4.0 CALIBRATION OF HISTORICAL NUMERICAL MODELS

Calibration is an important step in producing a reliable predictive model of groundwater flow. Model calibration is the process of making changes to the hydraulic properties and other inputs to the historical groundwater flow models so that the simulated historical groundwater levels more closely match observed groundwater levels. The Roca Honda mine model has been well calibrated to predevelopment and transient historical conditions so that it can be used to evaluate changes in groundwater levels from mine dewatering.

The calibration process for the Roca Honda groundwater flow models was carried out in three steps. The first step was to collect observations of groundwater levels, called calibration targets, for the steady-state predevelopment flow model and the transient 1930-2012 flow model. The second step was the calibration of the predevelopment flow model to groundwater level data collected prior to the start of significant groundwater pumping in the southern San Juan Basin. This involved visual and statistical comparisons of the observed and simulated groundwater levels. The third step was the calibration of the transient 1930-2012 flow model to groundwater level data collected during this time period when pumping of public water supply wells and historical mine dewatering caused changes in groundwater levels from predevelopment conditions. This involved visual comparison of observed (historical) and simulated groundwater levels. Any changes in hydraulic properties made to the transient 1930-2012 flow model were also made in the pre-development model so that both models were consistent.

Calibration targets, i.e., groundwater levels measured in wells, were collected for the Gallup, Dakota, and Westwater aquifers in and around the vicinity of the Roca Honda mine. Data sources for the calibration targets included the BDR (RHR, 2011b), data provided by Hydroscience (2009c), and reviews of water-well permit data files.

Calibration of the pre-development groundwater flow model yielded good visual matches to observations of groundwater levels and very good calibration statistics. Calibration of the transient 1930 to 2012 groundwater flow model yielded very good visual matches over many decades, including recent years and time periods with large changes in groundwater levels from mine dewatering. The very good calibrations to two independent data sets demonstrate that the historical groundwater flow models can reproduce observed groundwater flow behavior. The predictive model is therefore a valid tool for estimating the effect of projected RHR mine dewatering on the groundwater system.

4.1 Calibration of Predevelopment Flow Model

The predevelopment groundwater flow model was calibrated to observed groundwater levels (calibration targets) for the period prior to the start of significant groundwater pumping in the southern San Juan Basin representing conditions corresponding to the year 1930, prior to the commencement of significant withdrawals from aquifers of the San Juan Basin. Groundwater levels from the period ending in 1957 were also included in the calibration target dataset for a few areas for which no earlier data were available because wells had not been drilled there.

Calibration targets for the predevelopment groundwater flow model were compiled from several sources, primarily an INTERA dataset and compilations by Hydroscience (2009c). The INTERA database provided predevelopment groundwater levels for a wide range of locations within the San Juan Basin, whereas the Hydroscience compilation provided many additional targets in the southern San Juan Basin. The data sources described well locations using Township-Range-Section, with each section subdivided into quarters, and in some cases, eighths. This method of well location provides a relatively accurate method of locating the wells, relative to the scale of the model grid cells, but does not provide an exact location for each well. INTERA converted the Township-Range-Section location descriptors to a GIS projection.

Groundwater level data for the Gallup, Dakota, and Westwater aquifers from the Hydroscience and INTERA predevelopment database were also used to create contour maps of groundwater levels in each aquifer to represent the general pattern of groundwater flow during predevelopment conditions (Figures 2.8 to 2.10). The contour maps provided a visual comparator for evaluating the predevelopment calibration in these important aquifer units. Contour maps developed by Stone et al. (1983) and Kernodle (1996) were also used.

4.1.1 Methods

Both qualitative and quantitative methods were used to evaluate the predevelopment model calibration results. The qualitative method involved visual comparison between contour maps of observed (historical) and simulated groundwater levels. Quantitative methods used to evaluate model calibration included statistical analysis of simulated groundwater levels to observed groundwater levels at target locations. The following objectives were used to guide the predevelopment model calibration:

- Contours of simulated groundwater levels should resemble contours of observed groundwater levels in the Gallup, Dakota, and Westwater aquifers (Figures 2.8 to 2.10).
- Simulated groundwater levels should provide reasonable matches to calibration targets.
- Simulated water-balance fluxes (i.e., volume per unit time of water flow) should be within the range established by previous work.

Hydraulic conductivity values, mountain-front recharge rates, and areal recharge rates were systematically adjusted to produce simulated groundwater levels that matched the calibration targets and the contour maps of predevelopment groundwater levels in the three aquifers.

Traditional calibration measures (Anderson and Woessner, 1992), such as the mean error and the mean absolute error, quantify the average error in the calibration process. The basis for these statistics is the residual, which is simply the difference between the simulated groundwater level or head (h_s) and the observed groundwater level or head (h_m):

$$residual = (h_s - h_m) \tag{4.1}$$

The mean error is the mean of the residuals:

$$mean\ error = \frac{1}{n}\sum_{i=1}^{n}(h_s - h_m)_i \tag{4.2}$$

where n is the number of calibration targets or measurements. The mean absolute error is the mean of the absolute value of the residuals:

$$mean\ absolute\ error = \frac{1}{n}\sum_{i=1}^{n}|h_s - h_m|_i \tag{4.3}$$

The normalized root mean square error (NRMSE) is the square root of the sum of the squared residuals divided by the number of observations:

$$NRMSE = \left[\frac{1}{n}\sum_{i=1}^{n}(h_s - h_m)_i^2\right]^{1/2} \tag{4.4}$$

Both the *NRMSE* and mean absolute error are routinely used as basic calibration metrics for groundwater levels. For many groundwater flow models, the typical calibration criterion for groundwater head residuals is an *NRMSE* value that is equal to or less than 10% of the observed head range in the aquifers being simulated (Spitz and Moreno, 1996).

The mean absolute error is useful for describing model error on an average basis but, as a single measure, it does not provide insight into spatial trends in the distribution of the residuals. An examination of the spatial distribution of residuals is necessary to determine if they are randomly distributed over the model grid and thus are not spatially biased, that is, the residuals are not worse in one part of the groundwater model than another. Post plots of head residuals for the predevelopment steady-state groundwater levels can be used to judge the spatial aspects of the calibration. These plots indicate the magnitude and direction of the error between the observed and simulated groundwater levels.

During the calibration process, it is important to check the overall water balances periodically to ensure that the difference between simulated inflow and simulated outflow is small. The difference between the total simulated inflow and the total simulated outflow is called the mass balance error. These errors should be calculated for the model as a whole and for each layer. Typically, the overall percent difference should be less than 1%, and ideally less than 0.1% (Anderson and Woessner, 1992).

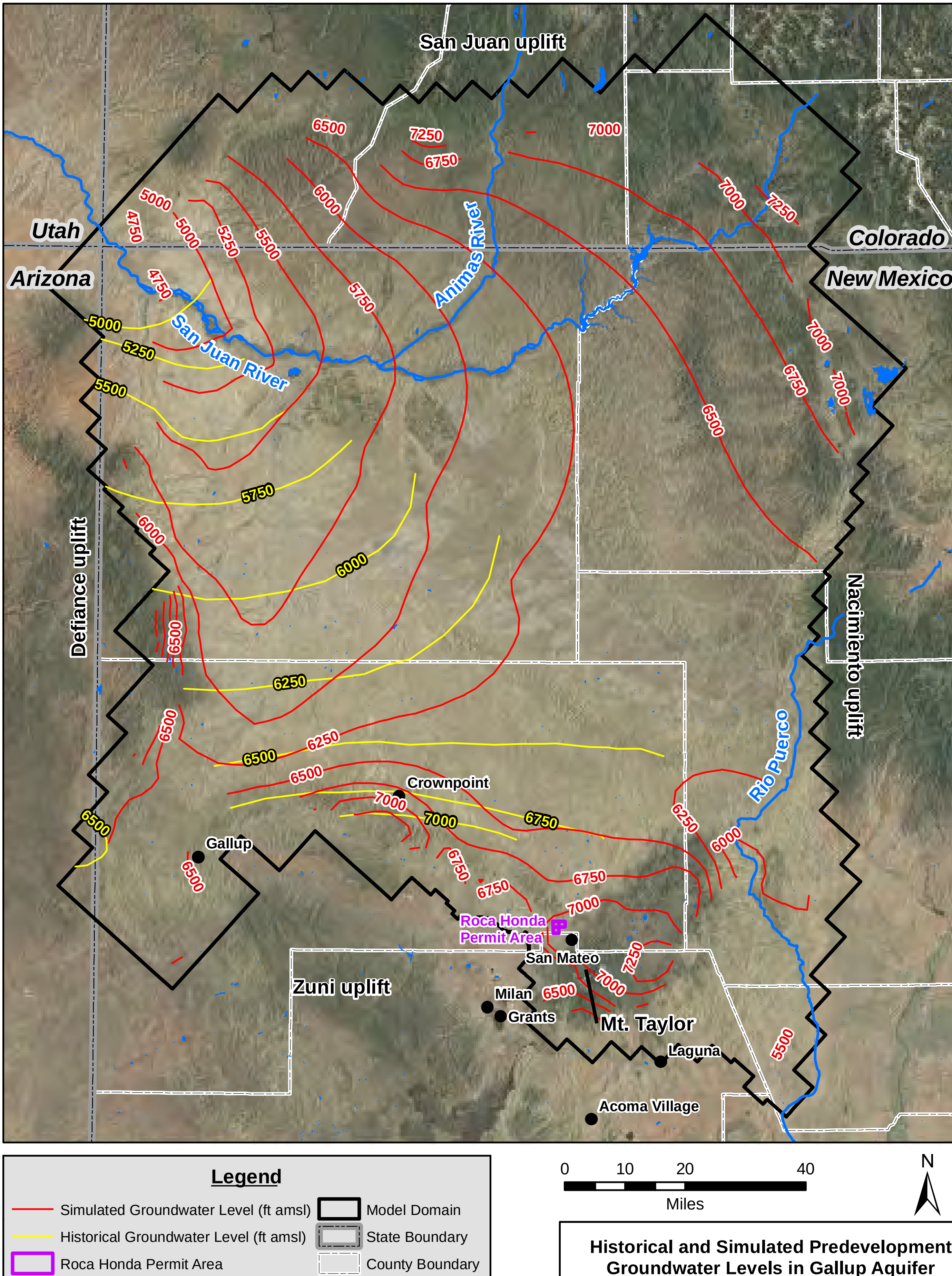
4.1.2 Results for Predevelopment Model Calibration

Calibrated hydraulic conductivity values are shown in Table 4.1. The final steady-state calibration yielded a good match to the contours of predevelopment groundwater levels for the Gallup (Figure 4.1), Dakota (Figure 4.2) and the Westwater (Figure 4.3) aquifers. Residuals are relatively small in absolute value in the Westwater aquifer, especially in and around the Roca Honda permit area (Figure 4.4). However, groundwater levels tend to be slightly over-predicted in the Ambrosia Lake sub-district and in the northwestern part of the domain (Figure 4.4 inset). Calibrated steady-state groundwater levels in the Westwater aquifer in the Ambrosia Lake Valley area range between 6,560 to 6,640 feet, which agrees well with Ganus's (1980) estimation that predevelopment heads in the Ambrosia Lake Valley area ranged between 6,550 and 6,600 feet. Residuals for the Dakota and Gallup aquifers (layers 6 and 8, respectively) also show a fairly good fit and little spatial bias (Figures 4.5 and 4.6, respectively). Residuals for calibration targets in groundwater model layers 2 and 3 are relatively small with both positive and negative values, thus showing little or no spatial bias (Figure 4.7). Residuals for layer 5 are all negative, indicating that simulated groundwater levels are lower than observed levels.

Plots of observed versus simulated groundwater levels for all layers (Figure 4.8a) reveal relatively little scatter from the 1:1 line that represents ideal behavior. A plot (Figure 4.8b) for targets in layers 6 (Gallup) through 10 (Westwater), also shows little scatter from the ideal 1:1 line. The observed and simulated groundwater levels are randomly distributed along either side of the 1:1 line, indicating that the distribution shows little or no bias and that the model is well-calibrated (Anderson and Woessner, 1992).

Table 4.1 Calibrated Hydraulic Conductivity Values for Hydrostratigraphic Units

Model Layer	Hydrostratigraphic Unit	Hydraulic Conductivity Zone	Description	Hydraulic Conductivity (ft/day)	
				Horizontal	Vertical
1	San Jose Formation	Tsj	Basin-wide	0.5	0.002
2	Animas and Nacimiento Fms	Tka	Basin-wide	0.01	0.0001
3	Ojo Alamo Sandstone	Toa	Basin-wide	0.3	0.001
	Kirtland and Fruitland Fms	Kkf			
	Pictured Cliffs Sandstone	Kpc			
4	Lewis Shale	Kls	Basin-wide	$5x10^{-5}$	$2.5x10^{-6}$
5	Cliff House Sandstone	Kch	Basin-wide	0.05	0.0003
	Menefee Formation	Kmf			
	Point Lookout Sandstone	Kpl			
	Crevasse Canyon Formation	Kcc			
6	Mancos Shale	Km1	Basin margin	$1x10^{-4}$	$1x10^{-4}$
		Km2	Upper Mancos	$3x10^{-3}$	$5x10^{-6}$
		Km3	Lower Mancos	$5x10^{-5}$	$2.5x10^{-6}$
7	Gallup Sandstone	Kg1	Southern basin	0.25	0.0025
		Kg2	Roca Honda permit area based on RHR pump test	1.5	0.002
8	Dakota Sandstone	Kd1	Basin-wide	0.1	0.0001
		Kd2	Ambrosia Lake sub-district	0.1	0.002
9	Brushy Basin Member of Morrison Formation	Jmbb	Basin-wide	$3x10^{-3}$	$5x10^{-6}$
10	Westwater Canyon Member of Morrison Formation	Jmw1	Northern basin	0.02	0.0002
		Jmw2	Southern basin	1.25	0.00125
		Jmw3	Ambrosia Lake sub-district	1.6	0.002
		Jmw4	Roca Honda permit area based on RHR pump test	0.5	0.001
		Jmw5	Gulf Mt. Taylor mine area based on historical dewatering rates	3	0.003
6 to 10	Mt. Taylor volcanic rocks	Tnv	Volcanics	$1x10^{-4}$	$5x10^{-6}$
		Tmv	Basalt and andesite flows		



Historical and Simulated Predevelopment Groundwater Levels in Gallup Aquifer

Figure 4.1

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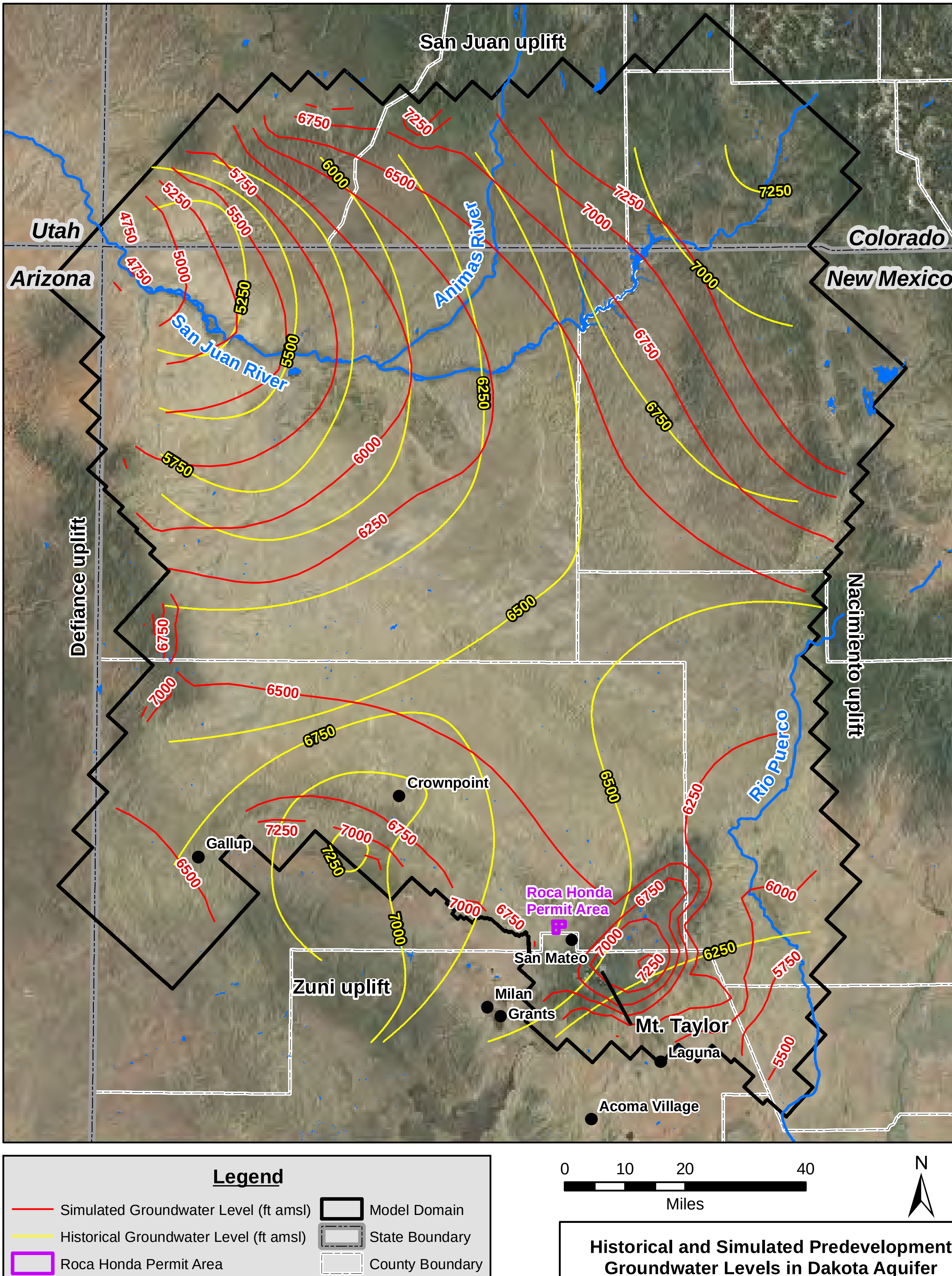

Historical and Simulated Predevelopment Groundwater Levels in Dakota Aquifer

INTERA

Figure 4.2

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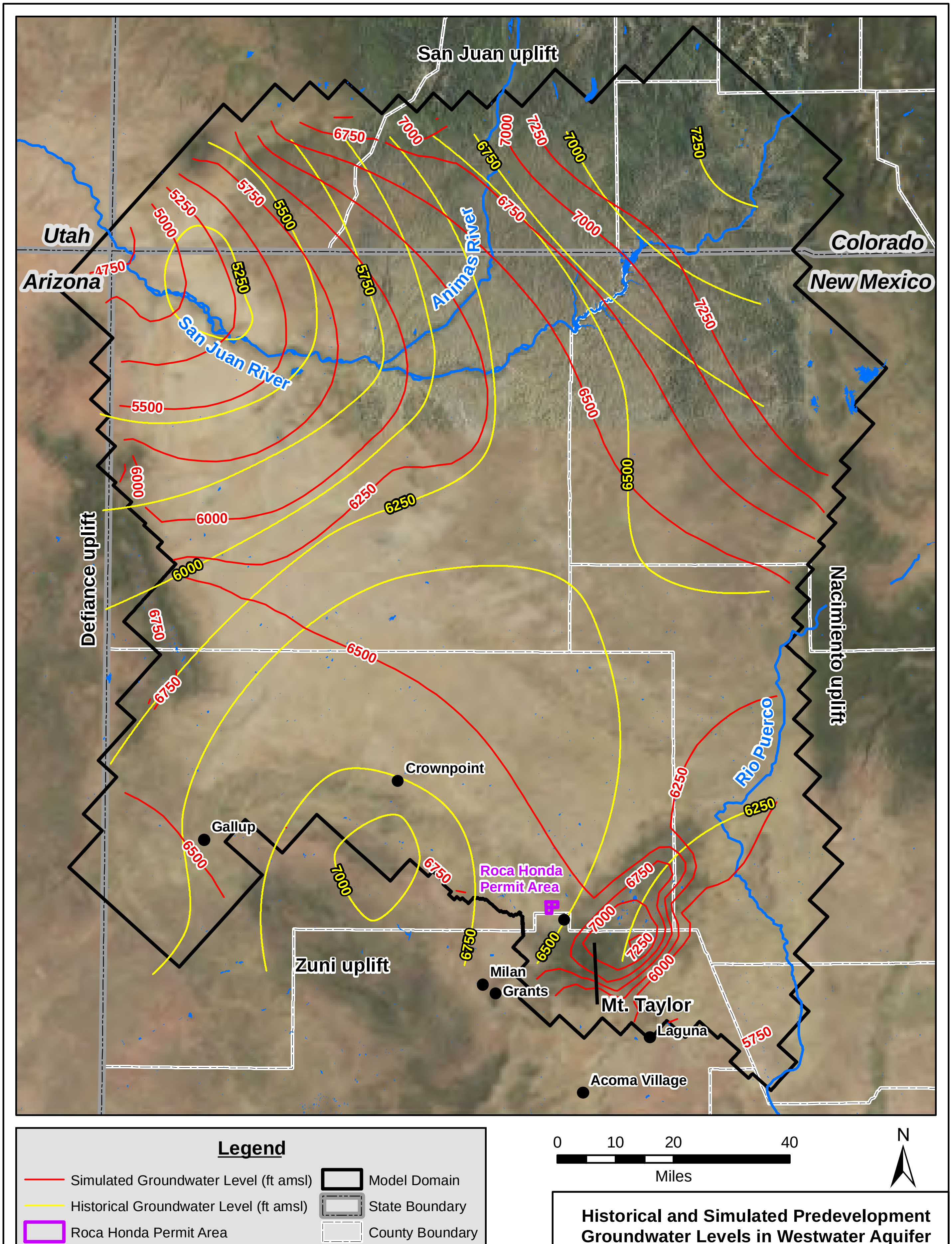

Historical and Simulated Predevelopment Groundwater Levels in Westwater Aquifer

INTERA

Figure 4.3

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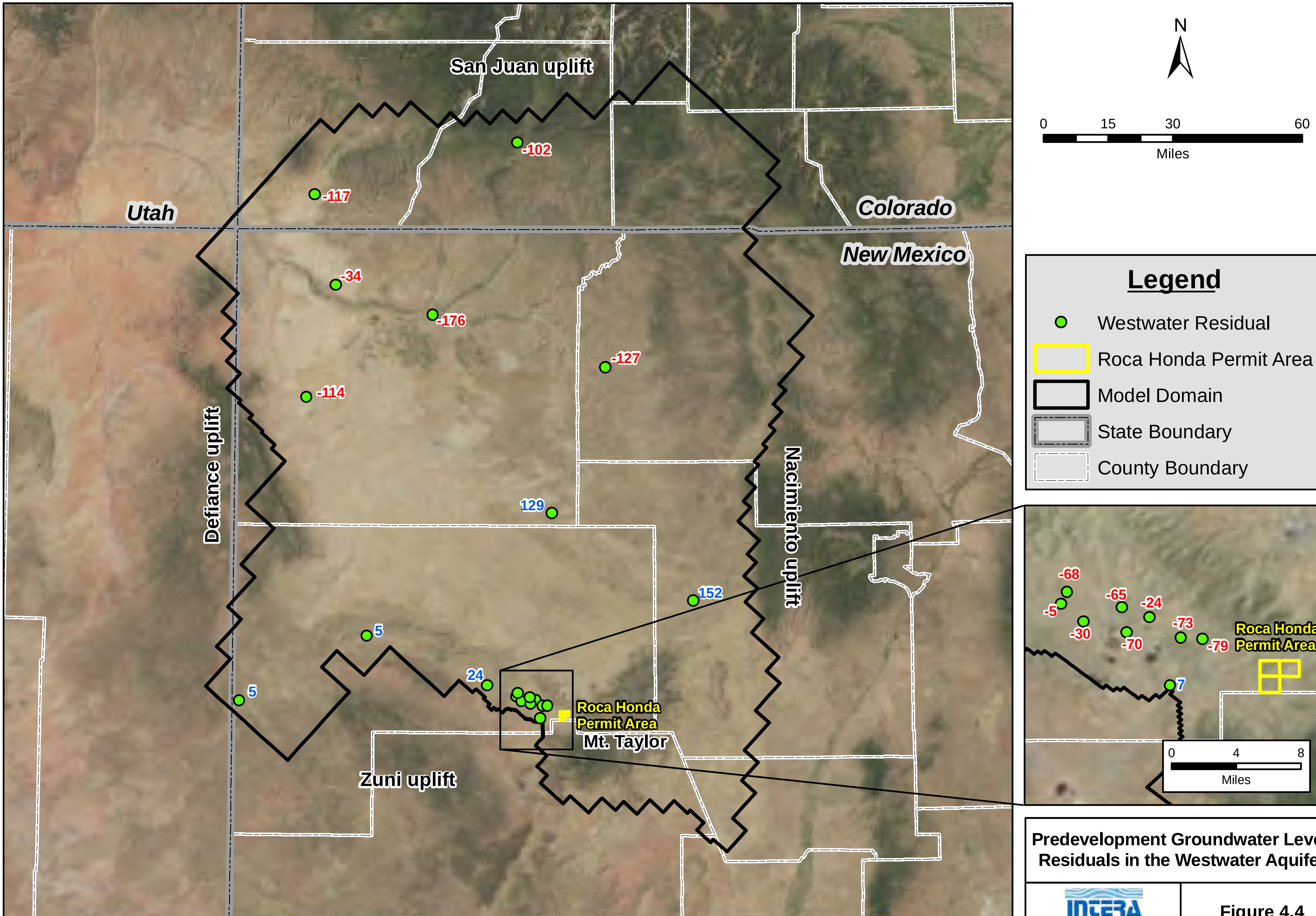

Predevelopment Groundwater Level Residuals in the Westwater Aquifer

INTERA

Figure 4.4

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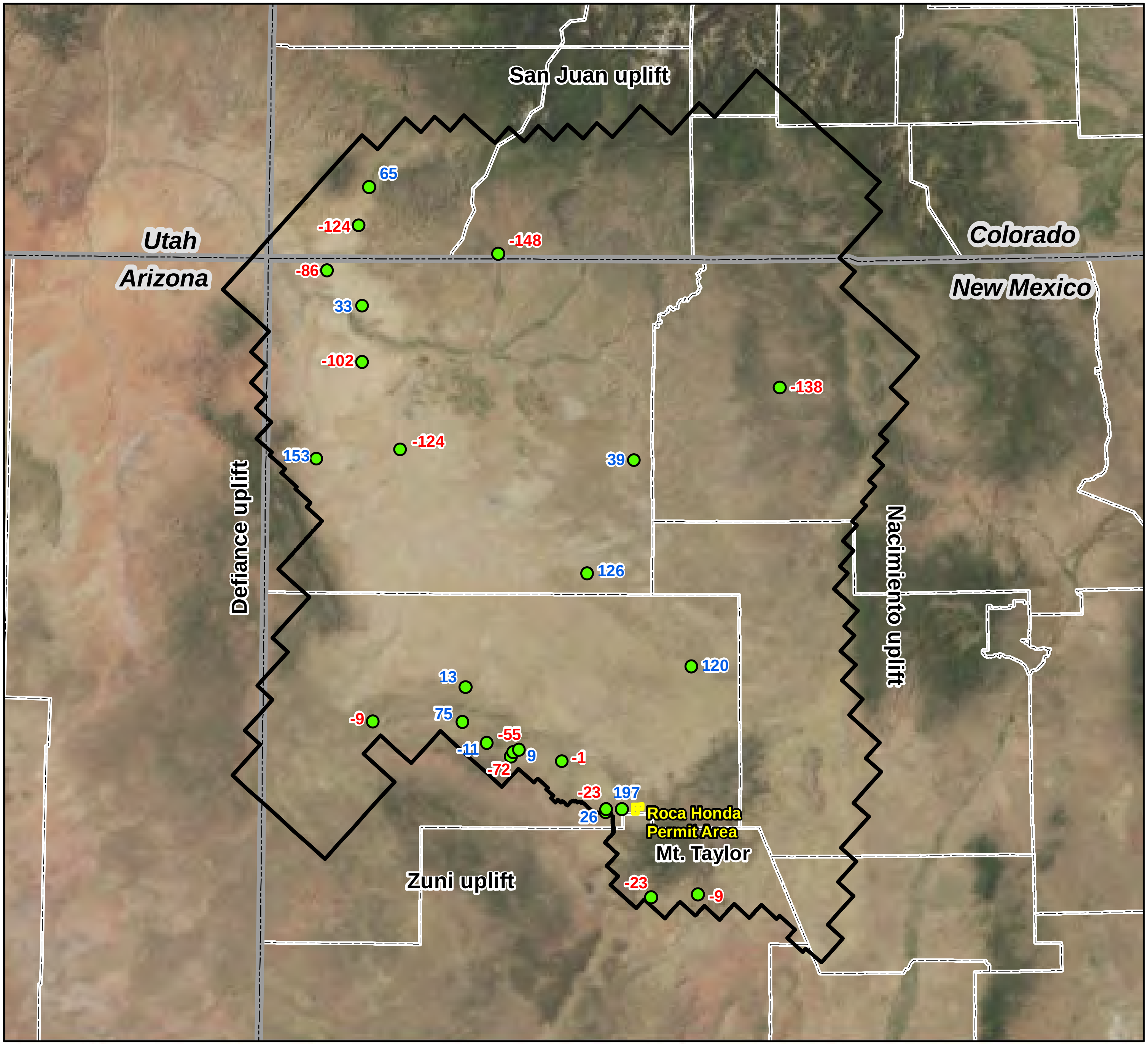

Predevelopment Groundwater Level Residuals in the Dakota Aquifer

INTERA

Figure 4.5

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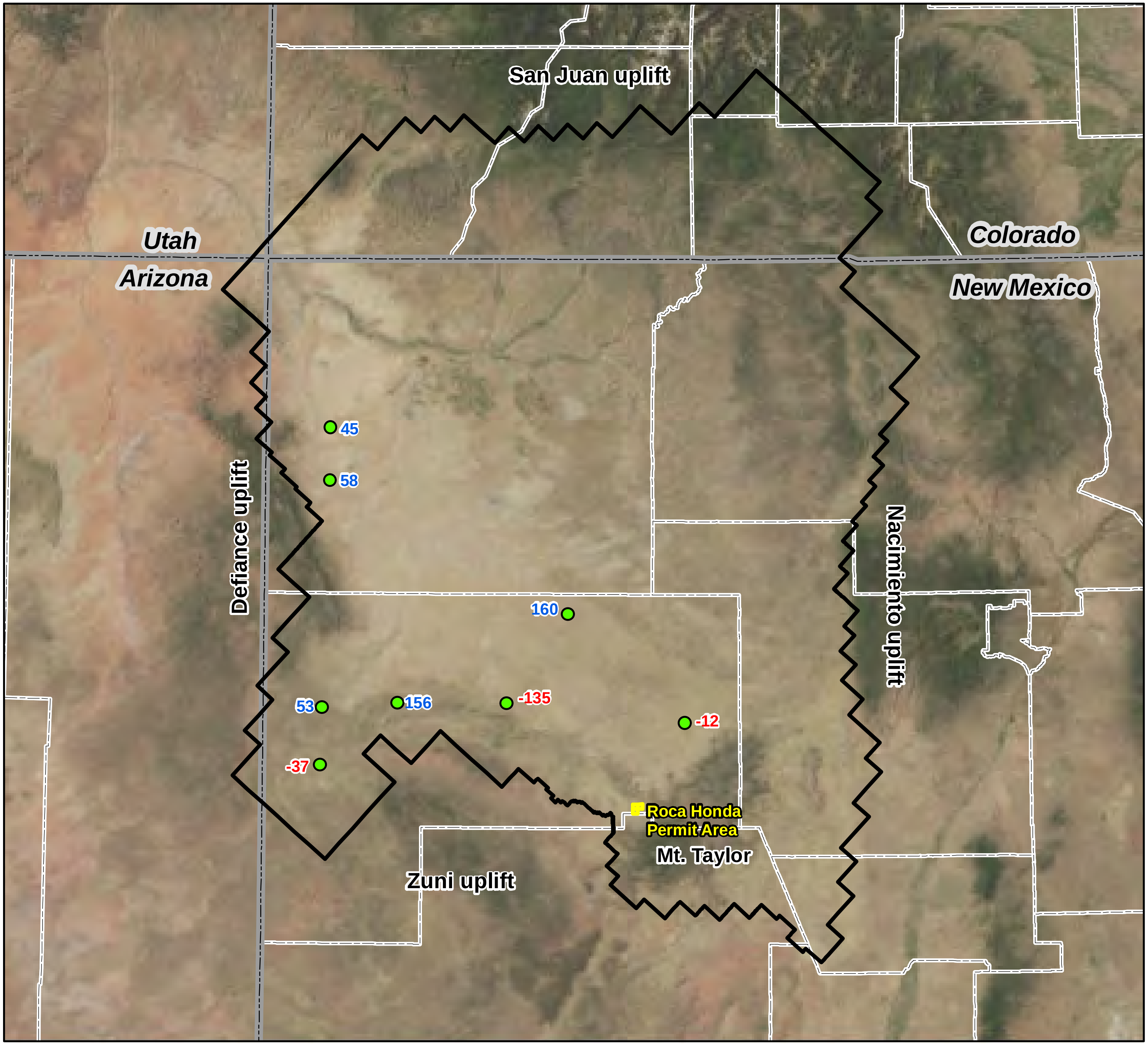

Predevelopment Groundwater Level Residuals in the Gallup Aquifer

INTERA

Figure 4.6

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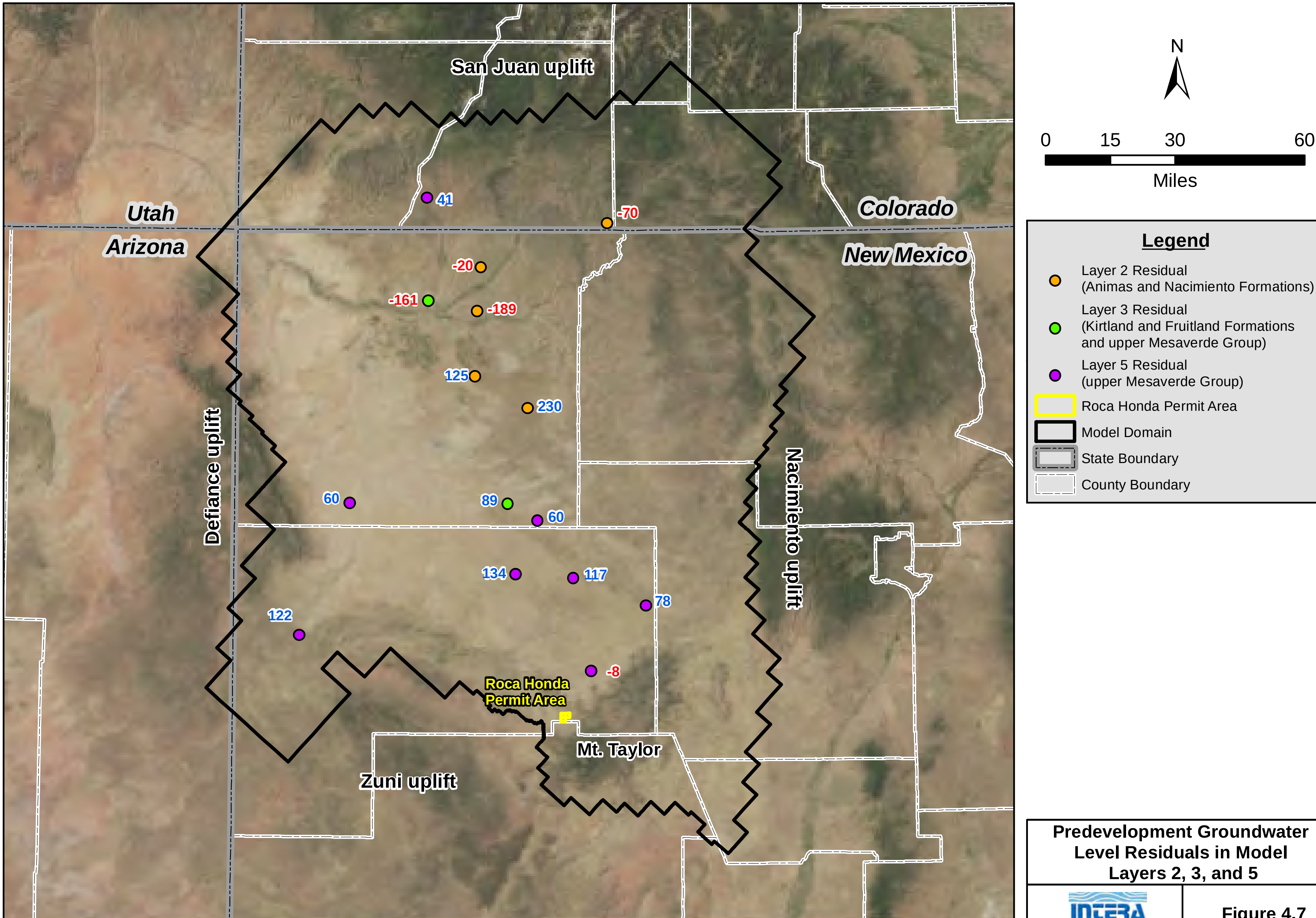

Predevelopment Groundwater Level Residuals in Model Layers 2, 3, and 5

INTERA

Figure 4.7

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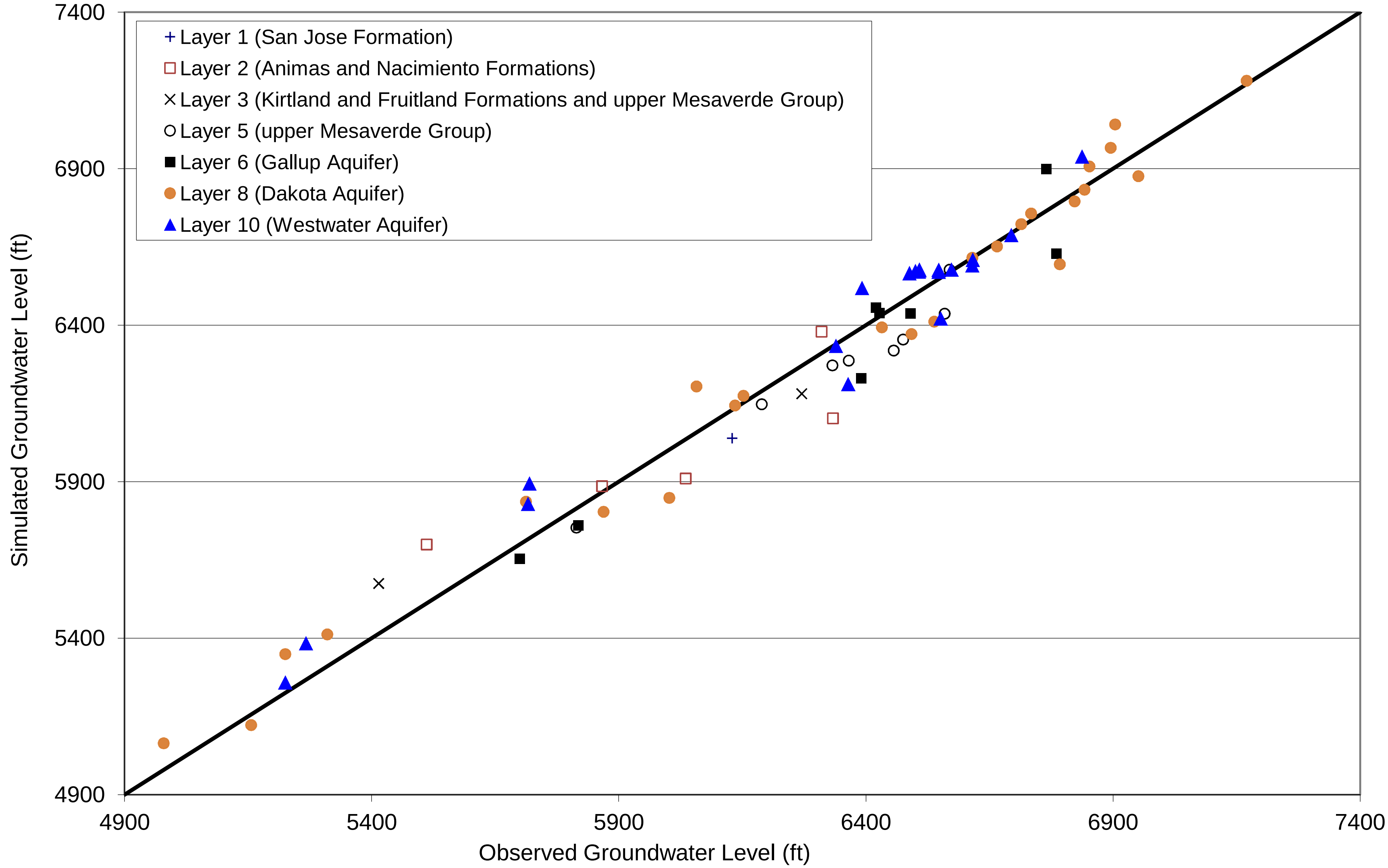

Simulated versus Observed Groundwater Levels of all Layers in the Calibrated Predevelopment Model

INTERA

Figure 4.8a

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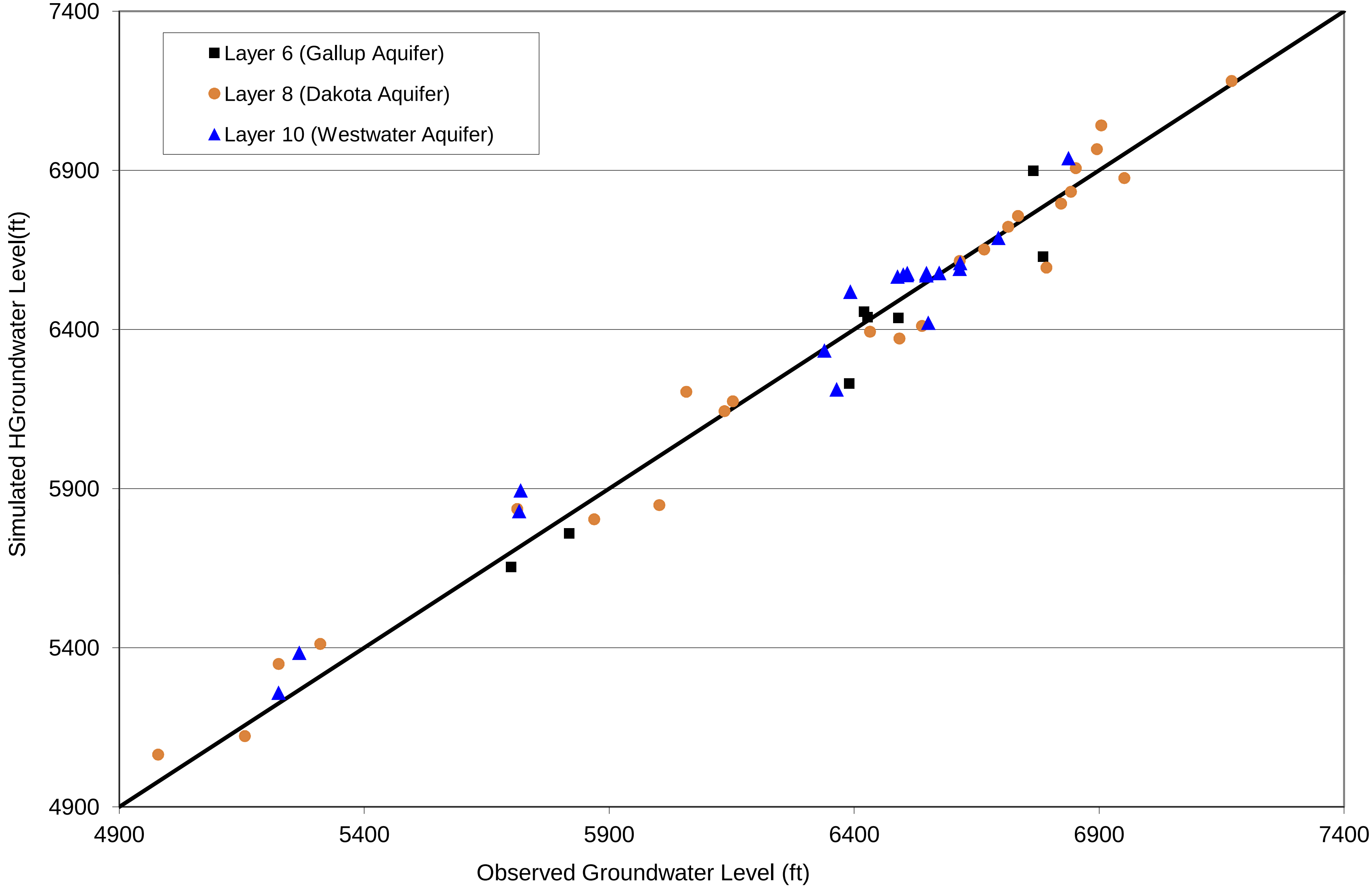


Simulated versus Observed Groundwater Levels of Layers 6 through 10 in the Calibrated Predevelopment Model

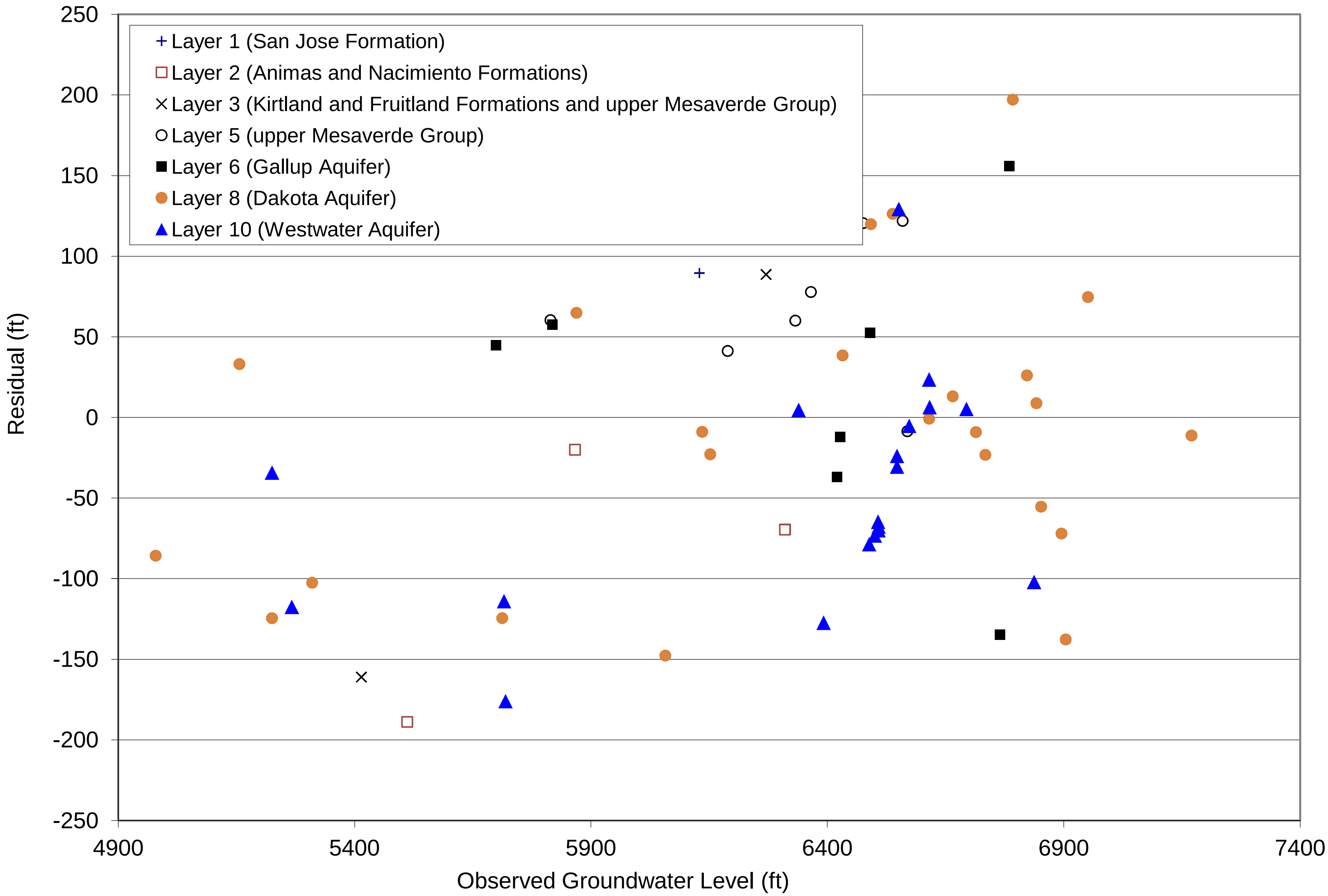
Figure 4.8b

Data scatter about the 1:1 line appears smaller in layers 6 through 10 compared to all layers. Similarly, plots of residuals versus observed groundwater levels show the desired random distribution of points, whether for all layers (Figure 4.9a) or just layers 6 through 10 (Figure 4.9b), and thereby indicate little or no bias in the calibration.

Statistics for the predevelopment model calibration's 69 residuals over all layers are quite good for a large-scale flow model (Table 4.2). Mean error is slightly more than 2 feet, mean absolute error is less than 80 feet, and *NRMSE* is 4.4% (Table 4.2), much less than the 10% guidance given by Spitz and Moreno (1996). When calculated for the residuals from layers 6 to 10 (Gallup down through the Westwater) only, the statistics improve slightly, with the exception of the mean error, which is -10.25 feet (Table 4.2).

Table 4.2
Residual Statistics from the Predevelopment Model Calibration

Statistic	All Layers	Layers 6 to 10
Number of residuals	69	44
Mean error (feet)	2.34	-10.25
Error standard deviation (feet)	97.02	90.05
Sum of squares (ft^2)	6.50×10^5	4.35×10^5
Mean absolute error (feet)	78.86	72.47
Minimum residual (feet)	-188.77	-175.87
Maximum residual (feet)	230.39	197.19
Range of target groundwater levels (feet)	2,191	2,191
Normalized root mean square error (dimensionless)	0.044	0.041



Residuals versus Observed Groundwater Levels of all Layers in the Calibrated Predevelopment Model

INTERA

Figure 4.9a

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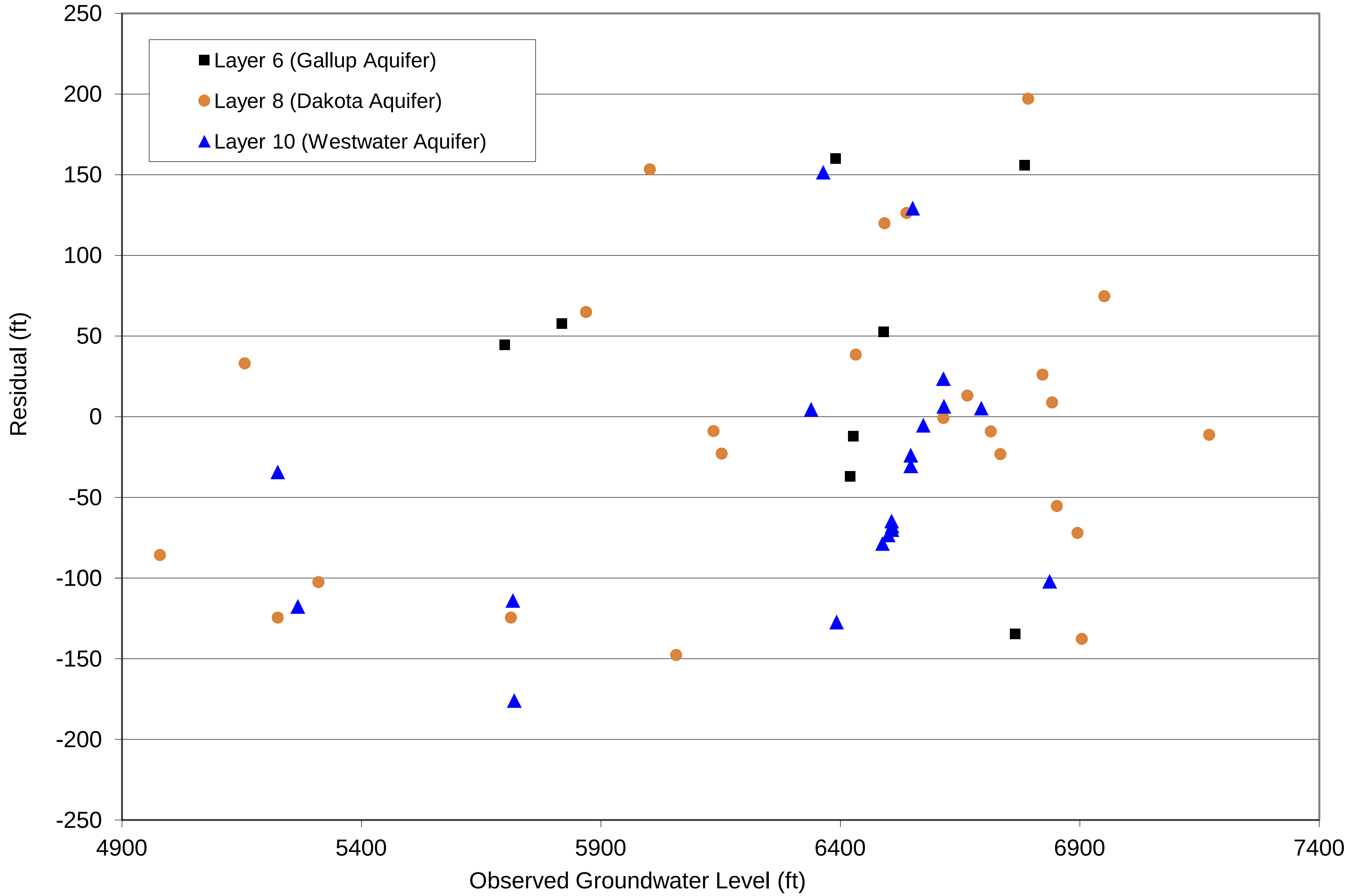

Residuals versus Observed Groundwater Levels of Layers 6 through 10 in the Calibrated Predevelopment Model

INTERA

Figure 4.9b

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The water balance fluxes for the calibrated predevelopment model reveal that infiltration from river beds is the largest single input to the San Juan Basin flow system (Table 4.3). The total mass balance error was -0.21% (Table 4.3). Mass balance errors should be less than 1%, and ideally less than 0.1% (Anderson and Woessner, 1992).

Table 4.3
Calibrated Predevelopment Model Flux Values

Water Balance Component	Flux Rate (ft^3/day)	Percent Total
Inflow		
Areal recharge	1,628,925	32.7
River infiltration	1,864,874	37.4
Deep Mountain-front recharge	1,299,301	26.0
Mountain-front recharge from Chuska Sandstone and Mt. Taylor	193,517	3.9
Total In:	*4,986,617*	
Outflow		
Discharge to perennial rivers	3,800,498	76.1
Discharge to ephemeral drainages	1,137,964	22.8
Discharge to Chuska Sandstone and Mt. Taylor	58,722	1.1
Total Out:	*4,997,184*	
Mass Balance Error (percent error)	**-0.21%**	

The total inflow groundwater flow rate for the predevelopment model is roughly 5,000,000 ft^3/day (58 ft^3/s), which is equivalent to a basin-wide average inflow rate of 0.042 in/yr. By definition, inflow should equal outflow for a steady-state groundwater flow model such as the predevelopment model. Total inflow for the calibrated predevelopment model falls within the range of 30 and 195 ft^3/s estimated for the San Juan Basin by Frenzel and Lyford (1982) and Kernodle (1996), respectively, and is very close to the 60 ft^3/s estimated by Lyford and Stone (1978).

4.2 Calibration of Transient 1930-2012 Model

The transient 1930-2012 model simulates the changes to the predevelopment groundwater levels caused by time-varying pumping for public water supplies and historical mine dewatering. Groundwater level values for the period of 1930 to 2012 were compiled and reviewed by INTERA and Hydroscience (2009c). The review yielded 27 transient calibration targets in the Gallup, Dakota, and Westwater aquifers. Transient calibration targets have one or more observations of groundwater level over time. Most of the targets had one or two observations, but 12 targets had more than two observations, particularly those in mine shafts and vents at former uranium mines.

4.2.1 Methods

Both qualitative and quantitative methods were used to evaluate the transient 1930-2012 model calibration results. The qualitative method involved visual comparison between contour maps of observed and simulated groundwater levels for specific time periods as well as comparison of simulated to observed groundwater levels at target locations. The quantitative check on the calibration compared simulated and reported dewatering rates and volume of water in historical uranium mining areas. The following objectives were used to guide the transient 1930-2012 model calibration:

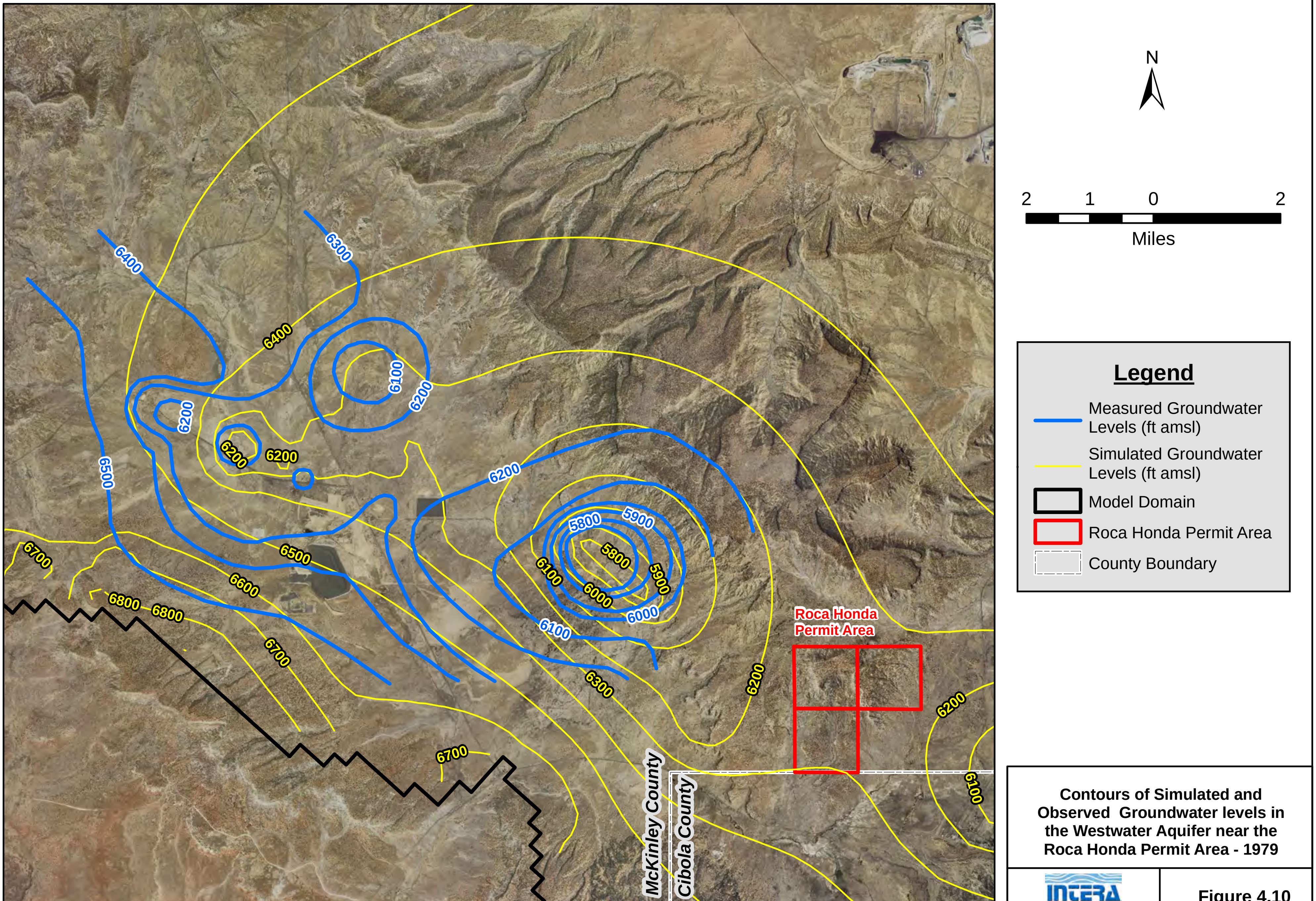
- Contours of simulated groundwater levels should resemble contours of groundwater levels observed in the Westwater aquifer at various time periods.
- Simulated groundwater levels should provide reasonable matches to the calibration targets over time.
- The dewatering rates and total volume produced from the transient 1930-2012 model should be similar to estimated pumping rates for the Ambrosia Lake and Church Rock mines from Stone el al. (1983).

Model parameters were adjusted by trial and error to achieve good matches to all three objectives listed above.

4.2.2 Results for Transient 1930-2012 Model Calibration

Comparison of contours of simulated groundwater levels to contours of groundwater levels observed in the Westwater aquifer near the Roca Honda permit area during three time periods demonstrated good agreement. There is good agreement for the 1979 contours (Figure 4.10), whereas the agreement between the 2007 simulated contours and the contours of observed groundwater levels from 2003 to 2007 is fairly good (Figure 4.11). Westwater groundwater level data were contoured for the RHR BDR (RHR, 2011b) and a comparison of simulated to 2010 observed contours shows good agreement (Figure 4.12).

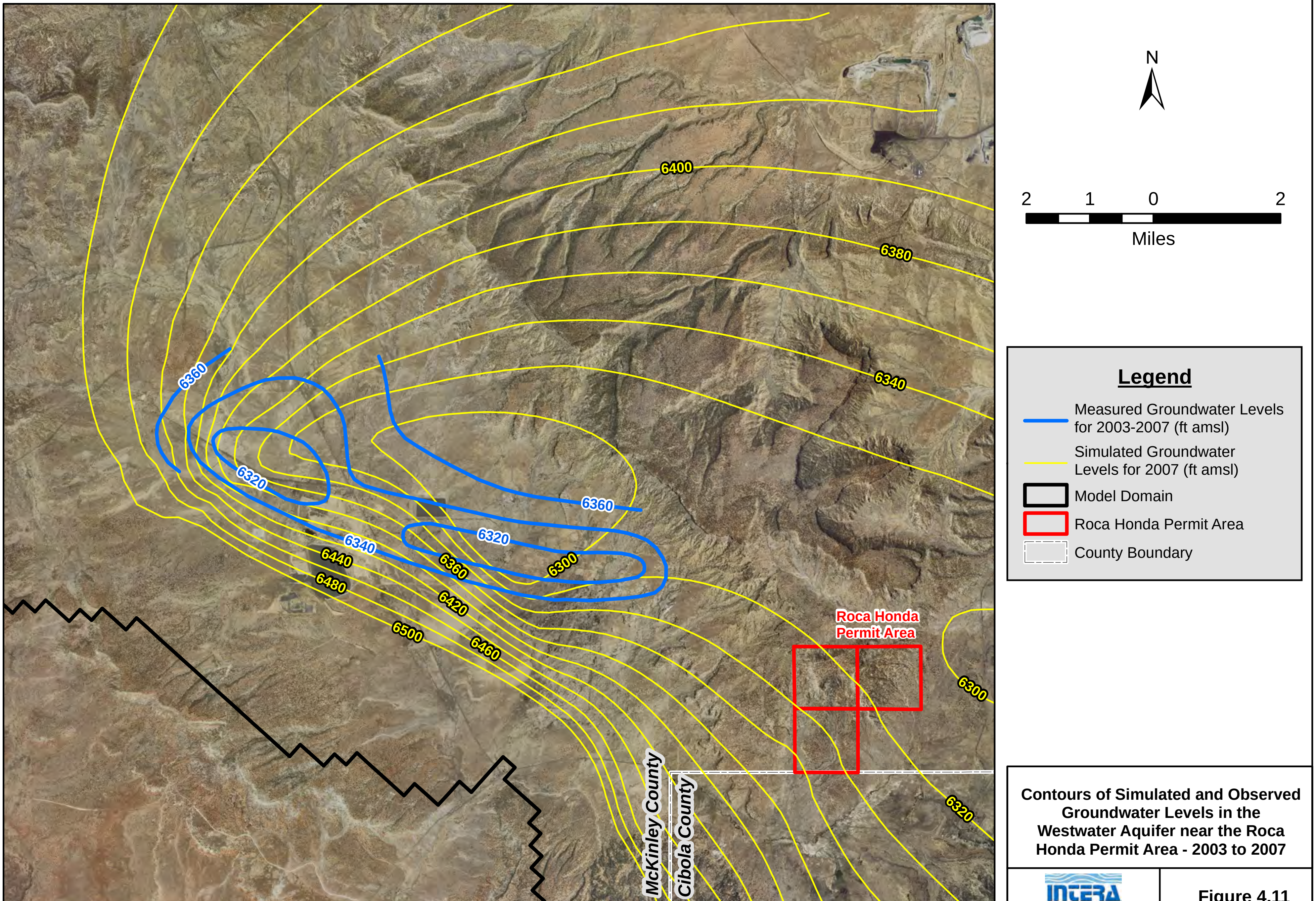
The final transient 1930-2012 calibration yielded a close match to eight Westwater well targets with single observations (Appendix C.1 to C.8) and a good match to two Westwater well targets with numerous observations (Appendix C.9 and C.10). Simulated and observed groundwater levels matched very closely in wells located in the Roca Honda vicinity (Appendix C.11 to C.14). These matches are important because the observations were made late in the simulation period, long after dewatering had ceased, and thus indicate that the transient 1930-2012 model accurately represents Westwater groundwater levels prior to the start of the predictive simulations. Good matches were also found for two wells in the Dakota aquifer (Appendix C.15 to C.16).



Contours of Simulated and Observed Groundwater levels in the Westwater Aquifer near the Roca Honda Permit Area - 1979

INTERA

Figure 4.10



Contours of Simulated and Observed Groundwater Levels in the Westwater Aquifer near the Roca Honda Permit Area - 2003 to 2007

INTERA

Figure 4.11

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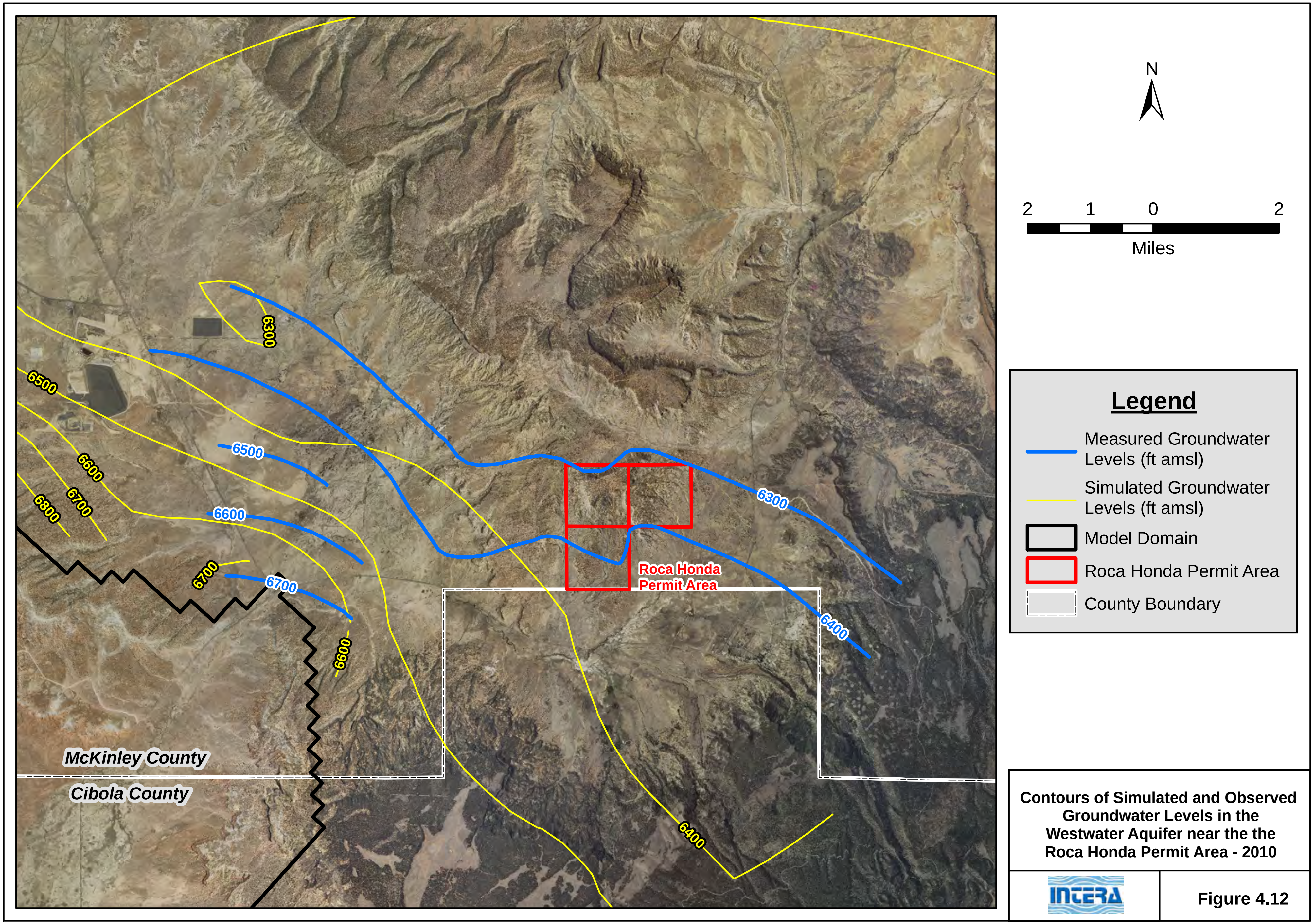

Contours of Simulated and Observed Groundwater Levels in the Westwater Aquifer near the the Roca Honda Permit Area - 2010

INTERA

Figure 4.12

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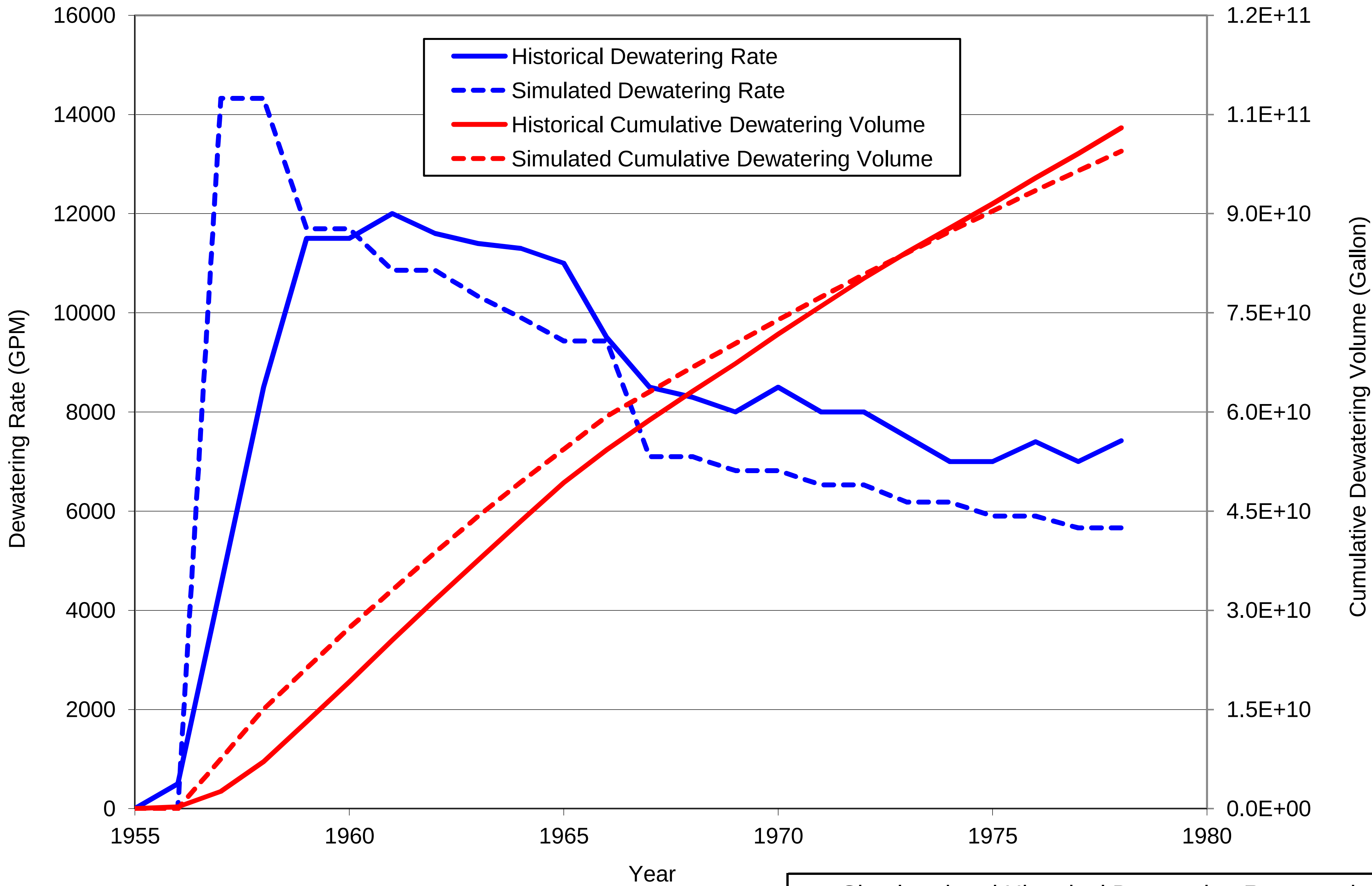
Simulated and observed groundwater levels measured in four mine shaft targets matched fairly well (historical Kerr-McGee mine shafts in Sections 17, 19, 35, and 36 shown in Appendix C.17 to C.18 and C.23 to C.24), whereas the others did not match as closely (shafts in Sections 24, 30, 30W, and 33 shown in Appendix C.19 to C.22). The hydrographs show good overall agreement, but the simulated groundwater levels do not reflect the relatively high-frequency changes observed in several shafts. Some of the observed shaft groundwater levels (Sections, 19, 24, and 30W) show the effects of additional mine dewatering after 1985 due to some pumps being turned back on around 1995 and ultimately turned back off a number of years later. Due to the constraints imposed by the selected modeling stress periods, INTERA was unable to capture this brief period of renewed pumping. However, the slopes of the recovery curves are very similar during periods without pumping. Similarly, comparison of measured and simulated groundwater levels at three locations in the Gallup (Figures C.25 to C.27) show that pumping in the Gallup, demonstrated by the changes in measured groundwater levels, is not represented in the model. All three sets of measurements are located more than 20 miles from the Roca Honda permit area. Simulated groundwater levels in the Gallup are lower than measured groundwater levels at two of the three locations, indicating that overall the model yields a conservative estimate of groundwater levels at those time periods and locations in the Gallup.

Simulated and reported dewatering rates and volumes were compared as a final check on the transient 1930-2012 model calibration for several locations. Plots for Ambrosia Lake mines compare reported rates (Stone et al., 1983) with simulated dewatering rates, as well as cumulative volume produced (Figure 4.13). Differences in the rate curves are caused by the number and size of stress periods used, but the total water produced shows excellent agreement (Figure 4.13). Reported and simulated dewatering rates and total produced volume for the Church Rock Mine are also very similar (Figure 4.14). Simulated dewatering rates and produced volumes for the Gulf Mt. Taylor (Figure 4.15) and Johnny M mines (Figure 4.16) were in agreement with data compiled by Hydroscience (2009a).



Simulated and Historical Dewatering Rates and Cumulative Volume for Ambrosia Lake Area Mines in the Westwater Aquifer

INTERA

Figure 4.13

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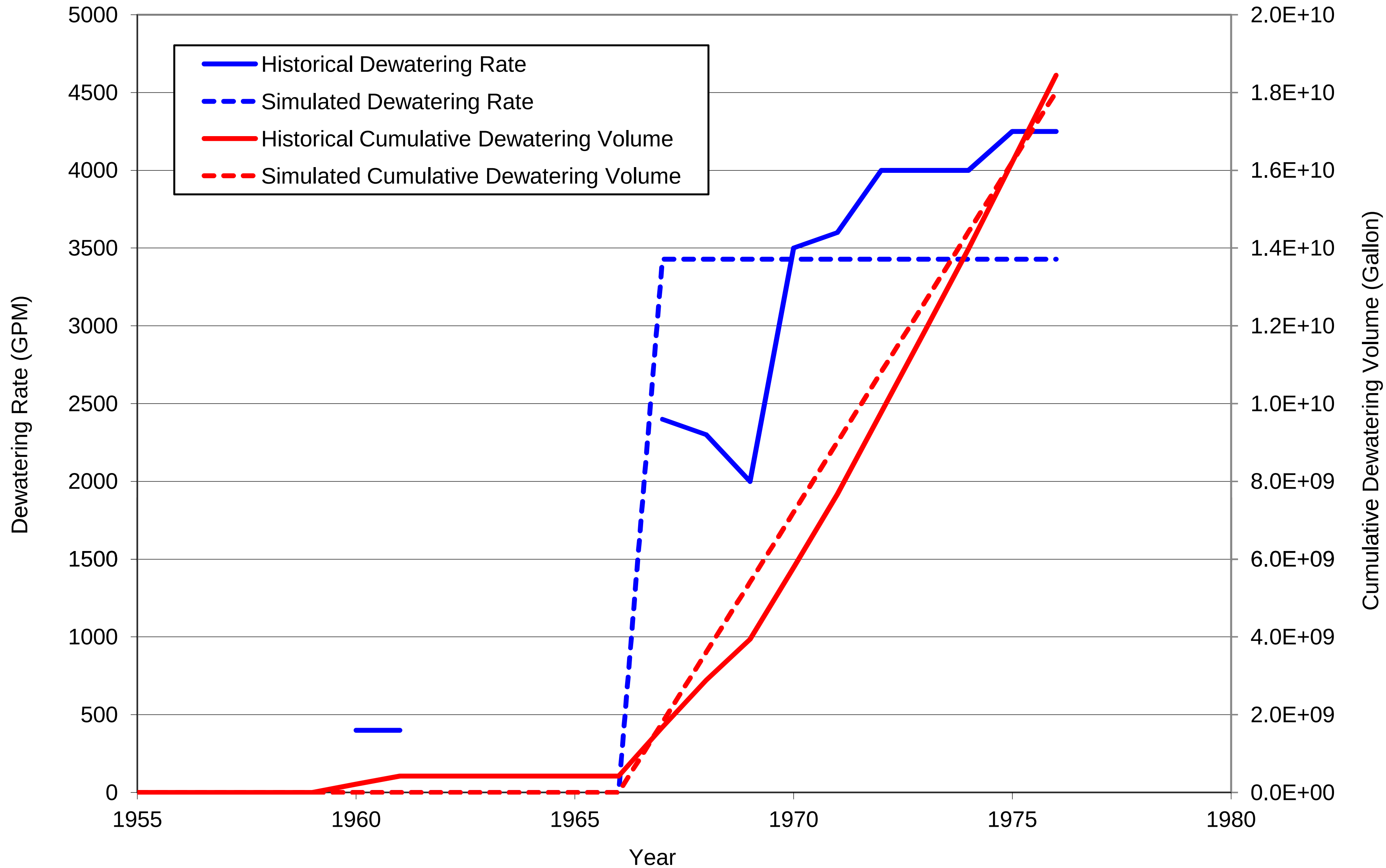

Simulated and Historical Dewatering Rates and Cumulative Volume for Church Rock Mine Area in the Westwater Aquifer

INTERA

Figure 4.14

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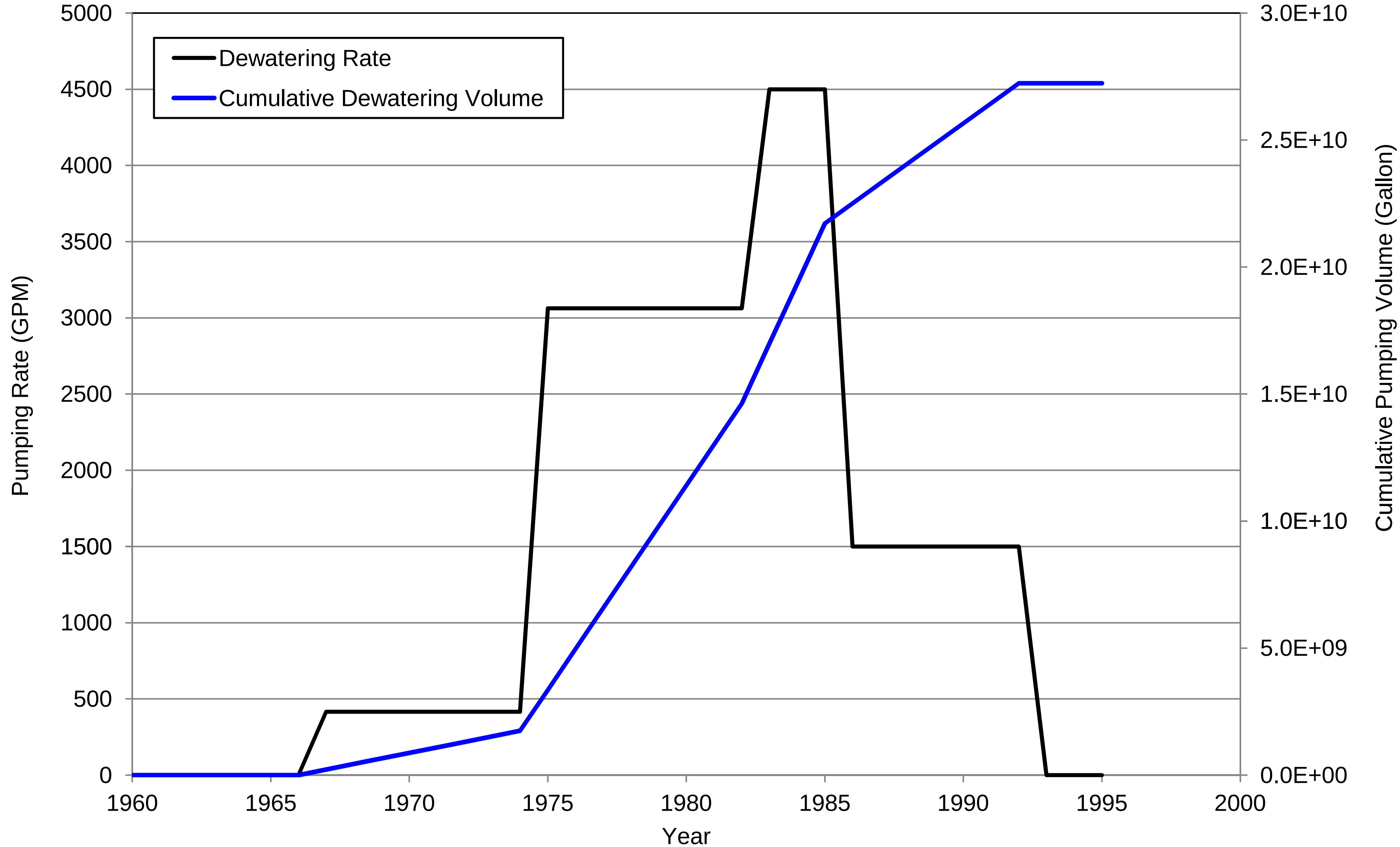

Simulated Dewatering Rates and Cumulative Volume for Gulf Mt. Taylor Mine in the Westwater Aquifer	
INTERA	Figure 4.15

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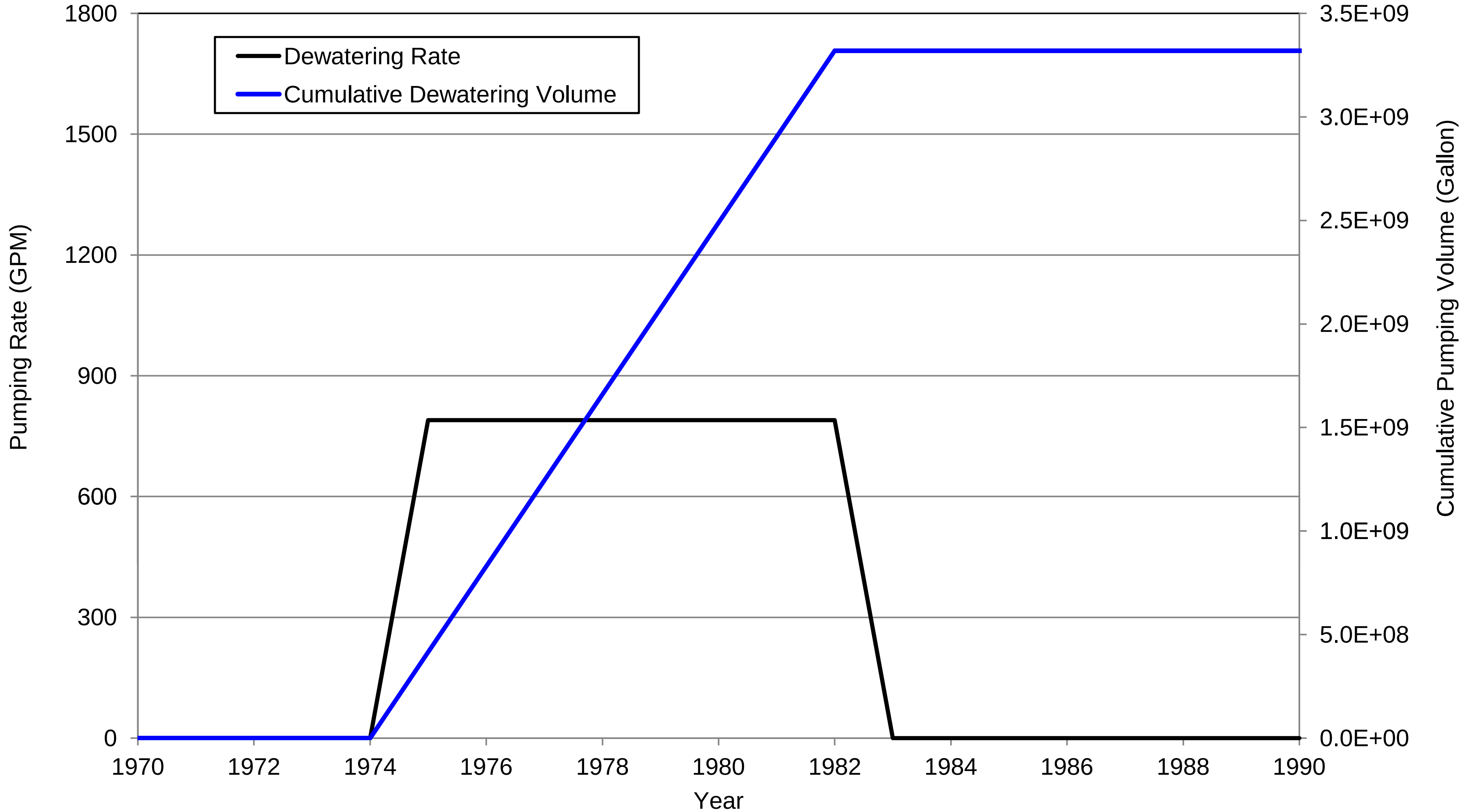

Simulated Dewatering Rates and Cumulative Volume for Johnny M Mine in the Westwater Aquifer

INTERA

Figure 4.16

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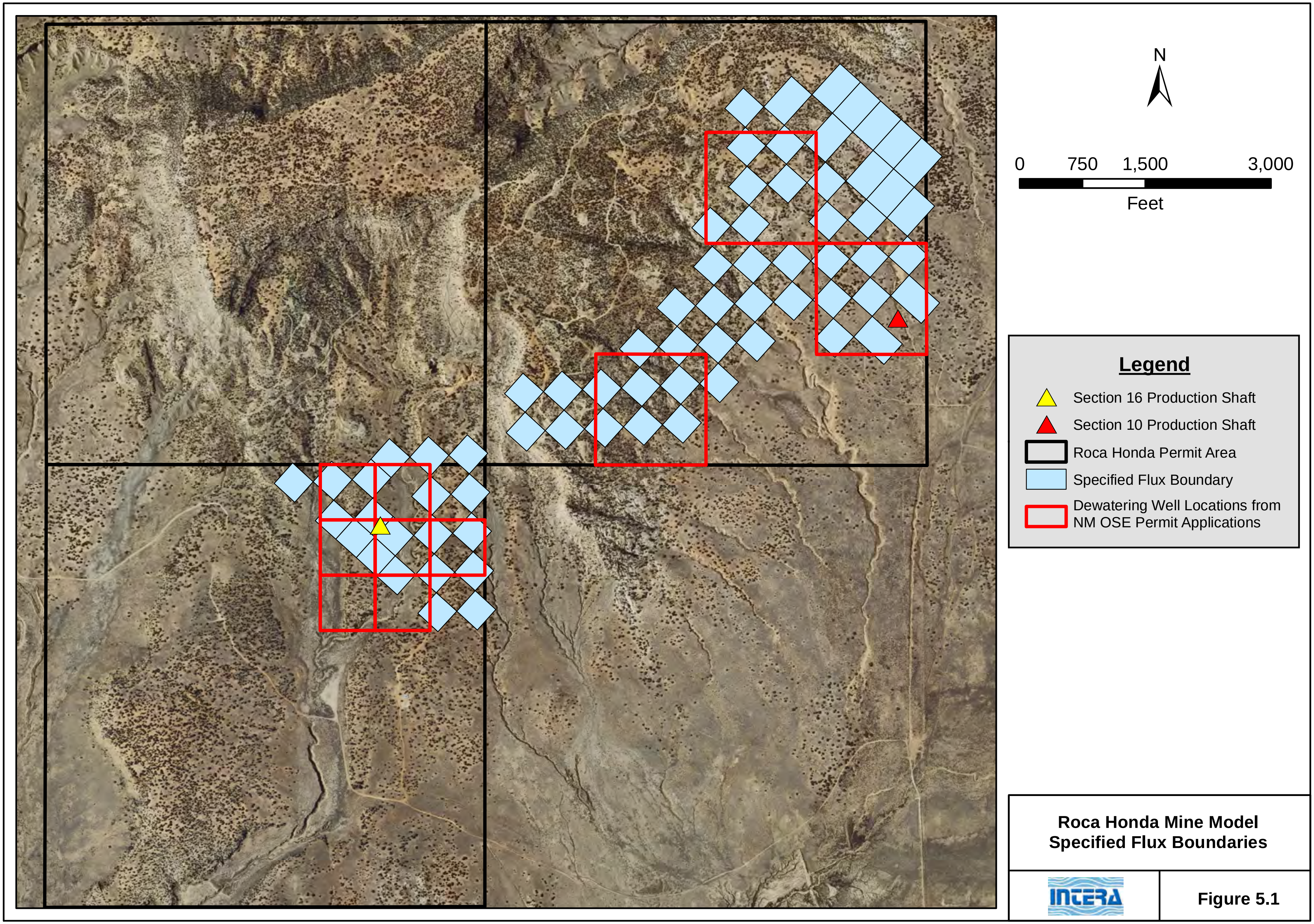
5.0 ROCA HONDA MINE DEWATERING IMPACT ASSESSMENT

Predictive simulations constructed from the calibrated transient 1930-2012 groundwater flow model were used to evaluate changes to groundwater levels in the aquifers affected by RHR's planned mine dewatering. The predictive simulations span the period from 2012, when mine construction is assumed to begin, to the year 2125, 100 years after the assumed end of mining.

This assessment determined changes in groundwater levels within the Gallup, Dakota, and Westwater aquifers, including locations near wells and springs, with respect to the four pumping scenarios (Section 3.1). The four pumping scenarios for predictive simulations are:

- Scenario 1 – Pumping occurs at the Crownpoint and City of Gallup public water supplies and dewatering occurs at the Lee Ranch coal mine. This scenario estimates the effects on future groundwater levels from current pumping stresses and represents current and future "baseline" conditions.
- Scenario 2 – Pumping occurs at the Crownpoint and City of Gallup public water supplies with dewatering at the Lee Ranch coal mine and dewatering at the Roca Honda mine. This scenario estimates the effects on future groundwater levels from current pumping stresses plus the Roca Honda mine dewatering.
- Scenario 3 – Pumping occurs at the Crownpoint and City of Gallup public water supplies with dewatering at the Lee Ranch coal mine and pumping of large water rights in the Gallup, Dakota, and Westwater aquifers in the vicinity of the Roca Honda permit area. This scenario estimates the effects on future groundwater levels from large water rights in the Gallup, Dakota, and Westwater on file with the NM OSE (Table 3.5).
- Scenario 4 – Pumping occurs at the Crownpoint and City of Gallup public water supplies with dewatering at the Lee Ranch coal mine, dewatering at the Roca Honda mine, and pumping of large water rights in the Gallup, Dakota, and Westwater aquifers in the vicinity of the Roca Honda permit area. This scenario estimates the effects on future groundwater levels from Roca Honda dewatering and pumping of large water rights in the Gallup, Dakota, and Westwater on file with the NM OSE (Table 3.5).

Dewatering at Roca Honda mine is conservatively assumed to follow the maximum time periods and maximum pumping rates shown in Table 1.1. Maximum dewatering rates were simulated as specified flux boundary conditions in all pumping scenarios that included Roca Honda dewatering. Figure 5.1 illustrates the location of the specified flux boundary conditions.



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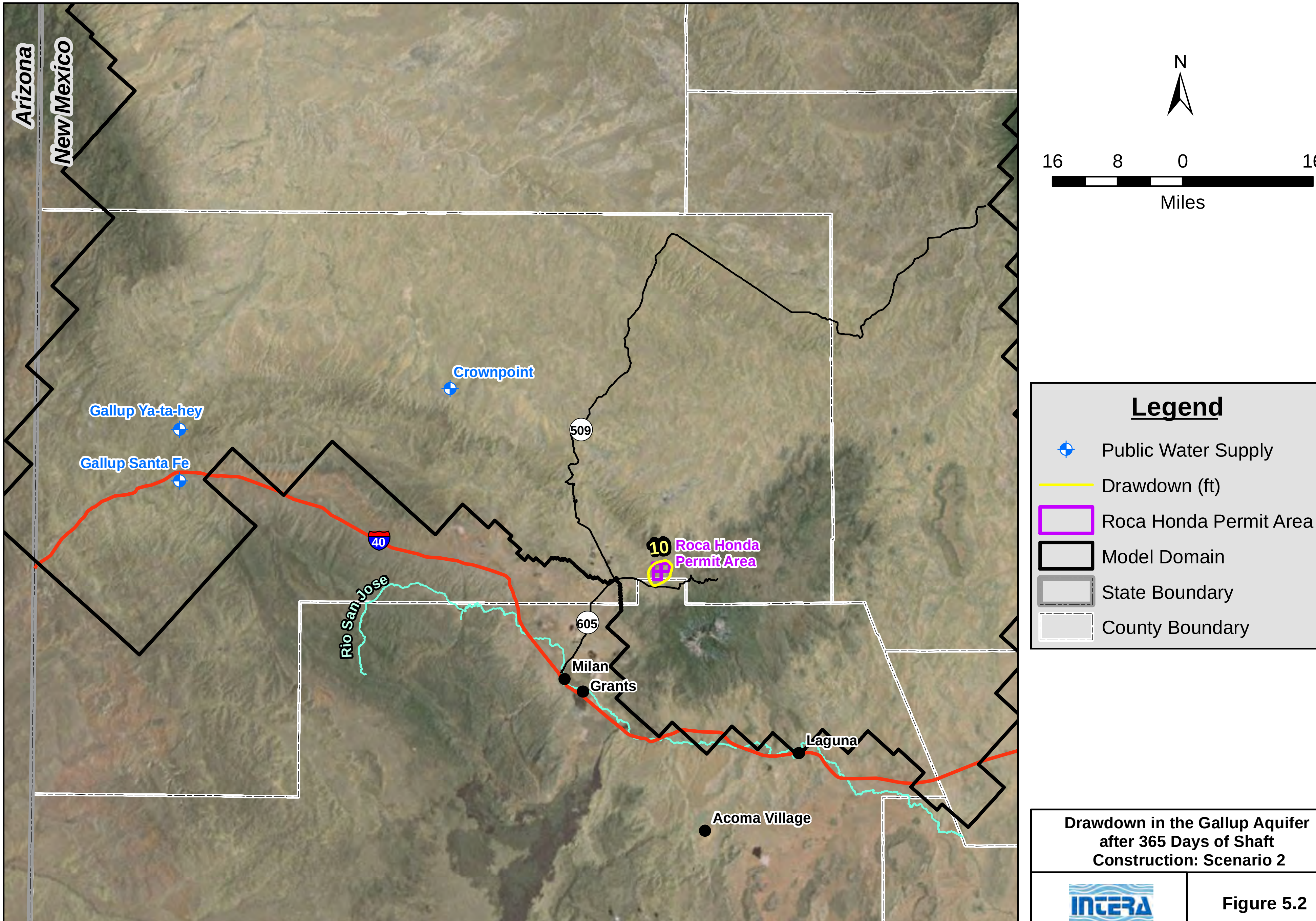
Changes to groundwater levels in pumping scenarios with Roca Honda dewatering (Scenarios 2 and 4) are determined by calculating the differences in groundwater levels for the Gallup, Dakota, and Westwater aquifers over time between Scenarios 1 and 2 and between Scenarios 1 and 4. Changes in groundwater levels from large water rights are determined by calculating the differences in groundwater levels in each aquifer between Scenarios 1 and 3. These differences in groundwater levels are called “drawdown” in the subsections that follow below.

5.1 Changes in Groundwater Levels from Roca Honda Mining (Scenario 2)

Drawdown in the Westwater, Gallup, and Dakota aquifers from dewatering at the Roca Honda mine will not affect groundwater levels at the public water supplies for Crownpoint and Gallup or at the pueblos of Laguna and Acoma. Drawdown at springs is predicted to be negligible. Drawdown at wells in the vicinity of the Roca Honda permit area is predicted to be 10 feet or more at nine wells screened in the Westwater, three of which are used for mining, three for domestic supply, one for livestock, and two for which the uses are unknown. Drawdown is predicted to be 10 feet or more at one domestic well screened in the Dakota, and three wells in the Gallup, of which one is used for exploration, one for livestock, and one has an unknown use. None of the six wells in the Mancos Shale is predicted to have drawdown greater than 3 feet. None of the 92 wells in model layer 5 (Point Lookout Sandstone, Menefee Formation, Crevasse Canyon Formation, and other upper Mesaverde Group units) is predicted to have drawdown of 10 feet or more. Drawdown values all decline once the maximum drawdown is reached. The following subsections provide more detailed discussion of the impacts.

5.1.1 Aquifer Drawdown

Maximum drawdown in the Gallup aquifer occurs at the end of the first year of depressurization for construction of the Roca Honda production shaft. After one year of depressurization pumping at a rate of 502 gpm (Table 1.1), the ten-foot contour of drawdown does not extend beyond the Roca Honda permit area (Figure 5.2). Maximum drawdown in the Dakota aquifer occurs at the end of the second year of depressurization for the production shaft, but the ten-foot contour of drawdown is restricted entirely within the Roca Honda permit area (Figure 5.3). Near the production shaft, drawdown in the Gallup reaches a maximum of 363 feet at the end of the first year, drops below 10 feet between the sixth and seventh year of mining, and then drops below 1 foot 23 years after the end of mining (Figure 5.4). Drawdown in the Dakota near the production shaft reaches a maximum 1,701 feet after 730 days of pumping, and declines more gradually than drawdown in the Gallup, dropping to approximately 14 feet at the end of the simulation period, which is 100 years after the end of Roca Honda mining (Figure 5.4). As illustrated in Figures 5.2 and 5.3, the ten-foot drawdown contours in the Gallup and Dakota aquifers do not reach the public water supplies at Crownpoint or the City of Gallup, or the pueblos of Laguna or Acoma.



Drawdown in the Gallup Aquifer after 365 Days of Shaft Construction: Scenario 2

INTERA

Figure 5.2

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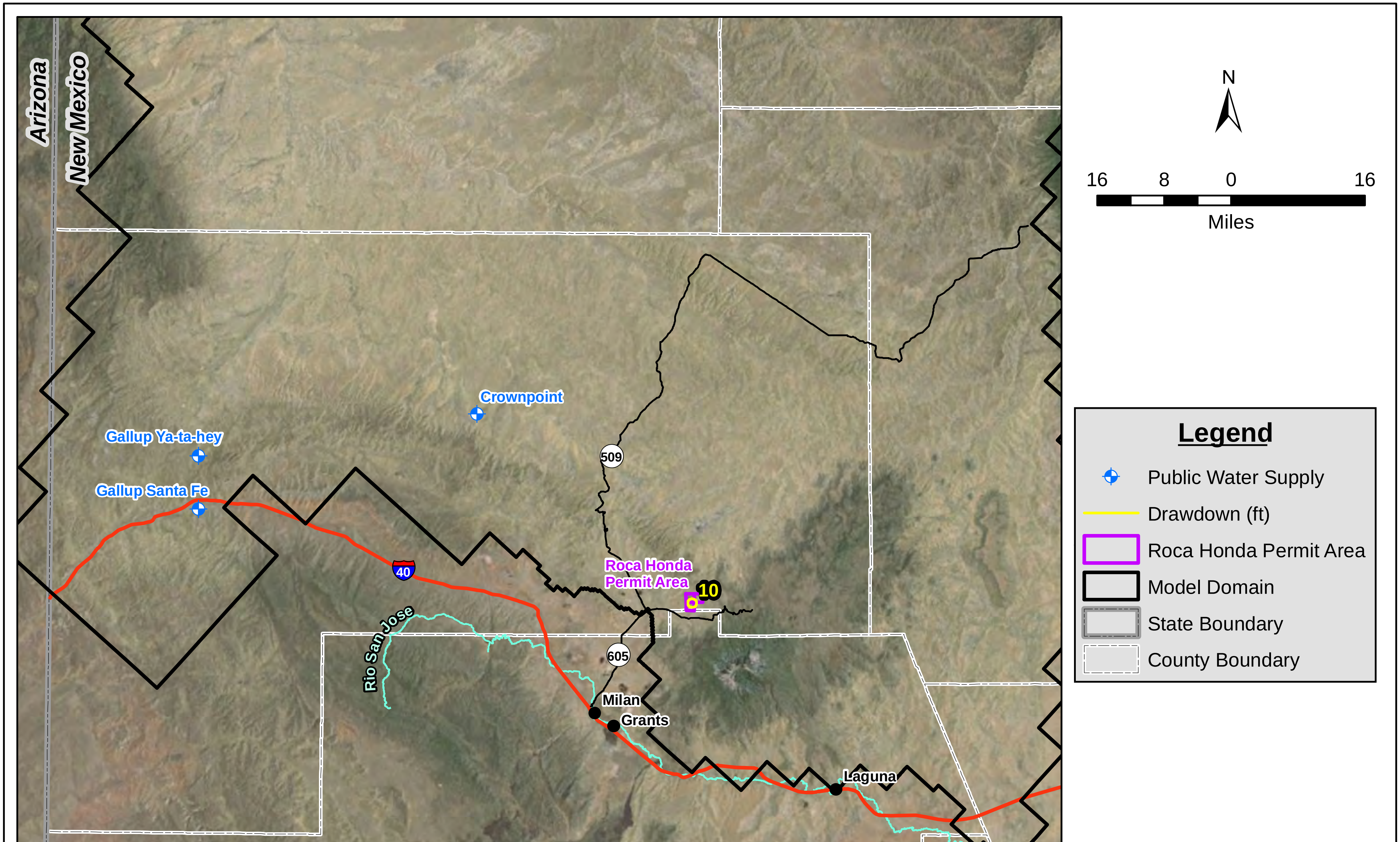

Drawdown in the Dakota Aquifer after 730 Days of Shaft Construction: Scenario 2

INTERA

Figure 5.3

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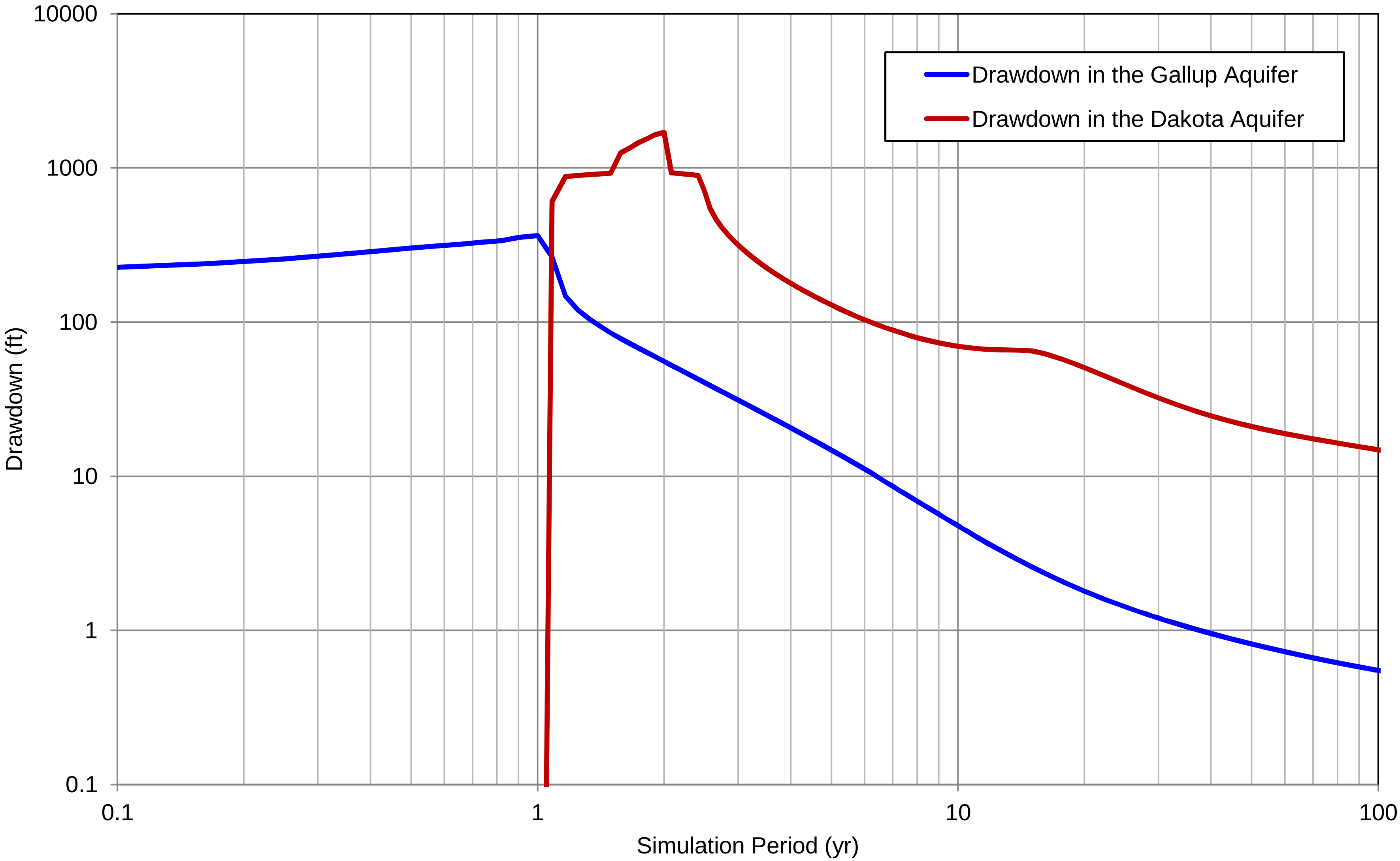

Drawdown at the RHR Production Shaft in the Gallup and Dakota Aquifers: Scenario 2

INTERA

Figure 5.4

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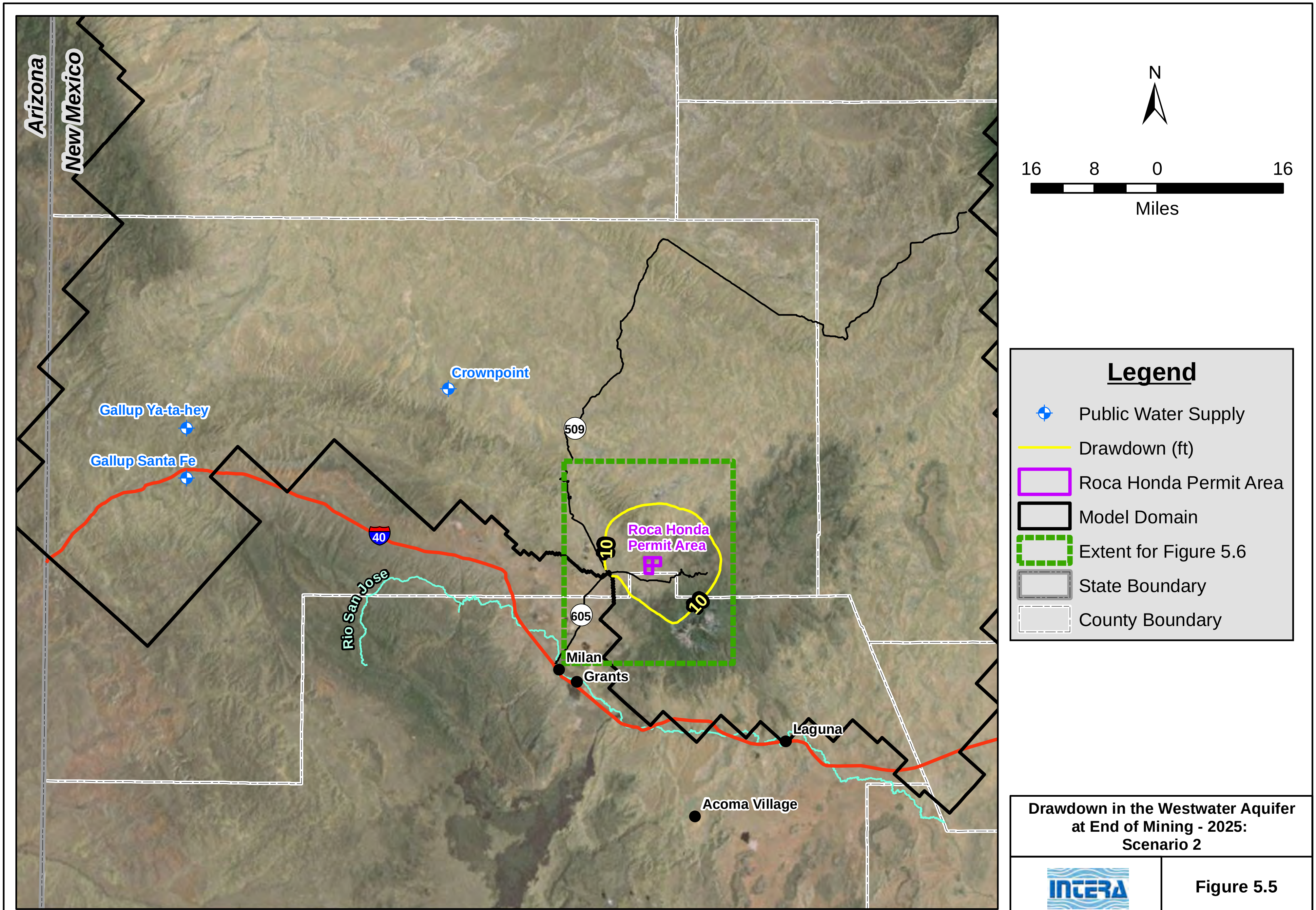
Figures 5.5 and 5.6 show the drawdown in the Westwater at the end of Roca Honda mining. The ten-foot contour of drawdown extends up to 7.5 miles beyond the permit area (Figure 5.5). Within the permit area, drawdown reached a maximum of 1,837 feet (Figure 5.6). Figures 5.7 and 5.8 show the drawdown in the Westwater 40 years after the end of mining. The ten-foot contour of drawdown extends up to 14.7 miles from the permit area (Figure 5.7), whereas the maximum drawdown has decreased to 66 feet (Figure 5.8). Figures 5.9 and 5.10 show the drawdown in the Westwater 100 years after the end of mining. The maximum extent of the ten-foot drawdown contour is 16.6 miles from the permit area (Figure 5.9), but the largest drawdown is only 30 feet (Figure 5.10). A supplementary simulation demonstrated that the maximum extent of the ten-foot drawdown contour from the permit area began to decrease after 100 years past the end of mining, so the farthest extent of groundwater impacts in the Westwater is 16.6 miles from the permit area, as shown in Figure 5.9.

The ten-foot drawdown contour in the Westwater will not reach the Acoma Pueblo, Laguna Pueblo, the Crownpoint water supply, or the two City of Gallup well fields based on groundwater model simulations using the maximum dewatering rates. Simulation results also show that the groundwater level in the Westwater at the production shaft will recover to 90% of its pre-mining level within 26 years after mining ends, and will recover to nearly 97% after 100 years.

Public water supply wells located within the model domain included those for Crownpoint and the City of Gallup (Section 3.7). The public water supplies for the Village of Milan and the City of Grants are located near the Roca Honda permit area, but their water supply wells are not constructed in hydrostratigraphic units that could be affected by Roca Honda dewatering. In the vicinity of the Roca Honda permit area, all other wells pump water for domestic consumption, irrigation, or livestock watering from various hydrostratigraphic units, including the Gallup, Dakota, Westwater, and water-bearing sandstones located in younger hydrostratigraphic units (e.g., model layer 5).

Table D.1 in Appendix D shows the potential change in groundwater levels caused by Roca Honda dewatering at each well used to produce water in the permit area vicinity as predicted by the model simulations. Monitoring and observation wells are not included. Groundwater levels are predicted to drop 10 feet or more at one domestic well in the Dakota and three wells in the Gallup, of which one is permitted for exploration, one for livestock, and one with an unknown use. Maximum drawdown in the Gallup wells occurs in the first year of Roca Honda dewatering and then declines thereafter. Maximum drawdown in the Dakota well occurs 57 years after the start of Roca Honda dewatering and then declines thereafter.



Drawdown in the Westwater Aquifer at End of Mining - 2025: Scenario 2

INTERA

Figure 5.5

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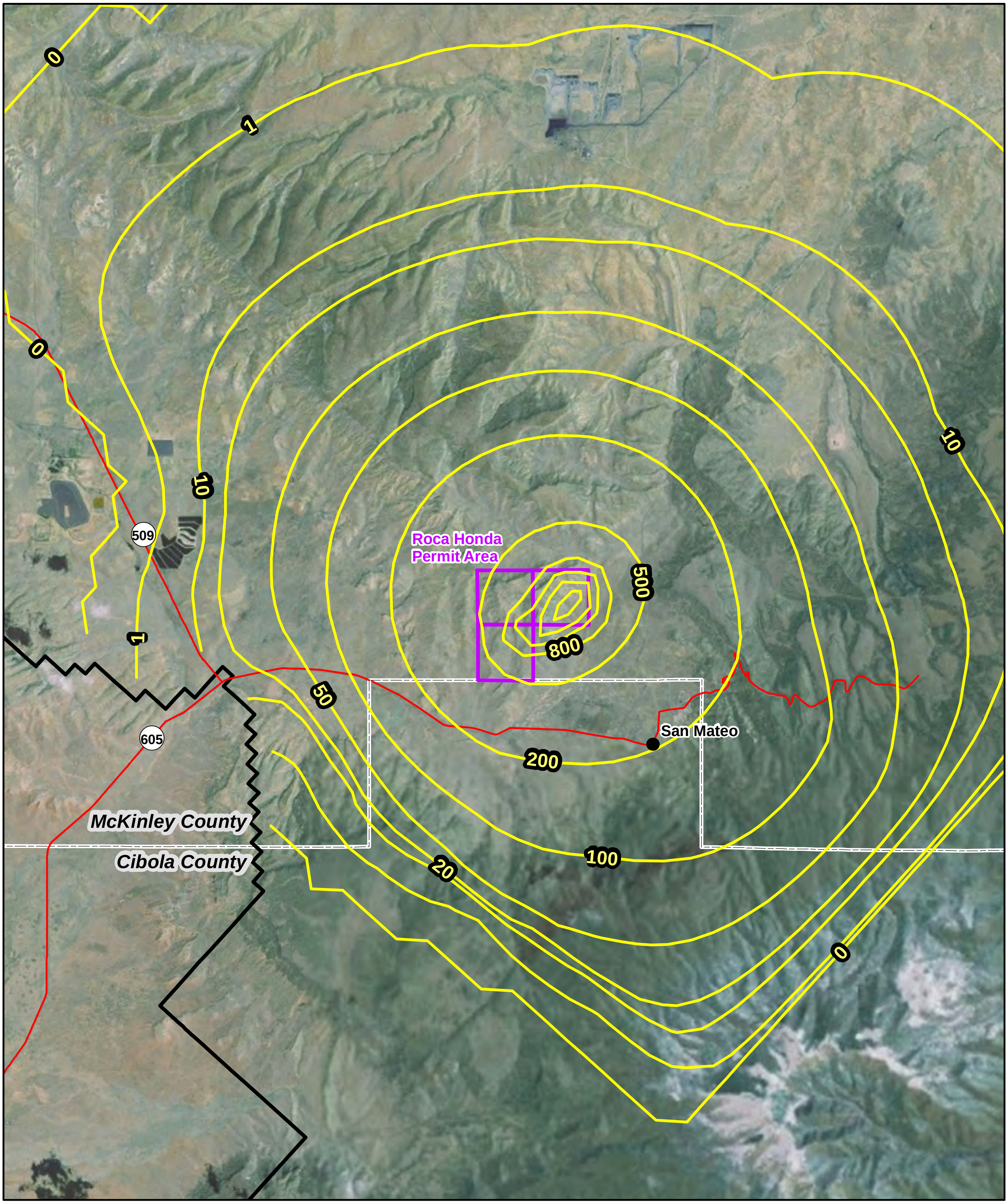

Maximum drawdown of 1,837 ft not shown.

Legend

Drawdown (ft)
Roca Honda Permit Area
Model Domain
County Boundary

2.5 1.25 0 2.5
Miles

Drawdown in the Westwater Aquifer at End of Mining - 2025: Scenario 2

Figure 5.6

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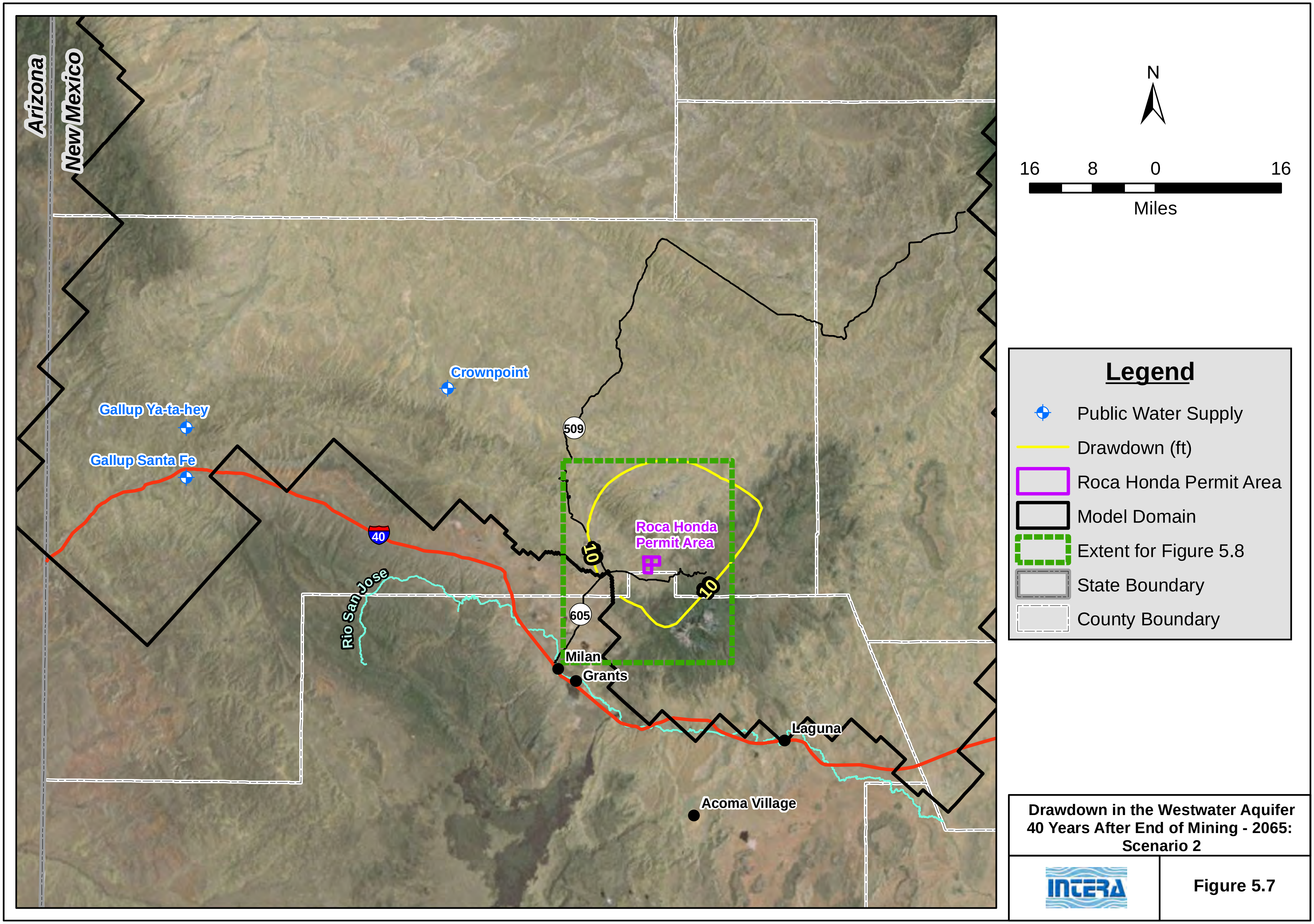

Drawdown in the Westwater Aquifer 40 Years After End of Mining - 2065: Scenario 2

Figure 5.7

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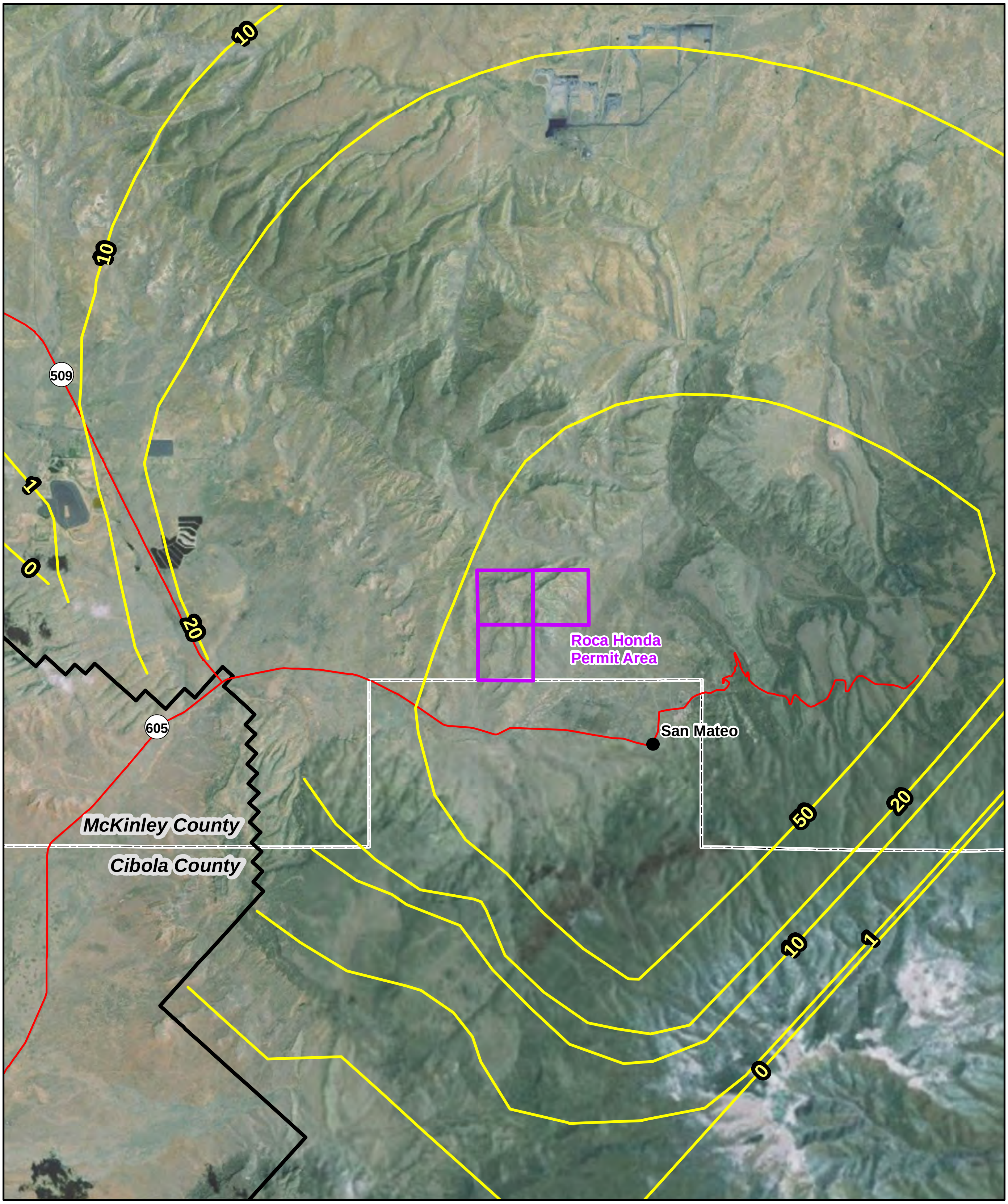

N

Maximum drawdown of 66 ft not shown.

Legend

Drawdown (ft)
Roca Honda Permit Area
Model Domain
County Boundary

2.5 1.25 0 2.5
Miles

Drawdown in the Westwater Aquifer 40 Years After End of Mining - 2065: Scenario 2

INTERA

Figure 5.8

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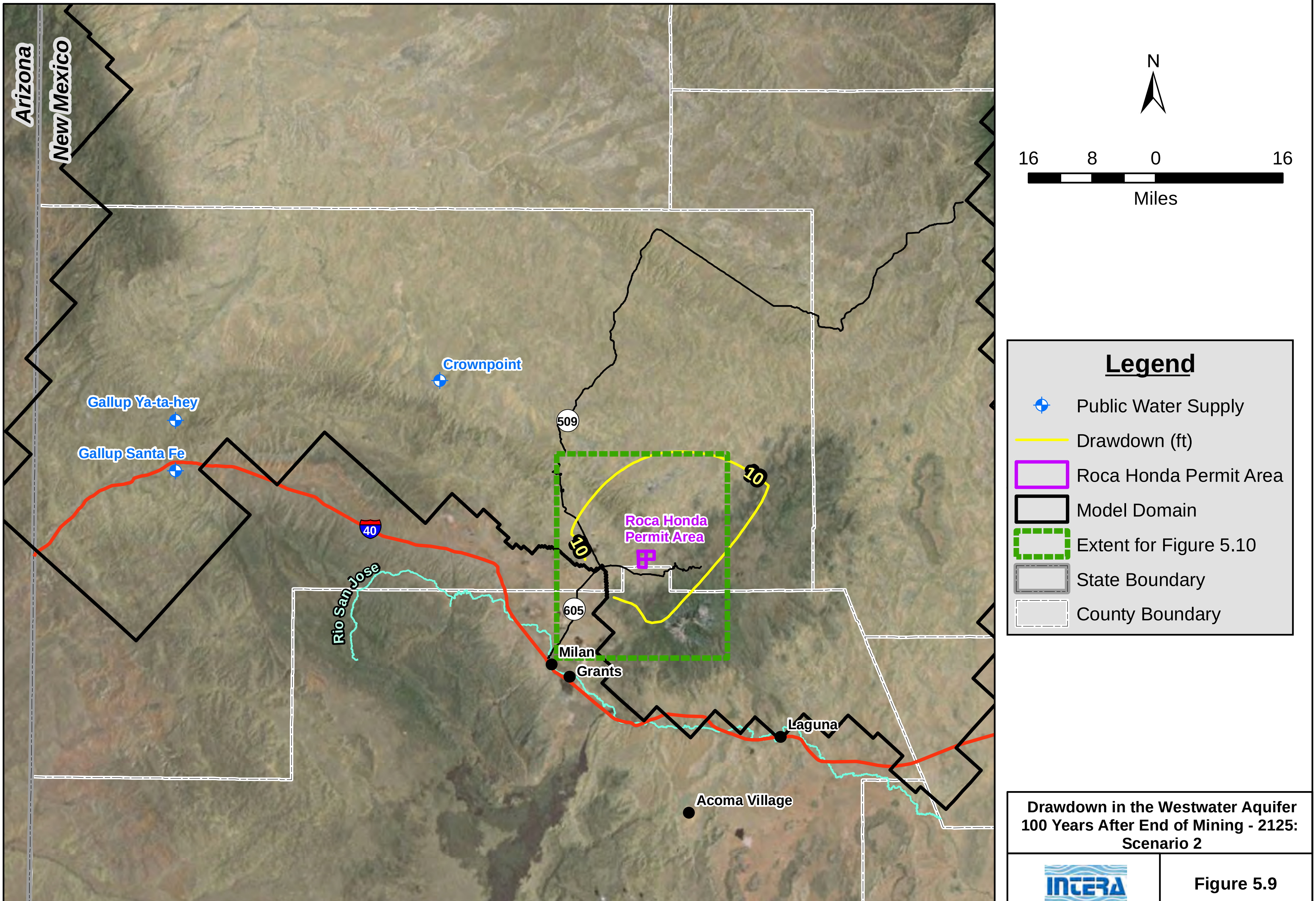

Drawdown in the Westwater Aquifer 100 Years After End of Mining - 2125: Scenario 2

INTERA

Figure 5.9

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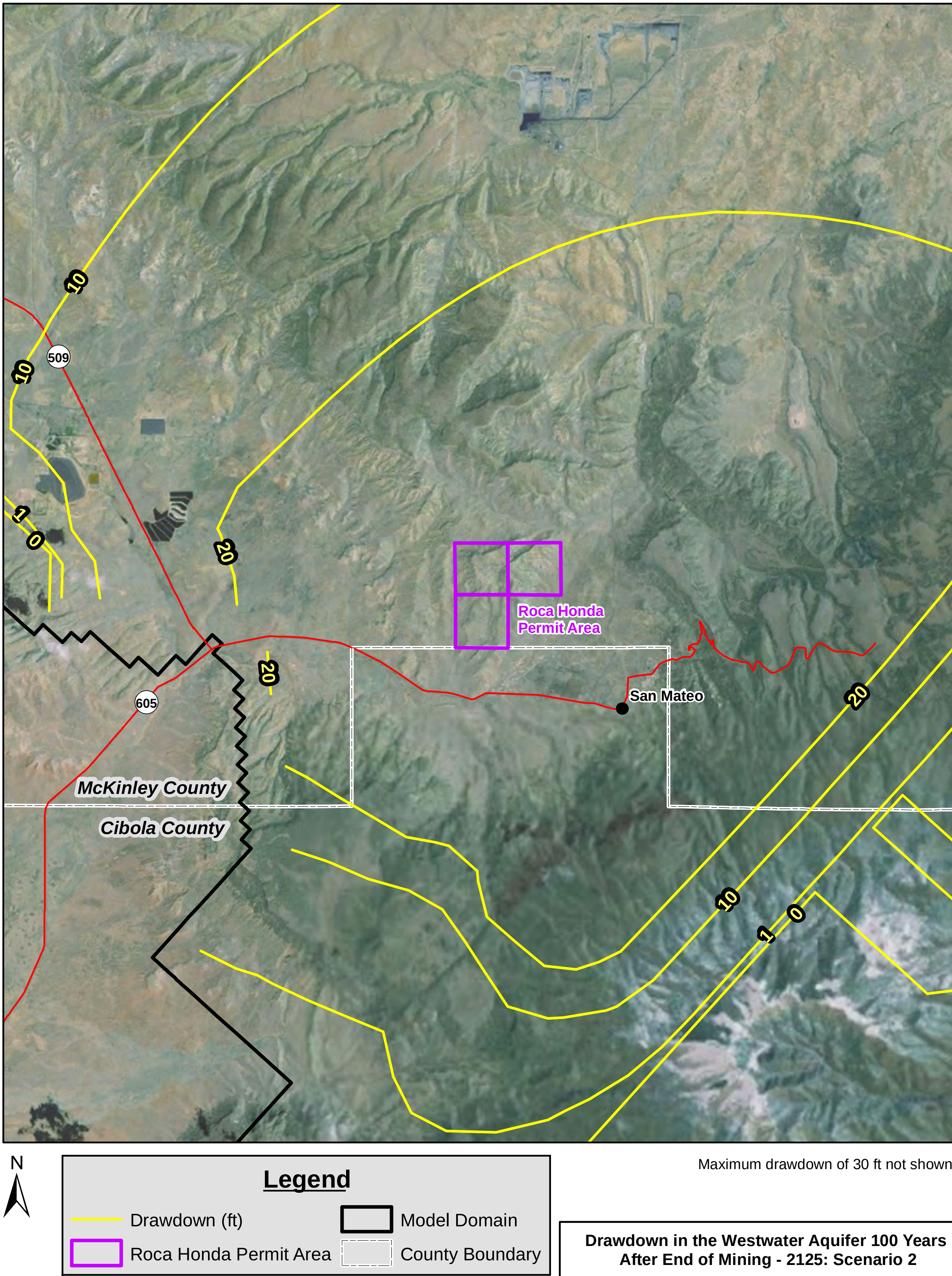


Maximum drawdown of 30 ft not shown.

Drawdown in the Westwater Aquifer 100 Years After End of Mining - 2125: Scenario 2

INTERA

Figure 5.10

File: S:\Projects\STR-001_Strathmore_Modeling\GIS\Mapdocuments\FinalModelReport\Chapter5\Figure05_10_DDJmw2125_RHM.mxd 10/30/2011

All six wells screened in the Mancos Shale (model layer 7) are predicted to have drawdown of less than 3 feet. Model layer 5, which represents the Point Lookout Sandstone and Menefee and Crevasse Canyon Formations, has 92 water supply wells, none of which is predicted to have drawdown greater than 10 feet, and only four wells are predicted to have drawdown greater than 5 feet. Nine Westwater wells are predicted to have 10 feet or more of drawdown, three of which are permitted for mining, three for domestic supply, one for livestock, and two for unknown uses. The three mining wells include two wells at the old Kerr-McGee Ambrosia Lake mine (now owned by BHP Billiton) and the mine shaft at the old Gulf Mt. Taylor (now Rio Grande Resources) mine. Maximum drawdown occurs at these wells between 14 and 29 years after the start of Roca Honda dewatering and then declines.

5.1.2 Drawdown at Springs

Table 5.1 shows the predicted changes in groundwater levels at 21 springs located in the vicinity of the Roca Honda permit area caused by Roca Honda dewatering. Maximum drawdown is predicted to be 0.1 inches (0.01 feet) or less at 20 of the 21 springs. Maximum drawdown is predicted to be 4.8 inches (0.4 feet) at Bridge Spring 113 years after the start of mine construction. Located on private property, Bridge Spring is the nearest spring to the permit area.

5.1.3 Drawdown Sensitivity to Changes in Westwater Hydraulic Properties

Standard practice for groundwater modeling requires an analysis of the sensitivity of model results to the model inputs, such as hydraulic properties (Anderson and Woessner, 1992). Such a sensitivity analysis examines whether the model results, e.g., drawdown in the Westwater, change as key model parameters change, e.g., hydraulic conductivity or specific storage in the Westwater. Nearly all pumping for dewatering will occur in the Westwater and the Westwater is simulated to have the largest drawdown values, so INTERA carried out additional simulations to investigate how changes in Westwater hydraulic properties affected the simulated ten-foot drawdown contours in the Westwater. Given that drawdown increases as hydraulic conductivity or specific storage decrease, some of the additional simulations examined whether the ten-foot drawdown contour changed significantly if values for Westwater hydraulic conductivity and specific storage were reduced. The last set of sensitivity simulations tested whether the very low hydraulic conductivity assumed for the Mt. Taylor core volcanics prevented drawdown from propagating towards the Acoma or Laguna Pueblos.

Table 5.1

Potential Changes in Groundwater Levels at Springs

NAME	NAD 1983 UTM 13N		Model Row	Model Column	Model Layer	Spring Surface Elevation from DEM (ft)	Grid Maximum Elevation (ft)	Grid Minimum Elevation (ft)	Surface Geology	Elevation Difference Between Spring and Formation Top (ft)			Scenario 2[1] Maximum Drawdown (ft)	Scenario 3[2] Maximum Drawdown (ft)	Scenario 4[3] Maximum Drawdown (ft)
	Easting (m)	Northing (m)								Gallup	Dakota	Westwater			
Azabache, Ojo	287137	3944068	26	105	2	6398	7276	6292	Kmf	1011	2307	2730	0.00	0.00	0.00
Bridge Spring	255994	3913748	75	102	2	7043	7053	7037	Kmf	211	1429	1790	0.43	17.97	18.27
Burro Springs	268041	3934954	28	70	1	6563	6660	6499	Kmf	1118	2262	2682	0.00	0.02	0.01
Cerro Spring	266570	3925896	30	99	2	6844	6931	6601	Kmf	1345	2686	3101	0.00	0.00	0.00
Chamisa Losa Spring	298065	3935212	26	110	1	6518	8028	6122	Kmm	118	238	693	0.01	0.01	0.02
Dado Spring, El	271825	3933069	28	88	2	6597	6692	6535	Kmf	1118	2539	2975	0.00	0.01	0.01
Doctor Spring	268481	3933463	28	74	1	6603	6791	6574	Kmf	1137	2314	2734	0.01	0.00	0.02
Fort Miguel Ruins Spring	266081	3921652	31	105	1	7098	7460	6961	Kmf	1585	2901	3322	0.01	0.10	0.11
Jose Manuel Spring	305193	3889614	29	115	1	5823	6597	5600	Jsr	48	52	431	0.00	0.01	0.02
Marquez, Ojo	287501	3911593	29	111	1	7351	8503	6610	Kph	443	3385	3826	0.00	0.01	0.00
Montoya Spring	272974	3940595	27	70	1	6434	6745	6368	Kph	987	2320	2740	0.01	0.00	0.01
Ojo de las Yuges	273918	3930117	28	105	1	6739	7319	6702	Kmf	1252	2710	3146	0.00	0.00	0.00
Padre, Ojo del	304915	3935029	25	111	1	5878	7237	5728	Kml	329	862	1322	0.00	0.00	0.00
Pena Springs	267041	3936245	28	66	1	6545	6650	6519	Kmf	1136	2235	2655	0.01	0.01	0.01
Redondo, Ojo	266717	3933478	28	71	1	6596	6672	6509	Kmf	1146	2297	2717	0.00	0.01	0.01
Salazar Spring	269379	3935012	28	73	1	6595	6745	6558	Kmf	1134	2302	2722	0.01	0.00	0.00
San Lucas Spring	262675	3924611	31	82	1	6901	7352	6899	Kmf	1146	2218	2638	0.01	0.01	0.01
San Ysidro Spring	263308	3932334	29	66	1	6646	6781	6604	Kmf	1153	2193	2613	0.00	0.00	0.00
Sap Hole Spring	264857	3922178	31	104	1	6923	7086	6902	Kmf	1389	2717	3138	0.00	0.00	0.00
Tecolote Springs, Ojo	284488	3903926	31	111	2	7793	8523	7099	Kpl	521	3047	3496	0.00	0.00	0.01
Yeguas, Ojo de las	273918	3930086	28	105	1	6745	7319	6702	Kmf	1258	2716	3152	0.00	0.00	0.00

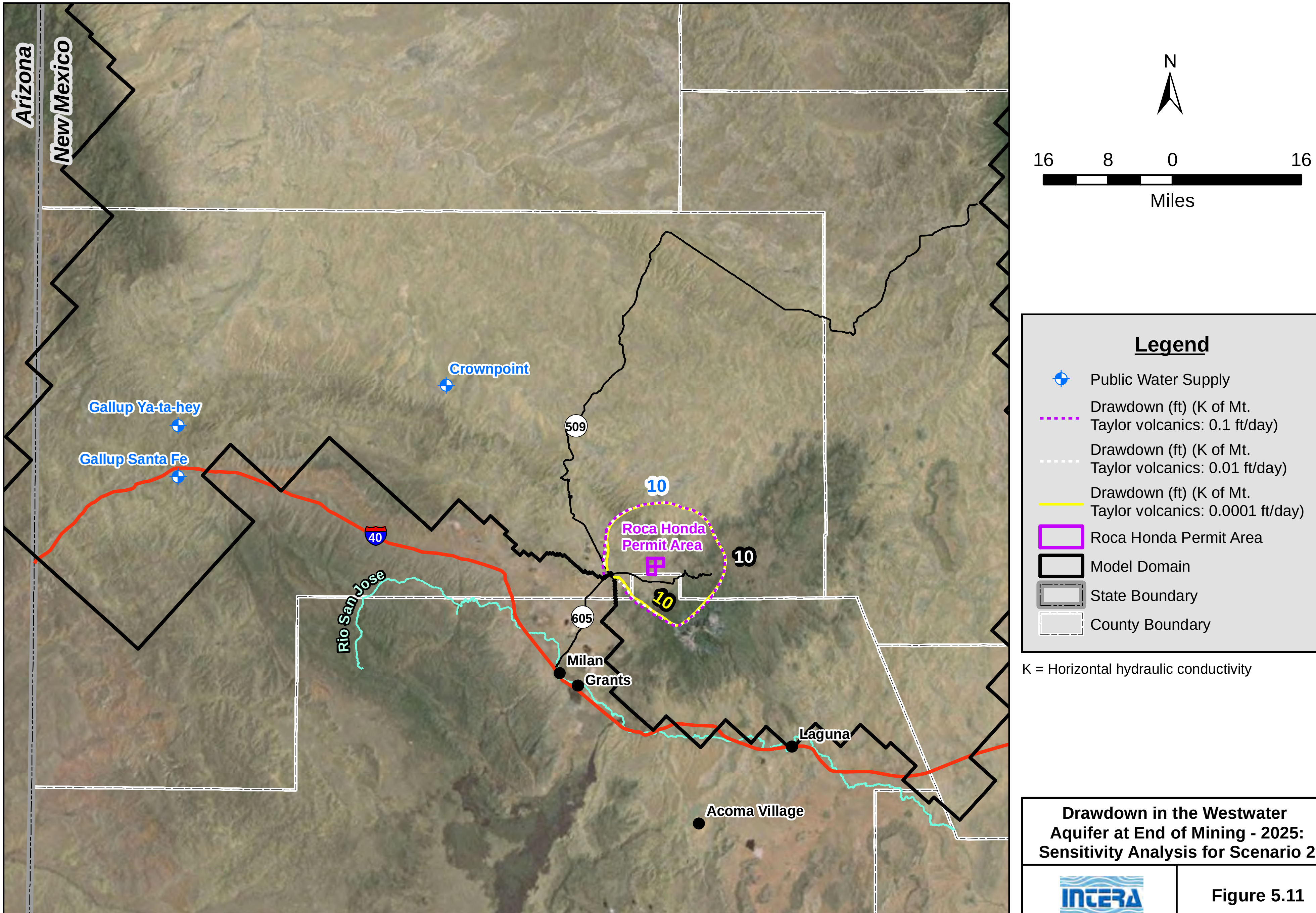
[1] Maximum drawdown for Scenario 2 equals the difference between the Scenario 2 groundwater level and the Scenario 1 groundwater level for the same location and time.

[2] Maximum drawdown for Scenario 3 equals the difference between the Scenario 3 groundwater level and the Scenario 1 groundwater level for the same location and time.

[3] Maximum drawdown for Scenario 4 equals the difference between the Scenario 4 groundwater level and the Scenario 1 groundwater level for the same location and time.

The first sensitivity simulations examined the changes in drawdown from decreasing the horizontal hydraulic conductivity and specific storage in part of the Westwater aquifer along the San Juan Basin's southern margin. This part of the Westwater aquifer is labeled as "Jmw2" in Table 4.1 and is depicted in Appendix B, Figure B.10. In the first simulation, the original horizontal hydraulic conductivity value of 1.25 ft/day was decreased to 0.125 ft/day. The simulation could not be completed because the reduced hydraulic conductivity could not support the maximum dewatering rate of 4,500 gpm. A follow-up simulation showed that reducing the hydraulic conductivity for the same part of the Westwater aquifer by 50% also could not be completed with the given maximum pumping rate. The other sensitivity simulations reduced the specific storage for the Westwater along the basin's southern margin to one-tenth and one-half of the original value (Table 3.2), but the simulations could not be completed because the reduced storage values also could not support the 4,500 gpm dewatering rate.

The final two sensitivity simulations increased the horizontal hydraulic conductivity of the Mt. Taylor volcanic cores that were set within the Gallup, Dakota, and Westwater aquifers (Section 3.6). Represented as hydrostratigraphic units "Tnv" and "Tmv" in Table 4.1 and depicted in Appendix B, Figures B.6, B.8, and B.10, the Mt. Taylor volcanic cores had a much lower horizontal hydraulic conductivity than the surrounding aquifer material. One simulation increased the hydraulic conductivity by a factor of one hundred, from 0.0001 to 0.01 ft/day. The other sensitivity simulation increased the hydraulic conductivity by a factor of one thousand to 0.1 ft/day, which is approximately one-tenth of the hydraulic conductivity value for Westwater units "Jmw2" and "Jmw3" (Table 4.1). Results at the end of Roca Honda mining indicate that there is no significant difference between the locations of the ten-foot drawdown contour in the Westwater from the sensitivity simulations and the original simulation (Figure 5.11). The ten-foot drawdown contours for the two sensitivity simulations extend only slightly farther to the southwest than the original simulation 40 years after the end of mining (Figure 5.12). At 100 years after mining, the ten-foot drawdown contours for the two sensitivity simulations extend slightly farther to the south and southwest but do not extend as far to the northeast as the original simulation (Figure 5.13). In all cases, the ten-foot drawdown contours in the Westwater for the sensitivity simulations will not reach the Acoma Pueblo, Laguna Pueblo, the Crownpoint water supply, or the two City of Gallup well fields. Thus, the ten-foot drawdown contour is not sensitive to the tested changes in Westwater hydraulic properties.



Drawdown in the Westwater Aquifer at End of Mining - 2025: Sensitivity Analysis for Scenario 2

INTERA

Figure 5.11

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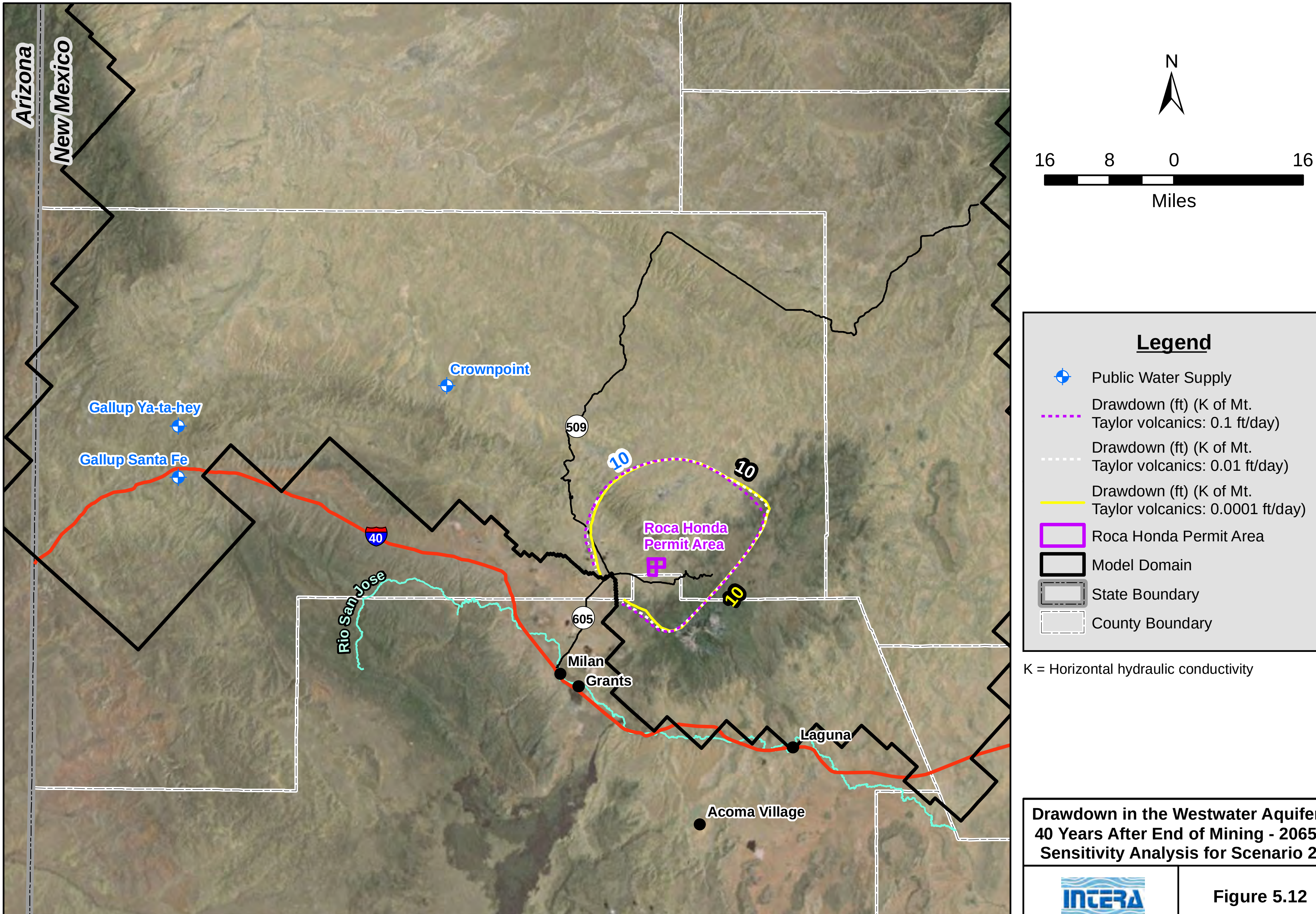

Drawdown in the Westwater Aquifer 40 Years After End of Mining - 2065: Sensitivity Analysis for Scenario 2

Figure 5.12

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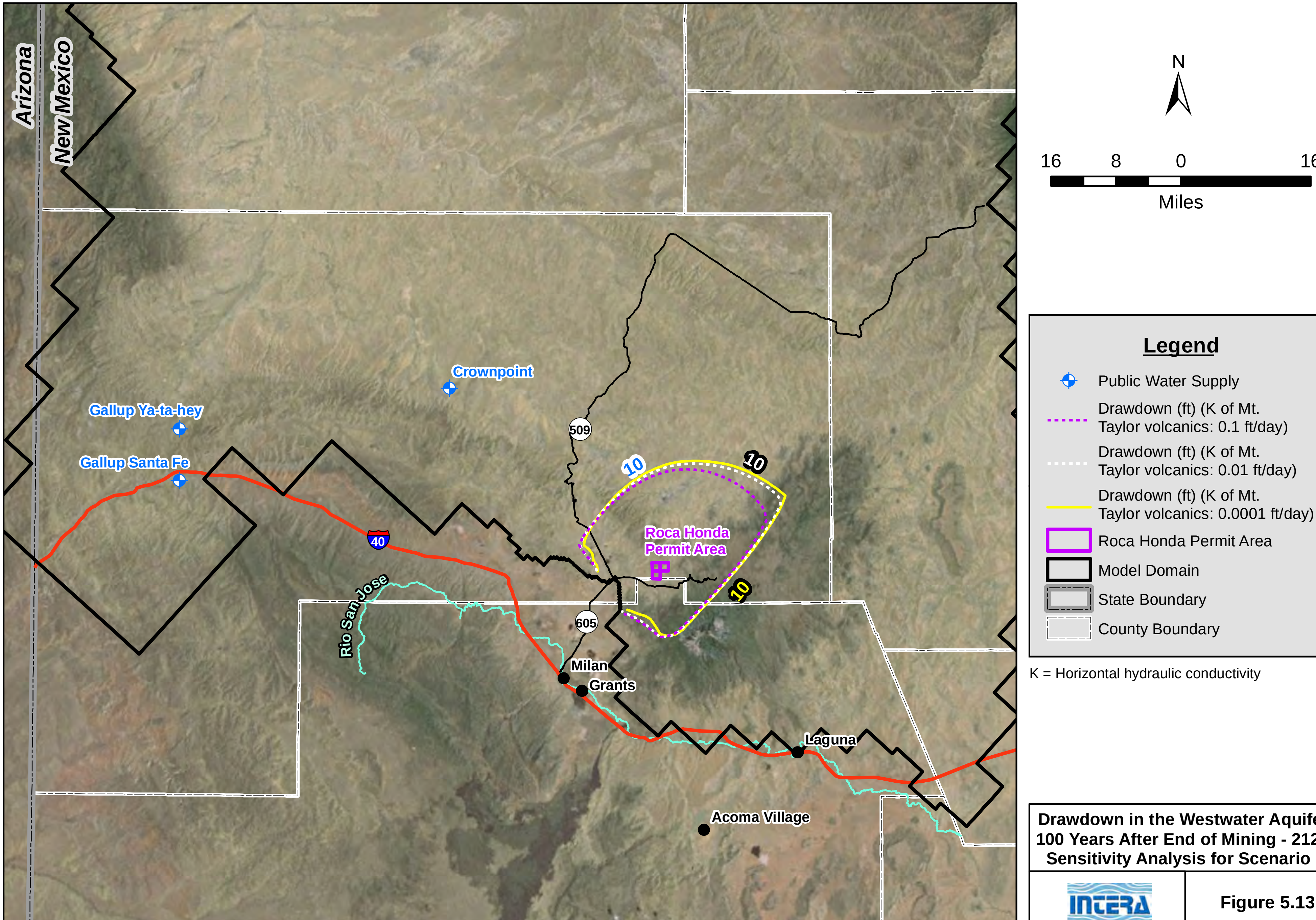


Legend

- Public Water Supply
- Drawdown (ft) (K of Mt. Taylor volcanics: 0.1 ft/day)
- Drawdown (ft) (K of Mt. Taylor volcanics: 0.01 ft/day)
- Drawdown (ft) (K of Mt. Taylor volcanics: 0.0001 ft/day)
- Roca Honda Permit Area
- Model Domain
- State Boundary
- County Boundary

K = Horizontal hydraulic conductivity

Drawdown in the Westwater Aquifer 100 Years After End of Mining - 2125: Sensitivity Analysis for Scenario 2

INTERA

Figure 5.13

File: S:\Projects\STR-001_Strathmore_Modeling\GIS\Mapdocuments\FinalModelReport\Chapter5\Figure05_13_DDJmw2125_RHM_Sensitivity.mxd 10/30/2011

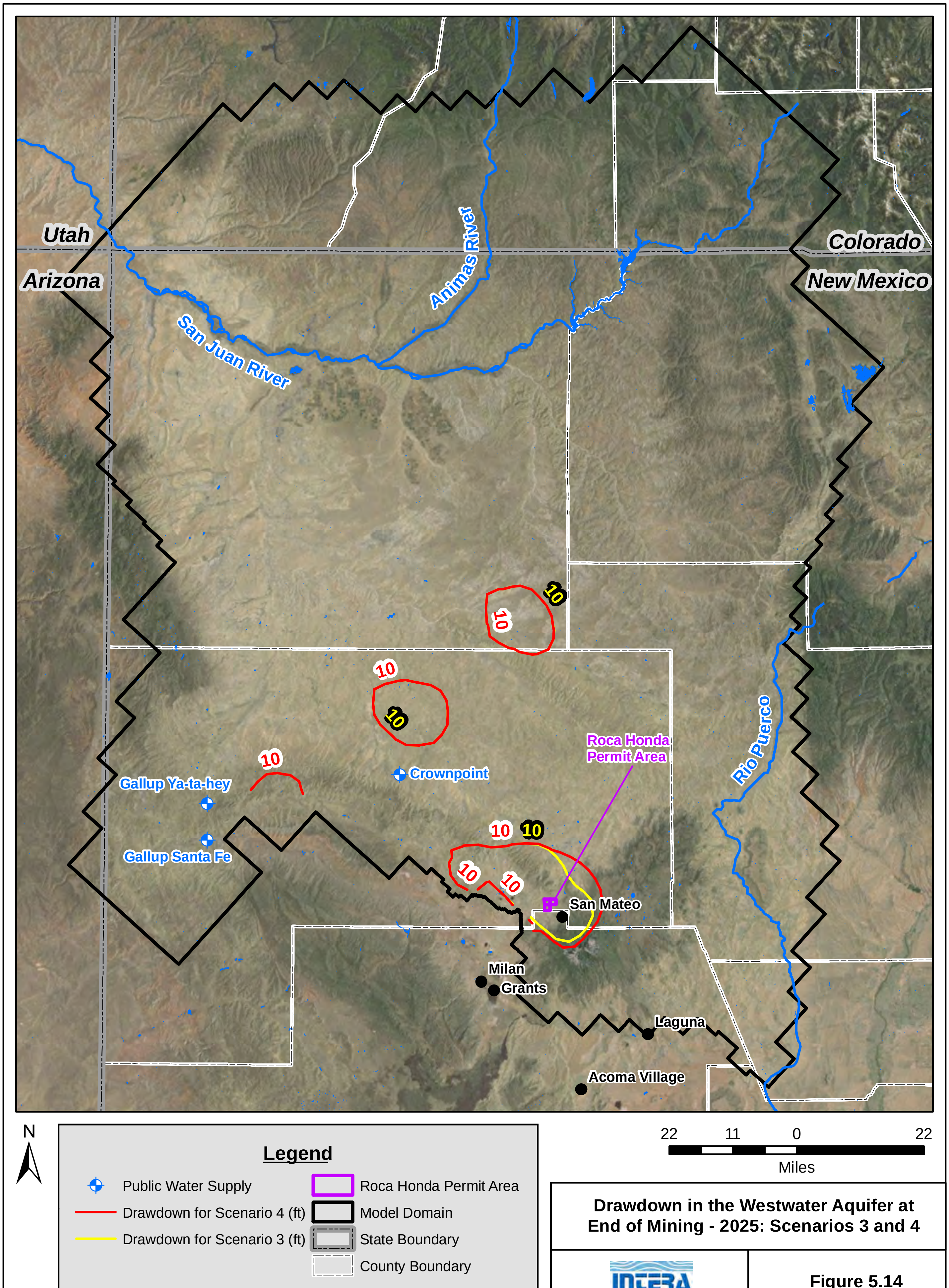
5.2 Changes in Groundwater Levels from Scenario 3

The predictive simulation for Scenario 3 was used to estimate the changes in Westwater groundwater levels from pumping of large water rights in the Westwater, Gallup, and Dakota aquifers near the Roca Honda permit area (Table 3.5) at rates equal to the permitted diversion in the vicinity of the Roca Honda mine, but without any Roca Honda dewatering. As described below, drawdown in the Westwater, Gallup, and Dakota aquifers from maximum pumping of large water rights in the vicinity of the Roca Honda mine, but without any Roca Honda dewatering, will affect groundwater levels at the public water supplies for Crownpoint and probably for the City of Gallup, but not for the pueblos of Laguna and Acoma. A drawdown of 18 feet is predicted for Bridge Spring. Drawdown at wells in the vicinity of the Roca Honda permit area is predicted to be 10 feet or more at nine wells screened in the Westwater, two wells screened in the Dakota, four wells screened in the Gallup, four wells screened in the Mancos Shale (model layer 7), and 81 wells screened in model layer 5 (Point Lookout Sandstone and Menefee and Crevasse Canyon Formations). Drawdown at these wells continues to increase throughout the entire simulation period, reaching the maximum at the end.

5.2.1 Aquifer Drawdown

Drawdown of 10 feet or greater in the Westwater under Scenario 3 is predicted to occur in four areas 13 years after the start of the simulation, which is the same year as the end of mining (Figure 5.14). Two of these areas with 10 feet or more of drawdown expand and merge in the central part of the San Juan Basin and affect the Crownpoint public water supply by the same time as 40 years after the end of mining (Figure 5.15). By the end of the simulation, 113 years after the start, the areas with 10 feet or more of drawdown have all merged so that the Crownpoint public water supply is still affected and the Yah-ta-hey well field for the City of Gallup is also affected (Figure 5.16). The ten-foot drawdown contour does not reach the pueblos of Laguna and Acoma.

Table D.1 in Appendix D shows the drawdown at each well in the permit area vicinity for Scenario 3. Drawdown greater than 10 feet affects many more wells than those impacted by Roca Honda dewatering alone, especially wells simulated in model layers 5 and 7. Drawdown is predicted to be 10 feet or more at four wells in the Gallup (one livestock well, two exploration wells, and one well with unknown use) and two wells in the Dakota (one domestic well and one well with unknown use). Drawdown of 10 feet or more is predicted for nine wells in the Westwater: three are permitted for mining, three for domestic supply, one for livestock, and two for unknown uses. Four of the six wells screened in the Mancos Shale (model layer 7) are predicted to have drawdown greater than 10 feet. Of the 92 wells screened in model layer 5, which includes the Menefee and Crevasse Canyon Formations and Point Lookout Sandstone, 81 wells are predicted to have drawdown greater than 10 feet. Drawdown at all wells continues to increase throughout the entire simulation period, reaching the maximum at the end of the simulation.



Drawdown in the Westwater Aquifer at End of Mining - 2025: Scenarios 3 and 4

INTERA

Figure 5.14

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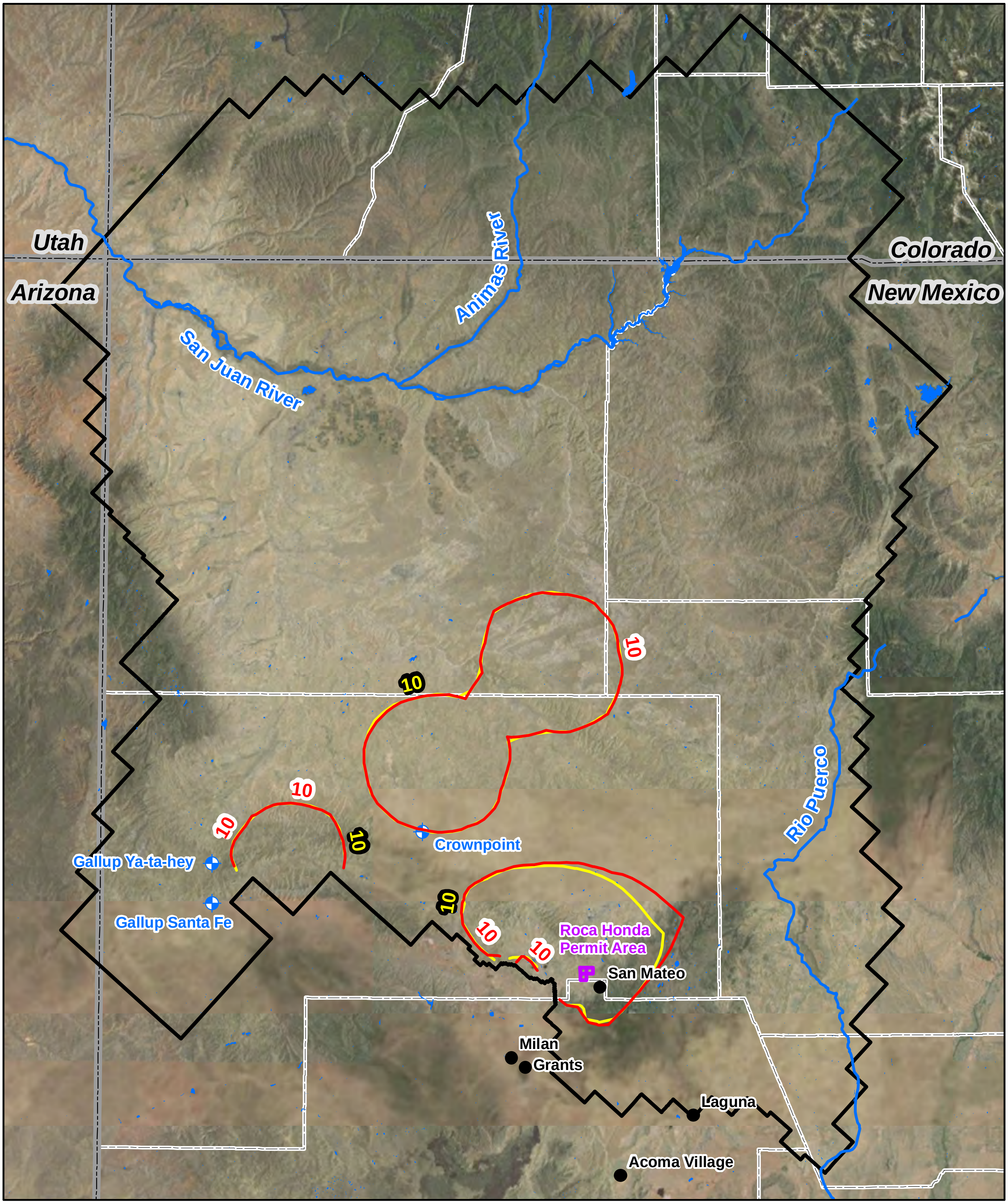

Legend

- Public Water Supply
- Drawdown for Scenario 4 (ft)
- Drawdown for Scenario 3 (ft)
- Roca Honda Permit Area
- Model Domain
- State Boundary
- County Boundary

Drawdown in the Westwater Aquifer 40 Years After End of Mining - 2065: Scenarios 3 and 4

INTERA

Figure 5.15

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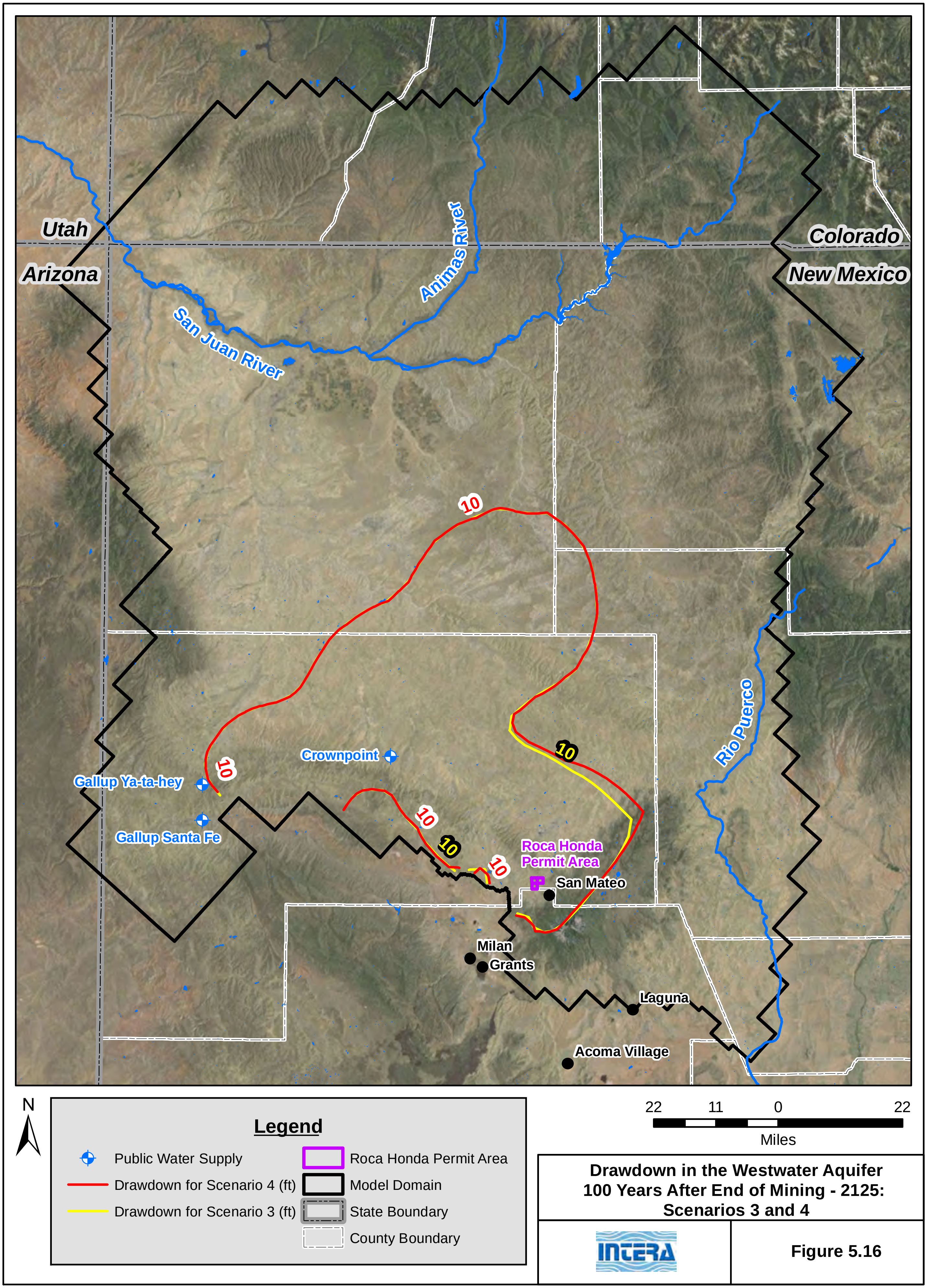

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5.2.2 Drawdown at Springs

The column labeled “Scenario 3” in Table 5.1 shows the predicted changes in groundwater levels for Scenario 3 at 21 springs located in the vicinity of the Roca Honda permit area. The drawdown is predicted to be 0.1 feet or less at 20 of the 21 springs. Drawdown is predicted to be 18 feet at Bridge Spring 113 years after the start of the simulation. Located on private property, Bridge Spring is the nearest spring to the permit area.

5.3 Changes in Groundwater Levels from Scenario 4

The predictive simulation for Scenario 4 was used to estimate the changes in Westwater groundwater levels from pumping of large water rights in the Westwater, Gallup, and Dakota aquifers in the vicinity of the Roca Honda mine at rates equal to the permitted diversion and including Roca Honda dewatering. As described below, drawdown in the Westwater, Gallup, and Dakota aquifers from maximum pumping of all water rights in the vicinity of the Roca Honda mine with Roca Honda dewatering will affect groundwater levels at the public water supplies for Crownpoint and probably the City of Gallup, but not at the pueblos of Laguna and Acoma. A drawdown of 18 feet is predicted for Bridge Spring. Drawdown at wells in the vicinity of the Roca Honda permit area is predicted to be 10 feet or more at nine wells screened in the Westwater, two wells screened in the Dakota, four wells in the Gallup, four wells screened in the Mancos Shale (model layer 7), and 81 wells screened in model layer 5 (Point Lookout Sandstone and Menefee and Crevasse Canyon Formations). Adding the Roca Honda dewatering, which is the only difference between Scenarios 3 and 4, does not increase the number of wells or springs affected compared to Scenario 3 (Section 5.2). Drawdown at all wells continues to increase throughout the entire simulation period, reaching the maximum at the end of the simulation.

5.3.1 Aquifer Drawdown

Changes in groundwater levels for Scenario 4 are very similar to those for Scenario 3. Drawdown of 10 feet or greater in the Westwater under Scenario 4 is localized in four areas at the end of mining (Figure 5.14). Two of these areas with 10 feet or more of drawdown expand and merge in the central part of the San Juan Basin and affect the Crownpoint public water supply 40 years after the end of mining (Figure 5.15). By the end of the simulation, 100 years after the end of mining, the areas with 10 feet or more of drawdown have all merged so that the Crownpoint public water supply is still affected and the Yah-ta-hey well field for the City of Gallup is also affected (Figure 5.16). The ten-foot drawdown contour does not reach the pueblos of Laguna and Acoma.

Table D.1 in Appendix D shows that the drawdown at each well in the permit area vicinity for Scenario 4 is the same as or greater than the drawdown for Scenario 3. Drawdown is predicted to be 10 feet or more at four wells in the Gallup (one livestock well, two exploration wells, and one well with unknown use) and two wells in the Dakota (one domestic well and one well with unknown use). Drawdown of 10 feet or more is predicted for nine wells in the Westwater: three are permitted for mining, three for domestic supply, one for livestock, and two for unknown uses. Four of the six wells screened in the Mancos Shale (model layer 7) are predicted to have drawdown greater than 10 feet. Of the 92 wells screened in model layer 5, which includes the Menefee and Crevasse Canyon Formations and Point Lookout Sandstone, 81 are predicted to have drawdown greater than 10 feet. Drawdown at all wells continues to increase throughout the entire simulation period, reaching the maximum at the end of the simulation.

5.3.2 Drawdown at Springs

The column labeled "Scenario 4" in Table 5.1 shows the predicted changes in groundwater levels for Scenario 4 at 21 springs located in the vicinity of the Roca Honda permit area. The drawdown is predicted to be 0.1 feet or less at 20 of the 21 springs. Drawdown is predicted to be 18.3 feet at Bridge Spring 113 years after the start of the simulation. Located on private property, Bridge Spring is the nearest spring to the permit area.

6.0 SUMMARY AND CONCLUSIONS

INTERA believes the following to be true based on utilization of the best available data and state-of-the-art analysis of that data:

1) The proposed Roca Honda mine is located within the San Juan Basin. Temporary dewatering will occur in three aquifers: the Gallup Sandstone, the Dakota Sandstone, and the Westwater Member of the Morrison Formation during a 13-year period of mine construction and operation. All dewatering will cease with the end of mining.

2) Numerical models of historical groundwater flow in the San Juan Basin were constructed and calibrated to observed historical groundwater levels. INTERA significantly improved on the existing USGS model by modifying boundary conditions, incorporating new data on aquifer parameters and stratigraphy in the vicinity of the Roca Honda permit area, increasing the number of calibration measurements for the steady-state calibration, and carrying out a transient calibration. The calibrated Roca Honda mine models are the best available tools for predicting potential groundwater level changes from proposed dewatering at the Roca Honda mine. The following key results support this conclusion:

    a. Calibration statistics revealed an NRMSE of 4.4% indicating a very good steady-state calibration (Spitz and Moreno, 1996).

    b. The model mass balance error was very low, -0.21%, and a mass balance error of less than 1% indicates a good mass balance calibration (Anderson and Woessner, 1992).

    c. Water balance calculations for the calibrated predevelopment model showed that the total groundwater inflow was within the range of previous models and closely agreed with an estimate from Lyford and Stone (1978).

    d. Comparison of simulated groundwater levels over time for the Dakota and Westwater aquifers from the transient numerical flow model with groundwater levels measured at over two dozen locations demonstrated a good fit between simulated and actual groundwater data. Comparison of contours of simulated groundwater levels in 1979, 2007, and 2010 demonstrate a close match to observed groundwater levels. Simulated dewatering rates and volumes for Ambrosia Lake mines, the Church Rock mine area, the Gulf Mt. Taylor mine, and the Johnny M mine all closely matched rates from Stone et al. (1983) and other data sources.

3) The public water supplies for the Village of Milan and the City of Grants will not be affected by Roca Honda dewatering. Roca Honda dewatering because they pump groundwater from aquifers that are stratigraphically separated from the Westwater aquifer by thick shale with low hydraulic conductivity.

4) Drawdown in the Westwater, Gallup, and Dakota aquifers from dewatering at the Roca Honda mine will not affect groundwater levels at the public water supplies for Crownpoint and Gallup, or at the pueblos of Laguna and Acoma. Drawdown at springs is predicted to be negligible.

5) The maximum extent from the permit area boundary of the ten-foot drawdown contour in the Westwater aquifer is predicted to be 17 miles. Drawdown at wells in the vicinity of the Roca Honda permit area is predicted to be 10 feet or more at nine wells screened in the Westwater, three of which are used for mining, three for domestic supply, one for livestock, and two for unknown uses. Drawdown is predicted to be 10 feet or more at one domestic well screened in the Dakota, and three wells in the Gallup, of which one is permitted for exploration, one for livestock, and one with an unknown use.

6) The pumping rates and pumping time periods used to represent Roca Honda dewatering in the mine dewatering simulation (Scenario 2) represent a worst-case scenario because actual Roca Honda dewatering rates will increase gradually over the 13-year mining period. Thus, Scenario 2 provides a conservative estimate of potential changes in groundwater levels from Roca Honda dewatering.

7) Results from predictive simulations that represented maximum pumping of large water rights in the Gallup, Dakota, and Westwater aquifers in the vicinity of the Roca Honda permit area but did not include Roca Honda dewatering (Scenario 3) demonstrated that drawdown of 10 feet or greater will occur at the public water supply wells for Crownpoint and the City of Gallup 40 years after the end of mining. Groundwater levels near the Acoma and Laguna Pueblos will not be affected. Groundwater levels at Bridge Spring are predicted to decline 18 feet 113 years after the start of the simulation. The results predict that 100 wells used for domestic, irrigation, livestock, or other purposes will have maximum groundwater level decreases of 10 feet or more. Drawdown at these wells continued throughout the entire simulation period and reached the maximum at the end of the simulation.

8) The model predicts that adding Roca Honda mine dewatering to the predictive simulations that represented maximum pumping of water rights in the vicinity of the permit area (Scenario 4) will not result in significant changes in groundwater levels.

9) The model predicts that maximum pumping of all water rights in the vicinity of the permit area together with Roca Honda dewatering (Scenario 4) will result in groundwater level drawdown of 10 feet or greater for Crownpoint and the City of Gallup water wells 40 years after the end of mining, but not the groundwater levels near the Acoma and Laguna Pueblos. Bridge Spring is predicted to have a water level decrease of 18 feet. As for Scenario 3, the same set of 100 wells used for domestic, irrigation, livestock or other purposes is predicted under Scenario 4 to have maximum water level decreases of 10 feet or more, with large increases in drawdown at some wells and small increases at other wells. Drawdown at these wells continued throughout the entire simulation period and reached the maximum at the end of the simulation.

10) The model predicted that proposed Roca Honda dewatering will not adversely affect the water resources of the Village of Milan, Acoma Pueblo, Laguna Pueblo, the City of Grants, the community of San Mateo, the Crownpoint area, or the City of Gallup. Mine dewatering will not have any adverse impacts on area springs. Thirteen water supply wells in the upper Mesaverde Group, Gallup Sandstone, Dakota Sandstone, and Westwater Member of the Morrison Formation are predicted to have changes in groundwater levels of 10 feet or more.

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