring Mountains, and the Nevada–California state line marked. Inset shows the site with respect to the western United States. Select mountain ranges labeled with white text and select basins labeled in black text. Cross section A–A′ marked.