BURNS McDONNELL

September 24, 2018

Mr. Toby Dougherty
City Manager
City of Hays, Kansas
1507 Main Street
Hays, Kansas 67601

Re: R9 Ranch Modeling Results – Revision 2

Dear Toby:

Attached is the revised report on the R9 Modeling results. During their review of the model files and the R9 Ranch Modeling Results provided by Burns & McDonnell (BMcD) to DWR on February 13, 2018, Balleau Ground Water, Inc. (BGW) identified a technical error in the operation of the Streamflow Routing Package (SFR) used by BMcD in preparing the modeling-results report. Due to this error, the model was not correctly routing flow from cell to cell along the river flow paths. BMcD corrected this error, completed the model runs with the SFR package operating correctly, and revised the modeling results report to reflect the amended results.

As a part of BMcD's identification and correction of the technical error in the SFR package noted above, BMcD conducted a comprehensive review of all runs of the model to verify that the SFR package was functioning correctly. This included a review of the short-term (1991-2007) runs of the model, which revealed that the SFR package was not accurately accounting for streambed downcutting. This error was also corrected.

Please note that the revised groundwater model report does not address the "alternative" approaches to groundwater modeling offered by BGW or Keller-Bliesner Engineering, which were discussed in BMcD's September 13, 2018 letter to Mr. Dougherty and forwarded to the Chief Engineer.

Below is a listing of the substantive revisions made to the report, to assist with your review.

1. The text describing Figure 4 on page 5 was revised to note that at 4,800 acre-feet of municipal pumping the water level drop is 0.2 feet instead of 0.6 feet as originally reported. Figure 4 was also revised accordingly.
2. Table 1 was revised to account for the corrected model runs.
3. On Page 7, the discussion of the differences between the Scenario 2 and Scenario 1 output was revised to reflect the new model results.
4. The text describing Figure 6 on pages 7–8 was revised to state that there is only 0.3 feet of additional drawdown on the Ranch, instead of 0.5 feet of drawdown as provided in the original report. Figure 6 was revised accordingly.
5. Table 2 was updated in accordance with the revised model runs.

6. The discussion of the results of the Scenario 3 baseline 51-year run on pages 10 and 11 was revised.
7. The discussion of the differences between Scenario 3 and Scenario 4 was updated on page 11.
8. Figure 9 was revised and the discussion of Figure 9 on page 11 was updated to reflect that the drawdown on the Ranch was reduced to 0.4 additional feet (from 0.7 feet) in the northeastern portion and to 0.8 feet (from 1.5 feet) in the southwestern portion.
9. The comparison of the results of Scenario 5 with Scenarios 3 and 4 on page 12 was revised.
10. Figure 10 was revised.
11. The discussion of the results of Scenario 6 were revised on page 14.
12. Figure 11 was revised.
13. Figure 13 was revised.

The corrected model runs result in somewhat more water available to the Cities and further support the conservative approach taken by BMcD in the original model report. Nevertheless, the results of the corrected model runs do not change BMcD's overall conclusions contained the original model report. The water level changes and model mass balance from the corrected model runs support the conclusion that 4,800 acre-feet per year is a sustainable pumping rate for the R9 Ranch.

If you have any questions regarding the revisions to the report, please contact me at 816.695.3940 or pmccormick@burnsmcd.com.

Sincerely,
BURNS & MCDONNELL

Paul McCormick, P.E.
Associate Geological Engineer

Enclosure
cc: Jon Quinday – City of Russell
John T. Bird – Glassman, Bird, Brown & Powell
David Traster – Foulston Siefkin
Daniel Buller – Foulston Siefkin

BURNS & McDONNELL

September 24, 2018

Mr. Toby Dougherty
City Manager
City of Hays, Kansas
1507 Main Street
Hays, KS 67601

Re: R9 Ranch Modeling Results – Revision 2

Dear Toby:

The Cities of Hays and Russell, Kansas (Cities) purchased the R9 Ranch (R9 Ranch) in 1995 for potential development as an alternative water supply source to diversify their long-term water supply portfolios and secure a drought-resistant raw water resource. The Cities intend to develop and operate a municipal wellfield at the R9 Ranch in a sustainable manner that maintains the resource as a viable long-term water supply. Operating the well field in this manner includes considering the effects of pumping on the local aquifer and surrounding users. This letter report details the results of Burns & McDonnell's (BMcD) work to evaluate the long-term maximum average pumping rate for the R9 Ranch and the effects that the planned municipal wellfield development and pumping will have on the surrounding aquifer.

The R9 Ranch covers approximately 6,900 acres and is located approximately five miles southeast of Kinsley, Kansas (Figure 1). The R9 Ranch has historically been used for irrigated agricultural purposes, such as growing corn, alfalfa, and soybeans. Irrigation was accomplished using 53 irrigation wells supplying water to 41 center-pivot irrigation areas. Perfected irrigation water rights on the R9 Ranch total 7,719 acre-feet per year. Change applications have been filed with the Kansas Department of Agriculture, Division of Water Resources (DWR) and the total quantity of water available for municipal use after DWR's reductions for consumptive use is 6,756.8 acre-feet per year.

Geology on the R9 Ranch is generally comprised of Quaternary aged sands and gravels. Along the Arkansas River corridor, recent age alluvial deposits are found at the surface. As distance from the river corridor increases, the recent alluvial deposits blend into the Meade formation, with dune sand at the surface. Differences between the characteristics of the alluvial deposits and the Meade formation are minimal, and they are typically referred to jointly as undifferentiated Pleistocene deposits. They are composed mostly of sand and gravel with some lenses of silt and clay, and occasional areas containing caliche. These are the aquifers utilized for pumping on the R9 Ranch.

Beneath the Meade formation are sands and gravels of the Pliocene aged Ogallala Formation which is composed principally of fine sands and gravels. Bedrock beneath the Ogallala is composed of the Lower Cretaceous aged Dakota formation. This formation is composed of fine to medium grained sandstones with some shale and clay.

Depth to bedrock varies across the R9 Ranch, increasing from west to east. Top of bedrock elevation at the Arkansas River is approximately 2,185 feet above mean sea level (amsl), and top of bedrock elevation at the east boundary of the R9 Ranch is approximately 2,125 feet amsl. The saturated thickness of the aquifer varies from 45 feet along the Arkansas River to 140 feet on the eastern portion of the R9 Ranch, with an average saturated thickness of approximately 100 feet.

Historic water use at and around the R9 Ranch was typically in the form of center-pivot irrigation systems. Center-pivot systems require relatively high flows, on the order of 600 to 800 gallons per minute (gpm). This pumping typically occurs only for a portion of the year, during the irrigation and growing season. Comparatively, the proposed municipal wells will pump at the lower rate of approximately 350 gpm for longer periods of time. Operationally, the proposed municipal wells will cycle on and off monthly. This operational frequency, combined with the lower pumping rate, reduces the overall stress applied to the aquifer compared to the stress caused by the higher-intensity, shorter-duration pumping of center-pivot irrigation. Therefore, the calculated water levels from the municipal well scenarios are often higher than the water levels calculated based on historic irrigation pumping.

Groundwater Modeling

Quantifying the long-term yield of the R9 Ranch was accomplished using a three-dimensional groundwater flow model developed for the Big Bend Groundwater Management District No. 5 (GMD5). The model utilizes the United States Geological Survey (USGS) MODFLOW™2000 three-dimensional groundwater flow modeling code. A detailed report of the construction and calibration of the model can be found in the Balleau Groundwater, Inc. (BGW) report titled *Hydrologic Model of Big Bend Groundwater Management District No. 5*, dated June 2010 (BGW Report).

BMcD acquired the BGW Report and model files from the DWR through a Kansas Open Records Act (KORA) request. BMcD and the Cities are very appreciative of the guidance and cooperation provided by DWR staff during this modeling effort and development of this work product.

The model area encompasses the entirety of GMD5 and a substantial area up-gradient of GMD5, as well as an area down-gradient. The R9 Ranch is located in the west-central portion of GMD5, centrally located within the extents of the three-dimensional groundwater flow model. The model framework is composed of seven layers representing the major geologic divisions in the regional stratigraphy. For calculation purposes, the model is further divided into nine units, to differentiate between areas with varying hydrologic characteristics within layers. The model is divided into a one-half mile by one-half mile grid. It includes the recharge, streamflow, and pumping data for a 68-year period, from December 1939 through December 2007.

BMcD utilized Groundwater Vistas Version 6.0 (GWV) pre- and post-processing software to run the GMD5 model. GWV provides a graphical user interface to streamline data entry and processing of the model results. The model construction, hydrogeological parameters, and well pumping data contained in the root MODFLOW files obtained through the KORA request were imported into GWV. BMcD did not make any changes to the data or hydrogeological parameters of the GMD5 model.

BMcD completed an initial run to verify that the model was correctly imported and set up in GWV. Verification was accomplished by direct comparison to the results from the GMD5 model. Mass balance results, drawdown values and water level contours were compared to the values from the BGW Report and the model output files obtained through the KORA request.

The water level, drawdown, and mass balance results calculated during the evaluation run correlated very well with the values reported for the base case in the BGW Report and output files obtained through the KORA request. The variance between the inflow and outflow mass balance results was less than 1.49 percent on average and was well within the margin of error of the model described in the BGW Report. These variations could be caused by differences in the data handling methods from the pre-and post-processing software packages or in the rounding of numbers within the processing software. This close correlation indicates that the change in the pre- and post-processing method to operate the model did not significantly impact the model output.

Modeled Groundwater System

Water supplied to the aquifer under the R9 Ranch varies seasonally and annually, based on the climatic conditions. Water levels in the aquifer fluctuate in response to these changes. As stated previously, the Cities intend to operate the R9 Ranch well field in a sustainable manner for the long-term. To accomplish this, the average volume of water pumped from the well field should not exceed the average volume of water recharged to the aquifer. Multiple pumping scenarios were run using the model to evaluate the amount of water the aquifer on the R9 Ranch would yield while allowing for reasonable water level fluctuations.

The model calculates changes in water levels over time for the entire region. Localized effects caused by pumping can be evaluated by comparison of changes in water levels from a baseline case to a modeled scenario. To evaluate the long-term yield of the R9 Ranch, the model cells containing the R9 Ranch were identified as a sub-region and an accounting was kept of the flux in and out of the sub-region. The internal Hydrostratigraphic Units (HSU) package in GWV was utilized for the computation of the sub-regional water balance instead of the USGS ZONEBUDGET package which was utilized by BGW. These two packages perform the same function and provide equivalent results, effectively calculating the mass balance for a sub-region of the model. The model cells comprising the sub-region evaluated as the R9 Ranch HSU are illustrated in the inset in Figure 1, located at the end of this report.

Figure 2 illustrates the flow in and out of a groundwater system. Net values for the model parameters are calculated from the MODFLOW™2000 mass balance as inflow to the R9 Ranch HSU minus outflow from the R9 Ranch HSU for each parameter. The model was run to calculate the amount of water that flows into and out of the R9 Ranch HSU. Properties included in the mass balance analysis were recharge, evapotranspiration, well pumping, lateral groundwater flow (flow into and out of the HSU from the surrounding aquifer), streamflow and storage.

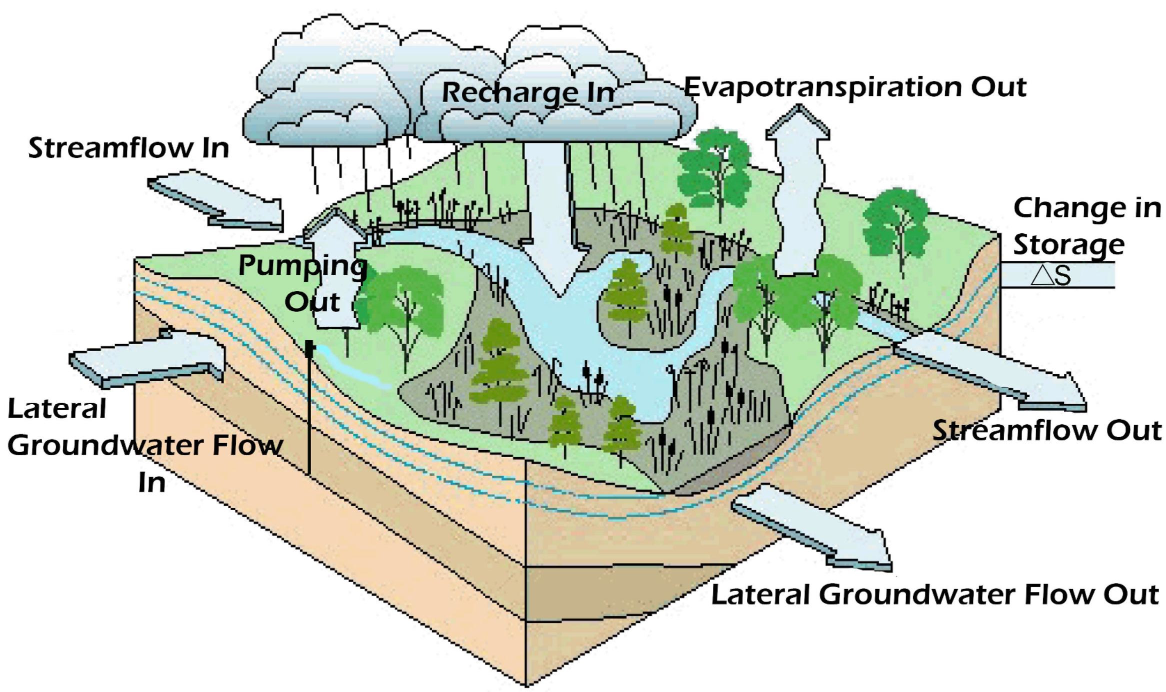


Figure 2 – Typical groundwater mass balance properties.

The Cities' principal objective is to develop and operate the R9 Ranch as a municipal water supply in a long-term sustainable manner as a source of raw water. To accomplish this, effects to the resource must be quantified under different wellfield development scenarios. Evaluation of these effects was accomplished by comparing the water levels generated by the historical irrigation and agricultural pumping with the proposed municipal pumping activities under varying time frames and hydrologic conditions.

Existing Conditions

The full BGW model simulates the period of time from December 1939 through December 2007. As described in the BGW Report, the period from 1991 to 2007 provides the highest quality data, as the pumped well volumes equal the metered volumes reported to DWR. BMcD utilized this time period to complete the initial evaluation of the R9 Ranch. As shown in Figure 3, water levels calculated by the model from 1991 through 2007 correlate well with the observed water levels from USGS monitoring wells located on the R9 Ranch.

BMcD utilized an iterative process to evaluate the maximum average pumping rate for the R9 Ranch. Multiple model runs were completed with the proposed municipal wells on the R9 Ranch operating at rates ranging from zero to 6,714 gpm. The water levels generated by the model were evaluated and a determination was made as to whether any changes in water levels were reasonable.

Intuitively, water levels rise as pumping rates decrease, and decline as pumping rates increase. When pumping is sustainable, water levels are reasonably stable. Figure 4 shows the change in water levels in comparison to pumping rates on the R9 Ranch for six of the iterative model runs. Water levels are dropping at higher pumping rates, rising at lower pumping rates, and are reasonably stable in the zone where the yield is sustainable. As can be seen in this figure, with 4,800 acre-feet of pumping, water levels are relatively stable with a drop of only 0.2 feet at the end of the 1991 to 2007 model runs. Based on the average saturated thickness of the aquifer under the R9 Ranch of 100 feet, this represents a reasonable change of less than 0.2 percent of the average available saturated thickness of the aquifer after 17 years.

BMcD ran numerous scenarios in the short-term model to evaluate the yield for the R9 Ranch for the period from 1991 through 2007. The two scenarios described below summarize the results of this preliminary evaluation of the short-term yield of the R9 Ranch:

1. **Short-Term Baseline Irrigation Scenario** – Used the existing model configuration with no changes. This scenario includes the irrigation and irrigation return wells associated with the historic R9 Ranch operations. (BGW utilized irrigation return wells in the initial model development to simulate the volume of water that infiltrates back into the aquifer

during irrigation operations. See the BGW Report for further description and explanation of how the return flows were calculated.)

2. **Short-Term Maximum Average Scenario** – The R9 Ranch irrigation and irrigation return wells were removed from the model. The 14 proposed municipal wells were inserted and assigned uniform pumping rates to extract a total of 4,800 acre-feet of water on a 24 hour per day, 365.25 day per year basis.

The scenario results are discussed below, and the mass balance is summarized in Table 1.

Scenario 1 – Short-Term Baseline Irrigation Scenario

For Scenario 1:

- Net pumping values on the R9 Ranch varied from a maximum of 6,322 acre-feet in 1991 to a minimum of 616 acre-feet in 1996. The net average pumped from the R9 Ranch during this period was 4,054 acre-feet per year.
- Annual recharge averaged 4,732 acre-feet.
- The Arkansas River was in a losing condition, contributing water to the aquifer.
- ET losses were approximately 1,100 acre-feet per year, on average.
- Approximately 1,350 acre-feet per year of groundwater flowed laterally off of the R9 Ranch.

Figure 5 shows the model-generated water levels at the end of the Scenario 1 model run, illustrating that groundwater flow is to the northeast. Based on this flow direction, there are very few groundwater wells down-gradient of the R9 Ranch, with the nearest approximately 1.5 miles away. The wells located closest to the R9 Ranch are located to the southeast, which is side-gradient to the direction of groundwater flow.

Scenario 2 – Short-Term Maximum Average Scenario

Scenario 2 was run with the R9 Ranch irrigation and irrigation return wells removed and the 14 proposed municipal wells pumping continuously. As can be seen in the inset image on Figure 1, some of the cells included in the R9 Ranch HSU extend beyond the R9 Ranch property boundary. Some of the center pivot circles from irrigation operations surrounding the R9 Ranch extend partially onto some of these cells. On average, approximately eight acre-feet of irrigation return flow per year is applied to those cells from the surrounding irrigator's operations. Since it is assumed that those irrigation operations will be ongoing, that irrigation return flow is included in the totals for the R9 Ranch HSU. This reduces the net average pumping from the R9 Ranch HSU to approximately 4,793 acre-feet per year.

Comparing the individual Scenario 2 net parameter results to those from Scenario 1:

- Net pumping increased by approximately 739 acre-feet per year, on average.
- Stream contribution was increased, most likely because of the increase in the volume of pumping and the constant rate of pumping as compared to the cyclical nature of irrigation pumping. Irrigation pumping is typically cyclical, with intermittent pumping at higher rates during the growing season.
- Recharge did not change.
- ET declined slightly, by 24 acre-feet per year most likely due to differences in the calculated water levels caused by continuous municipal pumping.
- Approximately 1,160 acre-feet per year of groundwater flowed laterally off of the R9 Ranch.

Figure 6 was created to more clearly illustrate and evaluate the effects of pumping 4,800 acre-feet per year from the R9 Ranch on the aquifer and surrounding users. For this figure, the water level contours at the end of the Scenario 1 were subtracted from the water level contours at the end of Scenario 2. As can be seen in Figure 6, pumping 4,800 acre-feet per year resulted in approximately 0.3 feet of additional drawdown at the northeastern R9 Ranch boundary after 17 years of pumping. A slight water level decrease such as this is expected, since Scenario 2 has a higher pumping rate than Scenario 1. Further examination of Figure 6 indicates that water levels in a few of the surrounding wells closest to the R9 Ranch would be approximately as much as 0.3 feet lower while the wellfield is operating at a constant rate of 4,800 acre-feet per year.

Short-Term Scenarios Summary

The 17-year period from 1991-2007 has the highest-quality data available for input to the model. For this reason, this period was utilized for the evaluation of the maximum average pumping rate of the R9 Ranch. Table 1 summarizes the net results of some key model parameters for Scenarios 1 and 2.

Table 1.
Short-Term Model Scenario Mass Balance Budget Summary

	Short-Term Model Run Scenarios	
Model Results **Net Average Model Mass Balance Parameters[1]**	**Scenario 1** **Baseline Irrigation**	**Scenario 2** **Maximum Average**
Pumping	-4054	-4793
Recharge	4732	4732
Evapotranspiration	-1098	-1074
Stream Leakance	1313	1766
Lateral Groundwater Flow	-1346	-1157
Change in Storage	465	553
Wells in Pumping Scenario	Irrigation & Return Wells	Proposed Municipal Wells

All units are acre-feet per year.
[1] Net flows are calculated as Inflow - Outflow, therefore negative values are flows out of the Ranch area, positive are flows into the Ranch area.

Long-Term Pumping Scenarios

To simulate the long-term effects of municipal pumping on the R9 Ranch, the 1991 through 2007 model data was used to develop a forecasting model representing a 51-year period (Long-Term model). The 1991 to 2007 data was duplicated twice, repeating the hydrologic conditions for those years in three 17-year cycles. Data from 1991 through 2007 was used for years 1 through 17, repeated for years 18 through 34, and again for years 35 through 51. The Long-Term model uses actual historic climatic and hydrologic conditions and provides a means to evaluate the long-term effects of pumping over a 51-year period.

Two changes were made to the hydrogeologic structure and parameters from the baseline model for the Long-Term model. Both changes were to the Arkansas River parameters; one to the projected streamflow, and the second to the streambed elevation. Those two changes are described in the following paragraphs.

Historic flow data in the Arkansas River compiled from the Dodge City and Kinsley gages reflect a significant decrease in streamflow after 2006. BMcD set the initial upstream flow in the Arkansas River to zero after year 16 in the Long-Term model to provide a conservative estimate and to recognize changing conditions resulting in reduced flows in the Arkansas River. Baseflow can still occur if the model calculated water level elevation in the aquifer rises high enough to cause the aquifer to discharge to the River. If that occurs, the streamflow routing package will calculate a discharge from the aquifer to the stream and generate baseflow for the River. However, the upstream baseflow contribution flowing into the model area that occurred historically is not contributing water to the model after year 16 of the Long-Term model.

The second change is to the riverbed elevation. As stated in the BGW Report, the modeled elevation of the Arkansas River was declining linearly each year. Down-cutting of a stream or river channel is caused by flow velocity eroding the bottom of the channel and carrying away fine-grained materials. Since flow in the stream channel during the period of the Long-Term model is significantly reduced, continued down-cutting is minimized, and the riverbed elevation was held constant.

BMcD ran the following scenarios to evaluate the long-term maximum average pumping rate at the R9 Ranch:

3. **Long-Term Baseline Irrigation Scenario** – All model hydrogeological parameters and pumping stresses simulated in the 1991 to 2007 model run were repeated three times. This scenario includes the historic R9 Ranch irrigation and associated irrigation return wells.

4. **Long-Term Maximum Average Scenario** – The R9 Ranch irrigation and associated irrigation return wells were removed from the model, and replaced with the 14 proposed municipal wells, which were inserted and assigned uniform pumping rates to extract 4,800 acre-feet of water on a 24 hour per day, 365.25 day per year basis.

5. **Long-Term Projected Operations Scenario** – The R9 Ranch irrigation and associated irrigation return wells were removed from the model, and replaced with the 14 proposed municipal wells, which were inserted and assigned pumping rates equal to the anticipated actual operations of the R9 Ranch as municipal supply wells. This includes phased installation of the municipal wells, cycling pumping between wells operating at the actual anticipated rates of operation, and increasing production over time based on the anticipated increases in demand.

Figure 7 illustrates the pumping and recharge conditions simulated in each of the Long-Term model scenarios listed above. The results of these three scenarios are discussed below and the mass balance results for key parameters from Scenarios 3 through 5 are summarized in Table 2.

Table 2.
Long-Term Model Scenario Mass Balance Budget Summary

	Long-Term Scenarios[2]			
Model Results **Net Model Mass Balance Parameters[1]**	**Scenario 3** **Baseline Irrigation**	**Scenario 4** **Maximum Average**	**Scenario 5** **Projected Operations**	**Scenario 6** **Projected Operations w/2% Drought**
Pumping	-4054	-4793	-2426	-2741
Recharge	4732	4732	4732	4390
Evapotranspiration	-646	-610	-488	-412
Stream Leakance	1579	1990	410	625
Lateral Groundwater Flow	-1909	-1670	-2506	-2206
Change in Storage	319	367	281	352
Wells in Pumping Scenario	Irrigation & Return Wells	Proposed Municipal Wells	Proposed Municipal Wells	Proposed Municipal Wells

All units are acre-feet per year.
[1] *Net flows are calculated as Inflow - Outflow, therefore negative values are flows out of the Ranch area, positive are flows into the Ranch area.*
[2] *1991-2007 data repeated three times. Assumes zero flow in Ark River after year 16.*

Scenario 3 – Long-Term Baseline Irrigation Scenario

The following describes the results of Scenario 3, and Figure 8 illustrates the model calculated water levels at the end of the scenario. Groundwater flow continues to be to the northeast.

- Net pumping values on the R9 Ranch varied from a maximum of 6,322 acre-feet to a minimum of 616 acre-feet. The net average volume pumped from the R9 Ranch during this period was 4,054 acre-feet per year.

- Annual average recharge to the R9 Ranch was 4,732 acre-feet.
- The aquifer was receiving water from the Arkansas River.
- ET losses were lower on average than the 1991 to 2007 baseline scenario, most likely due to reduced flows in the River.
- Approximately 1,900 acre-feet of water flowed laterally off of the R9 Ranch within the aquifer.

Scenario 4 – Long-Term Maximum Average Scenario

Scenario 4 was run with the R9 Ranch irrigation and irrigation return wells removed and the 14 proposed municipal wells pumping continuously throughout. An annual average of approximately eight acre-feet of irrigation return flow per year was included from surrounding irrigator's ongoing operations, making the net average pumping 4,793 acre-feet per year. Figure 7 presents the R9 Ranch municipal pumping modeled for this scenario.

Evaluating the individual parameters in comparison to Scenario 3:

- Higher pumping rates in this scenario reversed the gradient at the River, resulting in an average net gain to the aquifer from the River.
- Average annual recharge remained the same.
- Average ET was approximately equal to the baseline scenario.
- There was approximately 1,670 acre-feet per year of groundwater flow leaving the R9 Ranch laterally.

Comparison of the results of Scenario 4 and Scenario 3 illustrates the effect of pumping an average of 4,800 acre-feet per year from the R9 Ranch for 51 years. Figure 9 was created by subtracting the water level contours at the end of the Scenario 3 from the water level contours at the end of Scenario 4.

As illustrated in Figure 9, Scenario 4 pumping resulted in approximately 0.4 feet of additional drawdown at the R9 Ranch boundary in the northeast portion of the R9 Ranch at the end of 51-years. Approximately 0.8 feet of additional drawdown is seen at the southwestern border of the R9 Ranch during this same period. Drawdown contours extend across the River to the northwest because it is not a hydraulic boundary when there are periods of zero flow in the River.

The higher apparent impact to the southwestern portion of the R9 Ranch is due to the change from historic operations. Irrigation in the southwestern portion of the R9 Ranch was minimal during the period from 1991 to 2007, as most of the ranch farming operations had moved away from this area. Since there was very little to zero historic irrigation pumping in the southwest portion of the R9 Ranch, the drawdown effect appears higher with the introduction of new pumping.

Scenario 5 – Long-Term Projected Operations Scenario

Scenario 5 was developed to simulate the actual projected operation of the municipal wellfield on the R9 Ranch. The R9 Ranch irrigation and irrigation return wells were removed and the 14 proposed municipal wells inserted. The R9 Ranch is intended to be developed in a phased manner, rather than fully constructed and brought online all at once. Initial development is currently anticipated to begin in the northeast portion of the R9 Ranch, with later phases being developed moving to the southwest. A constant flow of approximately one million gallons per day will be required to maintain a minimum flow in the pipeline. For the operations scenario this flow was initially distributed among proposed Wells A through H. Pumping was increased in June, July and August of each year to reflect increased demand during the hot summer months. In later years, as demands increased, pumping rates were increased and additional wells (I through N) were added to deliver the required yield. Figure 7 illustrates the annual average pumping rates for this scenario.

An annual average of approximately eight acre-feet of irrigation return flow per year was included from surrounding irrigator's ongoing operations, making the net average pumping 2,426 acre-feet per year.

Evaluating the individual parameters from Scenario 5 in comparison to Scenarios 3 and 4:

- The average net pumping rates in this scenario are approximately 2,300 acre-feet per year lower.
- The aquifer was gaining approximately 410 acre-feet of water from the River channel.
- Annual average recharge did not change.
- Average ET loses were slightly higher than in Scenarios 3 and 4, due to higher water levels from lower pumping rates.
- There was approximately 2,500 acre-feet per year of groundwater flow laterally leaving the R9 Ranch.

Figure 10 was created by subtracting the water level contours at the end of Scenario 3 from the water level contours at the end of Scenario 5. Comparison of the drawdown at the end of Scenario 5 and Scenario 3 illustrates the differences between projected operations pumping from the R9 Ranch and irrigation pumping over the same time frame. As can be seen in Figure 10, operations pumping resulted in water levels over most of the R9 Ranch and surrounding area that were higher than the water levels caused by historical irrigation pumping. There was approximately 0.5 feet of water level rise on average at the R9 Ranch boundary to the north and east at the end of the 51-year period. The area between contours in Figure 10 are colored, with darker colors representing higher water levels, and lighter colors representing lower water levels.

Similar to the Scenario 4 results shown in Figure 9, drawdown at the southwest end of the R9 Ranch increased slightly. This higher drawdown is due to the lack of historic irrigation pumping in that area from 1991 to 2007.

Long-Term Drought Scenarios

At DWR's request, additional scenarios incorporating a two percent drought were run with the Long-Term model. Kansas regulations define a two percent drought as the equivalent of the 1952 to 1957 historical period. To simulate a two percent drought, the recharge and ET data from the original GMD5 model for 1952 through 1957 was extracted and inserted into the Long-Term model as years 35 through 39. This places the drought two-thirds of the way through the 51 year model run, when projected municipal demands have increased.

To establish a basis for comparison to the drought conditions, the Long-Term Baseline Irrigation Scenario (Scenario 3) was re-run utilizing the two percent drought recharge and ET data. This run calculated water levels for the Baseline Irrigation Scenario with the reduced recharge values from the simulated drought. Figure 11 was generated to illustrate the difference between the model-predicted baseline water level with and without the drought at the end of the Long-Term model run. As expected, adding the two percent drought conditions resulted in lower water levels throughout the area, and over five feet lower in the area east of the R9 Ranch.

Scenario 6 – Long-Term Operations with two percent Drought Scenario

Scenario 6 was developed to simulate the potential operation of the R9 Ranch during a two percent drought. Figure 12 illustrates the simulated recharge and the average pumping rate for this scenario.

For Scenario 6, the R9 Ranch irrigation and associated irrigation return wells were removed and replaced with the 14 proposed municipal wells. An annual average of approximately eight acre-feet of irrigation return flow per year was included from surrounding irrigator's ongoing operations, resulting in net average pumping of 2,741 acre-feet per year.

As seen in Figure 12, the operations pumping scheme from Scenario 5 was modified for Scenario 6 during the drought years (model years 35 through 39). Pumping begins with the same pattern as Scenario 5, but increases substantially once the drought begins. After the drought ends the pumping returns to the Scenario 5 pattern. This pumping scenario maximizes the amount pumped from the R9 Ranch during the drought without exceeding a ten-year rolling average of 4,800 acre-feet.

Table 2 summarizes the results calculated for Scenarios 3, 4, 5 and 6. An evaluation of the individual parameters calculated for Scenario 6 compared with those from Scenarios 3, 4 and 5 indicates:

- Average net pumping rates in this scenario are lower than Scenarios 3 and 4, but higher than Scenario 5.
- Stream leakance indicated a higher average net gain to the aquifer from the River than in Scenario 5, but lower than Scenarios 3 and 4.
- Average recharge dropped significantly during years 35 through 39, and by an average of approximately 340 acre-feet per year for the entire period of the model.
- Average ET losses were similar to Scenario 5 and slightly lower than Scenarios 3 and 4.
- An average of approximately 2,206 acre-feet of water per year of groundwater flowed laterally from the R9 Ranch.

Figure 13 was created by subtracting the model generated water levels from the baseline two percent drought run from the water levels generated from running Scenario 6 with R9 Ranch projected municipal drought operations pumping. Comparison of the water levels at the end of Scenario 6 with baseline R9 Ranch pumping under two percent drought conditions demonstrates the differences in the water level caused by operations pumping from the municipal wells during a two percent drought.

As can be seen in Figure 13, drought operations pumping resulted in water levels throughout most of the R9 Ranch and surrounding area that are higher than the water levels caused by historic irrigation pumping. There was approximately 0.4 feet of water level rise on average at the R9 Ranch boundary to the north and east at the end of the 51-year period. The area between contours in Figure 13 are colored, with darker colors representing higher water levels, and lighter colors representing lower water levels. Drawdown at the southwest end of the R9 Ranch is again slightly higher because historic irrigation pumping was minimal in that area from 1991 to 2007.

Summary and Conclusions

Table 3 summarizes the mass balance water budget results from all six scenarios discussed in this report. Comparison of the results from the various scenarios illustrates that the changes in the amount of water assigned to each of the key parameters in each of the modeled scenarios. This is due to the pumping influences and their effects on the flow from various contributing sources.

The Cities' intent in developing a municipal water supply wellfield on the R9 Ranch is to provide a long-term viable raw water resource for the future. Scenarios 3, 4, 5 and 6 were developed from the existing model to simulate the effects of the R9 Ranch pumping over a 51-year period. Evaluating the changes in water levels caused by changes in pumping through an iterative process resulted in Scenario 4, indicating that a sustainable, long-term pumping rate at the R9 Ranch is approximately 4,800 acre-feet per year.

The Long-Term model was run with the proposed municipal wells pumping 4,800 acre-feet per year. Evaluation of the water levels and results of the model mass balance at the end of this run supports a long-term average yield of 4,800 acre-feet. The calculated water levels fluctuate throughout the time period of the model, but overall changes in water level are minimal at approximately 0.5 feet. This is a change of approximately one-half of one percent of the average saturated thickness of the aquifer at the R9 Ranch.

Actual projected operations on the R9 Ranch after conversion to municipal use were modeled to illustrate the anticipated effects of the pumping on the R9 Ranch and surrounding area. Scenario 5 indicates that there will be an average reduction in pumping on the R9 Ranch as compared to the historical irrigation usage. The model calculated water levels indicate that this will result in an average increase in water levels throughout the area.

The R9 Ranch is also intended to provide additional drought tolerance for the City's water supply. Scenario 6 was included to evaluate how the R9 Ranch and surrounding area would react under simulated two percent drought conditions. The results of this scenario indicate that even in the event of a two percent drought, water levels would be higher throughout the area at the projected operational pumping rates than they would be if the historic irrigation pumping were continuing.

BURNS & McDONNELL

Based on the model results, 4,800 acre-feet per year is a reasonable value for the long-term maximum average yield of the R9 Ranch. Applied on a 10-year rolling average, extraction of this volume of water will not result in detrimental effects on the aquifer under the R9 Ranch and surrounding area. Operating the R9 Ranch in this manner will protect the resource and maintain it as a long-term viable raw water supply for the Cities future water supply.

Sincerely,
BURNS & MCDONNELL

Paul A. McCormick, P.E.
Associate Geological Engineer

PAUL A. McCORMICK LICENSED 13350 9/24/18 KANSAS PROFESSIONAL ENGINEER

cc: Jon Quinday – City of Russell
John T. Bird – Glassman, Bird, Brown & Powell
David Traster – Foulston Siefkin
Daniel Buller – Foulston Siefkin

Table 3
Sustainable Yield Calculation Summary

	Short-Term Model Run Scenarios		Long-Term Scenarios[2]			
Model Results **Average Net Model Mass Balance Parameters[1]**	**Scenario 1** **Baseline Irrigation**	**Scenario 2** **Maximum Average**	**Scenario 3** **Baseline Irrigation**	**Scenario 4** **Maximum Average**	**Scenario 5** **Projected Operations**	**Scenario 6** **Projected Operations w/2% Drought**
Pumping	-4054	-4793	-4054	-4793	-2426	-2741
Recharge	4732	4732	4732	4732	4732	4390
Evapotranspiration	-1098	-1074	-646	-610	-488	-412
Stream Leakance	1313	1766	1579	1990	410	625
Lateral Groundwater Flow	-1346	-1157	-1909	-1670	-2506	-2206
Change in Storage	465	553	319	367	281	352
Wells in Pumping Scenario	Irrigation & Return Wells	Proposed Municipal Wells	Irrigation & Return Wells	Proposed Municipal Wells	Proposed Municipal Wells	Proposed Municipal Wells

All units are acre-feet per year.

[1] *Net flows are calculated as Inflow - Outflow, therefore negative values are flows out of the Ranch area, positive are flows into the Ranch area.*

[2] *1991-2007 data repeated three times. Assumes zero flow in Ark River after year 16.*

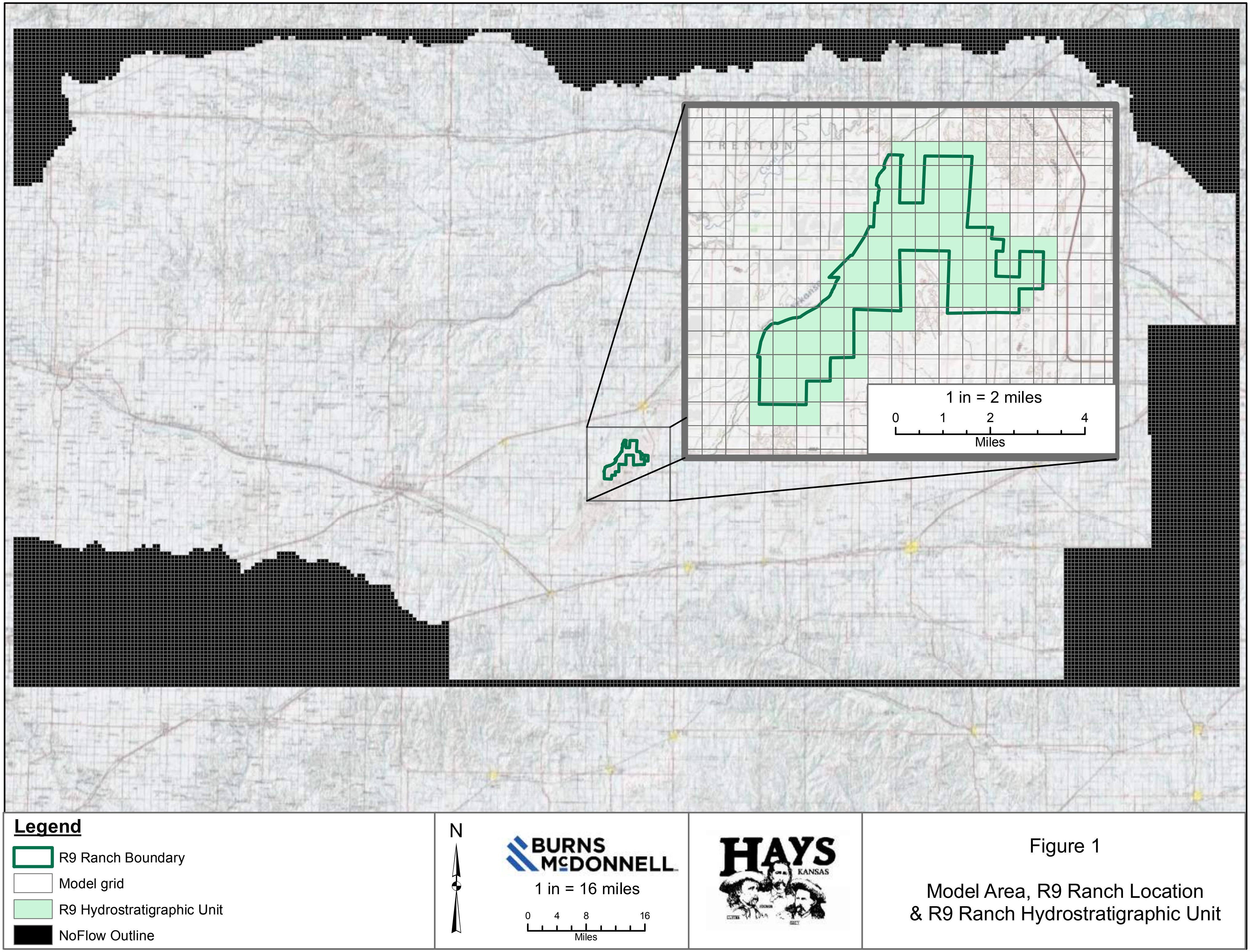
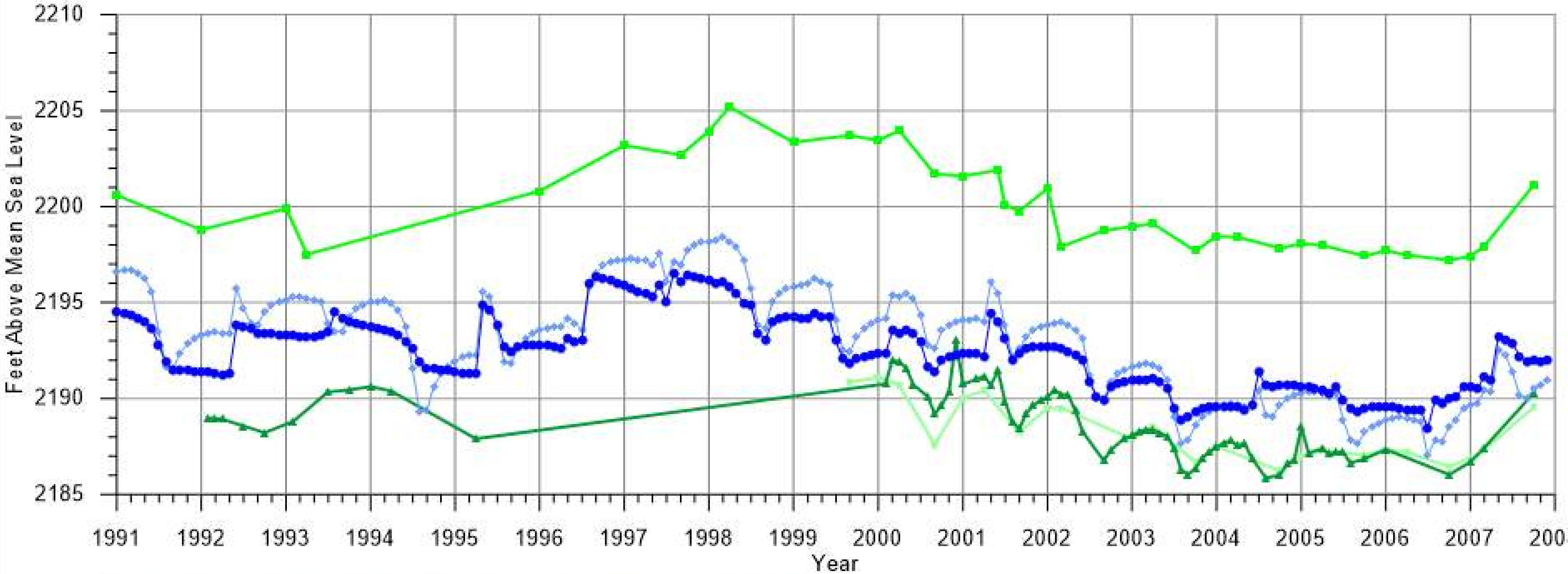
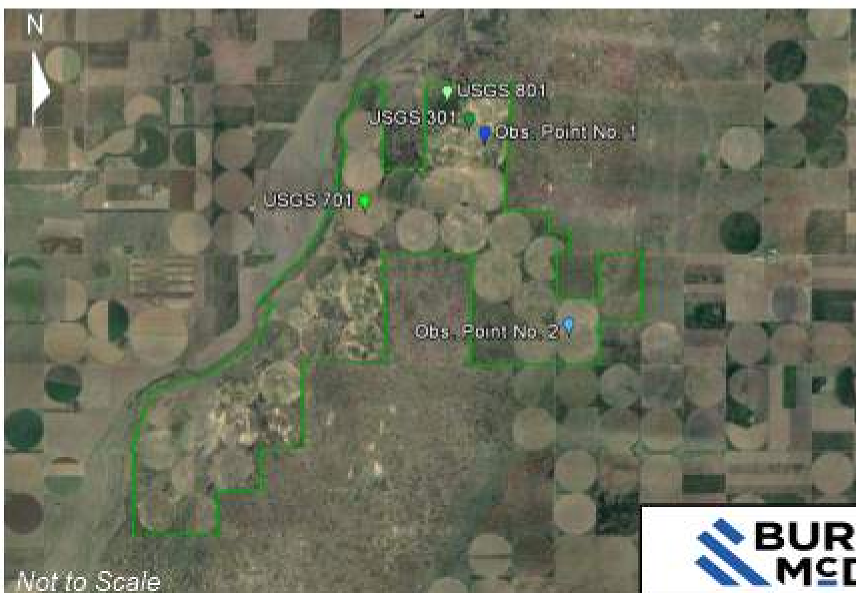


Figure 1

Model Area, R9 Ranch Location & R9 Ranch Hydrostratigraphic Unit





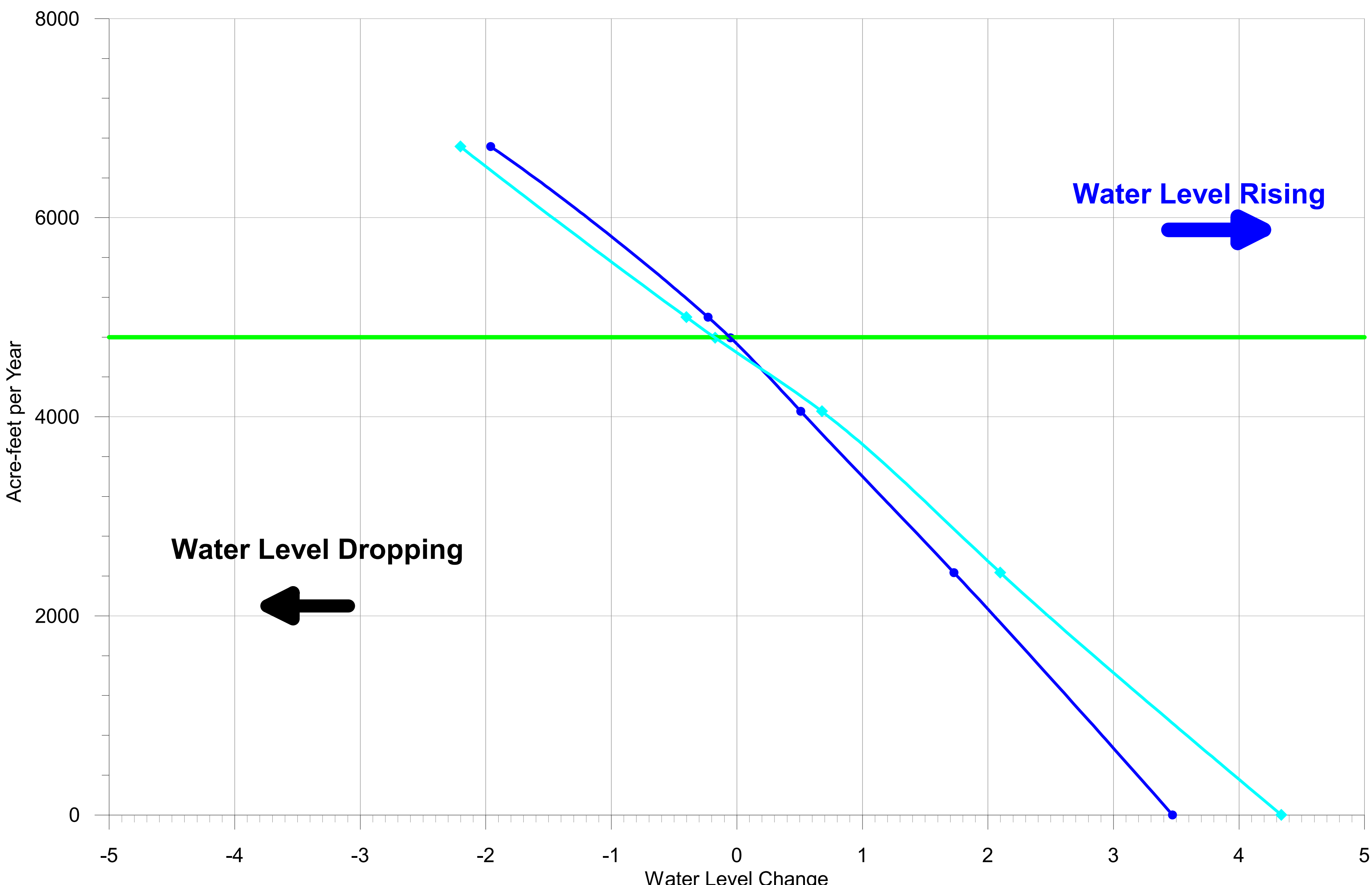
BURNS McDONNELL

Project No. 91211

File Name: Water Levels GMD5 Model.grf

Figure 3

Observed and Modeled Water Levels on the R9 Ranch



Legend

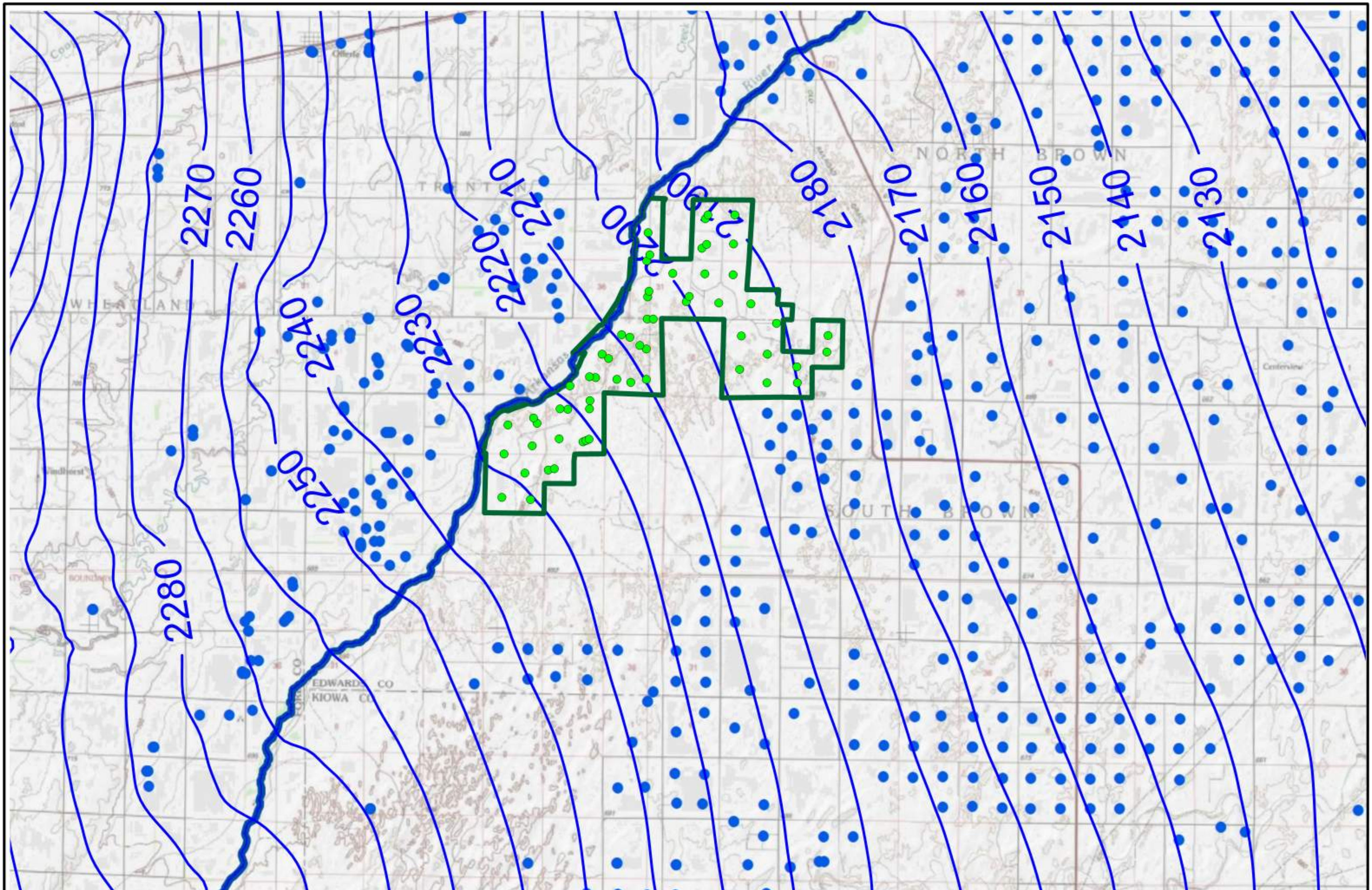
- Observation Point No. 1
- Observation Point No. 2
- 4800 Acre-feet per year

BURNS McDONNELL

Project No. 91211

File Name: Fig 04 - Sus Yield Regression.grf

Figure 4
Sustainable Pumping Range
with Reasonable Water Level Change
1991 - 2007 Simulation



Legend

- Water Level Contour
- R9 Ranch Boundary
- Historic R9 Irrigation Well
- Surrounding Irrigation Well

N

BURNS McDONNELL

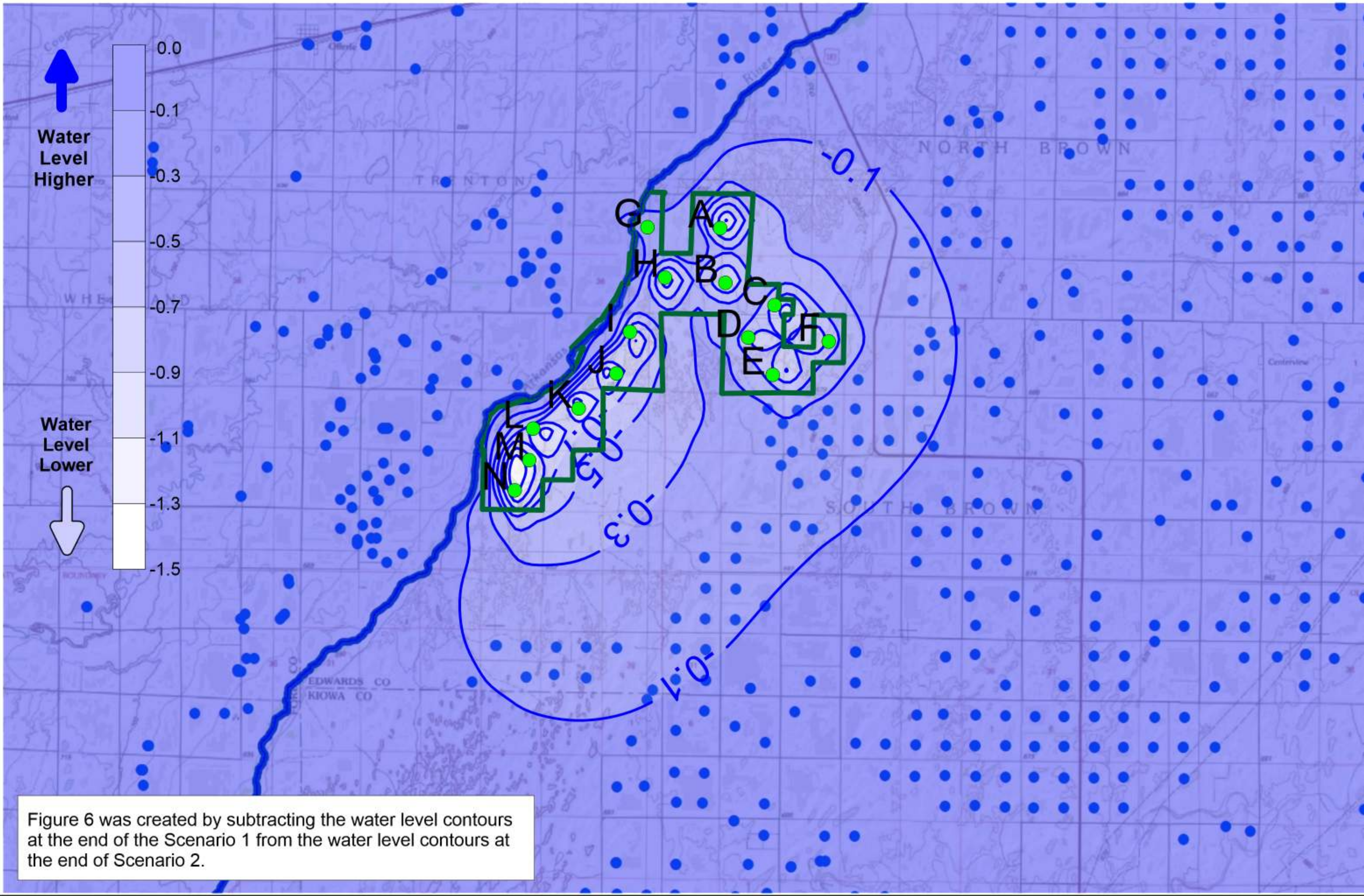
0 3,000 6,000 12,000
Feet

1 inch = 2 miles

HAYS KANSAS

Figure 5

Model Generated Water Levels
Scenario 1 - Historic Irrigation Pumping
1991 - 2007 Simulation



Legend

- Water Level Contour
- R9 Ranch Boundary
- Proposed Municipal Well
- Surrounding Irrigation Well

N

BURNS McDONNELL

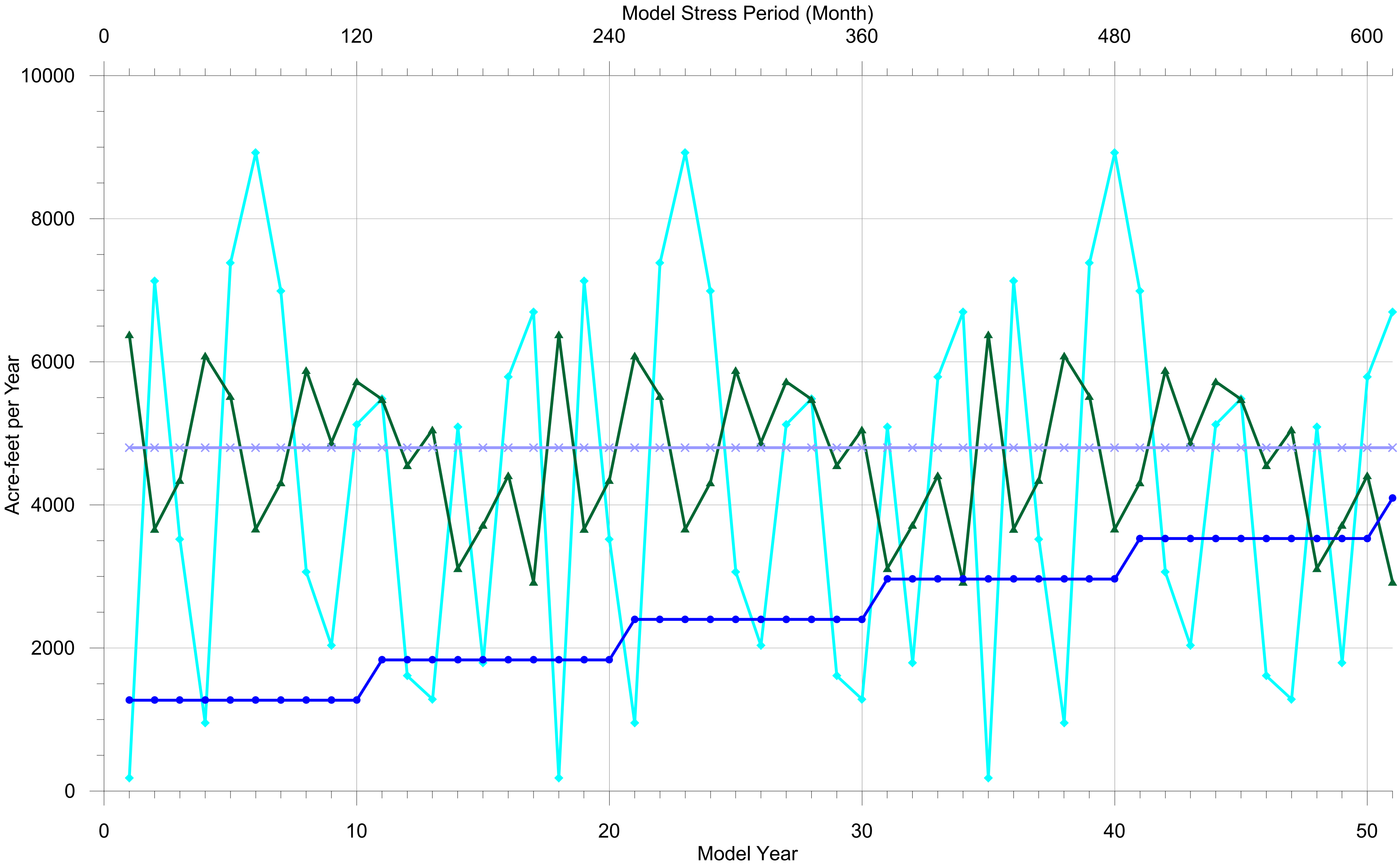
0 3,000 6,000 12,000
Feet

1 inch = 2 miles

HAYS KANSAS

Figure 6

Model Generated Difference in Water Levels
Scenario 2 - Historic Irrigation Pumping vs.
Proposed Municipal Wells Pumping 4800 AF/Year
1991 - 2007 Simulation



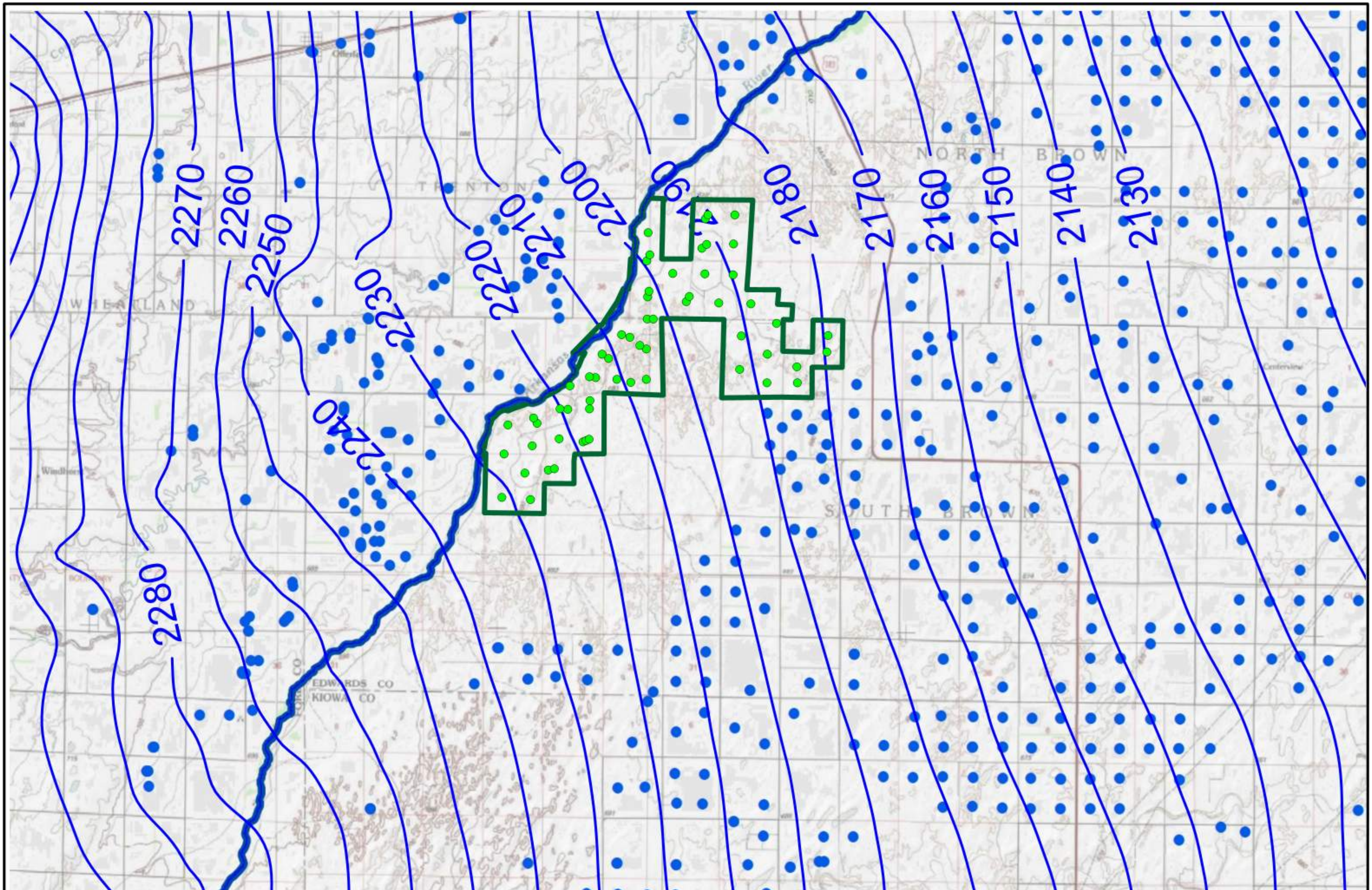
Legend

- Scenario 3 - Modeled Baseline 51-Year Pumping
- Scenario 4 - Modeled 51-Year Projected Sustainable Pumping
- Scenario 5 - Average Annual 51-Year Operations Pumping
- Scenarios 3, 4, & 5 - Modeled Recharge

BURNS McDONNELL

Project No.	File Name:
91211	Fig 7 - 51 yr Pumping.grf

Figure 7
Simulated Recharge & Pumping
Scenarios 3, 4, and 5
51-Year Simulation



Legend

- Water Level Contour
- R9 Ranch Boundary
- Historic R9 Irrigation Well
- Surrounding Irrigation Well

N

BURNS McDONNELL

0 3,000 6,000 12,000
Feet

1 inch = 2 miles

HAYS KANSAS

Figure 8

Model Generated Water Levels
Scenario 3 - Baseline with
Historic Irrigation Well Pumping
51-Year Simulation

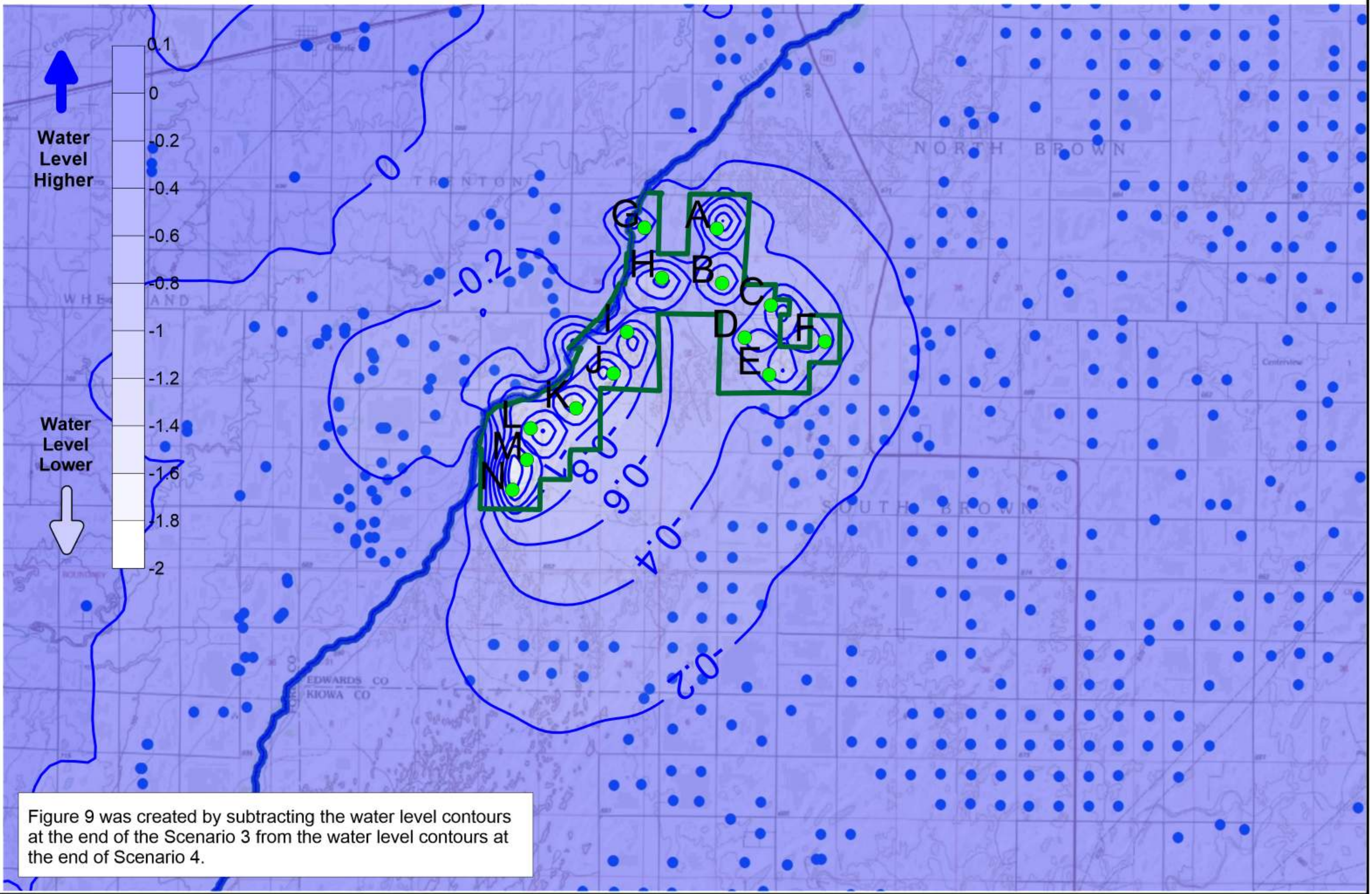


Figure 9 was created by subtracting the water level contours at the end of the Scenario 3 from the water level contours at the end of Scenario 4.

Legend

- Water Level Contour
- R9 Ranch Boundary
- Proposed Municipal Well
- Surrounding Irrigation Well

N

BURNS McDONNELL

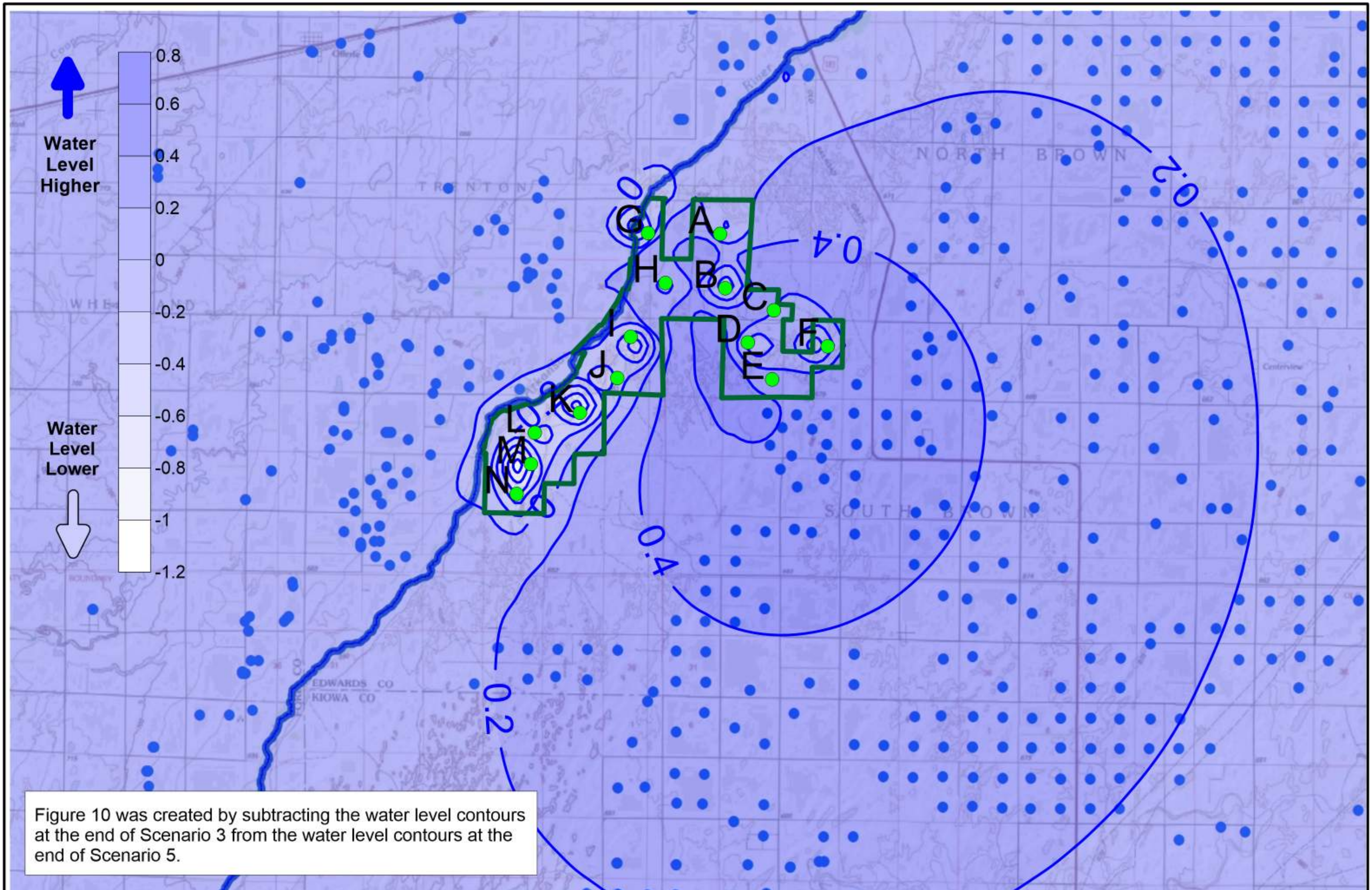
0 3,000 6,000 12,000
Feet

1 inch = 2 miles

HAYS KANSAS

Figure 9

Model Generated Difference in Water Levels
Scenario 4 - Historic Irrigation Pumping vs.
Proposed Municipal Wells Pumping 4800 AF/Year
51-Year Simulation



Legend

- Water Level Contour
- R9 Ranch Boundary
- Proposed Municipal Well
- Surrounding Irrigation Well

N

BURNS McDONNELL

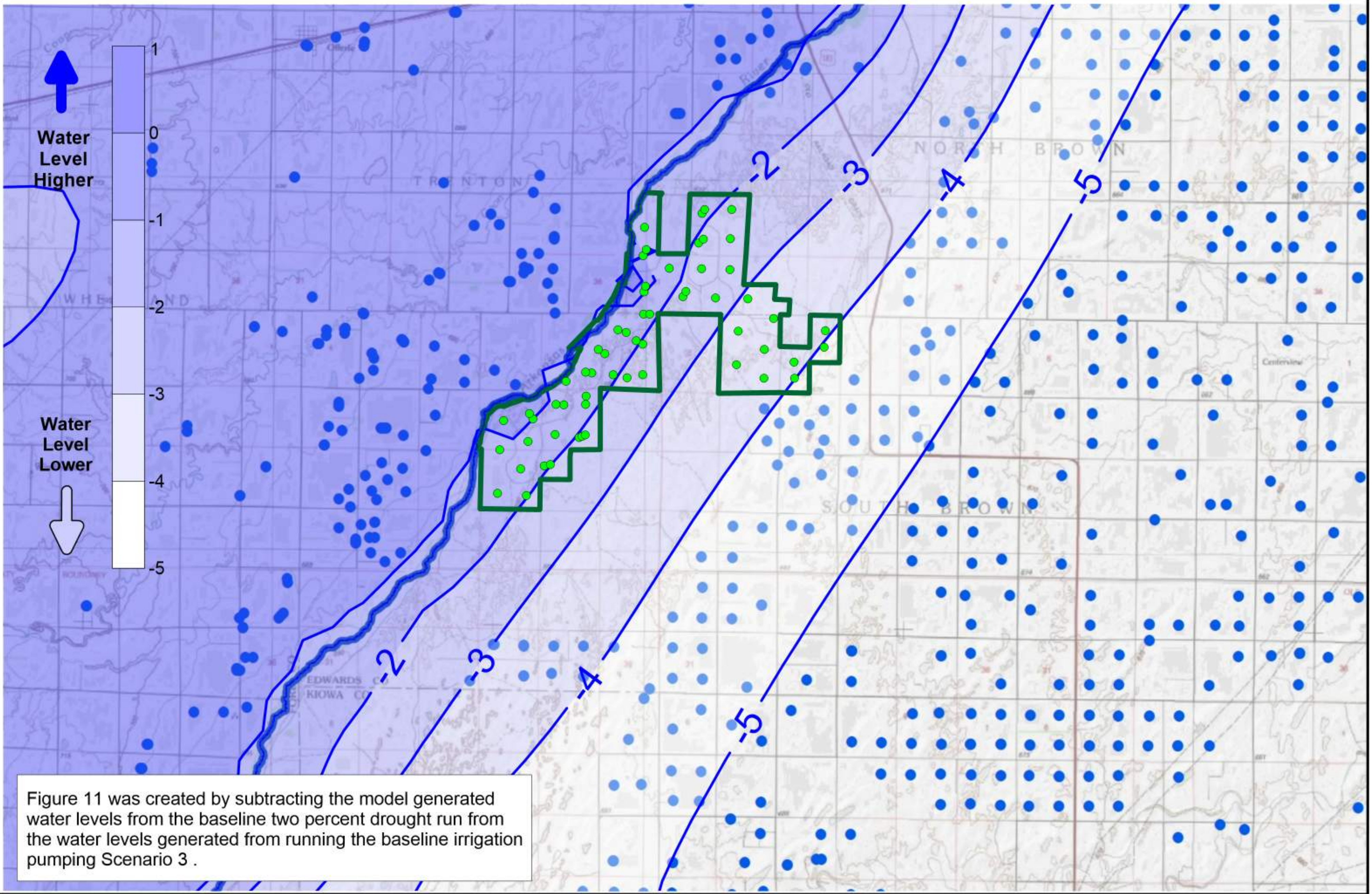
0 3,000 6,000 12,000 Feet

1 inch = 2 miles

HAYS KANSAS

Figure 10

Model Generated Water Level Difference
Scenario 5 - Historic Irrigation Pumping vs
Proposed Municipal Well Operations Pumping
51-Year Simulation



Legend

- Water Level Contour
- R9 Ranch Boundary
- Historic R9 Irrigation Well
- Surrounding Irrigation Well

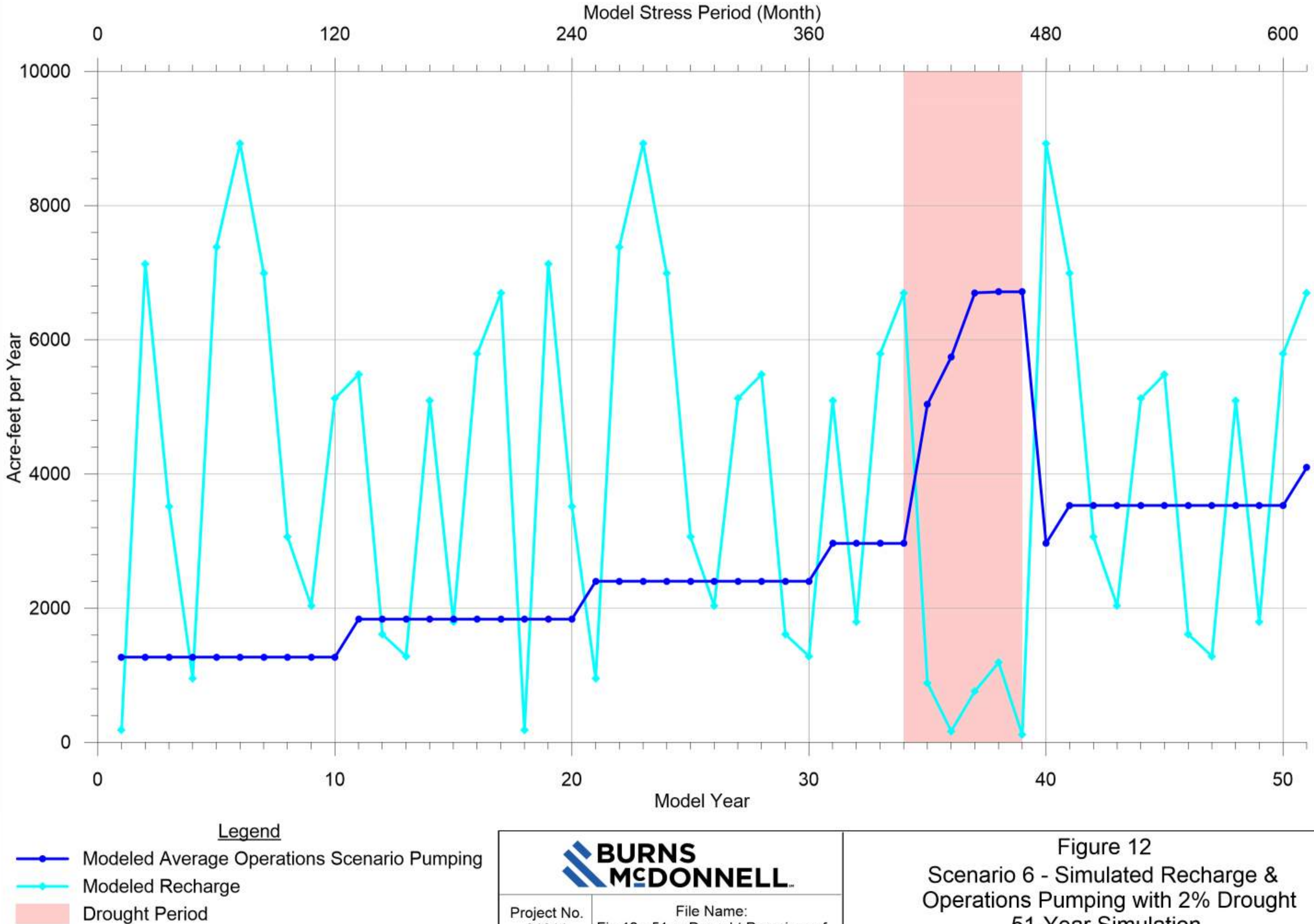
N

0 3,000 6,000 12,000
Feet

1 inch = 2 miles

Figure 11

Model Generated Water Level Difference
Baseline Historic Irrigation Pumping vs
Historic Irrigation Pumping During 2% Drought
51-Year Simulation



BURNS McDONNELL

Project No. 91211	File Name: Fig 12 - 51 yr Drought Pumping.grf

Figure 12
Scenario 6 - Simulated Recharge & Operations Pumping with 2% Drought
51-Year Simulation

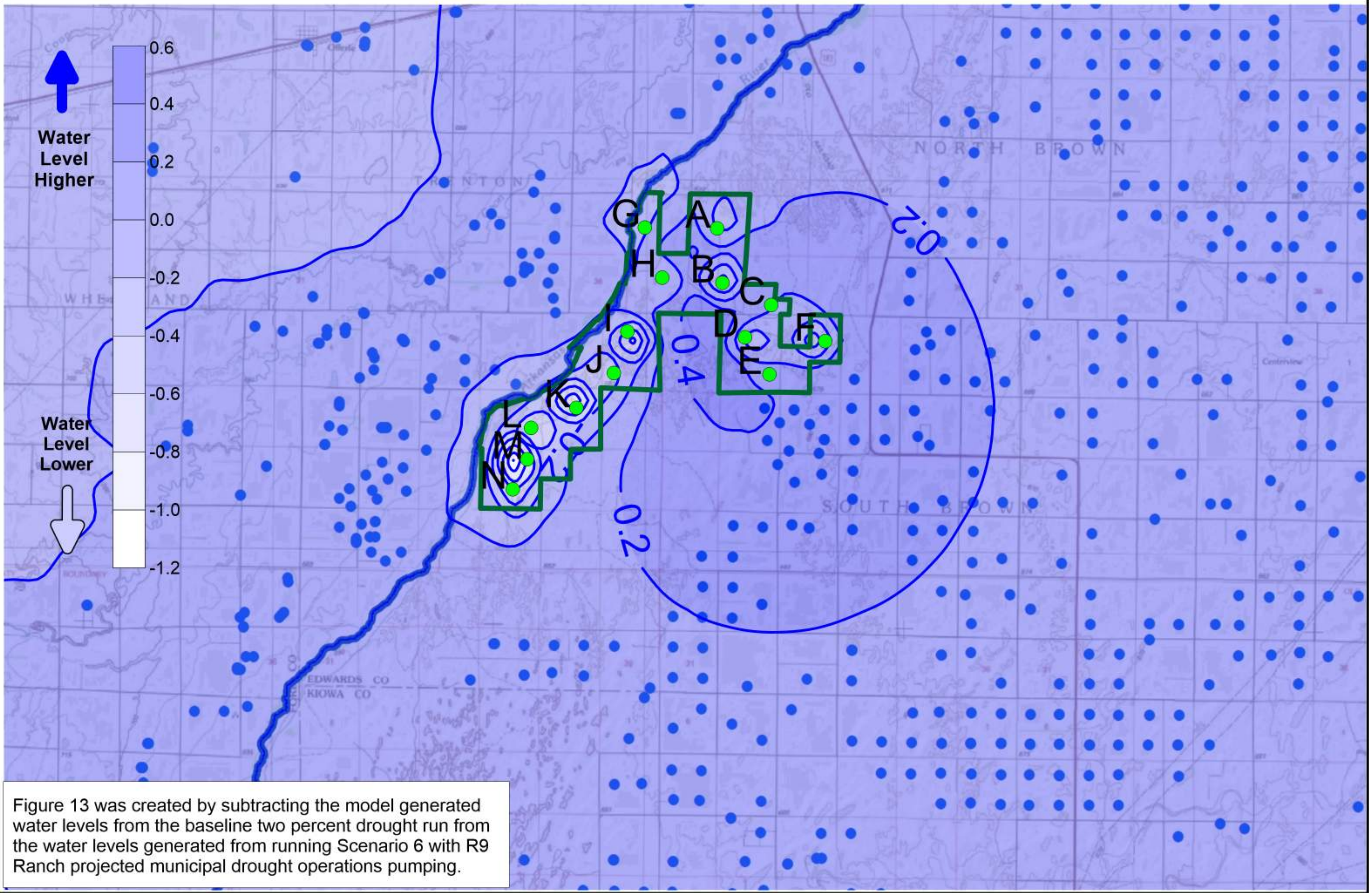


Figure 13 was created by subtracting the model generated water levels from the baseline two percent drought run from the water levels generated from running Scenario 6 with R9 Ranch projected municipal drought operations pumping.

Legend

- Water Level Contour
- R9 Ranch Boundary
- Proposed Municipal Well
- Surrounding Irrigation Well

N

BURNS McDONNELL

0 3,000 6,000 12,000
Feet

1 inch = 2 miles

HAYS KANSAS

Figure 13

Model Generated Water Level Difference
Scenario 6 - Historic Irrigation Pumping vs
Proposed Municipal 2% Drought Operations Pumping
51-Year Simulation