Appendix B

Groundwater Modeling Report

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Groundwater Modeling Services to Support the Amargosa Road Solar Power Project EIS Technical Memorandum

by
GeoTrans, Inc.

Introduction

The purpose of this report is to document the results of modeling simulations performed to evaluate the potential hydraulic effects of pumping 400 afy on nearby water resources, such as Devils Hole which is the only naturally occurring habitat for the Devils Hole Pupfish and discharge at Ash Meadows, for the EIS. Figure 1 shows the location of the Project area. Modeling was performed using the Death Valley Regional Flow System (DVRFS) Model (Belcher, 2004). The DVRFS model is the only existing model of the study area. This model was calibrated to both pre-pumping and pumping conditions. The Amargosa Basin is one of the areas covered by the model in which there has been significant pumping, and water-level changes measured in the area were used to guide calibration of the model. As with any model, improvements can always be made, and the predictive results should be evaluated accordingly.

Groundwater Model Background

This model was developed by the U.S. Geological Survey (USGS) over a period of approximately eight years. The effort was funded primarily by the Department of Energy (DOE) through programs at the Nevada Test Site and at Yucca Mountain, with support and review by other Federal Agencies, including the National Park Service. The present model was developed in two phases. The first phase was the development of a three-dimensional flow model to simulate pre-development (steady-state) conditions, using geologic models developed separately by a contractor for the Underground Testing Area (UGTA) Project and by the USGS for the Yucca Mountain Project. The second phase of the DVRFS model development involved construction of a new geologic model, and development and calibration of the resulting new flow model to both pre-development and post-development conditions. The model produced from the second phase has commonly been called the "transient" model. GeoTrans was instrumental in the development of the UGTA model, and represented the UGTA Project during the development of the DVRFS model by the USGS. GeoTrans worked closely with the USGS, reviewing many of the products and modeling datasets, but did not perform any of the actual development effort.

In the following discussion, the term "model" will generally apply to the three-dimensional USGS DVRFS transient flow model.

Documentation of the model (DVRFS report) is available online (http://pubs.usgs.gov/sir/2004/5205/). In addition to the report itself, there are many supporting documents on geologic and hydrologic investigations performed to support

development of the model. Hydrologic investigations relevant to the Amargosa Desert include measurements of evapotranspiration (ET) at Ash Meadows, in Death Valley, and in Oasis Valley; estimation of ET at Franklin Lake playa and near Franklin Well (Amargosa River); construction of a dataset for pumping in the Amargosa Desert (and other areas); and measurement of groundwater recharge underneath the Amargosa River and irrigated fields in the Amargosa Farms area.

The model is developed using MODFLOW-2000 (Harbaugh et al., 2000), using a grid with a lateral spacing of 1,500 meters, and a variable vertical spacing. There are 16 model layers, with an interpretation of the water table used as a reference surface from which to base the elevation of the upper model layer. A large number of layers is needed to capture the geologic complexity incorporated into the geologic framework model, which is itself a simplification and interpretation of the actual geology. The model assumes that all layers are fully saturated, and that dewatering does not occur. Thus, transmissivities do not become smaller with drawdown, and the model is approximately mathematically linear. Because the Drain package is used to simulate springs, the model would not be strictly linear if drawdown is sufficient to cause water levels in a cell to decrease below the specified elevation of a drain. In addition, if drawdown is sufficient to cause appreciable decreases in the saturated thickness of the aquifer being pumped, the model will tend to underestimate the drawdown and overestimate the productivity of the aquifer.

The model was calibrated using a non-linear regression technique which optimizes modeling parameters to minimize the objective function, which was the sum of squared weighted residuals. A residual is defined as the difference between the observed (or estimated) value for a calibration target, and the corresponding simulated value. Hydraulic heads, water-level changes, discharge rates in spring areas, and lateral boundary fluxes were used as calibration targets. As the objective function represents the entire model, rather than concentrating on the Amargosa Farms and Ash Meadows areas, the agreement of simulated water-level change and measured change at Devils Hole is reasonable, but could be improved with additional work.

Following publication of the DVRFS report, a minor error was detected in the geologic model in the Oasis Valley area. The simulations reported here were performed with the updated model, which was downloaded from the above web site. Also, the modeling pumping and return flow datasets were updated in 2003 by the USGS to include updated estimates of groundwater withdrawal and return flow from irrigation (Moreo and Justet, 2008). This updated dataset was also used in the simulations reported here.

It should be noted that the USGS pumping dataset has different groundwater withdrawal amounts than the State Engineer's groundwater withdrawal inventory for the Amargosa Desert Hydrographic Basin. The USGS used satellite imagery and consumptive use estimates to create their groundwater withdrawal inventory. The State Engineer's inventory is based upon metered amounts or estimates provided by water rights owners. Since the DVRFS model was calibrated using the USGS pumping inventory, the same datasets were used in this study.

Groundwater Model Limitations

As stated earlier, the DVRFS model is the only existing groundwater flow model of the study area. Before evaluating predictions of drawdown at Devils Hole or change in discharge at Ash Meadows using the DVRFS model, the reader needs to be aware of the limitations of using a regional-scale groundwater model to evaluate potential water resource impacts at springs or other sites (e.g., Devils Hole) that are local in scale (feet). These limitations include 1) model grid size (1,500 m x 1,500 m), 2) calibration to regional groundwater flow conditions, 3) estimates in historic pumping dataset and 4) simplification of geology. The DVRFS model report (p. 350) states "the use of the (DVRFS) model to address regional-scale issues or questions is the most appropriate use of the model." All the model results presented here are not accurate to the feet scale, but several meters. The DVRFS model gives you a qualitative sense of how water levels change over time at a given location, not quantitative.

Before conducting predictive modeling simulations, it is important to compare calculations of water-level change at Devils Hole with measured changes. Figure 2 shows the comparison through 2003, the end of the updated pumping and return flow dataset. Provisional water-level data after 1989 was received from National Park Service (NPS, 2006). Several features should be noted:

1. Both the measurement dataset and the simulated levels show declining water levels prior to the start of significant pumping in the Ash Meadows area. The simulated rate of decline is faster than the observed rate. The model is also slower to respond to changes in pumping rates.
2. The effects of pumping in Ash Meadows are readily apparent in both the measurements and simulated results beginning in approximately 1970, but the simulated change is greater than the measured change.
3. In the original 1998 model, during three periods beginning approximately in 1975, 1987, and 1998, there are simulated declines that do not occur in the measured values. The model values do not recover as much as the measurements following cessation of nearby pumping. In the updated 2003 model, the simulated decline starting around 1975 still remains to a lesser degree, but the other two declines have been corrected. We suspect there is still an error in the historical pumping dataset prepared by the USGS for the 1975 period.
4. The effects of seasonal barometric changes, seasonal pumping, and earthquakes are not incorporated in the model.
5. Beginning in 1996, until 2003, the model simulates a decline in water levels.

In summary, the model overpredicts the drawdown caused by historical local pumping by approximately 30%. However, the model does a reasonable job in matching the water level trends at Devils Hole after the 1970s. Even with the model limitations and assumptions presented above, the model can still be used as a qualitative tool to provide information on the potential impacts to local groundwater resources.

Groundwater Model Simulations and Assumptions

After updating the USGS DVRFS model through 2003 with the revised pumping and return flow dataset, GeoTrans conducted several groundwater modeling scenarios using this updated model. Based on discussions with Project team members the following modeling scenarios were proposed and/or simulated as part of this Project:

1. Run existing DVRFS model an additional 200 years past the transient calibration period with 2003 pumping (i.e., No Action).
2. Same as Scenario 1 except add the proposed action of 400 afy from the proposed Project well (600 afy during the 39 month construction period) from 2010-2039 (i.e., Proposed Action).
3. After transient calibration period, incrementally decline Amargosa Farms pumping to stabilize water levels at Devils Hole.
4. After transient calibration period, turn off injection wells in Amargosa Farms.
5. After transient calibration period, reduce recharge in Amargosa Farms based on Stonestrom et al. 2003 and 2007 findings.

Scenarios 3 through 5 were added to examine the effects of reducing groundwater withdrawal and change in return flow and recharge from the Amargosa Farms area on Devils Hole water levels.

The following assumptions were made during the modeling scenario simulations:

1. No climatic effects – The current recharge dataset was used for the 200 year simulations. The effect of water rights users irrigating more or less due to climate than 2003 amounts was not estimated.
2. The Project groundwater withdrawal of 400 afy for the 30 year operational period (600 afy during the 39 month construction period) was added to the 2003 pumping dataset since the USGS estimate for 2003 was below the duty (603 afy) minus the Project pumping (400 afy). It is assumed that existing pumping from the Project well plus the 400 afy from the Project would not exceed the duty of 603 afy in the 200 year simulations.
3. Water infiltration from mirror washing was not accounted for because it is assumed to not contribute to groundwater recharge.

Groundwater Model Results

Figure 3 shows the simulated water-level elevation at the end of 2003 based on the revised pumping and return flow datasets. The water level contours indicate that the potentiometric surface of the valley fill indicate a broad and gently sloping gradient from the northeast toward the central axis of the valley and southwest toward the Funeral Mountains.

Figure 4 shows simulated drawdown contours at the end of 2003. This map represents the change in water level from pre-development (1912) to 2003. Within the Amargosa

Basin, the most rapid water level declines occurred in the Amargosa Farms area, which is consistent with observed water level changes from other studies (Kilroy, 1991). Devils Hole is approximately 15 miles from the proposed pumping and the simulated drawdown at Devils Hole in 2003 is approximately 1.8 ft.

Scenario 1 (Existing Pumping or No Action) Results

For scenario 1 (no action), 2003 pumping and return flow was repeated every year for the next 200 years to determine the change in water levels at Devils Hole. Figure 5 shows change in simulated water-level contours from 2003 to 2203. Drawdown is predicted to be more than 10 feet over a large area including Ash Meadows NWR.

Figure 6 shows that simulated water levels at Devils Hole decline over 13 feet after 200 years due to existing pumping. Note "time zero" is assumed to be the simulated water-level elevation on December 31, 2003 from the model, not pre-development conditions. An important conclusion from Scenario 1 is that the cumulative effect of 2003 groundwater withdrawal levels continuing into the future will cause an impact to Devils Hole and Ash Meadows even though the magnitude and timing of this impact is uncertain. It is likely water levels at Devils Hole will fall below the U.S. District mandated level, but as stated in the last sentence the timing cannot be quantified at this time.

Scenario 2 (Proposed Action) Results

For the proposed action, the 400 afy of groundwater withdrawal was simulated from the proposed Project well. Project pumping is assumed to start in 2010 and concludes in 2039 since the Project life is 30 years. The first 39 months (construction phase) of the Project will require 600 afy of groundwater instead of the long-term groundwater withdrawal of 400 afy. Table 1 shows the location of the proposed Project well. The Project well was pumped from Layer 1 in the model since Layer 1 was deeper than the depth of the well.

Table 1. Proposed Project Groundwater Withdrawal

App. No.	Easting (m)	Northing (m)	Duty (afy)	Proposed w/d (afy)	Model Row	Model Column	Model Layer
15893	542362.42	4044948.68	603	183	116	71	1

Figure 7 shows the simulated water-level decline from the existing pumping and the Project pumping from 2003 to 2203. The Project pumping reduces simulated water levels at Devils Hole by approximately 0.05 ft or 0.6 in after 200 years. Recall this reduction in water levels is approximately 30% higher due to the model overpredicting water level declines at Devils Hole historically (See Figure 2). Also, the DVRFS model calibration is not accurate to 0.05 ft but meters and is not designed to exactly measure drawdown at a spring location several miles away, such as Devils Hole because of its 1) grid size (1,500 m x 1,500 m), 2) calibration to regional groundwater conditions, 3) estimates in historic pumping dataset and 4) simplification of geology. Thus, the regional model has a limited capability to accurately evaluate incremental changes in pumping tens of miles away on Devils Hole, but it is the only groundwater flow model available.

The Project groundwater withdrawal should result in a minimal effect on Devils Hole water levels and local water users. There will be a small difference in groundwater recharge between the shift from an agricultural to industrial beneficial use. Studies have been performed on irrigation return flow adjacent to the property (Stonestrom et al. 2003 and 2007), but give a range of values for recharge from two different methods: 1) 0.1 to 0.5 m/yr (4 to 20 in/yr) from vertical profiles of water potential and environmental tracers and 2) 9-22% of infiltrated irrigation from chloride mass-balance estimates. The reason the model does not show zero water-level change at Devils Hole due to Project pumping is due to the USGS estimate for 2003 groundwater withdrawal from the Project well being lower than 203 afy.

Scenario 3 Results

Figure 8 shows the effect on simulated water-level change at Devils Hole of incrementally (i.e., 10%) reducing groundwater withdrawal within the Amargosa Basin. In order to stabilize water levels at Devils Hole, pumping in the basin would have to be reduced between 80 and 90% from 2003 levels. Thus, Project pumping would have a negligible effect on the stabilization and/or recovery of water-level changes at Devils Hole. Even if all pumping in Amargosa Basin ceased after 2003, recovery of water levels at Devils Hole would not start occurring for approximately 37 years and take longer than 88 years to fully recover.

Scenario 4 and 5 Results

Figure 9 shows the effect of turning off return flow to the valley-fill deposits from irrigation in the model. Simulated water-level change at Devils Hole would increase approximately an additional 2.3 feet or 18% due to shutting off return flow. Scenario 5, which is reducing recharge to the valley-fill deposits based on the 2003 and 2007 Stonestrom et al. (Stonestrom) studies, was not simulated because the result would fall between the two curves on Figure 9. As discussed earlier, Stonestrom measured the amount of infiltration beneath an irrigated field adjacent to the Project site. The amount of infiltration was measured between 0.1 and 0.5 m/yr. Changing the recharge in the model to any amount in this range would produce a water-level change curve that would fall between the two curves on Figure 9.

Ash Meadows Discharge

Discharge occurs at Ash Meadows because of the presence of the water-bearing carbonate aquifer exposed in the low-lying hills northeast of the discharge area, and the presence of an impediment to flow that causes water levels to be elevated to the land surface. Dudley and Larson (1976) indicate that groundwater flows southwestward toward Ash Meadows in the carbonate aquifer under confined conditions. Water is forced upward “along faults that segment the hills east of Ash Meadows. This produces a mound of unconfined water which discharges laterally into shallower local aquifers.”

The USGS code ZONEBUDGET (Harbaugh, 1990) was used to evaluate the changes in water movement for the Amargosa Basin including discharge at Ash Meadows. Under the present-day pumping rates, the model predicts that only minor changes to the discharge rate at Ash Meadows would have occurred by 2003, the end of the model calibration period (Figure 10). When the present-day pumping is continued into the future, the model predicts that impacts to the discharge will occur. In 2203, the discharge is predicted to be reduced from approximately 18,095 acre feet per year (afy) to 15,607 afy. When the Project pumping is added, the discharge rate in 2203 is predicted to be reduced to approximately 15,600 afy or a minimal difference of 7.4 afy or 0.05%.

Results of other hydrologic studies

It would be reasonable to ask whether the historical water-level changes calculated by the model are consistent with the conclusions of other investigators. Two recent investigations evaluated Devils Hole water levels and concluded that pumping, rather than climatic changes, was the cause of historic declines in water levels. The first (Fenelon and Moreo, 2002) evaluated water level changes in wells over a large area that included the Amargosa Desert and Ash Meadows. They considered pumping, changes in recharge rates, earthquakes, and barometric pressure changes as factors that would cause water levels to change. Figure 17 of their report shows the correlation between pumping in the Amargosa Farms area and downward water-level trends over the period of 1992 to 2000 in the Amargosa Farms area. In the Devils Hole area, they consider whether pumping in the Amargosa Farms area could impact Devils Hole water levels, but do not conclude that it has. They also conclude that pumping from well Army 1 near Mercury, NV (see Figure 1) has not impacted Devils Hole water levels based on the lack of response to a reduction in production from Army 1 that began in 1994. They also note that Devils Hole may still be recovering from the pumping in Ash Meadows. The slow recovery to local pumping would suggest that responses to reduction of pumping much further away would be difficult to measure, especially with other stresses changing.

Bedinger and Harrill (2006) evaluated changes in Devils Hole water levels using a regression procedure. They constructed simple Theis models of drawdown caused by pumping at Ash Meadows, the Amargosa Farm area, and Army 1. Temporal changes in pumping rates at these three areas were calculated through superposition. A regression procedure, with water level at Devils Hole as the dependent variable, was used to calculate the relative effects of pumping in these three areas. They determined in a preliminary analysis that consideration of climate variability explained very little of the variability in Devils Hole water levels. The Theis solutions were calculated using hydrologic parameters that might be considered appropriate for the aquifers, but they could not successfully determine these values during “model calibration” because of parameter correlations. They determined that the pumping at Ash Meadows, the Amargosa Desert (Amargosa Farms area) and Army 1 explained 98% of the variability in the annual mean water levels over the period 1962 through 2002. Based on the figures in their report, and the regression parameters, the drawdown in 2002 caused by Ash Meadows pumping was approximately 0.25 feet (and decreasing because of the almost complete cessation of this pumping in 1978), by Amargosa Desert pumping was

approximately 0.5 feet (and increasing), and by Army 1 pumping was approximately 0.2 feet (and decreasing because of decreases in pumping rates beginning in 1995).

Summary

1. Comparison of simulated and observed changes in water levels at Devils Hole through 2003 indicated that the DVRFS model overestimated the change in water level caused by pumping in Amargosa Basin. There may be an error in the historical pumping dataset that affects this comparison. Although the model could be improved by additional work specifically in the Amargosa Desert and Ash Meadows areas, the pumping estimates developed for the model are reasonable.
2. The cumulative effect of 2003 groundwater withdrawal levels continuing into the future (No Action scenario) will cause an impact to water levels at Devils Hole and discharge at Ash Meadows even though the magnitude and timing of this impact is uncertain due to model limitations.
3. The Proposed Action scenario predicts that Project pumping will cause water levels in Devils Hole to decline by approximately 0.05 ft after 200 years. When considering these predictions, it is important to recognize that the model overpredicted the decline in water levels caused by pumping in the Amargosa Basin and is not accurate to 0.05 ft but meters due to its original objective of modeling groundwater flow at a regional scale.
4. The model predicts that the Project pumping will reduce the discharge rate from springs at Ash Meadows a amount of 7.4 afy or 0.05%.
5. Groundwater pumping in the Amargosa Farms area has caused tens of feet of drawdown near the pumping wells. Simple modeling using the Theis equation and superposition, coupled with regression procedures, indicates that the pumping in the Amargosa Farm area is the primary cause of the present-day drawdown at Devils Hole.

Abbreviations or Acronyms

afy – acre-feet per year
DOE – Department of Energy
DVRFS – Death Valley Regional Flow System
ET - evapotranspiration
ft – feet
in – inches
m – meters
NPS – National Park Service
NWR – National Wildlife Refuge
UGTA – Underground Testing Area
USGS – United States Geological Survey
yr – year

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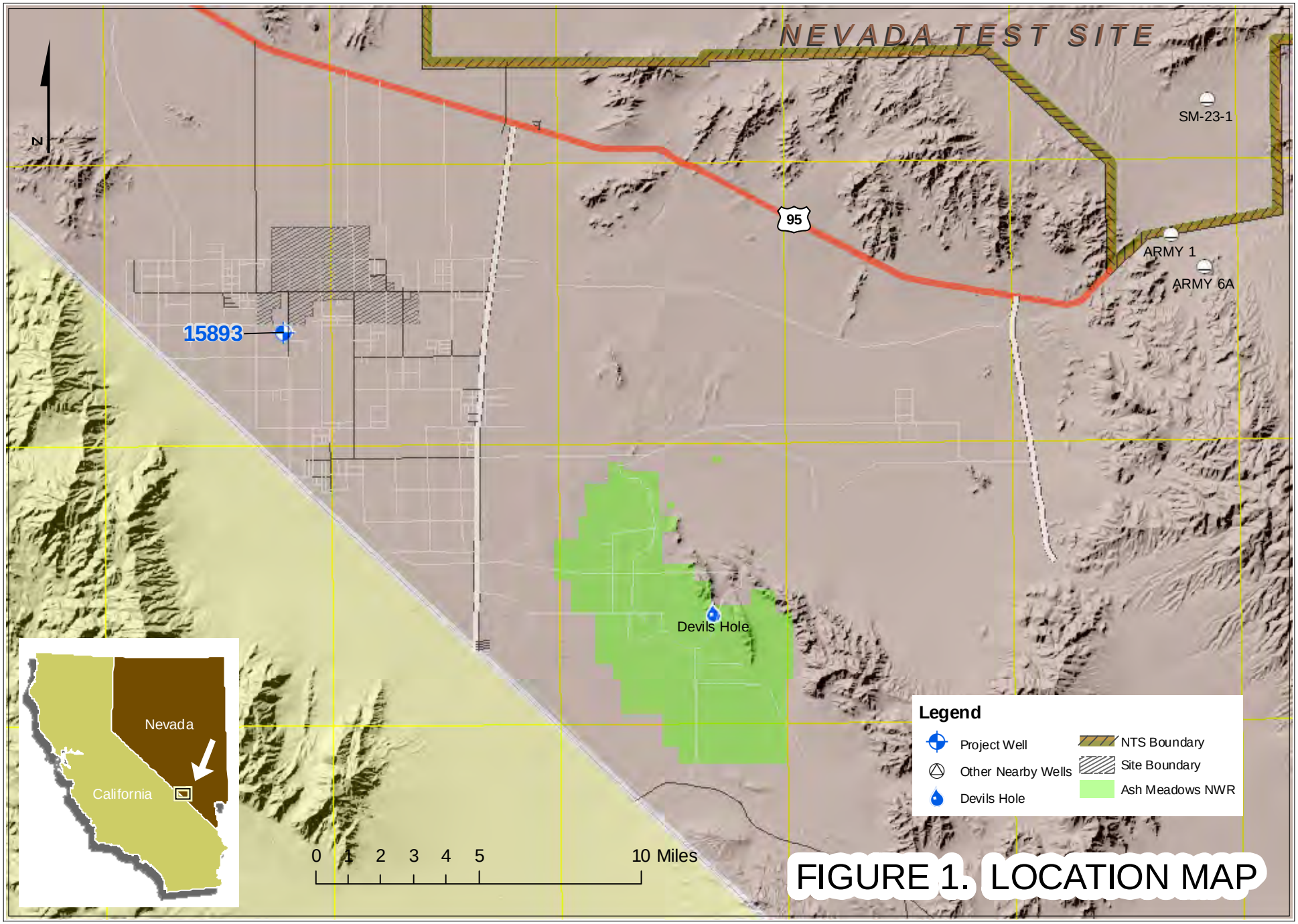

FIGURE 1. LOCATION MAP

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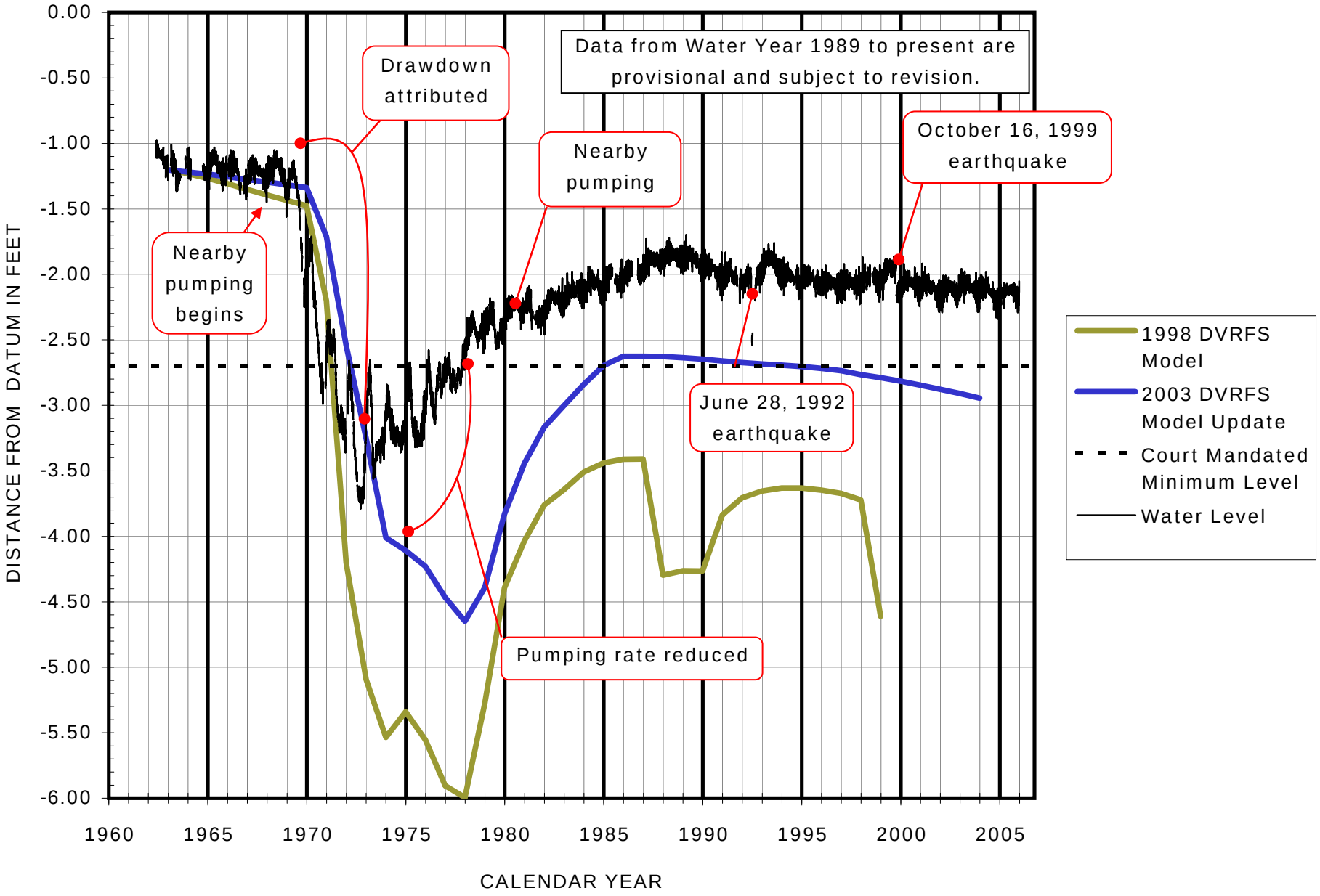
Figure 2. Level of Pool in Devil's Hole
Daily Mean (5/23/1962-12/31/2005)



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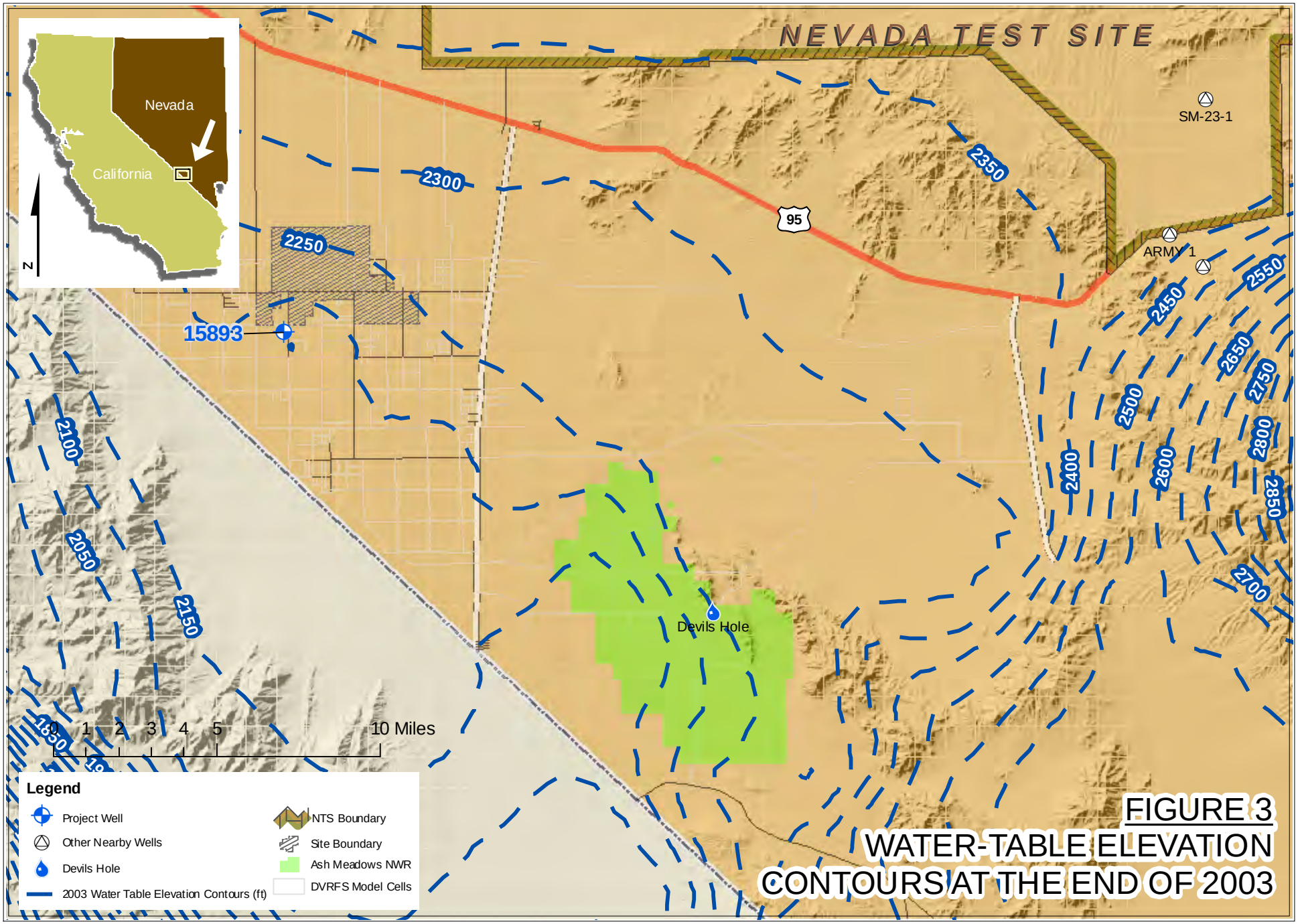

FIGURE 3
WATER-TABLE ELEVATION CONTOURS AT THE END OF 2003

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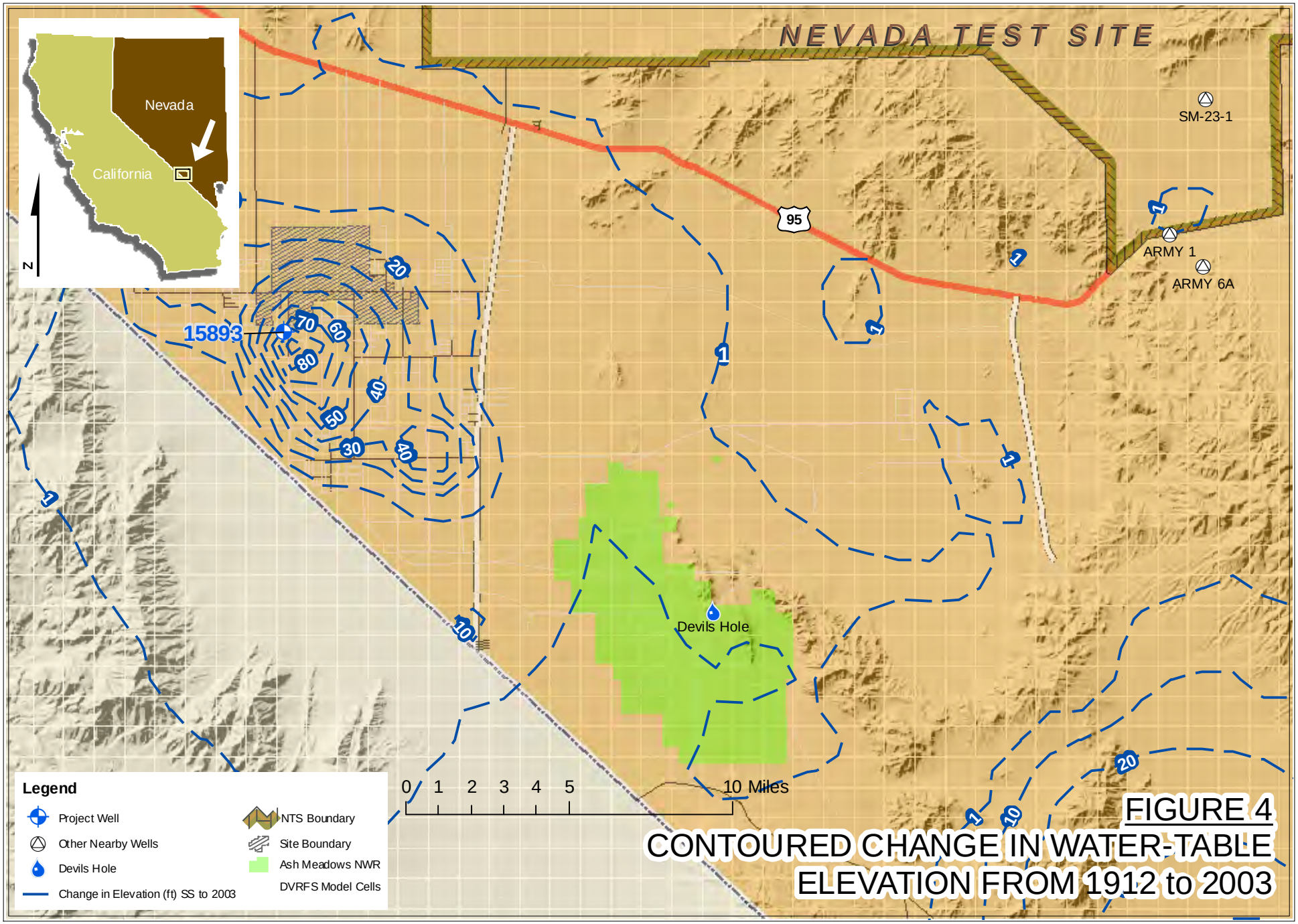

FIGURE 4
CONTOURED CHANGE IN WATER-TABLE ELEVATION FROM 1912 to 2003

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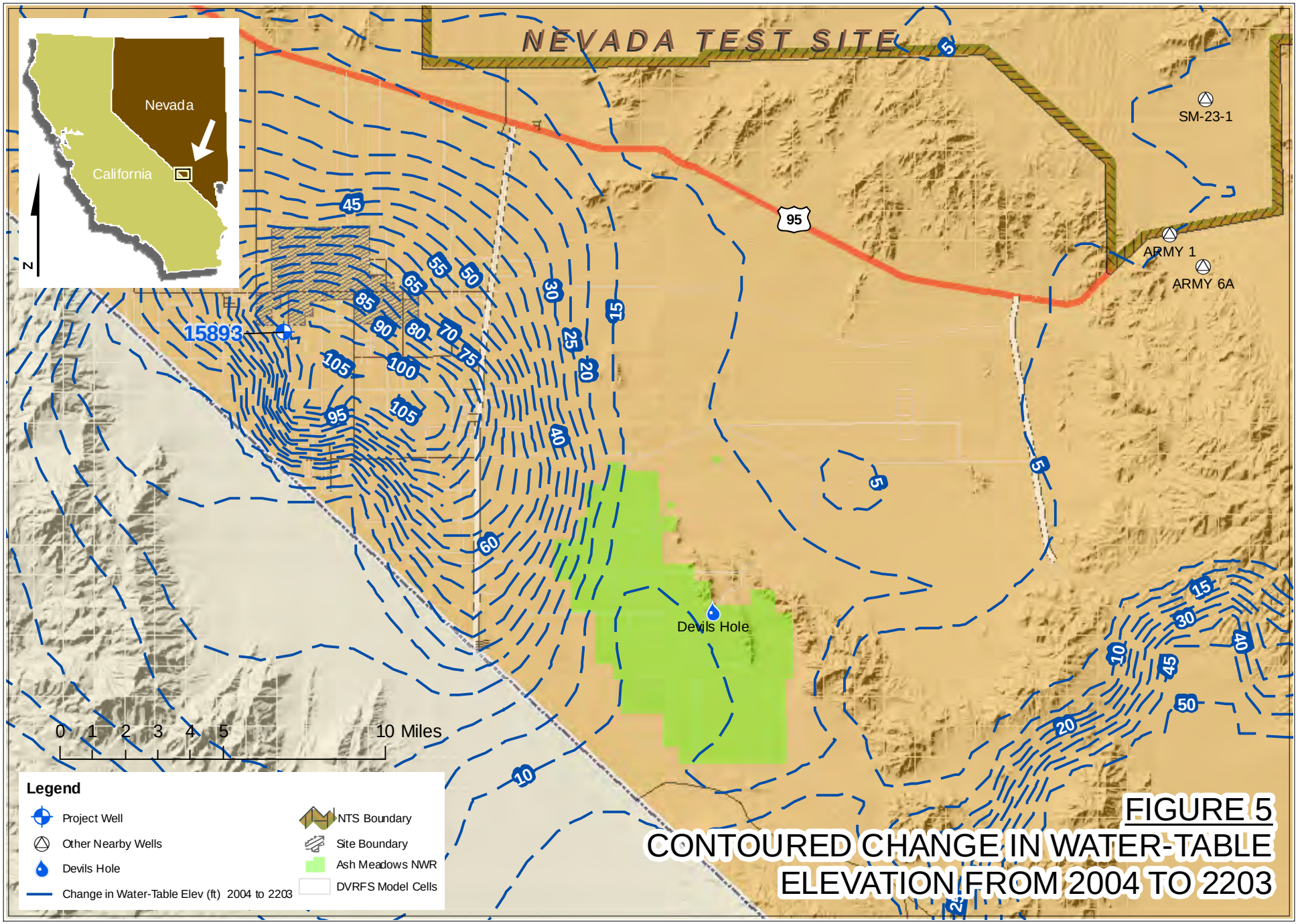

FIGURE 5
CONTOURED CHANGE IN WATER-TABLE ELEVATION FROM 2004 TO 2203

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Figure 6. Change in Water-Level Elevation at Devil's Hole from 2003 to 2203

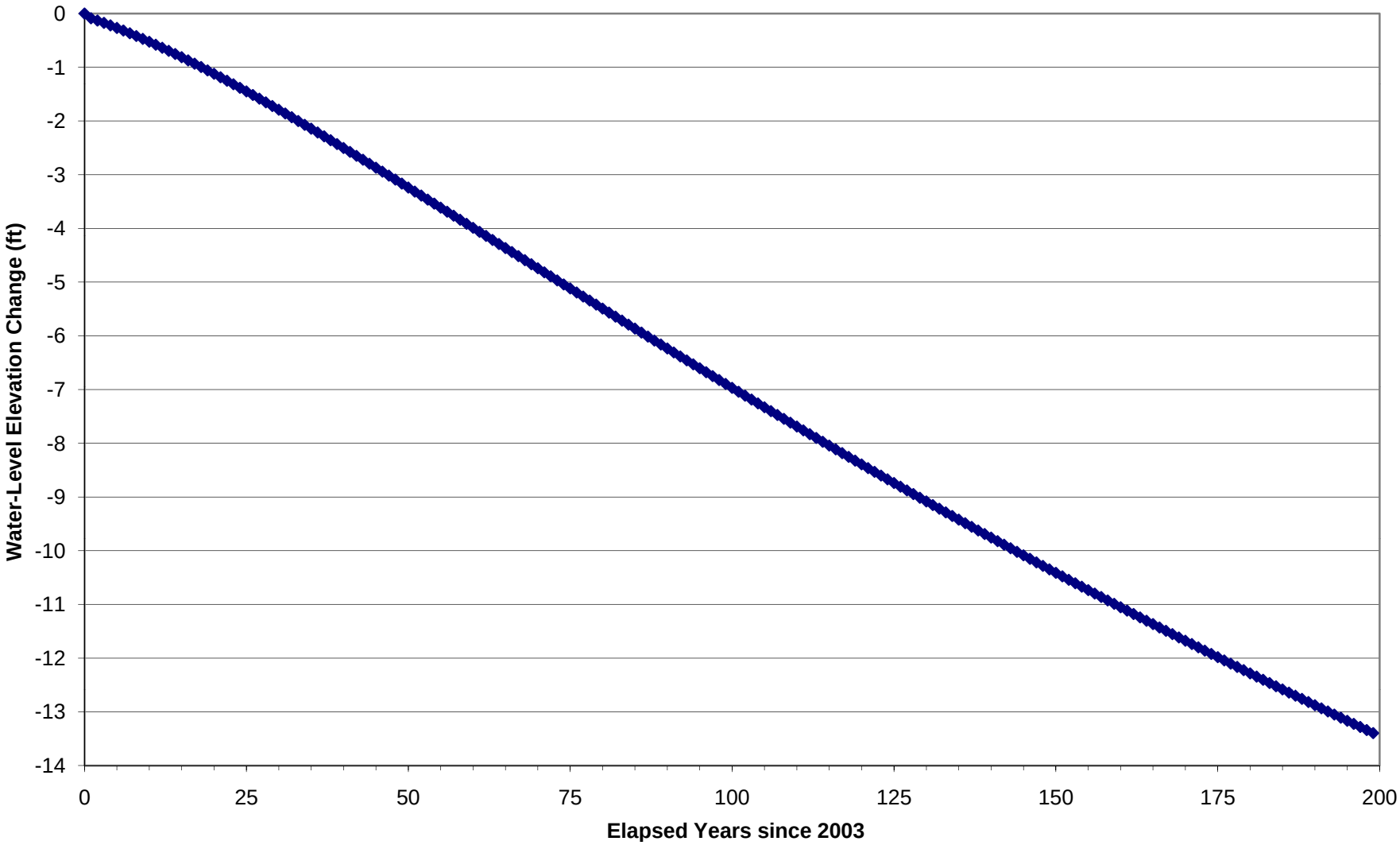

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Figure 7. Change in Water-Level Elevation at Devil's Hole from Proposed Action Pumping from 2003 to 2203

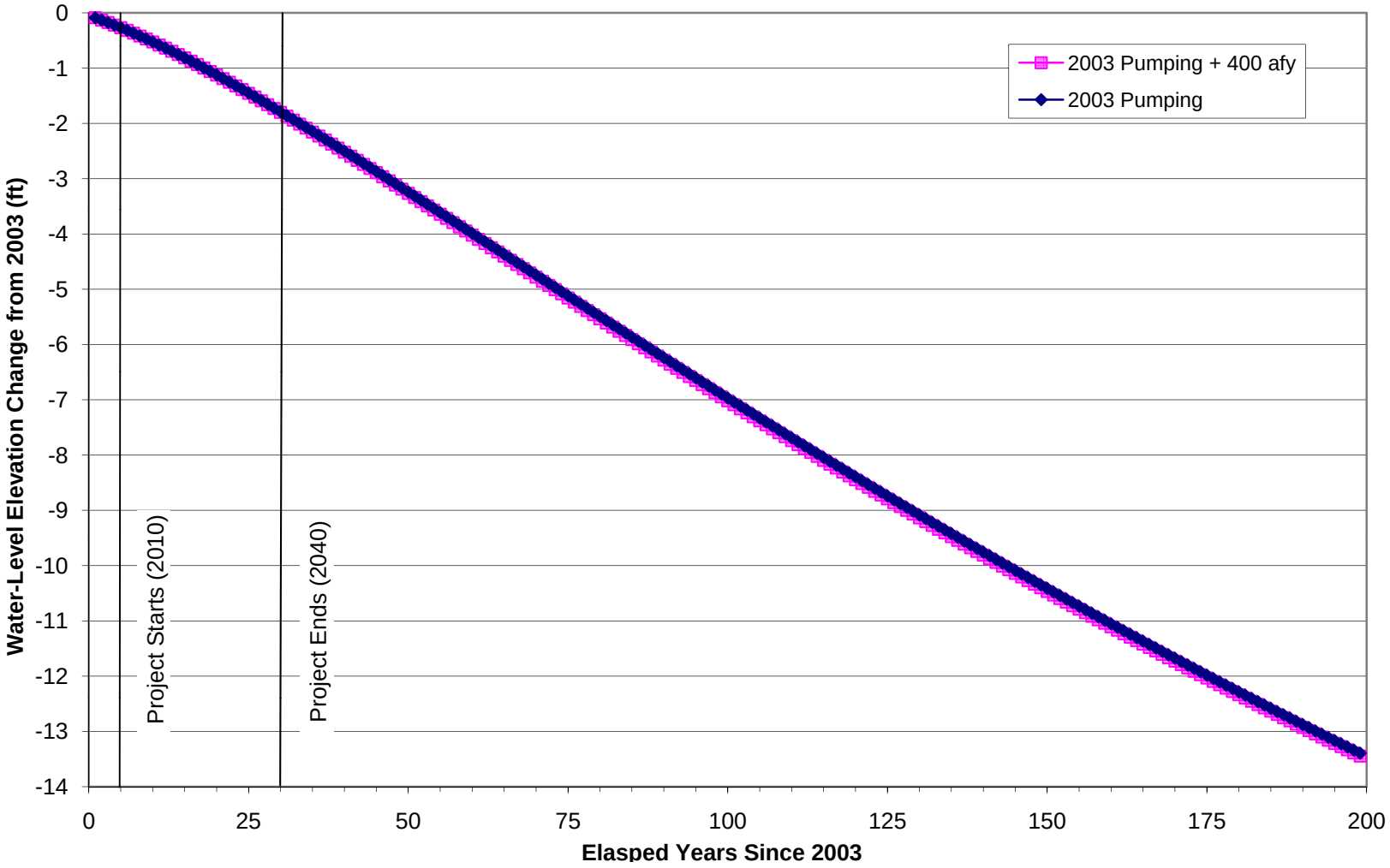

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Figure 8. Effect of Reduced Amargosa Basin Pumping on Devil's Hole Water Levels from 2003 to 2203

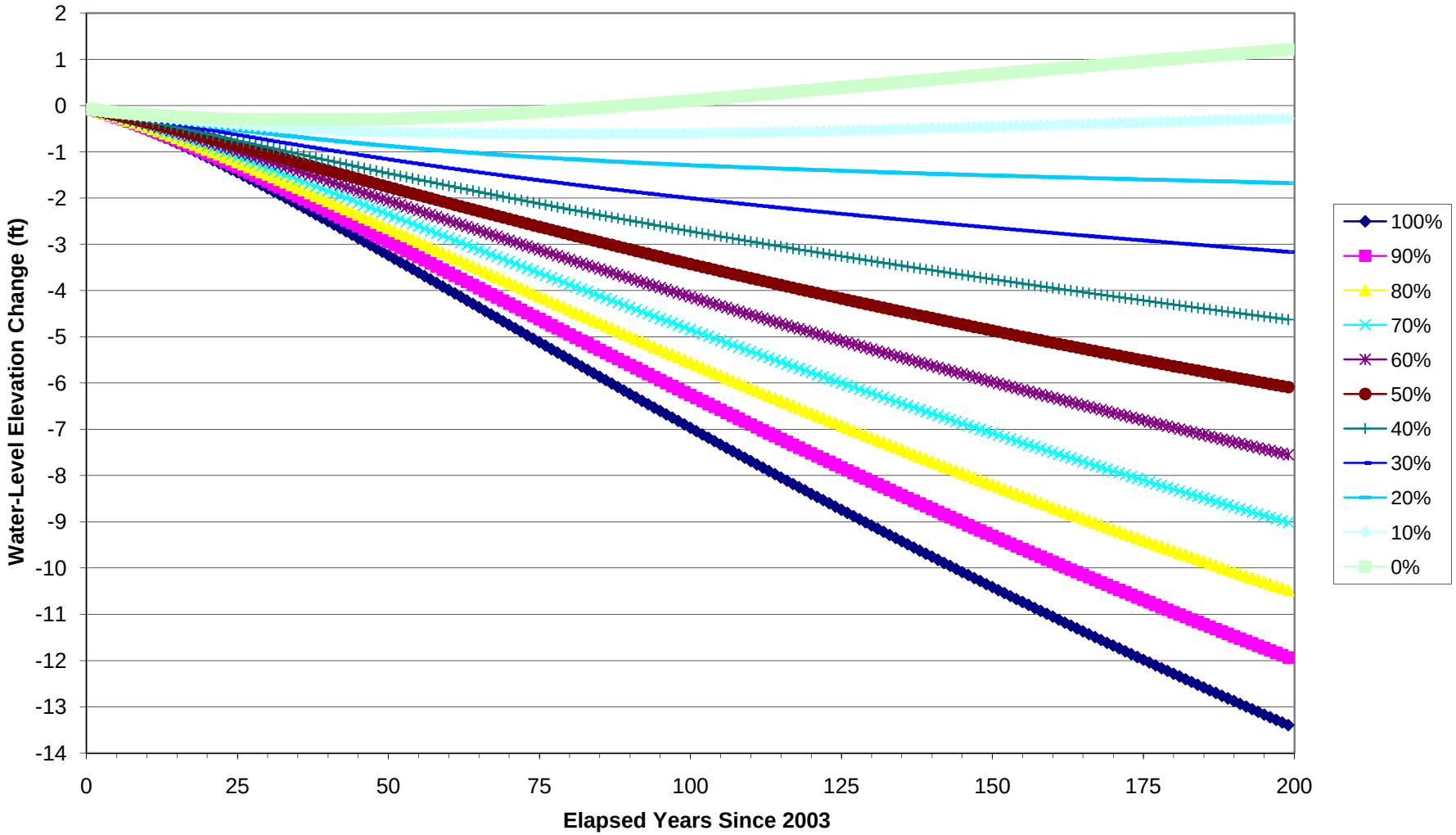

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Figure 9. Effect of No Return Flow in Amargosa Basin from 2003 to 2203

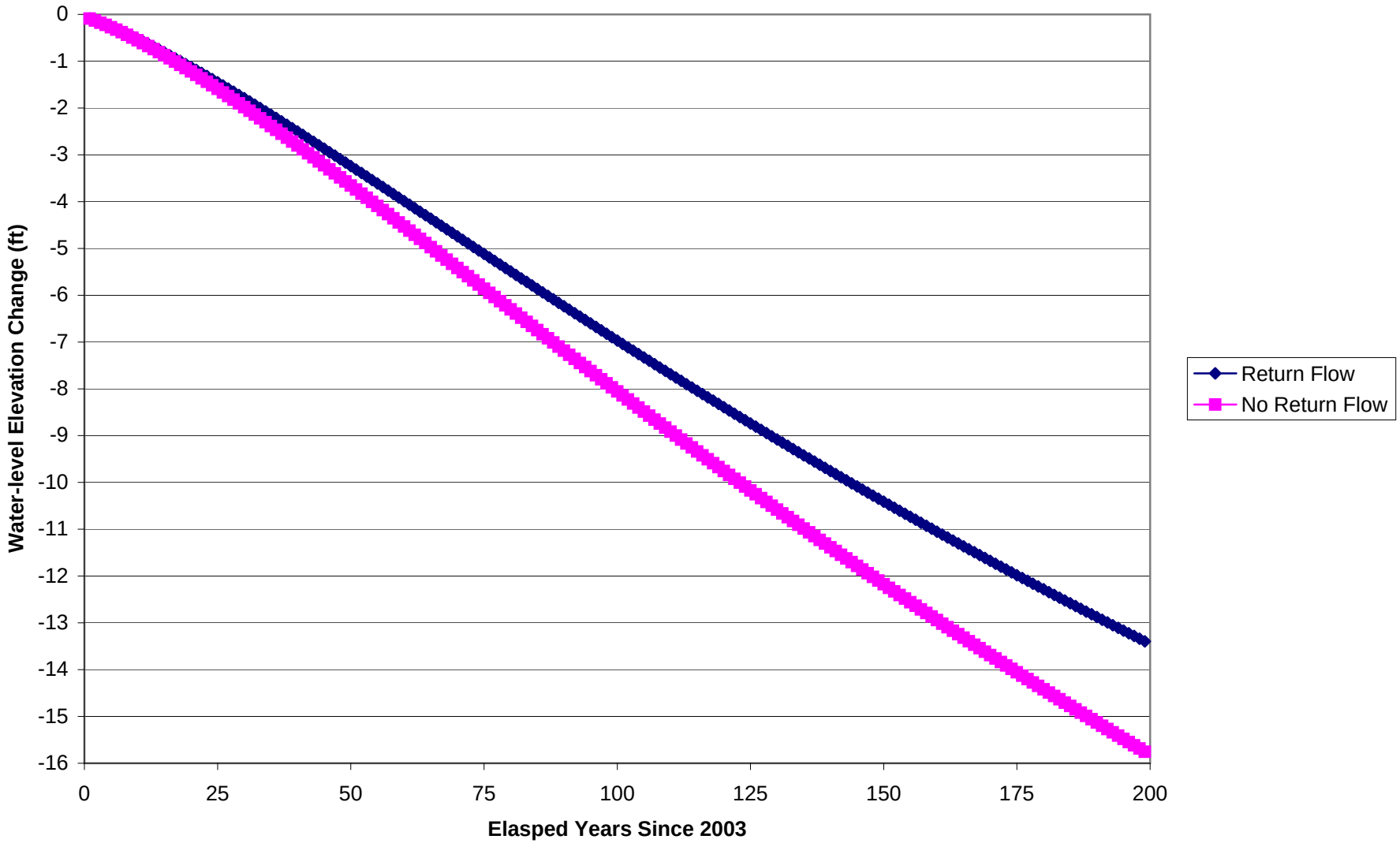

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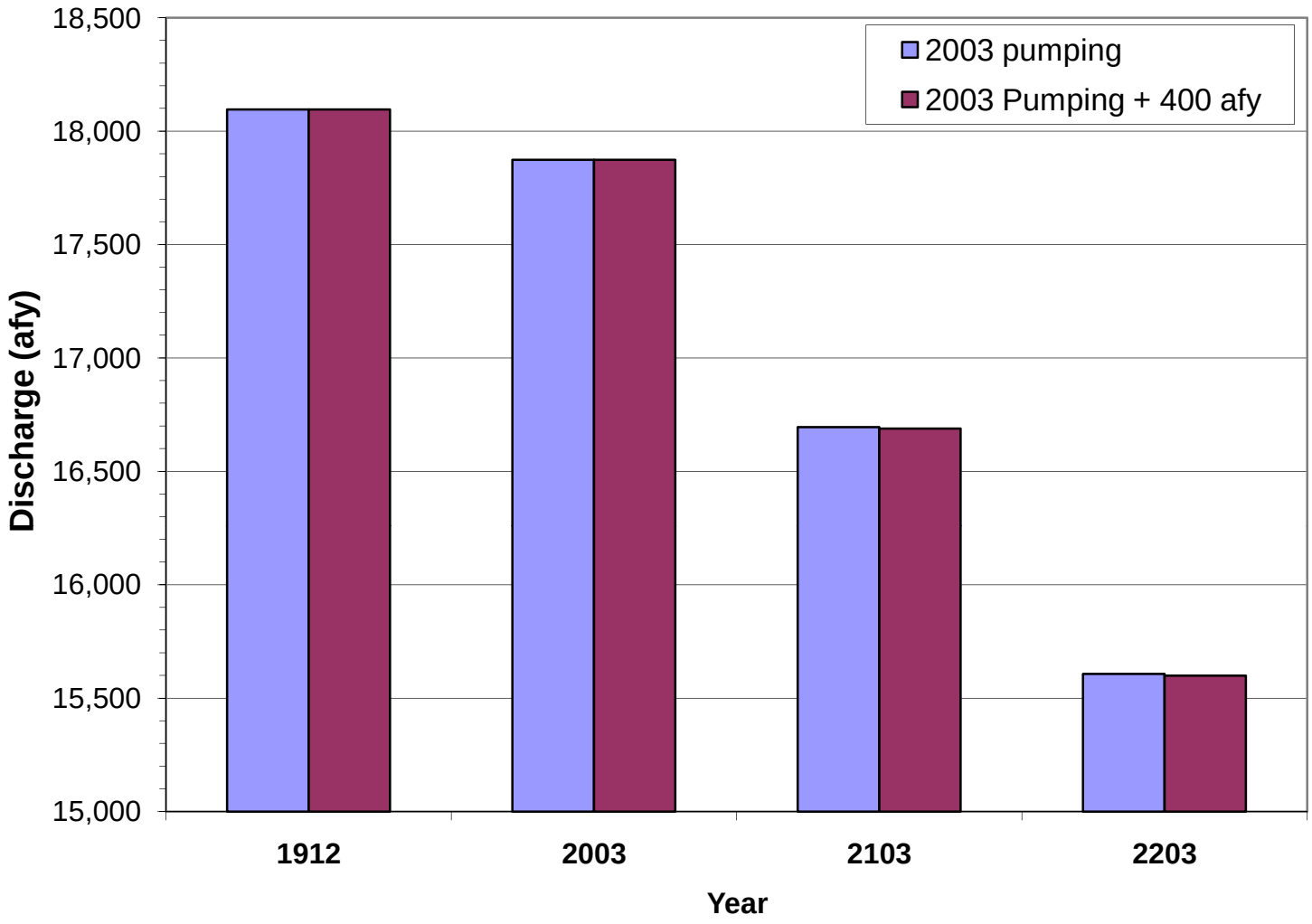
Figure 10. Comparison of the simulated effects of 2003 pumping, and 2003 pumping plus project pumping, on the discharge at Ash Meadows



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