Integrating Less-Common Data Sources to Improve Groundwater Model Calibration

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Abstract MODFLOW-SURFACT was used to create and calibrate a three-dimensional groundwater flow model to simulate the effects of Nevada Copper Corp.'s proposed Pumpkin Hollow mining project on the local and regional hydrogeologic system. This model illustrates the value of (1) incorporating existing accepted models, where possible, (2) using anecdotal evidence in conjunction with hydrogeological data to guide model construction, and (3) using GIS, database and automated calibration tools to streamline the process of incorporating both public and site-specific data.

Keywords groundwater, modeling, calibration, dewatering

Introduction

When beginning a regional-scale groundwater modeling project, little data may be available from the client regarding regional hydrogeologic conditions. However, public data sources often can provide information for model construction and calibration. These data sources may not be utilized because of the time and cost to confirm and organize the data. For example, separate governmental agencies may have different data records for the same well, but under different names and with different estimated coordinates. Collating and correlating these data sources can be a daunting task. However, with the aid of databases, spreadsheet tools, and GIS, the data manipulation can ultimately reduce the time and cost of model construction and calibration while improving the model's accuracy and lending additional credence and defensibility to the model.

Nevada Copper Corp.'s proposed Pumpkin Hollow mining project in west-central Nevada, USA provides a case study in which numerous public data sources were combined with site-specific data to create a well-calibrated regional groundwater flow model (NCC model). Fig. 1 provides a site location map for the modeled area.

One of the concerns with the proposed mining project was the potential to impact water supplies in the nearby Mason Valley, an intensively developed agricultural area that relies on irrigation from groundwater and surface water sources. An additional concern was the project's location within the Walker River Basin. Walker Lake, the terminus of the Walker River, is a closed-basin lake that has experi-

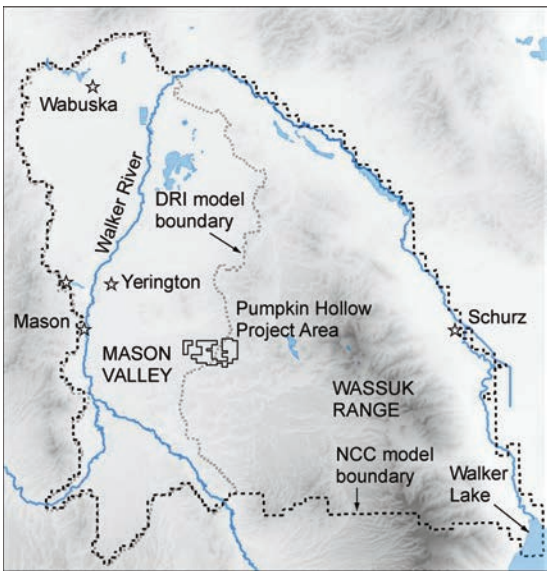

Fig. 1 Model Location Map.

enced more than 45 m of water level decline since 1882 as a result of agricultural diversions. Consequently, prediction of potential impacts from the project was critical, and the goal during model development was to create a well-calibrated model based to the extent possible on publicly available data that had undergone thorough quality assurance review.

Methods

At the start of the project, in conjunction with review of data provided by the client, a detailed literature review and data search was conducted to identify publicly available data sources. Public data sources included:

- An integrated surface water and groundwater model of Mason Valley, constructed and calibrated by the Desert Research Institute [DRI](Carroll *et al.* 2010, Collopy and Thomas 2010)
- United States Geological Survey (USGS) Digital Elevation Model (DEM),
- Geologic maps (Bingler 1978, Proffett and Dilles 1984),
- Geologic data sets in GIS format from Nevada Bureau of Mines and Geology (NBMG),
- Hydrogeologic data sets in GIS format from the USGS (Maurer *et al.* 2004),
- USGS and DRI studies compiling well pumping records (Huxel and Harris 1969, Schaefer 1980, Lopes and Allander 2009a and 2009b, Carroll *et al.* 2010, Collopy and Thomas 2010),
- Nevada Division of Water Resources (NDWR) well permits and point-of-diversion (POD) information, and
- Groundwater elevation and stream flow data from the USGS.

Many of the data sets necessary for model construction were accumulated by downloading from the internet. Some well and geologic data were hand-entered or digitized from the associated studies and maps. The majority of the DRI model electronic files were obtained by requesting them from DRI directly, but for confidentiality reasons not all files could be provided. Those that could not be directly provided were summarized numerically by DRI in such a manner that confidentiality was preserved.

After all data sets were obtained, significant formatting, generalization and correlation had to be performed to create a unified MODFLOW-SURFACT model. The DRI model of the Mason Valley formed the western half of the NCC model. The DRI model discretization was generalized laterally to fit the scale of the NCC model, but the estimates and distributions of all of the water balance components were retained from the DRI model. The NCC model grid was selected to be more refined in the proposed mine area (100 × 100 m) and telescope out to 500 m elsewhere. GIS was used to generalize the DRI grid from its original uniform 100 × 100 m to the new, variable grid. GIS was also used to generalize or aggregate (if applicable) all the other DRI model inputs including stream flow routing, ditch flows and PODs, evapotranspiration, irrigation-related recharge, hydraulic conductivity, and mountain block recharge to match the new grid. The seasonal component of DRI's model was averaged to represent steady-state conditions, since the NCC model covered a multi-decade time frame.

Next, the steady-state observation data set to be used for model calibration was constructed. This represented a significant challenge, because many of the observation wells were the same wells used for irrigation and were represented in several different databases that sometimes used different coordinate systems as well as different estimated coordinates. All the observation and irrigation well data for the region were imported into a single database. Wells represented using the Public Land Survey System (PLSS) were assigned coordinates using GIS based on the centroid of the PLSS polygon. The database was used to match up wells based on application number and permit number. After as many matches as possible were made and the matched wells combined, all well data were imported into GIS for spatial evaluation. Additional wells were then matched based on spatial proximity combined with depth, installation date, or other criteria. Depth information was necessary for target layer assignment and pumping layer assignment for irrigation wells. If no depth information was available from any database for a particular well, average depths and screened intervals were assigned based on other wells spatially nearby that well. Then, a weighting scheme was employed for the observation data set which incorporated the uncertainties due to missing information.

The vertical discretization was designed to accommodate the proposed mining plan. The NCC model has 22 layers, which are for the most part flat and extend far below DRI's original two layers. This construction greatly simplified the incorporation of both regional and local geologic information but resulted in a cube with inactive (no-flow) cells representing the elevations above ground surface. This complicated the incorporation of DRI's top model layer, which had variable elevation. Irrigation wells, streams, ditches, and evapotranspiration had to be assigned to the correct layers. This was accomplished using a combination of GIS and database processing to match the elevations of the features to the correct model layer. The results of the irrigation well evaluation performed as part of the target data set construction were used to guide the layer placements of irrigation well screened intervals.

The hydraulic property distribution was assigned based on regional and local geology and USGS divisions of hydrogeologic units in Nevada, for which a GIS dataset was available (Maurer *et al.* 2004). Geologic cross-sections were used to generalize the regional lithologic units into Quaternary alluvium, Tertiary volcanics and sediments, Mesozoic intrusives, and Mesozoic volcanics and sediments. A three-dimensional geologic model was created from the cross-sections and other available geologic information, such as well logs and surface geologic maps. The model was created in Mining Visualization System (MVS) with cooperation from Tetra Tech and Nevada Copper geologists with experience in the local geology. The geologists felt that the boundary zone between the Tertiary and Mesozoic units (likely erosional or faulted) should be called out as a separate unit, due to anecdotal evidence from resource drilling that it was more highly fractured, potentially leading to a more transmissive unit. The regional lithologic units were used where the DRI model was not present, but DRI model lithologic units were used wherever they were present. Limited aquifer testing data were available, particularly as related to the large fault structures that cross the model domain. Anecdotal evidence and numerous cross-sections provided by mine site geologists were crucial in incorporating both the faults and the extensive geologic information near the proposed mine site. As a result, in the immediate vicinity of the mine, a number of previously unmapped faults and additional lithologic units such as hornfels and endoskarn were included.

Two methods were used to estimate precipitation-related recharge from the mountains in the model. For the portions of the model that corresponded to DRI's model, the DRI mountain block recharge values were represented as below-ground injection wells, mimicking the DRI method. For the area where the DRI model connected to the Wassuk Range and adjoined the proposed mine site, recharge was represented differently. The Precipitation Zone Method (PZM) of the USGS (Lopes and Medina 2007) was used to estimate average annual precipitation on the Wassuk Range. The elevation-based precipitation zones were calculated from the USGS DEM. Then, the calculated precipitation was converted to estimated recharge using the Maxey-Eakin recharge categories (Maxey and Eakin 1949). The portion of recharge that would flow out of the Wassuk Range and into the Mason Valley was compared to the DRI estimate for recharge in that same area, and the calculated recharge was adjusted using a multiplier to match the calibrated DRI mountain block recharge. That multiplier was applied to the calculated recharge for the portion of the Wassuk Range that fell within the model boundaries. DRI's values for irrigation-related recharge in Mason Valley were incorporated directly into the NCC model.

In addition to the steady-state hydraulic head observation targets, the model was calibrated to steady-state stream flow and transient drawdown data. Stream flow targets were obtained by downloading the data for USGS stream gages within the model domain from the USGS website. An average stream flow was calculated for each gage to use as a steady state stream flow target. Transient drawdown targets were created by calculating the drawdown over time from two long-term pumping tests conducted at the proposed mine site. The steady state model and transient model were calibrated in tandem using PEST (Doherty 2010) as an automated calibration tool to improve the efficiency and accuracy of the calibration process.

Results

The incorporation of DRI's model materially improved the NCC model's representation of Mason Valley. Initial model simulations indicated that the DRI portion of the model was already well calibrated due to scrupulously maintaining DRI's calibrated input parameters to the maximum extent possible. Hence, the DRI parameter zones were excluded from any adjustments, greatly simplifying the remaining calibration effort.

The use of PEST in the NCC model calibration significantly reduced the time necessary to complete calibration. PEST was first used to identify the parameters to which the calibration was sensitive. Then, PEST was used to optimize those parameter values, and the results were assessed for reasonableness and consistency with available data. Insensitive parameters were not subjected to optimization but were fixed at reasonable values based on available data.

The final calibration statistics for the steady-state hydraulic heads, transient drawdowns, and steady-state stream flow data sets are shown in Table 1. The steady state model was calibrated to within about 5 % and the transient model to within about 9 %. The steady state stream flow targets were primarily used qualitatively, since the actual magnitude and location of diversions inside Mason Valley was confidential and very little information was available regarding diversions downstream in the Walker Valley. Also, DRI used a complex Fortran code to determine return flows back into the Walker River; the NCC model simply simulates the return-flow ditches as streams draining excess water. The NCC model was expected to over-predict streamflow as a result, particularly outside the Mason Valley where diversions were not well-characterized. However, despite the uncertainties regarding stream flow, the numerical match was within 4 % in the Mason Valley and within 18 % overall. Fig. 2 is a plot of the measured versus simulated steady-state hydraulic head targets, and Fig. 3 illustrates the measured versus simulated drawdown in one of the two pumping tests.

Residual Statistics by Data Set	Hydraulic Head (meters)	Drawdown (meters)	Stream Flow (cubic meters per day)
Mean	3.62	-0.061	-96654
Absolute Mean	7.43	0.61	98359
Standard Deviation	24.78	0.91	105636
Number of Data Points	357	6371	11
Standard Deviation/Range	0.054	0.087	0.18
Absolute Mean/Range	0.016	0.059	0.17
Range of Calibration Data	461.47	10.42	584737

Table 1 *Final calibration statistics for NCC model, 2013*

On Fig. 2, the close fit to the 1:1 line and lack of excessive scatter indicate that the model is well-calibrated. Layers 3 and 4 have the most deviation from the 1:1 line, possibly because the targets had only one data point apiece, the most recent of which was from 1965. It is probable that conditions have changed since that date. Also, those were the uppermost points in the model and were near the top of the Wassuk Range. Because of the high gradients between the summit and foot of the mountains, such data points are hard to match.

On Fig. 3, the first pumping test calibration is visually good for NC07-19, NC10-GT02, and NC07-26. However, NC08-MW03 showed an unusual lack of recovery in the observed data, while the modeled drawdown data show typical drawdown and recovery behavior. There appears to have been a localized factor influencing drawdown at the well, since it would ordinarily be expected to recover after cessation of pumping. Without further information, the model could not include this local influence and would not be expected to reproduce the unusual recovery pattern observed in that well.

The calibration results for the second pumping test (not shown in Fig. 3) were similar, in that overall the matches were quite good, but an unusual fracture-related effect was observed in a set of three wells. Those wells had similar drawdowns even though they varied in distance between 28 and 203 meters from the pumped well. An equivalent porous medium model such as this regional-scale finite-difference model cannot reasonably incorporate these small-scale fracture-related effects.

Conclusions

The NCC model incorporated a number of data sets not commonly used in other modeling efforts. These included publicly available irrigation well and water level data sets that often are not used due to the time and expense necessary to reconcile inconsistencies between data sets. In addition, the existing DRI model was a rarely-available and highly useful data source. Finally, the extensive field investigation conducted at the site and close communication with the client's geological and other staff provided valuable anecdotal evidence regarding the local geology and faulting, which informed and greatly improved the geological representation in the NCC model. The use of the DRI model, the estimates of fault and aquifer properties based on anecdotal information, and the use of GIS, database tools and PEST resulted in a well-calibrated and defensi-

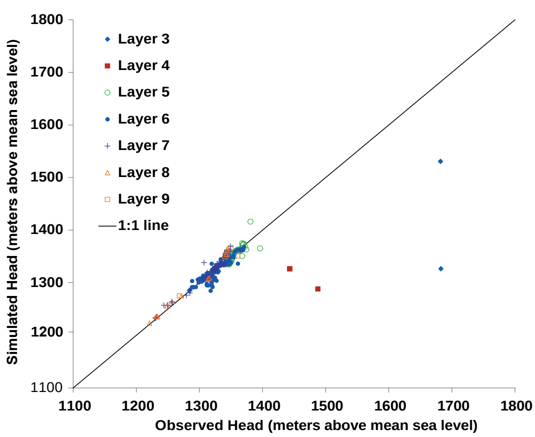

Fig. 2 *Observed versus model-simulated steady-state hydraulic heads.*

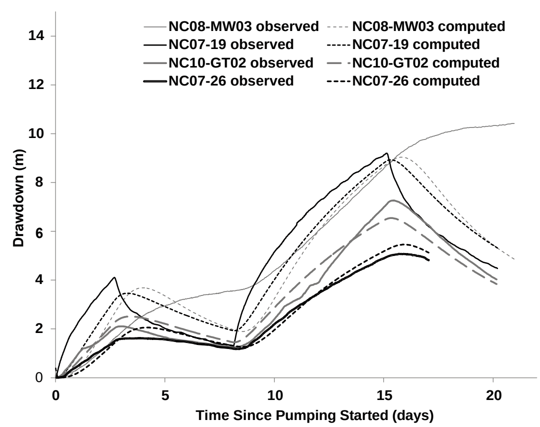

Fig. 3 *NCC model observed versus simulated drawdown for first pumping test data set.*

ble MODFLOW-SURFACT model that can be used to support engineering and permitting activities for the project, such as mine dewatering design and geochemical assessment of post-mining pit lake formation. Incorporating such less-commonly-used data sources can ultimately reduce the costs and improve the quality of a groundwater flow model.

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