model-calibration process. In previous models, the model parameters represented a lumped average for the properties of several different formations. The calibration period was extended from 1956 through 1996 and the number of wells providing information on changes in water levels caused by pumping increased from nine to 47. This work was based on a database that included and went beyond the one compiled by SSPA (1993), in part, by adding information for the Carmel Formation and the D Aquifer, and including eleven additional years of pumping stresses, water-level measurements, and spring and streamflow measurements.

Recalibration of the 1999 3D model to different assumptions of recharge and discharge rates determined that predictions of the effects of Peabody's pumping were not very sensitive to the assumed recharge rate. While the estimated hydraulic parameters changed when these models were recalibrated, indicating that the model was sensitive to recharge rate, the predicted impacts of the Peabody pumping on discharge and water levels remained only slightly changed. The many years of data on which these models' calibration were based resulted in models that produced similar results with regard to drawdown, and thus to effects on streams.

The 1999 PWCC model was periodically tested by obtaining Peabody and community annual water use, rerunning the model, and comparing the simulated drawdown at the BM observation wells against their measured drawdown. These simulations were done without any recalibration or any other changes. The model performed well, including simulating the effects of the significant reduction in Peabody's pumping at the end of 2005.

In 2013, it was determined that an update of the model was warranted, because of the number of years that had passed since the model was originally calibrated. During this effort, many updates were implemented:

- The simulation code was changed from MODFLOW-96 to MODFLOW-NWT, to take advantage of MODFLOW-NWT's improved ability to simulate water-table conditions and changes in water levels, such as would be caused by pumping.
- With the change in the simulation code, several newer MODFLOW packages became available to improve the model. These include:
    - o Multinode-Well (MNW) Package. This package allows the simulation code to calculate the pumping from each model layer for wells that penetrate several model layers, based on the hydraulic properties of each layer and the simulated water levels in the layers.

- o Streamflow Routing (SFR) Package. The SFR package simulates stream-aquifer interactions and calculates the rate of streamflow, allowing streamflow measurements to be compared against simulated streamflow at different locations. In combination with the collection of streamflow data collected since calibration of the 1999 model, this package allowed the model to estimate the recharge to the model area.

- Satellite spectral data were used to estimate evapotranspiration (ET) of groundwater along washes. This evaluation determined that a very significant percentage of the recharge to the groundwater system is discharged by ET.
- Individual springs were included in the updated model.
- The spatial variation in the hydraulic conductivity of the Navajo Sandstone was described by using the pilot-point approach, rather than using zones. The pilot-point technique, which was not available when the 1999 model was developed, results in more gradual spatial changes in hydraulic conductivity, and removes the arbitrary assignment of zonal boundaries.
- The model was calibrated to water levels during the period of 1956 through 2012, rather than drawdown during the period of 1956 through 1996. Both the 1999 model and the 2013 updated model used water-level data for the period prior to 1956. This change (using water levels rather than drawdown) results in a more robust calibration. The longer calibration period, besides simply using more data, includes the water level response to the approximately 60% reduction in pumping at the PWCC leasehold at the end of 2005.

OSMRE has been briefed on the new model on two different occasions, as the report describing the updated model is still in draft form (Tetra Tech, 2014).

The updated model was used to develop predictions of the cumulative effects of mining and associated use of water produced from the D and N aquifers. These predictive simulations and the simulation results are presented in Attachment 3, Predicted Effects of Pumping by PWCC 2014-2044 Water Use Projection. In these simulations, the pumping by PWCC was simulated as being at actual rates through 2012, at 1,500 af/y for the period of 2013 through the end of 2044, at 500 af/y during the final reclamation period from 2045 through the end of 2047, and 100 af/y for an additional ten years (through 2057) to support final reclamation and bond release. Community pumping was simulated at actual rates or estimates based on available recent pumping data through 2012, and at exponentially increasing rates based on annual average population growth rates provided by the Hopi Tribe and Navajo Nation. For the Hopi communities, the provided growth rates varied by community, and averaged 1.9%. The Navajo estimated their population growth at 2.48% at all communities. The per capita water use was assumed to be 100 gallons per capita per day, which is approximately 50% greater than current community use.

These predictive simulations indicated:

- The greatest effect on water levels was caused by PWCC's pumping prior to 2006, because of the higher pumping rates prior to 2006. Over a large area near the PWCC wellfield, water levels are recovering, and the effects will be diminishing in other areas. The simulated extent of PWCC's drawdown, defined by the 1-foot drawdown contour, in 2005 is very similar to the location of the confined/unconfined boundary as interpreted by the USGS. The extent of drawdown is predicted to increase a short distance between 2005 and 2044, but not to change noticeably between 2045 and 2057.
- Drawdown caused by community pumping is currently occurring throughout most of the model area, and will increase through time as the community pumping increases.
- The effect of pumping on stream flow is predicted to be minor at most streams. The streamflow at the Polacca gage is more sensitive than at the gages on other streams. The effect at the Polacca gage is predicted to be the result of both PWCC and community pumping.
- The effect of pumping at the four springs that are frequently monitored by the USGS is greatest at Pasture Canyon, where the effect is entirely the result of community pumping. No effects of pumping are apparent at the Unnamed Spring near Dinnehotso. The model did not simulate flow at Burro Spring or at Susunova Spring, but the drawdown evaluations indicate that the PWCC pumping will not affect flow at these springs.
- The model predicts that the groundwater infrastructure at Moenkopi, Tuba City, and Kayenta may need to be modified or supplemented to meet future water demands. The PWCC-caused drawdown will not extend to Moenkopi or Tuba City, and simulation results indicate that the reduction in production will be entirely the result of local pumping. At Kayenta, the model predicts that the production will be affected beginning in about 2050, due almost entirely to local community pumping. The water use by PWCC is predicted to have very little effect on the production capacity of the Kayenta wells.

The model predictions are quite similar to those obtained with the 1999 model with respect to the effects from community and PWCC pumping, but are more quantitative than available from the 1999 model. Even with the pumping anticipated under the 2014-2044 mine plan revision, the groundwater system will continue to recover from the effects of pumping prior to 2006. Effects of PWCC-caused pumping on streamflow, springs, and community water supplies will be very minor, but the effects of local pumping may be of concern.

Further, the discharge rates of springs are likely to be more sensitive to changes in local recharge than to drawdown caused by distant pumping. Springs are typically located near recharge areas, and temporal changes in their discharge rates caused by short-term changes in local recharge rates would be expected. Observations of springs discharging from the Wepo formation on the leasehold confirm the temporal variability of these smaller springs. Tree-ring studies performed throughout the southwestern U.S. document the variability of precipitation on the scale of decades (see, for example, Stahle and others, 2000). Even if good spring flow data were available, the variability in precipitation rates would make calibration to the spring discharge data difficult. Because of the character of these springs and of the groundwater system, the effects of Peabody's pumping are expected to be negligible. Measurement of pumping effects on springs will be difficult because of the expected small magnitude of these effects, seasonal changes of precipitation and evapotranspiration rates, and longer term changes in local precipitation rates.

In summary, groundwater models are the best tools available for evaluating the contributions of different pumping stresses on water levels and stream flows. Models of the N Aquifer flow system have been developed by both the USGS and by Peabody since the 1980's, with each successive effort improving on the previous. As additional data have been collected and improved computational tools made available, the models have incorporated more knowledge of the groundwater system.

The models have varied in detail; however, they were each based on the data available at the time of the model's development and incorporate the major components of the N Aquifer flow system. Further, each model has been subjected to a calibration process whereby the ability of the model to simulate historical measurements is demonstrated. The 2013 update of the 1999 model is greatly improved from the 1999 model, and has similar predictions relative to the effects of PWCC's pumping. They predict that water levels in the confined part of the N aquifer will be reduced by pumping but that the water levels will remain well above the top of the N aquifer. The effect of Peabody's pumping on discharge to streams has been and will continue to be minimal.

Effect on the Structural Integrity of the N Aquifer. Lowering of water levels by pumping has resulted in compaction of unconsolidated sediments in some areas of the western U.S.