BEFORE THE OFFICE OF ADMINISTRATIVE HEARINGS

STATE OF KANSAS

IN THE MATTER OF

THE APPLICATION OF THE CITIES OF HAYS, KANSAS AND RUSSELL, KANSAS FOR APPROVAL TO TRANSFER WATER FROM EDWARDS COUNTY, KANSAS PURSUANT TO THE KANSAS WATER TRANSFER ACT.	)))))))	**OAH NO. 23AG0003 AG**

Pursuant to K.S.A. Chapter 77.

DIRECT TESTIMONY OF PAUL McCORMICK, P.E., SENIOR ASSOCIATE GEOLOGICAL ENGINEER, BURNS & McDONNELL ENGINEERING COMPANY, INC.

ON BEHALF OF

THE CITIES OF HAYS AND RUSSELL, KANSAS

RELATING TO

R9 RANCH MODELING RESULTS SUMMARY

Q. Please state your name and present position.

A. My name is Paul McCormick, P.E. I am a Senior Associate Geological Engineer with Burns & McDonnell Engineering Company, Inc., an international design and consulting engineering firm based in Kansas City, Missouri.

Q. On whose behalf are you submitting testimony?

A. The City of Hays, Kansas and the City of Russell, Kansas (the "Cities").

Q. Please describe your educational background and employment experience.

A. I have a Bachelor of Science degree in Geological Engineering from Missouri University of Science & Technology, and am a licensed Professional Engineer in Kansas, Missouri, Iowa, Nebraska, and South Dakota. I have worked in the groundwater industry for 29 years providing design and consulting services for clients regarding hydrogeology, groundwater modeling, and water well and wellfield design for water supply purposes. My CV is attached as Exhibit PM-03 and incorporated as if set forth in full in this document.

Q. Has this direct testimony been prepared by you or under your direct supervision?

A. Yes, it has.

Q. Have you previously testified before the Kansas Department of Agriculture–Division of Water Resources or any other regulatory commission?

A. I have testified before the KDA-DWR a single time on behalf of the City of Wichita in Case No. 18 WATER 14014.

Q. Have you testified in any litigation in the prior four years?

A. No, I have not.

Q. Are you sponsoring any exhibits with your direct testimony?

A. Yes. In addition to PM-03, I Sponsor Exhibit PM-04, which is my expert report titled "R9 Ranch Modeling Results," and which is incorporated into my testimony as if set forth in full.

Q. What is the purpose of your direct testimony?

A. My opinions are set forth in more detail in my expert report, but in general, my testimony on this topic relates to evaluating long-term changes in groundwater conditions at the R9 Ranch in the event that the Cities' Change and Transfer Applications are approved and the Cities utilize the R9 Ranch as a municipal water source through use of the MODFLOW™ three-dimensional groundwater flow model developed by Balleau Groundwater, Inc. (the "BGW Model") for Big Bend Groundwater Management District No. 5.

Q. In summary, what did you conclude?

A. Highly summarized, the conclusions of my modeling work are:

- The R9 Ranch can sustainably support 4,800 acre-feet per year (AF/y) of groundwater withdrawal.
- For the period of 1991 to 2007, the BGW Model was used to generate water levels for the documented irrigation well pumping averaging 4,054 AF/y and the proposed municipal wells averaging 4,800 AF/y. Comparison of the model generated groundwater levels indicates that the municipal pumping results in an average additional 3.6 inches (0.3 feet) of water level decline at the R9 Ranch boundary over a 17-year period.
- For a 51-year period, the model-generated water levels were compared for the documented irrigation well pumping (averaging 4,054 AF/y) and the proposed municipal wells (averaging 4,800 AF/y). Comparison of the model-generated groundwater levels for these two model runs indicates that the municipal pumping results in an average

additional 7.2 inches (0.6 feet) of water level decline at the R9 Ranch boundary over the 51-year period.

- For a 51-year period, the model was used to generate groundwater levels for the documented irrigation well pumping (averaging 4,054 AF/y) and the Cities' actual planned groundwater usage based on phased construction of the infrastructure and operation of the municipal wellfield. Comparison of the model-generated groundwater levels from these two model runs indicates that groundwater levels will ***rise*** approximately 6 inches (0.5 feet) on average at the boundary of the R9 Ranch over the 51-year period.
- For a 51-year period, the model was used to generate groundwater levels for the documented irrigation well pumping (averaging 4,054 AF/y) and the Cities' actual planned groundwater usage based on phased construction of the infrastructure and operation of the municipal wellfield, with the addition of a drought comparable to the 1950s drought (considered to be the "drought of record" for Kansas). Comparison of the model-generated groundwater levels from these two model runs indicates that groundwater levels will ***rise*** approximately 4.8 inches (0.4 feet) on average at the boundary of the R9 Ranch over the 51-year period.
- DWR Regulations adopted at the behest of Big Bend Groundwater Management District No. 5 define "sustainable yield" as "the long-term yield of the source of supply, including hydraulically connected surface water or groundwater, allowing for the reasonable raising and lowering of the water table." K.A.R. 5-25-1(l). It was determined in consultation with the Chief Engineer that the increases and decreases described above were "reasonable",

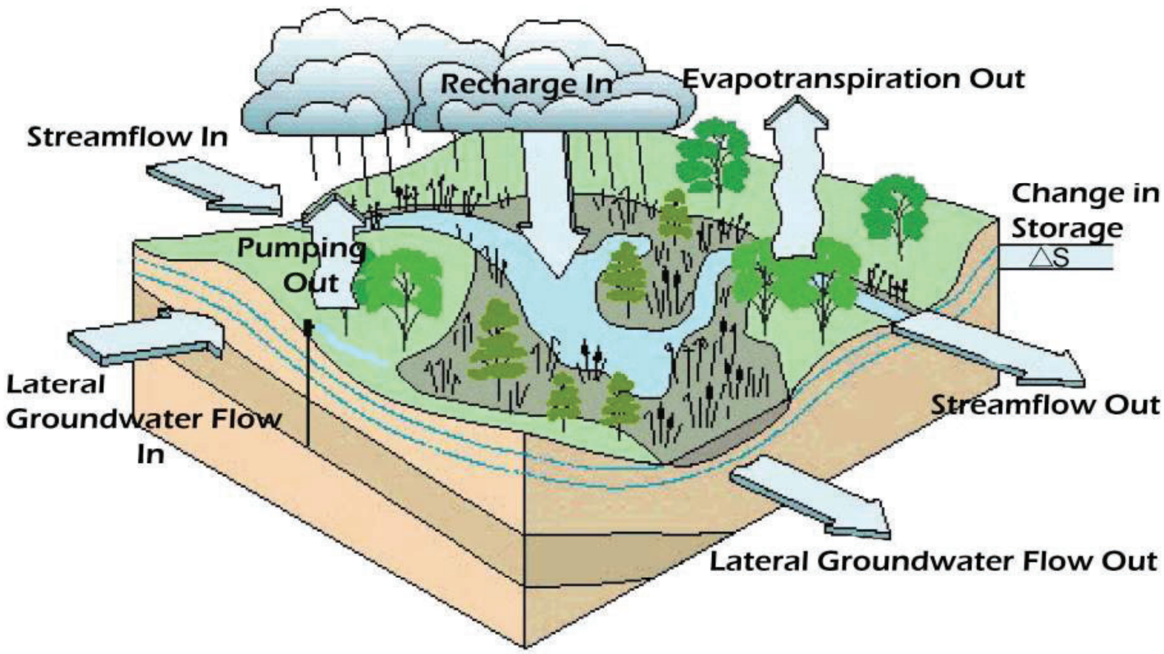
as those fluctuations are less than one percent of the average saturated thickness of the aquifer on the Ranch. *See*, *e.g.*, Master Order, ¶¶ 159-170.

Q. Please describe how you arrived at your conclusions.

A. As explained in more detail in my expert report, I quantified the long-term yield of the R9 Ranch as a municipal water source by utilizing the BGW Model to construct a conceptual representation of the physical groundwater system, including aquifer dimensions, hydraulic characteristics, and the recharge and discharge processes within the groundwater system at the R9 Ranch. The BGW Model applies mathematical processes to simulate and quantify the movement of groundwater through the aquifer system. The BGW Model was specifically designed "to address Big Bend Groundwater Management District No. 5 management questions regarding impacts of alternative actions on future hydrologic conditions, and to project future conditions in the aquifer and interrelated streams," so utilizing it to estimate the long-term sustainable yield of the R9 Ranch fits squarely within the purposes for which it was originally developed.

The Cities intend to operate the R9 Ranch well field in a sustainable manner for the long-term. Multiple pumping scenarios were run using the BGW Model to evaluate the amount of water the aquifer on the R9 Ranch would yield while allowing for reasonable water level fluctuations. Evaluation of these effects was accomplished by comparing the water levels generated by the DWR documented irrigation pumping that occurred from 1991 to 2007 with the proposed municipal pumping activities under varying time frames, operating scenarios, and hydrologic conditions.

Exhibit PM-04, Figure 3-2 is a graphical representation of a hypothetical groundwater system and illustrates the various flows that make up the water balance. Certain flows, such as recharge, are always positive and adding water to the system. Other flows, such as well pumping and evapotranspiration are always negative and removing water from the system. Flows from streams, lateral flow through the aquifer, and changes in storage within the aquifer can be either positive or negative, depending on the circumstances.



MODFLOW calculates the volume of water flowing into and out of each cell of a model for each of these parameters. To simplify the evaluation of this parameter data, net values for each parameter are calculated using the formula inflow minus outflow. The water budget parameters included in the BGW Model are recharge, evapotranspiration, well pumping, lateral groundwater flow, streamflow, and storage, all of which are described in detail in my expert report.

I used Groundwater Vistas Version 6.0 (GWV) pre- and post-processing software to run the BGW Model. First, I verified that the BGW Model was correctly imported and configured within GWV by a direct comparison of the GWV output files to the output files from the BGW Report and BGW Model output files, which correlated well, with a variance of less than 1.49% on average—well within the margin of error described in the BGW Report. I also confirmed that the model was accurately simulating real-world water levels by comparing the model-calculated water levels with observed water levels from USGS monitoring wells located on the R9 Ranch, which correlated well, indicating that the BGW Model was accurately simulating water levels on the R9 Ranch.

After confirming that the model was properly configured, I ran a series of short-term (17-year) and long-term (51-year) simulations to evaluate the impacts to the aquifer and sustainable yield of the Cities' use of the R9 Ranch as a municipal water source.

- ***Scenario 1 – Short-Term Baseline Irrigation***. Scenario 1 is a baseline output for the R9 Ranch to show the modeled impacts of using the R9 Ranch under the same irrigation conditions that were present from 1991 to 2007, which are the final 17 years of the model's time span.
- ***Scenario 2 – Short-Term Maximum Average***. Scenario 2 evaluates the impacts of operating the 14 proposed municipal wells so that they extract a volume of 4,800 AF/y continuously for 17 years, which is the maximum average quantity authorized for municipal use by the Master Order in the Change proceeding. This scenario was run using the 1991 to 2007 Model with the framework and inputs provided by BGW. The only change made to the 1991 to 2007 Model for Scenario 2 was the R9 Ranch irrigation wells (and the associated return flow) were removed and replaced by the 14 proposed municipal wells, which were set to pump continuously at uniform rates to extract a total volume of 4,800 AF/y.
- ***Scenario 3 – Long-Term Baseline Irrigation***. Scenario 3 estimates the water levels that would exist if the documented irrigation pumping that occurred from 1991 to 2007 continued on the R9 Ranch for 51 years and provides a baseline for comparison with predicted water levels associated with long-term municipal use under the scenarios addressed in my expert report.

- ***Scenario 4 – Long-Term Maximum Average***. Scenario 4 calculates the predicted impacts to the groundwater system on the R9 Ranch if the 14 proposed municipal wells were operated to extract the full volume of 4,800 AF/y for the 51-year period.
- ***Scenario 5 – Long-Term Projected Operations***. Scenario 5 calculates the predicted impacts to the groundwater system on the R9 Ranch if the 14 proposed municipal wells were operated in the manner actually anticipated to meet the Cities' predicted demand for the 51-year period. The proposed operations assign the 14 municipal wells pumping quantities 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 operational quantities, and increasing production over time based on anticipated increases in demand.
- ***Scenario 6 – Long-Term Operations with Two Percent Drought***. Scenario 6 was developed to simulate the potential effects of municipal water use from the R9 Ranch during a two percent drought if the 14 proposed municipal wells were operated in the manner actually anticipated to meet the Cities' predicted demand for the 51-year period. During the drought years, pumping is increased to reflect a higher reliance on the R9 Ranch wellfield to supply water due to the loss of the less drought-resilient Smoky Hill Wellfield and Big Creek sources (the Cities' existing water sources). 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.

Q. Does that conclude your direct testimony?

A. Yes, it does.

VERIFICATION

STATE OF Missouri)
)
COUNTY OF Jackson)

I Paul A. McCormick, being duly sworn, on oath state that I have read the foregoing and know the contents thereof, and that the facts set forth therein are true and correct to the best of my knowledge and belief.

PAUL A. McCORMICK
LICENSED
16559
5/26/23
KANSAS
PROFESSIONAL ENGINEER

By: [signature]
Paul A. McCormick, P.E.

The foregoing was subscribed and sworn to before me this 26 day of May, 2023.

[signature]
Notary Public

My Commission Expires:

3-14-24

ANGIE YELTON
NOTARY PUBLIC-NOTARY SEAL
STATE OF MISSOURI
JACKSON COUNTY
MY COMMISSION EXPIRES 3/14/2024
COMMISSION # 12381302

PAUL A. MCCORMICK, PE

Senior Associate Geological Engineer

Paul has more than 29 years of experience involving all aspects of hydrogeologic investigations and well design for water supply purposes. His leadership, project management and technical capabilities are a significant factor in the success of projects.

Paul has extensive experience in hydrogeologic investigations, water supply studies and numerical groundwater modeling. He has designed and overseen construction of multiple wells and wellfields throughout the world for municipal, industrial, and private concerns. His work includes providing technical expertise and guidance to develop well fields ranging in size from 2.0 to 125 MGD utilizing vertical well, radial collector well, and aquifer storage and recovery technologies. He has developed and utilized groundwater models for evaluation of groundwater flow, mass-transport in groundwater systems, contaminant migration, and remediation of groundwater contamination in varying hydrogeological environments. Paul has authored and co-authored presentations on the various hydrogeological subjects and served as an expert witness regarding groundwater issues and modeling.

EDUCATION

- BS, Geological Engineering

REGISTRATIONS

- Professional Engineer: (MO, KS, IA, SD, NE)

16 YEARS WITH BURNS & MCDONNELL

29 YEARS OF EXPERIENCE

SPECIFIC PROJECT EXPERIENCE

McPherson BPU, Kansas, New Well Field and Groundwater Model

McPherson, Kansas | 2016

Due to declining water levels within their existing well field, BPU required the development of a supplemental source of supply in order to meet projected future water use. Burns and McDonnell provided planning and evaluation for the development of an alternate water supply source for the McPherson BPU. Sources evaluated included both surface water and groundwater. The project includes preliminary design of the well field, approximately 20 miles of raw water pipeline and a new water treatment facility. Groundwater modeling and new water right applications are included in the project. Paul assisted in the development of a groundwater and solute transport model that simulated the impact of a new well on water levels in the aquifer and also evaluated the fate and transport of a chloride plume that is located several miles from the new well field property. The model was also used to support the water right applications needed for the new well field. The model was reviewed by the Kansas Division of Water Resources and the Groundwater Management District No.2.

Water Supply Development, City of Clinton

Clinton, Oklahoma, 2015

Paul is the senior hydrogeologist and engineer for the development of a groundwater supply for the City of Clinton. The City's surface water sources are drying up due to prolonged drought, and a groundwater supply is being developed to replace them. The project includes a minimum of five alluvial wells, raw water distribution, and a 4.0 MGD reverse osmosis treatment plant. Paul is the lead hydrogeologist for the design and construction of the water supply wells and the deep injection well for RO reject disposal. This deep injection well will be the first well in the state of Oklahoma specifically permitted for injection of non-hazardous municipal waste.

EXHIBIT
PM-03

PAUL A. MCCORMICK, PE

(continued)

Collector Well Preliminary Design, Florida Power & Light

Miami, Florida, 2013

To satisfy the increasing power demand in the area, FPL is undertaking the addition of two additional nuclear reactor units to a generating station. A backup cooling water supply is required, and in this location will be provided through the construction of collector wells. Paul was the lead hydrogeologist and groundwater flow modeler developing the design for the collector wells and well field. This required conducting extensive groundwater modeling to evaluate the aquifer response and yield in a challenging geologic environment. Regulatory requirements for permitting the wells were stringent, with oversight from numerous federal and state agencies including the Nuclear Regulating Commission, Fish and Wildlife Administration, Environmental Protection Agency, and numerous interested public entities. Through his modeling efforts Paul was able to optimize the collector well design and reduce the required number of wells from four down to two. This design minimized the costs to FPL, while meeting the very strict regulatory requirements. At 62.5 million gallons per day each, these will be the largest collector wells in the world, as well as the first collector wells constructed in a hard rock environment.

Collector Well Siting Study, Ameren UE

Near Mokane, Missouri, 2008

Paul was a project engineer for a hydrogeologic investigation that was completed to determine the suitability of the Missouri River alluvial aquifer as a groundwater source for a nuclear power plant's required capacity of 50,000 gallons per minute. The hydrogeologic investigation was designed to evaluate the aquifer and determine suitability and locations for appropriate sites for construction of horizontal collector wells.

City of Hays, Kansas, Water Supply Management

Hays, Kansas | 2012 - Present

City of Hays maintains three well fields for raw water supply, the Big Creek alluvial well field, the Smoky Hill River alluvial well field, and the Dakota bedrock well field. The vulnerability of these well fields to drought has fostered a culture of water scarcity that has limited Hays opportunities for economic development and growth. Paul is project manager and lead hydrogeologist/engineer for the development of a groundwater supply at the R9 Ranch, located 66 miles south of the City. The R9 Ranch well field will provide an additional groundwater supply to supplement the City's existing water portfolio and reduce their drought vulnerability. This project will be the first inter-basin transfer of water in the State of Kansas, and as such is undergoing extensive regulatory and public scrutiny. Paul is the lead groundwater flow modeler for the City. MODFLOW2000, a three-dimensional groundwater analysis package developed by the United States Geological Survey is being utilized to evaluate the changes to the water rights of the new well field, determine the sustainable yield of the aquifer, and evaluate the effects on surrounding well owners. Preliminary design of the well field of the well field includes 12 to 14 groundwater wells, 66 miles of pipeline, and associated pump stations and storage tanks.

Well Field Optimization & Improvement Study, Industrial Client

Borger, Texas, 2015

Paul was the project manager, hydrogeologist and engineer for a water supply improvement study for an industrial client requiring approximately 10 million gallons per day of raw water supply. The water is supplied from 26 wells in 3 well fields. The study evaluated well conditions, operation & maintenance practices, aquifer yield, and permitting issues. Recommendations included changes to operations and maintenance practices, well replacement scheduling, and optimization of future well design to maximize yield and sustainability. Work is ongoing and includes design of multiple replacement wells and associated infrastructure.

PAUL A. MCCORMICK, PE

(continued)

Aquifer Restoration, Union County Water Conservation Board

El Dorado, Arkansas, 2007 - Present

Paul provides project management and groundwater expertise to the UCWCB. Union County, Arkansas has been dependent on the Sparta aquifer for municipal, industrial, and agricultural water supplies. Groundwater withdrawals from the aquifer have resulted in a large cone of depression centered beneath the City of El Dorado. Continued increases in the withdrawal rate from the aquifer will likely result in continued expansion of the cone of depression, increased drilling and pumping costs for wells, decreased aquifer yield, and reduced water quality. The Union County Water Conservation Board has as its goal to restore water levels to the top of the Sparta Formation. Groundwater modeling by Burns & McDonnell provided information to allow the UCWCB to determine the level of conservation and rate of recovery necessary for implementation of a water conservation plan based on costs and resulting benefits. Aquifer management practices and artificial recharge has resulted in groundwater levels in the vicinity of El Dorado to recover approximately 115 feet since the start of the project.

Water Reuse Evaluation, City of Garden City

Garden City, Kansas 2022

Paul assisted in concept development, groundwater modeling, regulatory coordination, and system design and evaluation for the Dodge City water reuse evaluation. As a part of a feasibility study, our team explored six unique reuse options: direct potable, indirect potable via aquifer storage, irrigation, industrial, livestock watering and constructed wetland. Each alternative has a tangible benefit to the community and by working directly with key stakeholders, we were able to identify the true value of each option in terms of capital cost, operations and maintenance (O&M) cost, extending the longevity of existing potable water sources and regulatory compliance. Key recommendations include industrial reuse, passive recharge of the aquifer and direct recharge of the aquifer.

Wastewater Resuse Evaluation, City of Dodge City

Dodge City, Kansas, 2023

The City currently has zero discharge permit from its existing South Waste Water Treatment Plant (South WWTP) with effluent water currently being used for irrigation. Paul assisted in concept development, groundwater modeling, regulatory coordination, and system design and evaluation. As part of the project, Burns & McDonnell evaluated up to three potential treatment processes for a proposed ASR concept to meet industry best-practices for log removal credits for ASR. The team also led a discussion with KDHE to discuss the selected alternatives and key water quality parameters of interest to develop a consensus with KDHE on the selected concept. The team assembled a budgetary level opinion of probable cost for the selected alternative. The team conducted hydrogeological modeling of the Arkansas River, the Arkansas River Alluvium and the City's groundwater resources to determine the anticipated capture zone and level of recharge to the City's water supply. The team is continuing to work with the City and regulatory agencies to evaluate and apply for grant-funding opportunities and to proceed with modeling and the next steps of design for the proposed concept.

Aquifer Recharge Evaluation, Kansas Corporation Commission

Garden City, Kansas 2007

Declining water levels in western Kansas have caused extensive challenges for groundwater users near Garden City. The KCC undertook a study to evaluate the feasibility of using excess flow in the Arkansas River through existing irrigation ditches to divert the water to areas away from the stream that are suitable for recharging the alluvial and High Plains aquifer. Paul was the hydrogeologist/engineer and lead groundwater modeler for this study. As part of the project a hydrologic assessment of the ditches was conducted to evaluate their capacity and connection to the underlying aquifer. Then extensive

PAUL A. MCCORMICK, PE

(continued)

three-dimensional modeling of stream interaction and groundwater flow was conducted to determine the capacity of the ditches to recharge the aquifer.

Groundwater Remediation, City of Mandan

Mandan, North Dakota 2006

Paul assisted in the hydrogeological investigation and evaluation of a historic diesel fuel spill that was estimated to be as much as 4 million gallons. As part of the project, Paul identified well locations and generated well designs for recovery wells that were installed in the middle of a busy downtown municipal setting. Paul also provided hydrogeological evaluation of the aquifer geology to optimize the remediation system design and installation.

Water Supply Well, Ameren UE

Rush Island, Missouri, 2009

Paul was a project engineer for design and construction of two water supply wells for the Rush Island power plant. These vertical wells were deep bedrock wells constructed in a geologic setting with significant water quality and capacity challenges.

Well Field Evaluation, US Army Corps of Engineers

Hays, Kansas, 2013

Paul served as project manager and senior hydrogeologist for a study to evaluate the use of low head dams to artificially recharge the Smoky Hill River Alluvial Well Field for the City of Hays, Kansas. The project included an evaluation of well field yield, storage, water rights, and dam type and construction. The investigation consisted of data review, existing water rights analysis, aquifer storage capacity and use of low head dams to reduce the drought vulnerability of the resource.

Water Supply Well Design, Greenwood Utilities

Greenwood, Mississippi, 2013

Paul served as project hydrogeologist for the design of a vertical well for public water supply. He designed a 1200 gpm water well in a challenging geologic environment. The design was engineered to address issues of high turbidity cause by the aquifer materials.

Evaluation of Supply, Treatment, & Distribution System, Missouri-American Water Company

Parkville, Missouri, 2013

Paul was project engineer for a study concentrated on determining the most financially feasible methods to incrementally increase water supply to meet the demands of a system that has experienced significant residential growth over the past five years. As part of the study the existing well field was evaluated and additional wells sites were explored to determine the most cost effective raw water supply for a new water treatment plant.

Water Supply Well Evaluation, Greenwood Utilities

Greenwood, Mississippi, 2011

Paul served as project hydrogeologist for the evaluation of the design and construction of a water supply well. Highly turbid water was being produced due to problems with the design and construction of the existing well. Paul developed a plan to test

PAUL A. MCCORMICK, PE

and evaluate the well design, construction, and development to determine the source of the problem and develop a plan to mitigate.

Crystal River Well Field, Progress Energy

Crystal River, Florida, 2011

Paul was the senior hydrogeologist for the addition of six new vertical wells at the Crystal River well field. He was responsible for evaluating the previously completed hydrogeologic study and using the information to design and construct the well field expansion. Six existing wells were also rehabilitated to recover lost capacity. The expanded water supply was used to supply cooling water for electrical power generation.

East Chiller Water Supply Well, TECO

Houston, Texas, 2010

Paul was the design engineer for what was to be a 1500 gpm water well to supply chiller water for a hospital complex in Texas. During his evaluation of the hydrogeology Paul was able to design and implement changes that resulted in the well producing 2000 gpm.

Combined License Application, Ameren UE

Near Mokane, Missouri, 2010

Paul was a senior hydrogeologist on a study to support the COLA application for a nuclear power plant. His role was peer review of the evaluation of the regional and site specific hydrogeology for construction of two new reactor units.

Chloride Migration Evaluation, Kansas Corporation Commission

Burrton, Kansas 2009

Historic oil field brine contamination has resulted in significant levels of chloride in the Equus Beds aquifer near Burrton. This contamination is migrating to the east, and impacting surrounding groundwater users. The KCC was investigating the extent and spread of the contaminant plumes. Paul was the hydrogeologist/engineer and lead groundwater modeler tasked with evaluating the existing data, utilizing a MODFLOW groundwater model to determine the aquifer flow conditions, and conduction transport modeling to evaluate the migration of chloride through the subsurface.

Bentley Wellfield Rehabilitiation, City of Wichita

Wichita, Kansas, 2009

Paul served as the senior hydrogeologist and engineer for wellfield design, construction and testing of water supply wells of a supplemental wellfield in Wichita, Kansas. The Bentley Well Field Project was undertaken as part of the City of Wichita's Integrated Water Supply Plan to develop a wellfield utilizing induced infiltration through the river bank alluvium of the Arkansas River. Paul's responsibilities included well and wellfield design, field inspection, supervision of testing, regulatory contact and coordination, and final design reporting.

Water Supply Well No. 17, City of Junction City

Junction City, Kansas, 2008

Paul served as project hydrogeologist for a for design and construction of a new vertical well for the City of Junction City, Kansas. Well design, construction, performance testing and completion were assessed as part of the project.

PAUL A. MCCORMICK, PE

(continued)

Aquifer Recharge Evaluation, Kansas Corporation Commission

Garden City, Kansas 2007

Declining water levels in western Kansas have caused extensive challenges for groundwater users near Garden City. The KCC undertook a study to evaluate the feasibility of using excess flow in the Arkansas River through existing irrigation ditches to divert the water to areas away from the stream that are suitable for recharging the alluvial and High Plains aquifer. Paul was the hydrogeologist/engineer and lead groundwater modeler for this study. As part of the project a hydrologic assessment of the ditches was conducted to evaluate their capacity and connection to the underlying aquifer. Then extensive three-dimensional modeling of stream interaction and groundwater flow was conducted to determine the capacity of the ditches to recharge the aquifer.

Aquifer Evaluation, City of Sioux Falls

Sioux Falls, South Dakota, 2005

Paul was the project manager of a water supply study to investigate the available yield from the Wall Lake aquifer. The study was designed to determine the quantity and quality of groundwater immediately available from the aquifer as well as to evaluate the long-term effects of pumping on the aquifer water levels.

Wellfield Evaluation, City of Decatur

Decatur, Illinois 1998

Paul was the project manager for an extensive study to determine the potential for development of a wellfield in an alluvial aquifer to provide a groundwater supply for the City of Decatur. The study included a 30-day duration pumping test with eight wells pumping 15 million gallons per day and a MODFLOW three-dimensional model to determine capacity and optimize wellfield operation.

Well Evaluation, Georgia-Pacific Company

Brunswick, Georgia, 1996

Project manager for an aquifer study to identify zones of high chlorides. A large industrial client’s well was high in chlorides, causing processing problems. The well was logged using borehole geophysical methods and tested for water yield and quality. An aquifer zone was identified as contributing the chloride. This zone was plugged off, reducing chloride concentrations in the well water to below Drinking Water Standards and increasing the capacity of the well.

Collector Well Rehabilitation, City of Parkersburg

Parkersburg, West Virginia, 1996

Project engineer testing and rehabilitation of two of the city’s collector wells in the Ohio River alluvium. Study included long-term pumping tests, visual inspection of caissons and laterals, and recommendation and verification of rehabilitation methods.

Platte West Wellfield, Municipal Utilities District

Omaha, Nebraska, 1995

Project engineer for development of the Platte West Wellfield in the Platte River alluvial aquifer for the city. Development included installation of 12 large diameter, high capacity wells and a MODFLOW three-dimensional model of the aquifer optimize operation of the wells and to maximize yield.

PAUL A. MCCORMICK, PE

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Groundwater Freeze Barrier, Echo Bay Minerals

Timmins, Ontario, Canada, 1997

Paul relocated to Canada for five months as project engineer for construction of a groundwater freeze barrier system in a glacial till environment. He coordinated and managed the installation of the dewatering wells inside the freeze barrier, installation of the freeze wells, construction of roadways and site grading; supervised subcontractors and drilling crews; performed borehole logging activities, geotechnical surveys, quality control, and surveying duties.

Well Testing & Aquifer Evaluation, Seagram's

Torreon, Mexico 1996

In central Mexico, Paul was the project engineer for a hydrogeologic investigation to determine the yield of a well for a major industrial client. Water quality and yield testing was performed, as well as an interviewing government personnel and reviewing data collected by Mexican governmental agencies.

Fracture Trace Analysis, City of Alburtis

Alburtis, Pennsylvania 1998

Paul was the project engineer for a hydrogeologic investigation to identify sites for future municipal wells. The study utilized fracture trace analysis methods, as well as geologic and hydrogeologic data. A contaminant source survey was also performed that consisted of a review of federal and state databases to verify that there were no environmental concerns for the proposed sites.

Fracture Trace Analysis, Muskego School District

Muskego, Wisconsin 1998

Paul was the project engineer on a hydrogeologic investigation to identify sites for water supply wells for a public school system. The study utilized fracture trace analysis methods, as well as geologic and hydrogeologic data. A contaminant source survey was also performed that consisted of a review of federal and state databases to verify that there were no environmental concerns for the proposed sites.

DEPOSITIONS AND TESTIMONY

Expert witness before the Kansas Department of Agriculture – Division of Water Resources on behalf of the City of Wichita in Case No. 18 WATER 14014.

PROFESSIONAL SOCIETIES

National Groundwater Association
Past President of Missouri Groundwater Association

BURNS & McDONNELL

R9 Ranch Modeling Results Summary

Hays
Water Resources Department

City of Hays, Kansas

R9 Ranch Development

5/26/2023

EXHIBIT
PM-04

R9 Ranch Modeling Results Summary

prepared for

City of Hays, Kansas
R9 Ranch Development
Edwards County, Kansas

5/26/2023

prepared by

Burns & McDonnell Engineering Company, Inc.
Kansas City, Missouri

INDEX AND CERTIFICATION

City of Hays, Kansas
R9 Ranch Modeling Results Summary

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Certification

I hereby certify, as a Professional Engineer in the state of Kansas, that the information in this document was assembled under my direct personal charge. This Report is not intended or represented to be suitable for reuse by the City of Hays, Kansas or others without specific verification or adaptation by the Engineer.

PAUL A. McCORMICK
LICENSED
16559
5/26/23
KANSAS
PROFESSIONAL ENGINEER

Paul A. McCormick, P.E.
Kansas Professional Engineer #16559

Date: MAY 26, 2023

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LIST OF ABBREVIATIONS

Abbreviation	Term/Phrase/Name
AF	Acre-feet
AF/y	Acre-feet per year
BGW	Balleau Groundwater, Inc.
BGW Model	Model constructed by Balleau Groundwater, Inc. for Big Bend Groundwater Management District No. 5.
BMcD	Burns & McDonnell Engineering Company, Inc.
Cities	Cities of Hays and Russell, Kansas
DWR	Kansas Department of Agriculture, Division of Water Resources
ET	Evapotranspiration
GMD5	Big Bend Groundwater Management District No. 5
gpm	Gallons per minute
Hays	City of Hays, Kansas
KGS	Kansas Geological Survey
KORA	Kansas Open Records Act
MNW	Multi-Node Well
NWIS	National Water Information System
Russell	City of Russell, Kansas
SFR	Streamflow Routing
USGS	United States Geological Survey
WIMAS	Water Information Management and Analysis System

1.0 INTRODUCTION

This Supplemental Report has been generated at the request of the Cities of Hays and Russell, Kansas (Cities) to assist with the Water Transfer proceeding. None of the conclusions in the prior Report dated September 18, 2019, and submitted to the Chief Engineer in the Cities' Change Application proceeding, are modified by this Report. However, additional information is included to clarify and provide improved context with the intention of aiding the Presiding Officer and the Transfer Panel in evaluating the Cities' Water Transfer Application.

The Cities of Hays and Russell, Kansas (Cities) purchased the R9 Ranch in the mid-1990s for the purpose of developing it as an alternative water supply source to supplement and 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. This Report details the results of Burns & McDonnell's (BMcD) work to evaluate the long-term average quantity of water that can be sustainably diverted from the aquifer at the R9 Ranch, and the effects that the planned municipal wellfield development and pumping will have on the local aquifer and nearby water users.

The R9 Ranch covers approximately 6,900 acres and is located approximately five miles southwest of Kinsley, Kansas (Figure 1). The R9 Ranch has been used for irrigated agriculture, growing corn, alfalfa and soybeans since the R9 Ranch water rights were developed beginning in the mid-1970s. Irrigation was accomplished using 53 irrigation wells supplying water to 41 center-pivot irrigation systems. Perfected irrigation water rights on the R9 Ranch total. 7,647 acre-feet per year (AF/y). Change applications were 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 AF/y. The Cities have voluntarily accepted an additional ten-year rolling average limitation of 4,800 AF/y (referred to in DWR's Master Order approving the Cities' Change Applications as the "TYRA Limitation").

The planned development of the R9 Ranch as a municipal water source includes construction of fourteen (14) new municipal wells, to produce groundwater at an estimated rate of 350 gallons per minute (gpm) each.[1] Each well will be contained in an associated well house. A raw water collection pipeline system on the R9 Ranch will deliver groundwater to an approximately one-million-gallon storage tank, and a

[1] Permitted rates range from 700 to 1,500 gallons per minute but the Cities do not intend to divert water from the municipal wells at those higher rates. *See* Master Order, ¶¶ 190-96, 243-45, and Appendix G.

high-service pump station will pump water from the storage tank through a pipeline to Schoenchen, Kansas, and then to Hays and Russell. An electrical distribution network will also be required to provide power to the wells.

1.1 Expert Qualifications

I am a Senior Associate Geological Engineer with Burns & McDonnell Engineering Company, Inc., an international design and consulting engineering firm based in Kansas City, Missouri. I have a Bachelor of Science degree in Geological Engineering from Missouri University of Science & Technology, and am a licensed Professional Engineer in Kansas, Missouri, Iowa, Nebraska and South Dakota. I have worked in the groundwater industry for 29 years providing design and consulting services for clients regarding hydrogeology, groundwater modeling, and water well and wellfield design for water supply purposes. Additionally, I provide consulting services and expert testimony in litigation matters concerning these same subjects. I am being compensated $268 per hour for work on this project. Attached as Appendix A to this Report is my curriculum vitae.

1.2 Executive Summary and Conclusions

At the former Chief Engineer's request during the Cities' Change Applications proceeding, the MODFLOW™ three-dimensional groundwater flow model developed by Balleau Groundwater, Inc. (the "BGW Model") for Big Bend Groundwater Management District No. 5 (GMD5) was used to evaluate potential changes in groundwater conditions if the Cities' Change Applications were to be approved. The BGW Model was used to compare diversion of water from 14 simulated municipal well diversions with the documented "baseline" irrigation well diversions from a 17-year period, from 1991 to 2007.

The 1991 to 2007 time frame was primarily selected because the period of 1991 to 2007 has the most accurate pumping data available. Since 1990, the DWR has required metering and reporting of pumped quantities, which are then recorded to the WIMAS database. The pumping stress and return flow was calculated by BGW based on a procedure documented in the BGW Report. (*BGW Report*, page 64)

Using 1991 to 2007 (the "Short-Term Baseline Irrigation Scenario") as the baseline period for evaluating the impact the proposed water transfer will have on the source of supply is very conservative because diversions during that time frame averaged just 4,054 acre-feet annually at rates on the order of 600 to 800 gpm. That quantity is significantly less than the full perfected quantity of 7,647 AF/y permitted for irrigation use by the R9 Ranch water rights.

Additionally, a long-term, 51-year period was simulated using the BGW Model structure and data by duplicating the conservative irrigation diversions from 1991 to 2007 twice (the "Long-Term Baseline

Irrigation Scenario"). The irrigation pumping was then compared with several 51-year scenarios using the simulated municipal wells to project the long-term effects on the source of supply under the Cities' planned water transfer.

The conclusions of this modeling work are:

- The R9 Ranch can sustainably support 4,800 AF/y of groundwater withdrawal.

- For the period of 1991 to 2007, the BGW Model was used to generate water levels for the documented irrigation well pumping averaging 4,054 AF/y and the proposed municipal wells averaging 4,800 AF/y. Comparison of the model generated groundwater levels indicates that the municipal pumping results in an average additional 3.6 inches (0.3 feet) of water level decline at the R9 Ranch boundary over the 17-year period.

- For a 51-year period, the model-generated water levels were compared for the documented irrigation well pumping (averaging 4,054 AF/y) and the proposed municipal wells (averaging 4,800 AF/y). Comparison of the model-generated groundwater levels for these two model runs indicates that the municipal pumping results in an average additional 7.2 inches (0.6 feet) of water level decline at the R9 Ranch boundary over the 51-year period.

- For a 51-year period, the model was used to generate groundwater levels for the documented irrigation well pumping (averaging 4,054 AF/y) and the Cities' actual planned groundwater usage based on phased construction of the infrastructure and operation of the municipal wellfield. Comparison of the model-generated groundwater levels from these two model runs indicates that groundwater levels will ***rise*** approximately 6 inches (0.5 feet) on average at the boundary of the R9 Ranch over the 51-year period.

- For a 51-year period, the model was used to generate groundwater levels for the documented irrigation well pumping (averaging 4,054 AF/y) and the Cities' actual planned groundwater usage based on phased construction of the infrastructure and operation of the municipal wellfield, with the addition of a drought comparable to the 1950s drought (considered to be the "drought of record" for Kansas). Comparison of the model-generated groundwater levels from these two model runs indicates that groundwater levels will ***rise*** approximately 4.8 inches (0.4 feet) on average at the boundary of the R9 Ranch over the 51-year period.

DWR Regulations adopted at the behest of Big Bend Groundwater Management District No. 5 define "sustainable yield" as "the long-term yield of the source of supply, including hydraulically connected surface water or groundwater, allowing for the reasonable raising and lowering of the water table." K.A.R. 5-25-1(l). It was determined in consultation with the Chief Engineer that the increases and decreases described above were "reasonable", as those fluctuations are less than one percent of the average saturated thickness of the aquifer on the Ranch. *See*, *e.g.*, Master Order, ¶¶ 159-170.

2.0 BACKGROUND

The R9 Ranch is located approximately five miles southwest of Kinsley, Kansas, along the east bank of the Arkansas River. Surface soil in this area is generally loamy fine sand, and overlies terrace and alluvial deposits comprising the Arkansas River Alluvium. The terrace and alluvium aquifers consist of deposits of sand and gravel with interbedded layers of clay, silt and caliche. Most of the R9 Ranch is in the Middle Arkansas River Basin with a small area extending into the upper reaches of the Rattlesnake Creek Basin.

2.1 Geology

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 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 that have been utilized for irrigation pumping and will be used for the proposed municipal wells on the R9 Ranch.

Alluvial sands and gravels are deposited by flowing water in rivers and streams. Sediments are carried in the flowing water and deposited in the channel area. As flow velocity increases and decreases, the size of sediment that can be transported by the water changes. This results in coarser materials such as sand and gravel typically being deposited in the channel and finer materials such as silt and clay being deposited along the banks and in the floodplain. The river meanders back and forth across the floodplain over time, resulting in horizontal and vertical variations in material composition as different sized materials are deposited on top of each other.

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.

The aquifer on the R9 Ranch is generally wedge shaped, with the thinner portion to the west and the thicker portion to the east. The ground surface elevation generally rises from west to east by approximately 10 to 20 feet, while the top of bedrock elevation decreases west to east, from approximately 2,185 feet above mean sea level (amsl) at the Arkansas River, to approximately 2,125 feet amsl at the east boundary of the R9 Ranch. The saturated thickness of the aquifer varies from approximately 45 feet along the Arkansas River to approximately 140 feet on the eastern portion of the R9 Ranch, with an average saturated thickness of approximately 100 feet.

2.2 Water Use

Water use on and around the R9 Ranch is typically in the form of center-pivot irrigation systems. The center-pivot systems require relatively high flows, on the order of 600 to 800 gpm. This pumping typically occurs only for a portion of the year, during the irrigation and growing season. Comparatively, the Cities' proposed municipal wells will pump at the lower rate of approximately 350 gpm for longer periods of time, cycling on and off on a monthly basis. This operational schedule, combined with the lower pumping quantities of individual wells and fewer wells pumping at greater distance from each other, will reduce the overall stress applied to the aquifer compared to the stress caused by the higher-intensity, shorter-duration pumping of irrigation wells spaced closer together.

For these reasons, water levels observed during operation in the irrigation season, when center-pivot irrigation was occurring, are typically lower than the water levels calculated by the model when the municipal wells are pumping. Likewise, water levels observed during months when irrigation is not occurring will be higher than calculated water levels from the municipal well operations.

3.0 GROUNDWATER MODELING

A groundwater model is a mathematical representation of the essential features of a natural hydrogeological system. Groundwater models use documented data to construct a conceptual representation of the physical groundwater system, including aquifer dimensions, hydraulic characteristics, and the recharge and discharge processes within the system. Mathematical processes are then used to simulate and quantify the movement of groundwater through the aquifer system being modelled.

Any groundwater model is an approximation of the real groundwater system; the level of approximation depends on the data available and the purpose of the model. When developing a groundwater model, careful consideration must be given to the intended use, the hydrogeologic processes, and the appropriate model scale. These parameters should be consistent with the modeling goals and purposes. A groundwater model that represents the groundwater system with an adequate level of detail can be used as a predictive scientific tool to quantify the impacts on the system of specified hydrological or pumping stresses. Common applications of a groundwater model include:

- Evaluating recharge, discharge, and aquifer storage processes (water resource assessment),
- Quantifying the sustainable yield (economically and environmentally sound allocation policies),
- Predicting the impact of alternative hydrological or development scenarios (to assist decision making), and
- Risk-based resource management (assessment of alternative policies).

MODFLOW is a three-dimensional modular, finite-difference groundwater flow modeling software package developed in the early 1980's by the U.S. Geological Survey (USGS) (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996). Since its creation, MODFLOW has been continually updated and adapted with the development of new modular packages and related programs. MODFLOW is the most widely used program in the world for simulating groundwater flow. (USGS, *Groundwater Modeling*). It is the industry-standard software package used for computer simulation of common features in groundwater systems. Packages developed and added to MODFLOW include capabilities to simulate coupled groundwater/surface-water systems, solute transport, variable-density flow (including saltwater), aquifer-system compaction and land subsidence, hydraulic characteristic estimation, and groundwater management.

3.1 BGW Groundwater Model

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

BMcD acquired the BGW Report and BGW Model files from the DWR through a Kansas Open Records Act (KORA) request. The Chief Engineer and DWR's hydrologist met with BMcD on multiple occasions and consulted extensively with BMcD during the development of this Report and the related water modeling efforts. During that process, DWR vetted, provided input, and endorsed BMcD's modeling methodology and the conclusions addressed in this Report. 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.

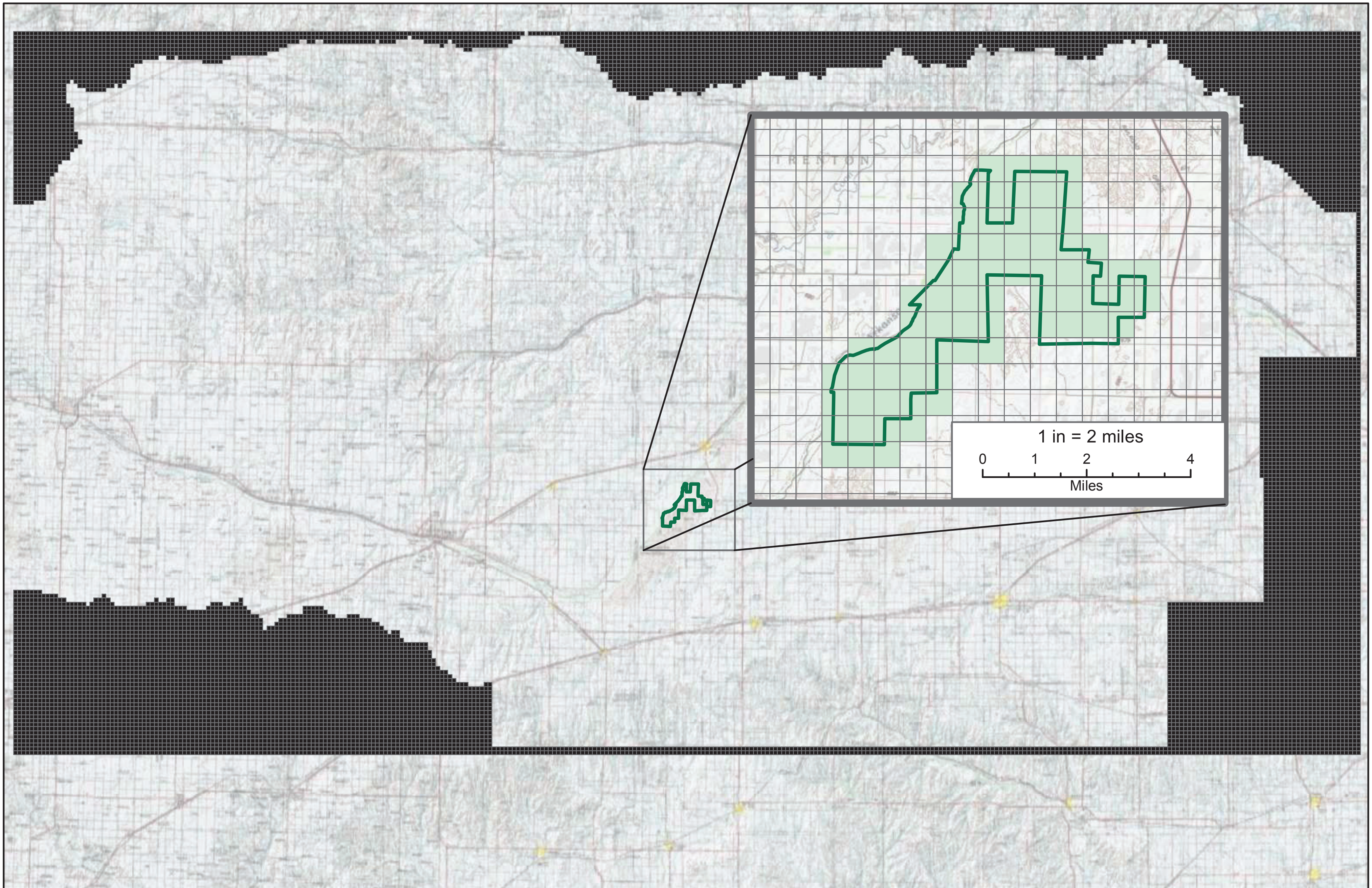
Figure 3-1 shows the BGW Model area, which encompasses the entirety of GMD5 and a substantial area up-gradient of GMD5, as well as an area down-gradient. The R9 Ranch is located in the west-central portion of GMD5, and centrally located within the BGW Model area.

3.1.1 *The BGW Model Purpose*

According to the BGW Report, the BGW Model "is designed to address Big Bend Groundwater Management District No. 5 management questions regarding impacts of alternative actions on future hydrologic conditions, and to project future conditions in the aquifer and interrelated streams." and "has the capacity to quantify the response to total stress or to isolate single stresses such as pumping." (BGW Report, page 6)

In addition, the stated purpose of the BGW Model is as follows:

> The purpose of developing a Big Bend GMD No. 5 hydrologic model is to clarify the physically-based relationships between water-management actions and the past hydrologic conditions, and to project future conditions in the aquifer and interrelated streams. Alternative water-management actions are to be examined as to their separate effects on conditions in the aquifer and streams. The model is intended to advance the understanding of the Big Bend GMD No. 5 hydrologic system by addressing watershed management, pumping water levels (PWL), sustainable aquifer lifetime, vertical-layering effect on the area of influence of wells, farm-water accounting of consumption and returns, moist-soil and wetland evapotranspiration (ET), among other factors. (BGW Report, page 8)



Legend

- R9 Ranch Boundary
- Model grid
- R9 Hydrostratigraphic Unit
- NoFlow Outline

N

BURNS McDONNELL

1 in = 16 miles

0 4 8 16

Miles

Hays Water Resources Department

Figure 3-1

Model Area, R9 Ranch Location & R9 Ranch Hydrostratigraphic Unit

After BGW constructed and calibrated the BGW Model, the DWR and S.S. Papadopulous & Associates, Inc. peer reviewed the BGW Model construction and calibration. The BGW Report states that:

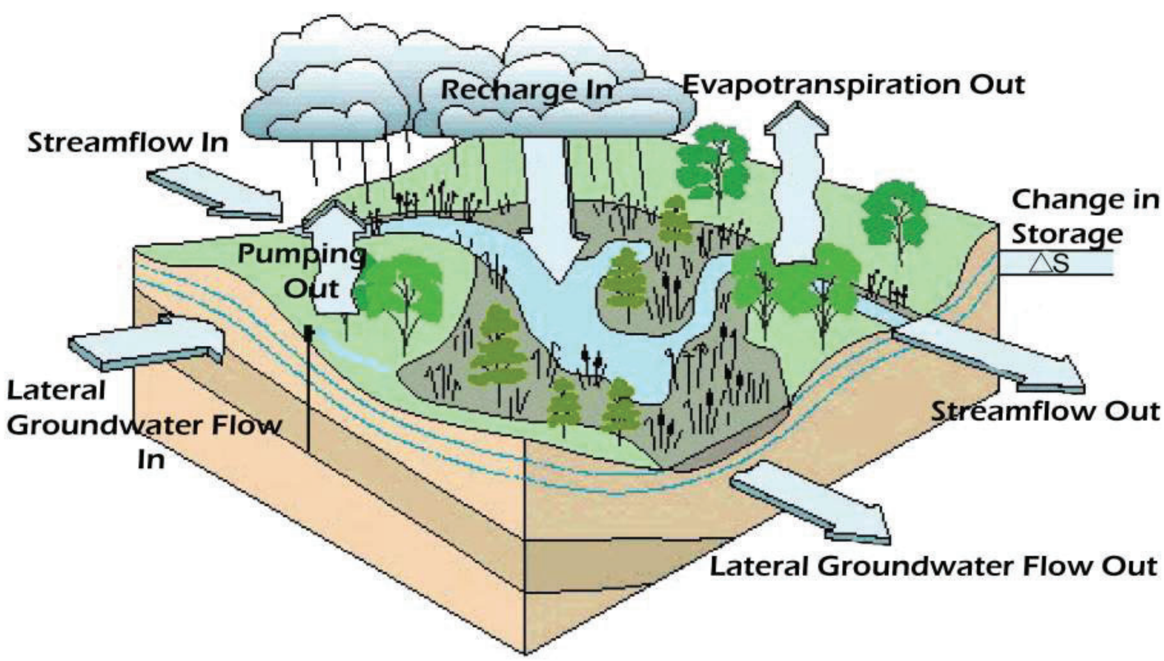
> The model performance in accounting for aquifer flow, water level and streamflow is checked against historical conditions. Seepage rates from Permian beds into Quaternary sediments are comparable with earlier estimates by others. The model is considered to be suitable to address the management objectives of Big Bend Groundwater Management District No. 5. The model is useful to account for the sources of water that respond to the stresses on the hydrogeologic system. (BGW Report, page 4)

This indicates that BGW considers the BGW Model to be calibrated to match historical water level observations and is useful for evaluating future changes to pumping conditions. Following its peer review, S.S. Papadopulous & Associates, Inc. concluded that the BGW Model construction and calibration was satisfactory. In addition, S.S. Papadopulous' peer review report concludes that the BGW Model "… can be used to evaluate water resource and water use related issues within the GMD 5 area." (*Peer Review,* page 15)

3.2 Modeled Groundwater System

Water supplied to the aquifer beneath 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

Figure 3-2: Typical Water Balance Parameters.



Cities intend to operate the R9 Ranch well field in a sustainable manner for the long-term. Multiple pumping scenarios were run using the BGW Model to evaluate the amount of water the aquifer on the R9 Ranch would yield while allowing for reasonable water level fluctuations. Evaluation of these effects was accomplished by comparing the water levels generated by the DWR documented irrigation pumping that occurred from 1991 to 2007 with the proposed municipal pumping activities under varying time frames, operating scenarios, and hydrologic conditions.

Figure 3-2 is a graphical representation of a hypothetical groundwater system and illustrates the various flows that make up the water balance. Certain flows, such as recharge, are always positive and adding water to the system. Other flows, such as well pumping and evapotranspiration are always negative and removing water from the system. Flows from streams, lateral flow through the aquifer, and changes in storage within the aquifer can be either positive or negative, depending on the circumstances.

MODFLOW calculates the volume of water flowing into and out of each cell of a model for each of these parameters. To simplify the evaluation of this parameter data, net values for each parameter are calculated using the formula inflow minus outflow. The water budget parameters included in the BGW Model are recharge, evapotranspiration, well pumping, lateral groundwater flow, streamflow, and storage.

3.3 Model Construction & Parameters

This section provides a brief overview of the key parameters of the BGW Model and its development. For a comprehensive discussion of the sources of data and methods used to construct the BGW Model, please refer to the BGW Report.

BMcD used the BGW Model to evaluate changes on the R9 Ranch because it is "designed to address questions about the impact of management action on future hydrologic conditions" (*BGW Report*, page 5), and has been peer reviewed and accepted by the DWR and S.S. Papadopulous, Inc. as the best management tool available at this time to evaluate hydrologic conditions in the study area. BGW organized and formatted data for MODFLOW input using Microsoft Excel, ArcGIS 2009, and Visual Basic pre- and post-processing tools to develop the BGW Model and generate the required MODFLOW files (*BGW Report*, page 4). BMcD utilized Groundwater Vistas Version 6.0 (GWV) pre- and post-processing software and Microsoft Excel to run the BGW Model.

BMcD imported the root MODFLOW files for the BGW Model that were obtained through a KORA request to DWR into GWV. These files contain data on BGW Model construction, hydrogeological parameters, and well pumping data. GWV provides a graphical user interface to streamline data entry and processing of model results. The MODFLOW calculation files generated by BGW were compared to the

MODFLOW calculation files generated by BMcD to verify that errors were not introduced into the BGW Model because of the use of different pre- and post-processing software packages. The comparison indicated that the BMcD runs of the BGW Model provided the same results as the BGW runs.

3.3.1 *Model Grid*

For the purposes of calculating groundwater flow and levels, MODFLOW models are divided into a network of cells called a grid. The BGW Model has grid cells that are one-half mile by one-half mile, which is appropriate for the regional size and scale of the BGW Model. There are 180 rows, 335 columns, and seven layers within the BGW Model, for a total of 422,100 grid cells. This equates to an area of 12,182 square miles ranging in thickness from 1,000 to 2,800 feet. BMcD made no changes to the grid of the BGW Model for its evaluation of the R9 Ranch.

3.3.2 *Hydrogeologic Framework*

The hydrogeologic framework of the BGW Model was developed by BGW through extensive research and work that is thoroughly documented in the BGW Report. This framework is a three-dimensional representation of the geology of the BGW Modeled area and represents the hydrogeologic characteristics of that area.

BGW separated the framework into seven layers representing the major geologic divisions in the regional stratigraphy. For calculation purposes, the BGW Model is further divided into nine units, to differentiate between areas with varying hydrologic characteristics within layers. Hydrogeologic parameters, such as hydraulic conductivity and permeability, are generalized into zones in each hydrogeologic unit, and were assigned to these layers and units by BGW using the methods described in the BGW Report. BMcD did not make any changes to this framework or to the hydrogeologic parameters specified by BGW for evaluation of the R9 Ranch.

3.3.3 *Recharge*

Natural recharge to the water table can be diffuse or localized. Diffuse recharge represents precipitation that falls over a large area and infiltrates and percolates to the water table. Localized recharge represents water infiltrating from surface water bodies to the ground water system. In the BGW Model diffuse recharge is accounted for using the MODFLOW recharge package, and localized recharge is accounted for through runoff and stream processes. Diffuse recharge is described in this section, and Section 3.3.2 discusses localized recharge through stream leakance.

Diffuse recharge simulates the addition of water to the aquifer due to rainfall and infiltration. The recharge amount is representative of the amount of water that infiltrates into the groundwater system, not the amount of precipitation. Do to the nature of the precipitation and infiltration process, direct measurement of actual recharge values is not possible.

> Groundwater recharge cannot be measured directly, such that observed groundwater recharge rates over large areas or over longer periods are rare. Currently and in the recent past, its calculation is based on hydraulic head observations or water-balance calculations (Moeck et al., 2020; Reinecke et al., 2021).

For the BGW Model multiple approaches were used to determine a range of plausible diffuse recharge rates, and the model calibration process was used to refine those values. The BGW Report documents the processes and steps taken. Recharge in the BW Model is applied on a monthly basis, and is based on recorded precipitation for an area and then a calculation process is used to determine the recharge amount applied to each cell (BGW Report, Table 3).

3.3.4 *Stream Leakance*

Flow in and recharge to and from streams is simulated with the MODFLOW Stream Flow Routing Package (SFR) in the BGW Model. Using the SFR package, recharge in streams results from specifying monthly runoff volumes from precipitation events in the BGW Model input files. The BGW Model routes the water down the stream channels defined in the BGW Model framework. The SFR package simulates the dynamic process of stream leakance based on the stage of the stream in the BGW Model. If the water table rises to an elevation that is higher than the streambed during wetter periods, water leaks from the aquifer into the stream and flows downstream in the stream channel as surface flow. If the water table is below the stage of the stream during drier periods, the SFR package simulates leakance from surface flow in the stream, if any, into the aquifer as induced recharge to the aquifer.

Streambed elevation and stage are critical components of the SFR input files. Due to streambed erosion, the Arkansas River streambed and stage elevation has shifted downward. BGW generalized this erosion in the Arkansas River as a six-foot decline in riverbed elevation from year 1960 to the end of 2007. BGW applied the decline linearly from 1960 to 2007, resulting in a uniform riverbed decline of approximately 0.13 feet each year. (*BGW Report*, page 59)

BGW selected the streams that are included in the BGW Model and developed the SFR streamflow input files. BMcD used the actual MODFLOW SFR calculation files developed by BGW for all of the 1991 to 2007 BGW Model runs to evaluate the R9 Ranch. For the 51-year forecast model runs of the BGW

Model, the actual BGW SFR calculation files were used for the first 17 years. For the subsequent 34 years the same stream parameters were used with the exception that the upstream flow contribution was set to zero and the streambed elevation was held constant. The upstream flow contribution was set to zero because flow in the Arkansas River has diminished and is not anticipated to increase. Therefore, it was decided that an estimate of zero upstream flow contribution would provide the most conservative evaluation of the river contribution. The riverbed elevation was held constant because without flow in the Arkansas River there is no longer a flow velocity mechanism causing streambed degradation.

3.3.5 *Evapotranspiration*

Evapotranspiration (ET) is the loss from the groundwater system through the processes of direct evaporation and transpiration by plants. This process is simulated with the ET package within MODFLOW using a maximum ET rate, a maximum ET surface, an extinction depth, and a calculation defining how ET changes as the water table elevation changes. BGW developed the ET package model inputs based on a reference crop rate (ET_0) for the BGW Model area using the Hargreaves method (Allen and others, 1998, Equation 52). Extinction depth in the BGW Model is 10 feet below the surface, and the BGW Report states that:

> Vegetation type appears not to be a sensitive factor for the strength of actual ET. Bare soil does not necessarily indicate low evaporation where the water table is shallow. Managing vegetation cover does not necessarily alter water-table depth, particularly where river stage and flood water overrides the other factors. We adopt the standard MODFLOW EVT package, which functions reasonably for the field conditions of interest. (BGW Report, Page 41)

BMcD did not change the ET model inputs and geographic distribution developed by BGW for the evaluation of the R9 Ranch.

3.3.6 *Groundwater Pumping*

Groundwater pumping in the BGW Model area was simulated using the multi-node well (MNW) package in MODFLOW. Groundwater pumping in the BGW Model has two components; pumping stress and return flow. Pumping stress is the volume pumped from wells in the BGW Model area. Return flow is the volume of water that is returned to the aquifer from percolation after irrigation application. There are also two types of wells considered in the BGW Model; non-irrigation and irrigation. Return flow for non-irrigation wells is zero. Return flow for irrigation wells is calculated based on a formula described in the BGW Report (*BGW Report*, page 64).

To summarize, pumping stress and return flow data for the period of:

- 1991 to 2007 is simulated based on the meter reports and with return flow applied on the corresponding reported acres.

- 1974-1990 is calculated based on the average 1991 to 2007 pumping data and using LANDSAT imagery to identify the irrigated acres for application of return flow.

- Prior to 1974 is calculated based on the water-right start date and with return flow applied to the average 1991 to 2007 reported acres.

BMcD used the MNW input files developed by BGW for the evaluation of the R9 Ranch. BMcD baseline BGW Model runs used the BGW MNW files without modification. For simulating hypothetical conditions, BMcD used the BGW Model structure and modified the BGW files by removing the diversion of water from the documented irrigation wells and associated return flows located on the R9 Ranch. Pumping stress data for 14 proposed municipal wells were inserted into the files, representing the proposed non-irrigation well use. Since the municipal wells are non-irrigation, there is no return flow associated with these wells.

3.3.7 *MODFLOW Calculations*

MODFLOW uses the input data files described in the preceding sections to simulate groundwater flow through the modeled area and changes in water level elevation. Generally, MODFLOW will use the input files to complete calculations for each cell that include:

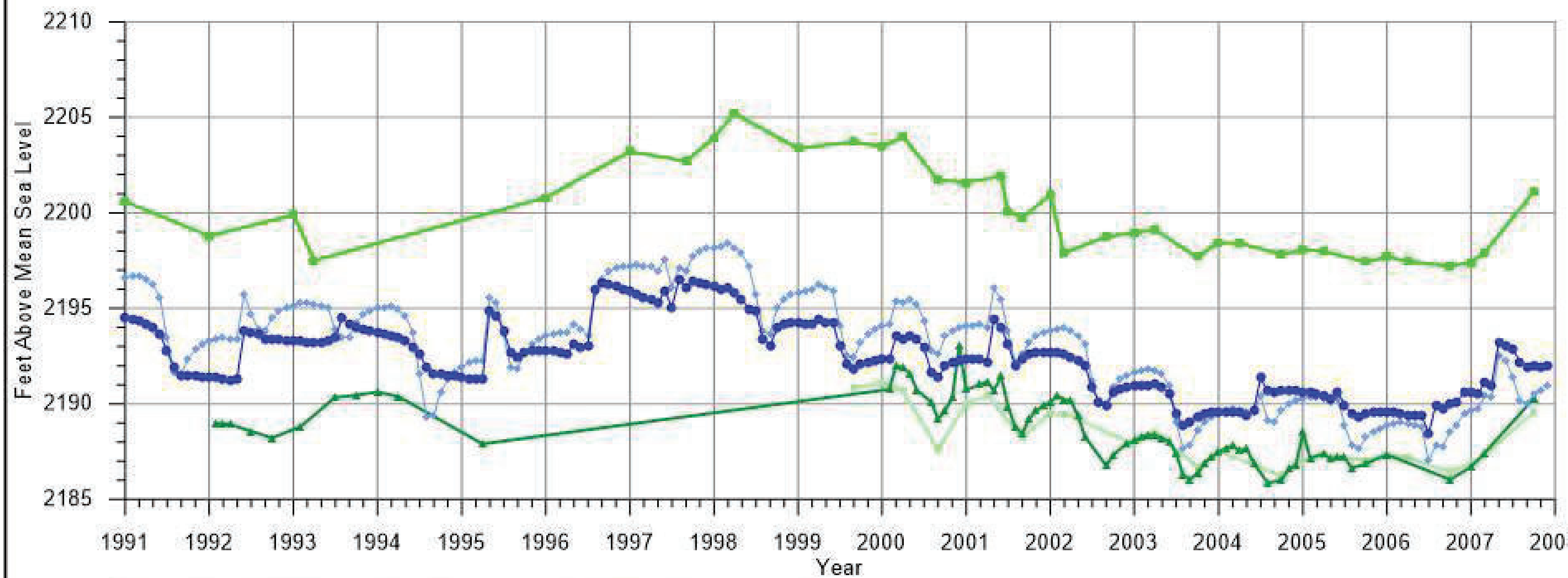
- Pumping is distributed as specified in the input file unless MODFLOW calculates that the aquifer cannot sustain the pumping volume specified in the input file. If the pumping stress is not sustainable MODFLOW will reduce the pumping quantity.
- Recharge is applied as specified in the input file.
- Evapotranspiration losses are calculated based on the specified inputs and the simulated water table elevations.
- Stream leakance is calculated based on the specified input parameters and the simulated water table elevation.
- Lateral groundwater flow from grid cell to grid cell is calculated based on the specified hydrogeologic framework.
- Changes in storage of the aquifer are calculated based on the water balance.

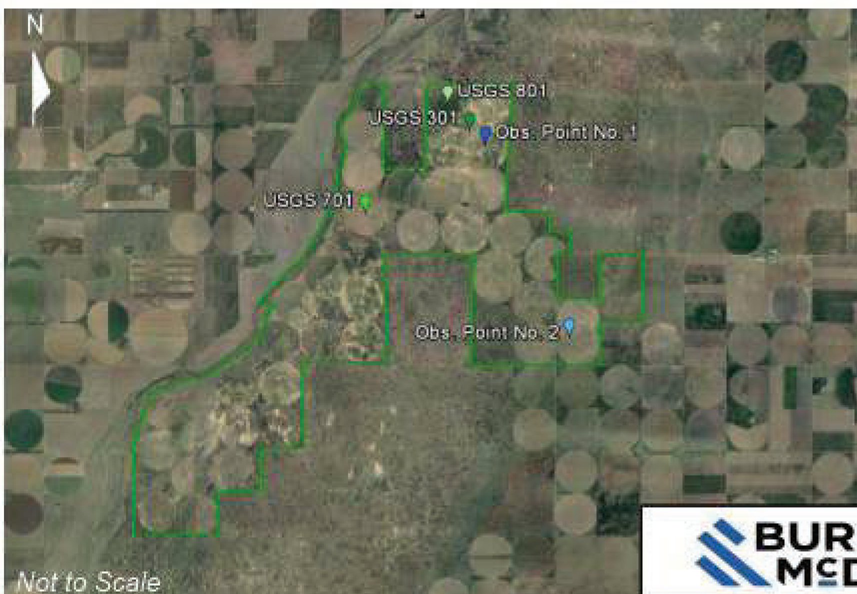
MODFLOW uses the input files to solve a variety of formulas to calculate water movement and elevation in the groundwater simulation. The solution consists of a groundwater level for every cell, a water budget that lists inflow into and outflow from the aquifer system for all hydrologic features, and cell-by-cell flow quantities.

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

The water level, drawdown, and water balance results from BMcD's initial run of the BGW Model 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 BGW Model described in the BGW Report. Slight variations in the results are expected and are often caused by differences in the data handling methods from the pre-and post-processing software or in the rounding of numbers within the processing software. The close correlation between the results obtained by BGW and BMcD indicates that the change in the pre- and post-processing methods to operate the BGW Model did not impact the BGW Model results.

To verify that the BGW Model was accurately simulating the water levels on the R9 Ranch specifically, BMcD compared the water levels calculated by our runs of the BGW Model with observed water levels from USGS monitoring wells located on the R9 Ranch (NWIS). Figure 3-3 shows the location of the observation points from the BGW Model and the location of the USGS observation wells. It also shows the water levels calculated by the BGW Model and the water levels measured in the USGS observation wells from 1991 through 2007. The calculated and observed water levels correlate well, indicating that the BGW Model is accurately simulating water levels on the R9 Ranch.





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Project No.	File Name:
91211	Water Levels GMD5 Model.grf

Figure 3-3

Observed and Modeled Water Levels on the R9 Ranch

4.0 EVALUATION OF THE R9 RANCH

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, the effects on the resource were quantified under several alternative wellfield development scenarios. BGW developed its model at the request of GMD5 for exactly this purpose. The BGW Model has been vetted by peer review and the DWR and determined to accurately simulate the hydrologic system. For this reason, and in consultation with and approval from DWR, BMcD used the BGW Model to evaluate the effects of changing groundwater use on the R9 Ranch from irrigation to municipal use.

As previously noted, the pumping and recharge data from the period from 1991 to 2007 is the highest quality data available. This is due to the annual reporting to DWR of pumped quantities from each point of diversion.[2] After being quality checked by the DWR, KGS stores the information in the WIMAS database. The 1991 to 2007 time frame also has accurate stream flow, precipitation, and evapotranspiration records available from various sources. BMcD selected this time period to complete the initial evaluation of the R9 Ranch since it contains the most accurate measured data available, instead of data that is inferred or estimated.

For the initial analysis of the R9 Ranch water levels, BMcD ran the BGW Model for the time period representing January 1991 through December of 2007. The groundwater elevations calculated by the BGW Model for the end of December 1990 were used as the starting elevations for the 1991 to 2007 runs of the BGW Model. BMcD did not make any changes to the hydrogeologic framework, model grid, or input files of the BGW Model; BMcD simply ran the BGW Model for a portion of its time frame.

The BGW Model calculates changes in water levels over time for the entire BGW Model area. To specifically evaluate the long-term yield of the R9 Ranch, the model cells containing the R9 Ranch were identified as a sub-region and GWV's internal Hydrostratigraphic Units (HSU) software package was used to keep an accounting of the flows into and out of that sub-region. BGW used the USGS ZONEBUDGET package to calculate sub-regional flows. These two packages perform the same function and provide equivalent results (*Guide to GWV*, page 379), effectively tracking the water balance for sub-

[2] The 1988 Kansas Legislature imposed a requirement on water right owners to file a complete and accurate annual water use reports with DWR, except for domestic use. K.S.A. 82a-732. Prior to 1988, water use reports were optional.

regional areas. The model cells comprising the sub-region evaluated as the R9 Ranch HSU are illustrated in the inset in Figure 3-1.

The HSU package was utilized to track the water balance of the sub-region to help clarify the data interpretation and reporting. The entire BGW Model was run for each of the scenarios described in this report. Cumulative model flow budgets from the scenario runs for the entire model result in values in the trillions. Cumulative model flow budgets for the HSU result in values in the millions. Focusing on the HSU area simplifies calculations, reporting, and understanding of the data. Since the only modifications to the model pumping rates were located in the sub-region represented by the HSU, focusing on the water budget of the HSU provides a valid representation of the resulting changes.

The simplest formula for calculation of a water budget is:

$$Inflow = Outflow \pm Change\ in\ Storage$$ [3]

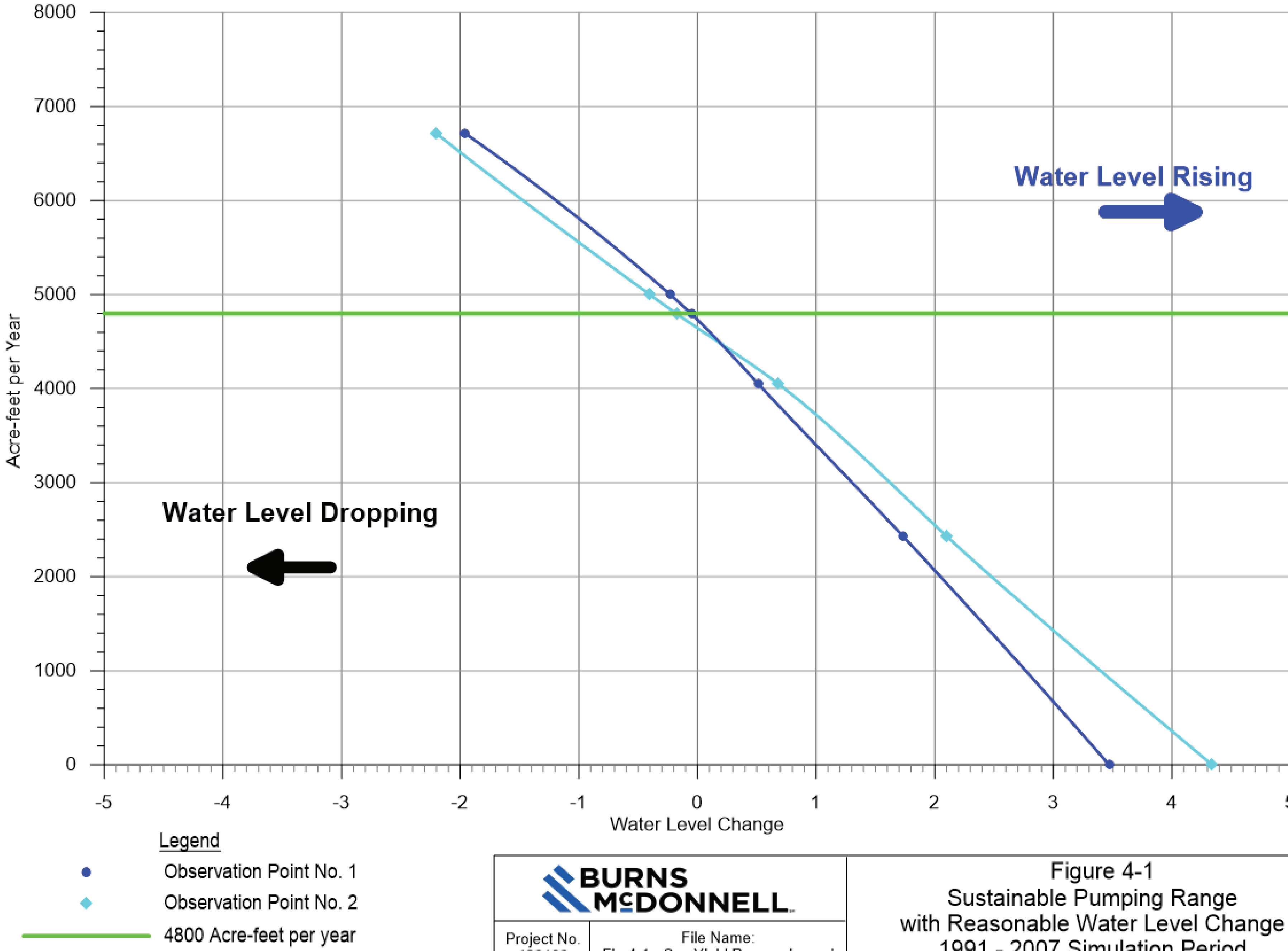
For the R9 Ranch HSU in the BGW Model, inflows include recharge and stream leakance. Outflows include pumping, evapotranspiration, and lateral groundwater flow. Release of water from storage is considered inflow, and water added into storage is considered outflow.

4.1 Initial Calculation of R9 Ranch Municipal Yield

After determining that the results from GWV returned the same results as BGW, BMcD removed the existing irrigation wells and return flows on the R9 Ranch for the 1991 to 2007 time period to simulate abandonment of the irrigation wells and to prepare to simulate the proposed municipal wellfield on the R9 Ranch. Irrigation return wells were used by BGW to simulate the return of water to the aquifer from the non-consumptive portion of the irrigation water applied to the area. BGW calculated the irrigation return flow and applied it on the corresponding reported irrigated acres. (*BGW Report*, page 64) Since the return flows are a product of the irrigation pumping, the return flows also need to be removed when the irrigation wells are removed.

Fourteen (14) municipal wells were then added into the BGW Model at the proposed locations on the R9 Ranch identified in the Cities' Second Amended Applications to Contingently Change the R9 Water

[3] Anderson & Woessner, Formula 2.1, pg 54



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Project No. 123193

File Name: Fig 4-1 - Sus Yield Regression.gpj

Figure 4-1
Sustainable Pumping Range
with Reasonable Water Level Change
1991 - 2007 Simulation Period

Rights, Case No. 15856 WATER 2019 and approved by the Chief Engineer in the Master Order at ¶¶ 246-47.[4]

Some of the cells included in the R9 Ranch HSU extend beyond the R9 Ranch property boundary, and some of the center pivot circles from irrigation operations around the R9 Ranch extend partially onto some of those cells. Since it is assumed that those irrigation operations will be ongoing, irrigation return flow for those wells is included in the totals for the R9 Ranch HSU. On average, approximately eight acre-feet of irrigation return flow per year is applied to the cells with neighboring irrigator's operations.

To develop a preliminary understanding of the changes in water levels at various pumping quantities, BMcD completed iterative runs of the 1991 to 2007 period of the BGW Model. The only change made to the BGW Model for these runs was the volume pumped from the 14 municipal wells. The net average volumes pumped ranged from zero to 6,714 AF/y. The water levels calculated by these model runs at observation points 1 and 2 were then graphed in relation to the volume pumped, as shown in Figure 4-1. These model runs provided the initial evaluation to determine what quantities could be pumped with relatively stable water levels.

Water levels rise as pumping quantities decrease and decline as pumping quantities increase. When pumping is sustainable, water levels are reasonably stable. As can be seen in Figure 4-1, at a volume of 4,800 AF/y pumped, the change in water levels caused by municipal pumping is relatively stable with a decline of only 0.2 feet after 17 years of pumping. The average saturated thickness of the aquifer under the R9 Ranch is 100 feet. A decline of 0.2 feet caused by the municipal pumping represents a reasonable change of less than 0.2 percent of the average available saturated thickness of the aquifer after 17 years.

4.1.1 *Scenario 1 – Short-Term Baseline Irrigation*

Localized effects caused by pumping can be evaluated by comparison of changes in water levels from a baseline scenario to a hypothetical scenario. A baseline output for the R9 Ranch HSU was compiled for this comparison by running the 1991 to 2007 BGW Model for the period of 1991 to 2007 with the input files generated by BGW. BMcD did not make any changes to the BGW hydrogeologic framework or MODFLOW input files for Scenario 1, BMcD simply ran the model for the last 17 years of its time span. Values shown in these tables in this Report are net average values for the 1991 to 2007 time period.

[4] The Cities' Second Amended Change Applications are available on DWR's website at https://agriculture.ks.gov/divisions-programs/dwr/water-appropriation/change-applications/hays-change-and-water-transfer.

Table 4-1: Summary of Scenario 1 Water Budget Results

	Short-Term Scenarios
Scenario Results *Average Net Model Mass Balance Parameters*	**Scenario 1** **Baseline Irrigation**
Inflow to the R9 Ranch aquifer system	
Recharge	4,732
Stream Leakance	1,313
Total Inflow	***6,045***
Outflow from the R9 Ranch aquifer system	
Pumping	4,054
Evapotranspiration	1,098
Lateral Groundwater Flow	1,346
Total Outflow	***6,498***
Change in Storage[1]	**-465**
Remainder[2]	12
Model Accuracy[3]	99.82%
Wells in Pumping Scenario	Irrigation & Return Wells

All units are acre-feet per year.

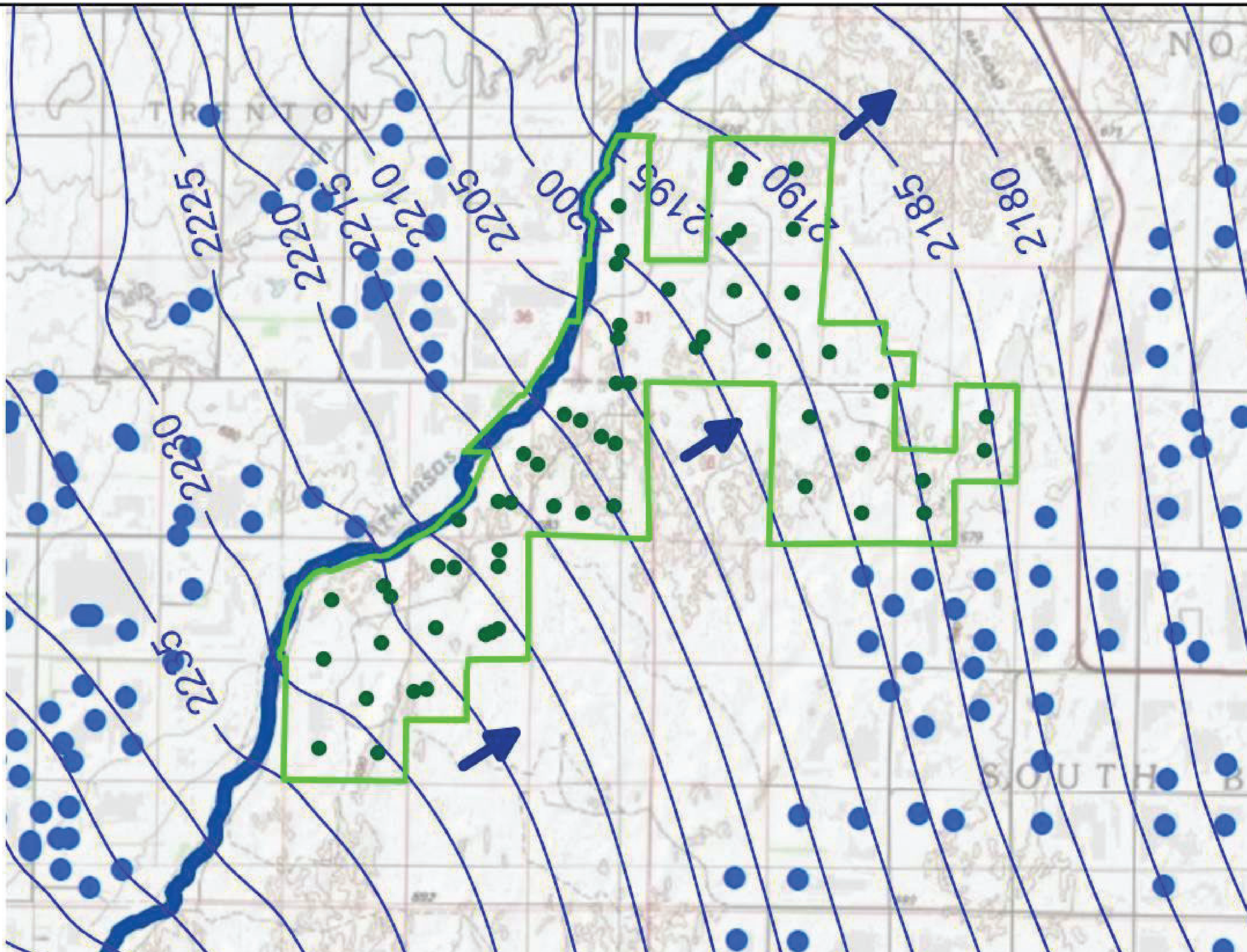
[1] *Negative values indicate an outflow from storage, positive values indicate water added to storage*

[2] *Remainder is the difference between Inflow and Outflow*

[3] *Model Accuracy is calculated by dividing the remainder by the larger of Inflow or Outflow*

The HSU package extracted and recorded the flows and water levels in the R9 Ranch HSU. Table 4-1 provides a numerical summary of the results of Scenario 1. Evaluation of this data results in the following observations of flows on the R9 Ranch:

- Annual recharge from precipitation averaged 4,732 AF/y.
- The net average volume pumped from the R9 Ranch by irrigation wells from 1991-2007 was 4,054 AF/y, which is approximately 53% of the full perfected quantity of 7,647 AF/y that the Cities have the right to divert for irrigation use under the R9 Ranch water rights.
- ET losses were an average of 1,098 AF/y.
- The Arkansas River was in a “losing” condition, where the groundwater table was lower than the water level in the river, so the river was contributing an average of 1,313 AF/y of water to the aquifer.



Legend

- Groundwater Flow Direction
- Water Level Contour
- R9 Ranch Boundary
- Historic R9 Irrigation Well
- Surrounding Irrigation Well

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Hays Water Resources Department

0 1500 3000 4500 6000
Scale in Feet

Figure 4-2

Model Generated Water Levels
Scenario 1 - Short-Term Baseline
Irrigation Pumping

- A net average of 1,346 AF/y of groundwater flowed laterally out of the R9 Ranch.
- The volume of groundwater in storage decreased by an average of 465 AF/y.

Figure 4-2 shows the model-generated water levels at the end of the Scenario 1 model run. This illustrates 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.

4.1.2 *Scenario 2 – Short-Term Maximum Average*

Scenario 2 evaluates the impacts of operating the 14 proposed municipal wells so that they extract a volume of 4,800 AF/y continuously for 17 years, which is the maximum average quantity authorized for municipal use by the Master Order in the Change proceeding. This scenario was run using the 1991 to 2007 Model with the framework and inputs provided by BGW. The only change made to the 1991 to 2007 Model for Scenario 2 was the R9 Ranch irrigation wells (and the associated return flow) were removed and replaced by the 14 proposed municipal wells, which were set to pump continuously at uniform rates to extract a total volume of 4,800 AF/y.

The results of Scenario 2 were compared to those from Scenario 1 to provide an evaluation of the difference between 1991 to 2007 irrigation pumping water levels and proposed municipal pumping water levels. Table 4-2 provides a numerical summary of the results of Scenarios 1 and 2 for comparison.

To summarize the comparison between water levels calculated for Scenario 1 and Scenario 2:

- Recharge did not change.
- Net pumping increased by an average of approximately 739 AF/y.
- ET losses decreased by an average of 24 AF/y.
- Stream leakance increased by 1,313 AF/y, on average.
- Lateral groundwater flow decreased by an average of 189 AF/y.
- The volume of groundwater taken from storage increased by an average of 88 AF/y.

Table 4-2: Summary of Scenario 2 Water Budget Results & Comparison to Scenario 1

	Short-Term Scenarios		
Scenario Results *Average Net Model Mass Balance Parameters*	**Scenario 1** **Baseline Irrigation**	**Scenario 2** **Maximum Average**	**Change Description**
Inflow to the R9 Ranch aquifer system			
Recharge	4,732	4,732	No change
Stream Leakance	1,313	1,766	Volume entering the R9 increased
Total Inflow	***6,045***	***6,498***	
Outflow from the R9 Ranch aquifer system			
Pumping	4,054	4,793	Volume leaving the R9 increased
Evapotranspiration	1,098	1,074	Volume leaving the R9 decreased
Lateral Groundwater Flow	1,346	1,157	Volume leaving the R9 decreased
Total Outflow	***6,498***	***7,024***	
Change in Storage[1]	**-465**	**-553**	Storage outflow increased. Volume in Storage decreased.
Remainder[2]	12	27	
Model Accuracy[3]	99.82%	99.62%	
Wells in Pumping Scenario	Irrigation & Return Wells	Proposed Municipal Wells	

All units are acre-feet per year.

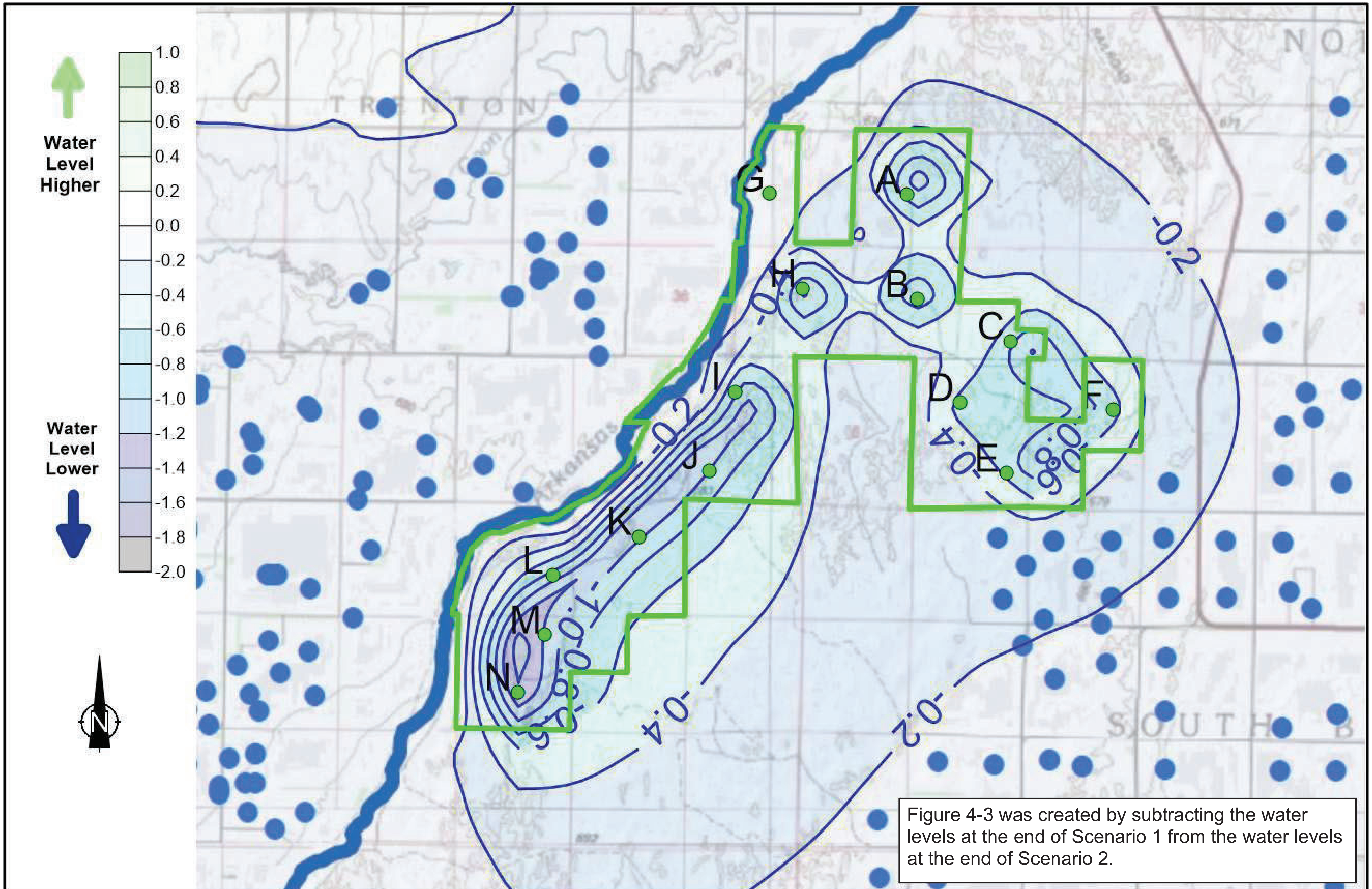
[1] *Negative values indicate an outflow from storage, positive values indicate water added to storage*

[2] *Remainder is the difference between Inflow and Outflow*

[3] *Model Accuracy is calculated by dividing the remainder by the larger of Inflow or Outflow*

Figure 4-3 was created to graphically illustrate the effects of pumping 4,800 AF/y from the 1991 to 2007 period from the R9 Ranch on the aquifer and surrounding users as compared to 1991 to 2007 irrigation pumping at an average of 4,054 AF/y. To generate this figure, the water levels calculated by the 1991 to 2007 Model at the end of the Scenario 1 were subtracted from the water levels calculated by the 1991 to 2007 Model at the end of Scenario 2. The differences between the water levels were then contoured to generate a graphical representation of the changes between the irrigation pumping and the proposed municipal pumping.

For the period from 1991 to 2007, pumping 4,800 AF/y from the municipal wells results in an average decline in the water level at the boundary of the R9 Ranch of approximately 3.6 inches (0.3 feet) after 17 years of pumping as compared to 1991 to 2007 irrigation pumping at an average of 4,054 AF/y. A slight water level decrease is expected since Scenario 2 has a higher average pumping quantity than Scenario 1.



Legend

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

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Hays Water Resources Department

0 1500 3000 4500 6000
Scale in Feet

Figure 4-3

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

Further examination of Figure 4-3 indicates that water levels in a few of the wells closest to the R9 Ranch would decline by an average of approximately 0.4 feet if the proposed municipal wellfield was operating under the modeled conditions, continuously extracting a volume of 4,800 AF/y for 17 years.

4.2 Predictive Scenario Development

As previously noted, one of the primary uses of a groundwater model is predicting the impact of alternative hydrological or development scenarios. The BGW Model "is designed to address Big Bend Groundwater Management District No. 5 management questions regarding impacts of alternative actions on future hydrologic conditions." (*BGW Report*, page 6) The R9 Ranch evaluation was completed by using the model framework and changing hydrologic inputs such as pumping quantities, well locations, recharge, and streamflow.

To predict the long-term effects of municipal pumping on the R9 Ranch water levels, the 1991 to 2007 BGW Model data and framework was reorganized to represent a 51-year period. The 1991 to 2007 data and framework were used because it is the most accurate data. Two modifications were made to the streamflow package inputs of the BGW Model framework (hydrogeologic parameters, geology, structure, etc.) for this purpose: (1) projected streamflow was reduced, and (2) streambed elevation was held constant. These changes are described in the following paragraphs.

BMcD set the initial upstream flow in the Arkansas River to zero after year 16 in the 51-year model runs. The upstream streamflow component represents surface water flowing into the model area in the Arkansas River channel. Historic flow data in the Arkansas River compiled from the Dodge City and Kinsley gages indicates that surface water flow occurred regularly, but there was a significant decrease in surface water flow after 2006. Changing the upstream flow contribution of the Arkansas River to zero after year 16 of the model addresses the issue and provides a more conservative simulation of the Arkansas River contribution to the groundwater system on the R9 Ranch by recognizing changing conditions resulting in reduced flows in the Arkansas River.

Baseflow in the Arkansas River can still occur if an unusual weather event results in significant runoff to the river or the model calculated water level elevation in the aquifer rises higher than the Arkansas River streambed elevation. In either event, the streamflow routing package will calculate a discharge from the aquifer to the stream and generate baseflow in the River, which will flow downstream and potentially provide recharge to the aquifer. Flow interactions between the stream and aquifer are reported in the 'stream leakance' component of the water budgets. However, the upstream baseflow contribution flowing into the model area that occurred from 1991 to 2007 is not contributing water to the model after year 16 in the 51-year model runs.

The second modification to the streamflow package 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 granular materials. Since flow in the stream channel during the 51-year period is significantly reduced by the lack of upstream contribution, continued down-cutting is minimized, and so the riverbed elevation was held constant.

To simulate the long-term effects of municipal pumping on the R9 Ranch, the 1991 to 2007 data was duplicated twice, repeating the hydrologic conditions for those years in three successive 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 51-year model runs thereby use actual historic climatic and hydrologic conditions to simulate the long-term effects of pumping.

4.3 Predictive Model Scenarios

BMcD ran three 51-year scenarios to evaluate the long-term effects of municipal pumping on the R9 Ranch water levels. These scenarios were intended to calculate the water levels to provide a baseline for comparison, an evaluation of the effects of pumping the full permitted quantity, and an evaluation of the actual predicted pumping quantities. The three 51-year predictive scenarios were:

- **Scenario 3 - Long-Term Baseline Irrigation:** This scenario estimates the water levels that would exist if the documented irrigation pumping that occurred from 1991 to 2007 continued on the R9 Ranch for 51 years and provides a baseline for comparison with predicted water levels associated with long-term municipal use under the scenarios addressed in this Report.

- **Scenario 4 - Long-Term Maximum Average:** This scenario calculates the predicted impacts to the groundwater system on the R9 Ranch if the 14 proposed municipal wells were operated to extract the full volume of 4,800 AF/y for the 51-year period.

- **Scenario 5 - Long-Term Projected Operations:** This scenario provides information about the predicted impacts to the groundwater system on the R9 Ranch if the 14 proposed municipal wells were operated in the manner actually anticipated to meet predicted demand for the 51-year period. The proposed operations assign the 14 municipal wells pumping quantities 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 operational quantities, and increasing production over time based on anticipated increases in demand.

Figure 4-4 illustrates the pumping and recharge conditions simulated by Scenarios 3, 4 and 5. The results of these three scenarios are discussed in the following sections.

4.3.1 *Scenario 3 – Long-Term Baseline Irrigation*

Scenario 3 provides a baseline calculation of water levels if the documented 1991 to 2007 irrigation pumping averaging 4,054 AF/y continued throughout a 51-year period. This scenario used the input files generated for the BGW Model with no changes, with the exception of the two changes to the Arkansas River inputs discussed in Section 4.2: removal of the upstream flow component after year 16; and holding the streambed elevation constant.

Table 4-3: Summary of Scenario 3 Water Budget Results

	Long-Term Scenarios[4]
Scenario Results *Average Net Model Mass Balance Parameters*	**Scenario 3** **Baseline Irrigation**
Inflow to the R9 R9 aquifer system	
Recharge	4,732
Stream Leakance	1,579
Total Inflow	***6,311***
Outflow from the R9 R9 aquifer system	
Pumping	4,054
Evapotranspiration	646
Lateral Groundwater Flow	1,909
Total Outflow	***6,609***
Change in Storage[1]	**-319**
Remainder[2]	21
Model Accuracy[3]	99.68%
Wells in Pumping Scenario	Irrigation & Return Wells

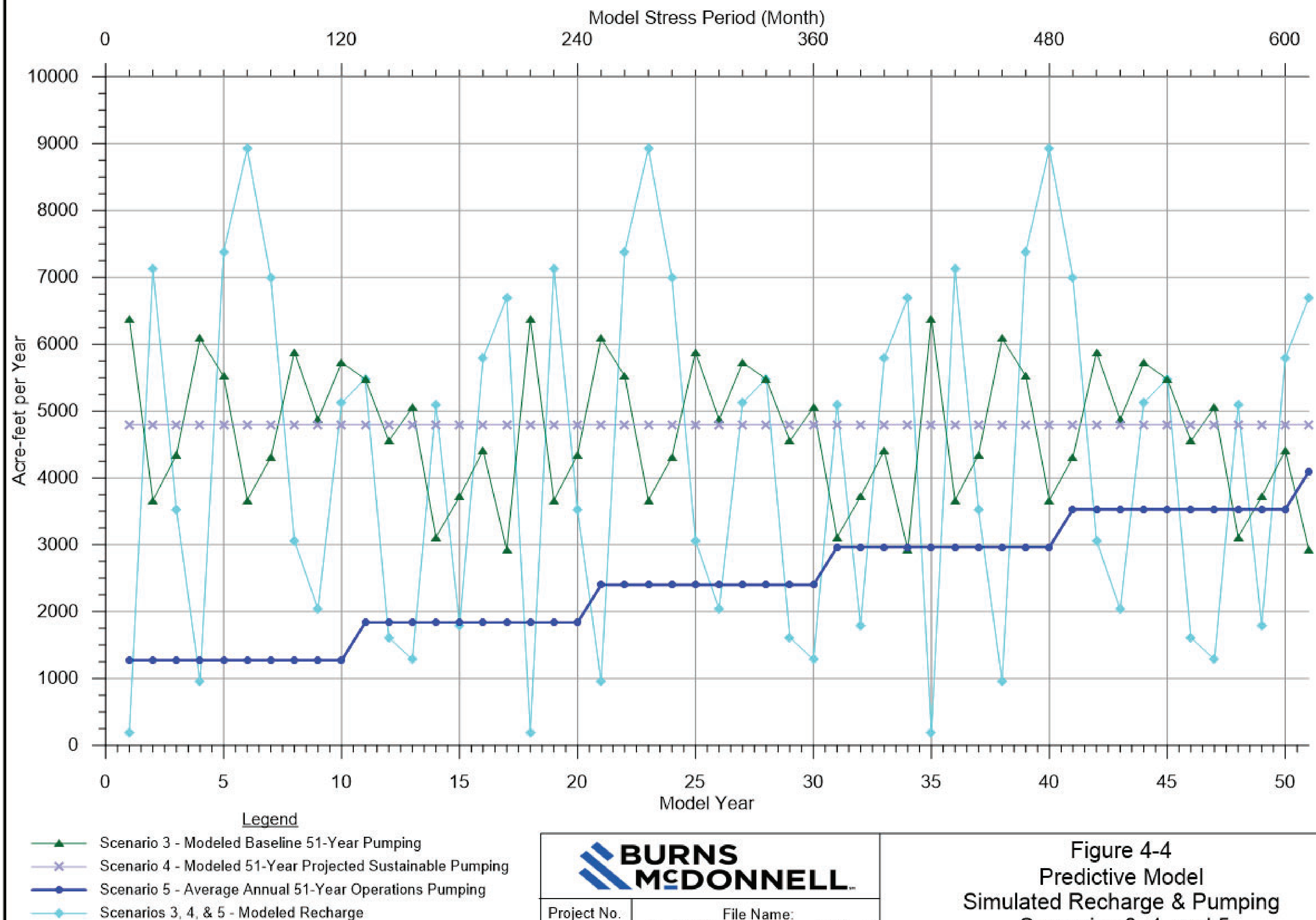
All units are acre-feet per year.

[1] *Negative values indicate an outflow from storage, positive values indicate water added to storage*

[2] *Remainder is the difference between Inflow and Outflow*

[3] *Model Accuracy is calculated by dividing the remainder by the larger of Inflow or Outflow*

[4] *1991-2007 data repeated three times. Assumes zero flow in Ark River after year 16.*



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Project No.	File Name:
123193	Fig 4-4 R9 Pumping Scen 345.gpj

Figure 4-4
Predictive Model
Simulated Recharge & Pumping
Scenarios 3, 4, and 5

Table 4-3 provides a numerical summary of the key water balance parameters on the R9 Ranch for Scenario 3. A descriptive summary is below:

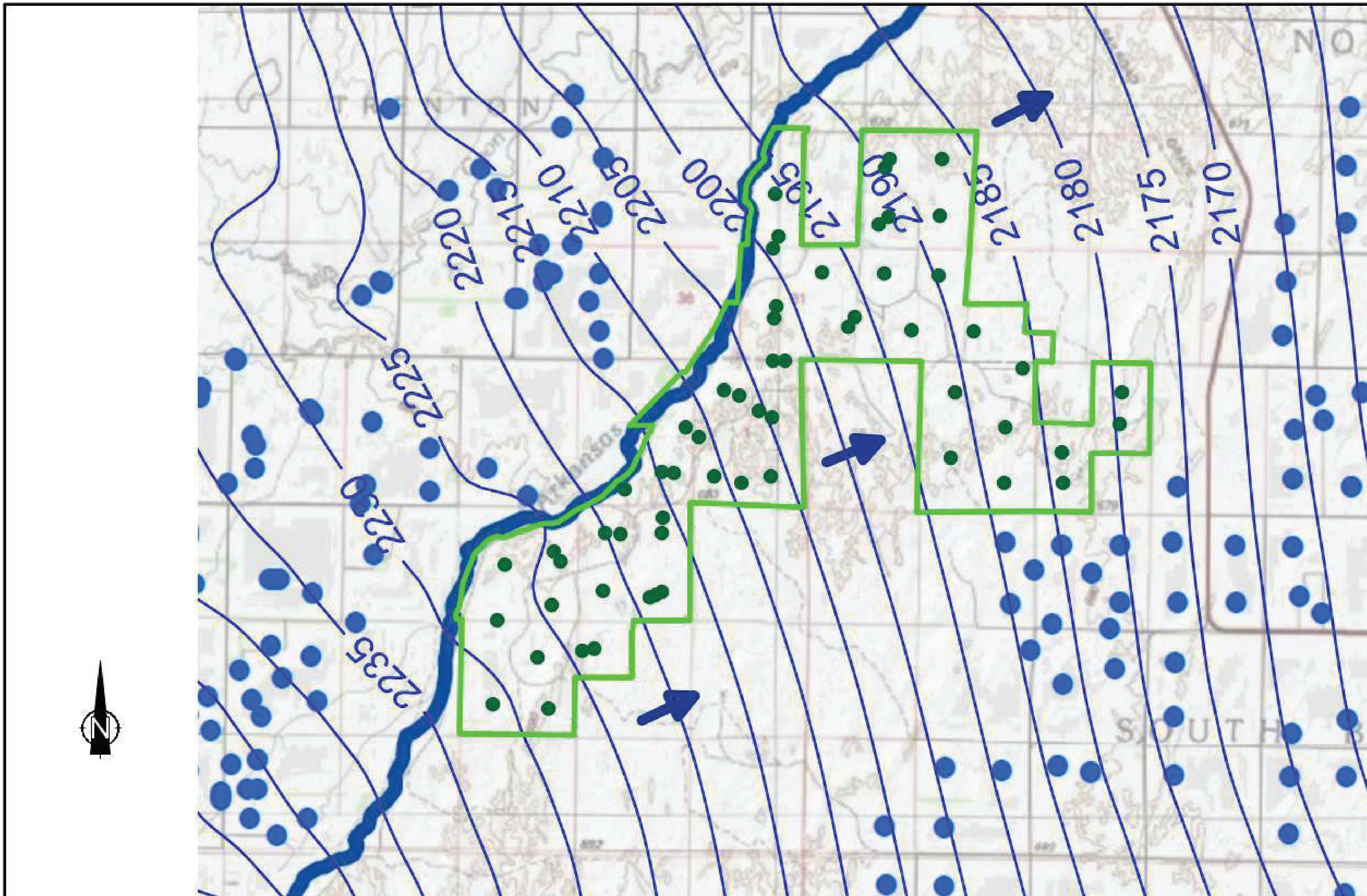
- Average recharge to the R9 Ranch was 4,732 AF/y.
- The net average volume pumped from the R9 Ranch during this period was 4,054 AF/y. Net pumping values on the R9 Ranch varied from a maximum of 6,322 to a minimum of 616 acre-AF/y.
- ET losses averaged 646 AF/y.
- The Arkansas River was in a losing condition, contributing an average of 1,579 AF/y to the aquifer.
- An average of 1,909 AF/y of groundwater flowed laterally out of the R9 Ranch.
- The volume of groundwater in storage decreased by 319 AF/y on average.

Figure 4-5 illustrates the groundwater flow conditions calculated by the 51-year predictive runs of the BGW Model for Scenario 3. Groundwater flow on the R9 Ranch is to the east northeast.

4.3.2 *Scenario 4 – Long-Term Maximum Average*

Scenario 4 is intended to predict impacts to the groundwater system on the R9 Ranch if the 14 proposed municipal wells are operated to extract the full volume of 4,800 AF/y continuously for the entire 51-year period.

This scenario used the input files generated for the BGW Model framework without any changes other than the two modifications to the Arkansas River inputs discussed in Section 4.2: removal of the upstream flow component after year 16; and holding the streambed elevation constant. The pumping inputs were also modified for this scenario by removing the R9 Ranch historic irrigation and irrigation return wells. The 14 proposed municipal wells were added and set to pump continuously at uniform rates for a total withdrawal of 4,800 AF/y. 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 on the R9 Ranch 4,793 AF/y. Figure 4-4 includes an illustration of the R9 Ranch municipal pumping modeled for this scenario.



Legend

- Groundwater Flow Direction
- Water Level Contour
- R9 Ranch Boundary
- Historic R9 Irrigation Well
- Surrounding Irrigation Well

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Hays Water Resources Department

0 1500 3000 4500 6000
Scale in Feet

Figure 4-5

Model Generated Water Levels
Scenario 3 - Long-Term Baseline
Irrigation Pumping

Table 4-4: Summary of Scenario 4 Water Budget Results & Comparison to Scenario 3

	Long-Term Scenarios[4]		
Scenario Results *Average Net Model Mass Balance Parameters*	**Scenario 3 Baseline Irrigation**	**Scenario 4 Maximum Average**	**Change Description**
Inflow to the R9 R9 aquifer system			
Recharge	4,732	4,732	No change
Stream Leakance	1,579	1,990	Volume entering the R9 increased
Total Inflow	***6,311***	***6,722***	
Outflow from the R9 R9 aquifer system			
Pumping	4,054	4,793	Volume leaving the R9 increased
Evapotranspiration	646	610	Volume leaving the R9 decreased
Lateral Groundwater Flow	1,909	1,670	Volume leaving the R9 decreased
Total Outflow	***6,609***	***7,073***	
Change in Storage[1]	**-319**	**-367**	Storage outflow increased. Volume in Storage decreased.
Remainder[2]	21	16	
Model Accuracy[3]	99.68%	99.77%	
Wells in Pumping Scenario	Irrigation & Return Wells	Proposed Municipal Wells	

All units are acre-feet per year.

[1] Negative values indicate an outflow from storage, positive values indicate water added to storage

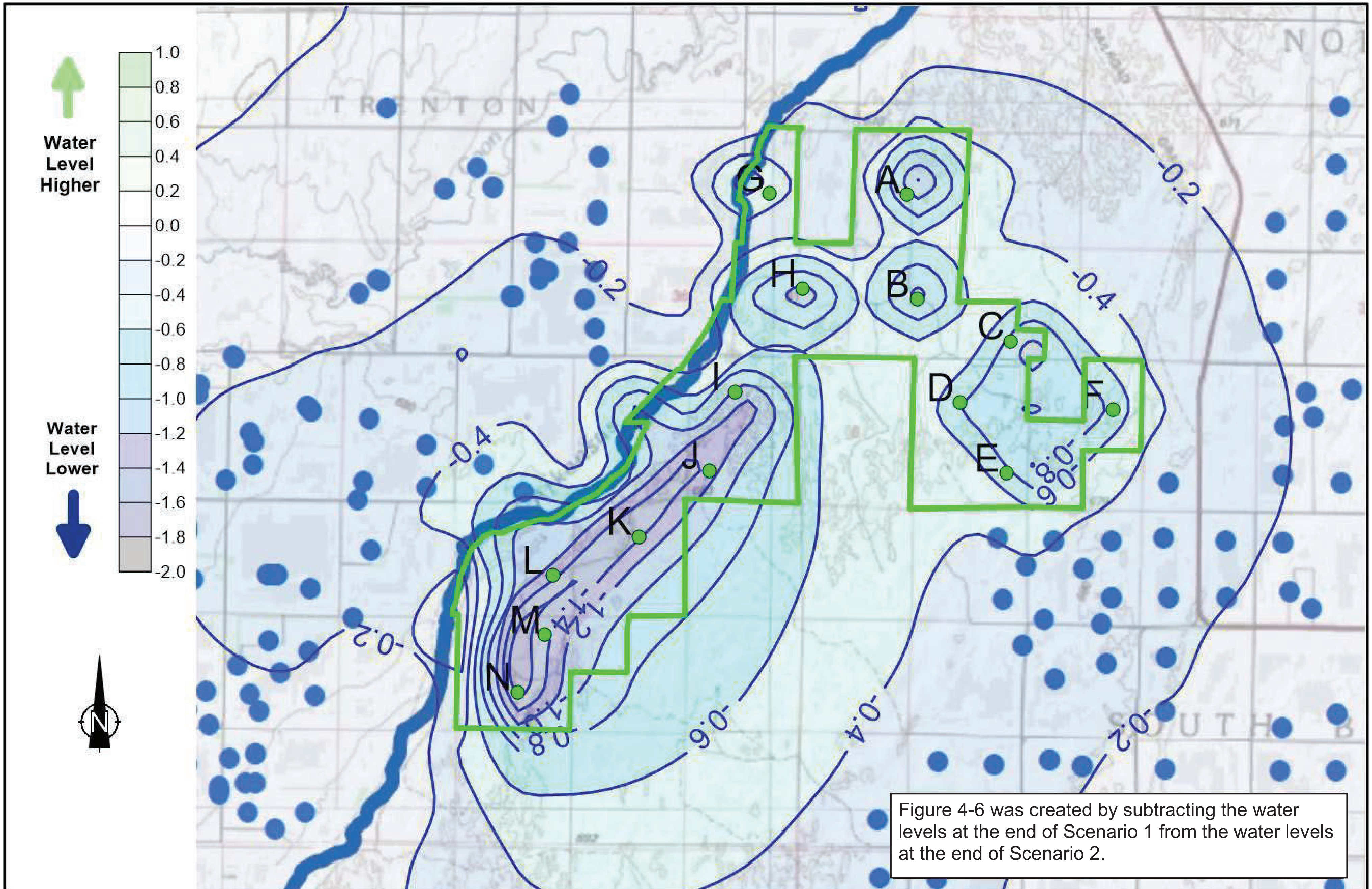
[2] Remainder is the difference between Inflow and Outflow

[3] Model Accuracy is calculated by dividing the remainder by the larger of Inflow or Outflow

[4] 1991-2007 data repeated three times. Assumes zero flow in Ark River after year 16.

Table 4-4 provides a numerical summary of the results of Scenario 4, and a comparison of those results to Scenario 3. Summarizing the individual parameters in comparison to Scenario 3:

- Recharge remained the same.
- The net average volume pumped from the R9 Ranch during this period was 739 AF/y higher than Scenario 3, on average. Net pumping values on the R9 Ranch were held constant at 4,793 AF/y throughout the simulation.
- ET losses were an average of 36 AF/y lower.
- Stream leakance was an average of 411 AF/y higher in this scenario.
- There was an average of 239 AF/y less groundwater flow leaving the R9 Ranch laterally.
- The average annual outflow from storage increased by 48 AF/y, indicating the total volume of groundwater in storage decreased.



Legend

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

BURNS McDONNELL

Hays Water Resources Department

0 1500 3000 4500 6000
Scale in Feet

Figure 4-6

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

Comparison of the results of Scenario 4 and Scenario 3 demonstrates the effects on the water table caused by pumping an average of 4,800 AF/y from municipal wells instead of from continued irrigation pumping at the documented 1991 to 2007 quantities from the R9 Ranch for a 51-year period. Figure 4-6 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 to illustrate these differences.

As can be seen in Figure 4-6, even if the Cities pumped their maximum allowable quantity of 4,800 AF/y each year for 51 consecutive years, it would only result in approximately 0.4 feet of additional drawdown at the R9 Ranch boundary in the northeast portion of the R9 Ranch as compared to irrigation pumping at 1991 to 2007 quantities. Approximately 0.8 feet of additional drawdown is seen at the southwestern border of the R9 Ranch during this same period (although no neighboring wells are in this vicinity). Drawdown contours extend across the River to the northwest because it is not as effective a hydraulic boundary when there are periods of zero surface 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 R9 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. However, the minimal irrigation pumping on that portion of the property does not reflect irrigation pumping from years prior to 1991 on the R9 Ranch, nor does it reflect the quantities approved for withdrawal for irrigation use pursuant to the Cities' water rights, which are significantly greater.

4.3.3 *Scenario 5 – Long-Term Projected Operations*

Because the Cities will not be pumping the entire quantity available for municipal use under their water rights each and every year, Scenario 5 was developed to simulate the actual projected operation of the municipal wellfield on the R9 Ranch. 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 property, 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.

Table 4-5: Summary of Scenario 5 Water Budget Results & Comparison to Scenario 3

	Long-Term Scenarios[4]		
Scenario Results *Average Net Model Mass Balance Parameters*	**Scenario 3 Baseline Irrigation**	**Scenario 5 Projected Operations**	**Change Description**
Inflow to the R9 R9 aquifer system			
Recharge	4,732	4,732	No change
Stream Leakance	1,579	410	Volume entering the R9 decreased
Total Inflow	***6,311***	***5,142***	
Outflow from the R9 R9 aquifer system			
Pumping	4,054	2,426	Volume leaving the R9 decreased
Evapotranspiration	646	488	Volume leaving the R9 decreased
Lateral Groundwater Flow	1,909	2,506	Volume leaving the R9 increased
Total Outflow	***6,609***	***5,420***	
Change in Storage[1]	**-319**	**-281**	Storage outflow decreased. Volume in Storage increased.
Remainder[2]	21	3	
Model Accuracy[3]	99.68%	99.94%	
Wells in Pumping Scenario	Irrigation & Return Wells	Proposed Municipal Wells	

All units are acre-feet per year.

[1] *Negative values indicate an outflow from storage, positive values indicate water added to storage*

[2] *Remainder is the difference between Inflow and Outflow*

[3] *Model Accuracy is calculated by dividing the remainder by the larger of Inflow or Outflow*

[4] *1991-2007 data repeated three times. Assumes zero flow in Ark River after year 16.*

As with the other predictive scenarios, this scenario used the BGW Model framework without any changes, except the two modifications discussed in Section 4.2 to the Arkansas River inputs: removal of the upstream flow component after year 16; and holding the streambed elevation constant. The pumping inputs were also modified for this scenario by removing the R9 Ranch irrigation and irrigation return wells and adding the 14 proposed municipal wells. For the operations scenario, pumping was initially distributed among proposed Wells A through H and was increased in June, July and August of each year to reflect increased demand during the hot summer months. In later years, as simulated demands increased, pumping quantities were increased and additional wells (I through N) were added to deliver the required yield. Figure 4-4 includes an illustration of the R9 Ranch municipal pumping modeled for this scenario.

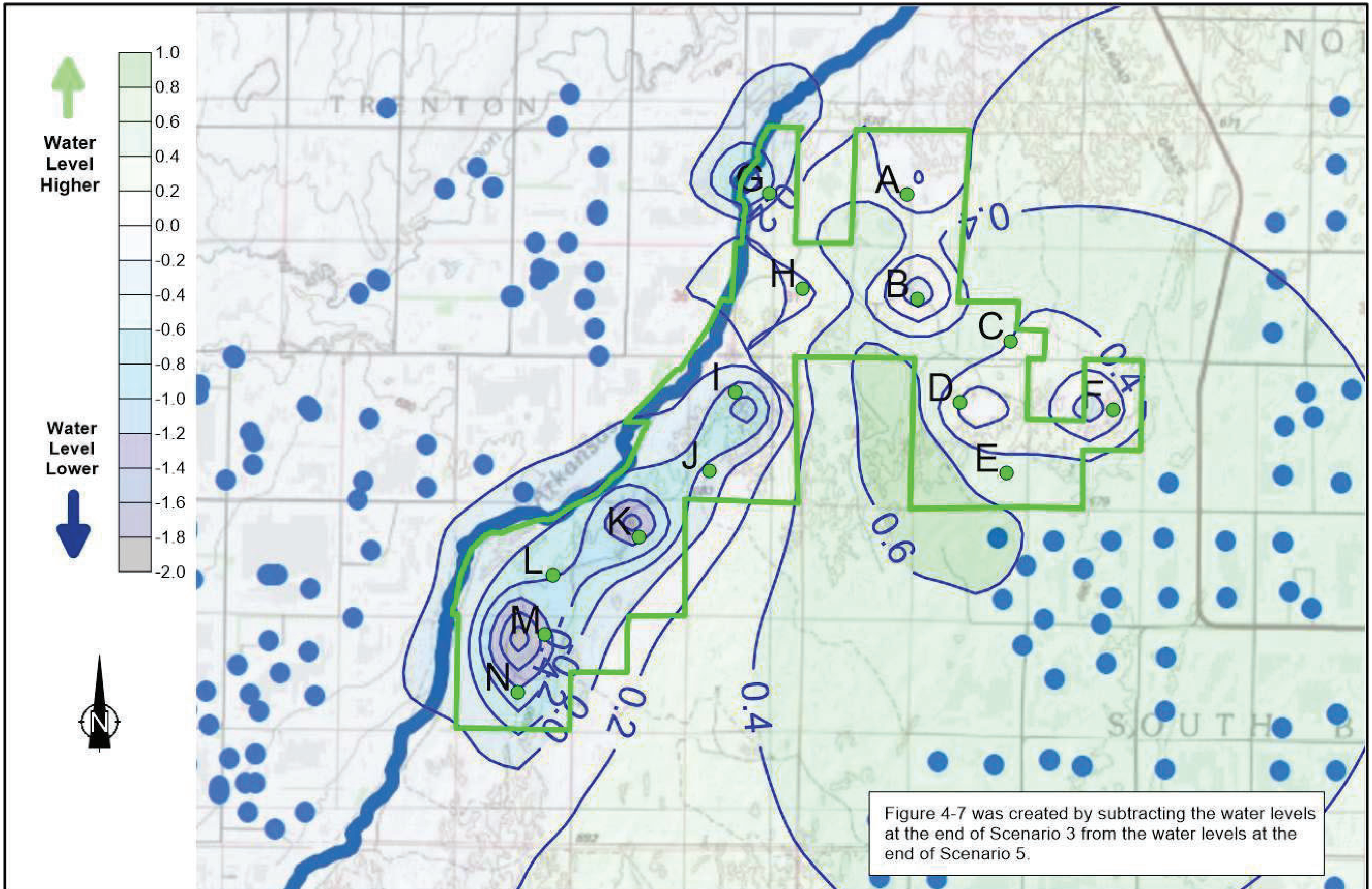
An annual average of approximately eight acre-feet of irrigation return flow per year was included from surrounding irrigator's ongoing operations, making the net average pumping 2,426 AF/y.

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

- Annual average recharge did not change.
- The average annual net quantity pumped in this scenario decreased by 1,628 AF/y. This is because the specified pumping quantities for the municipal wells was lower than the average annual irrigation rate from 1991 to 2007.
- ET decreased by an average of 158 AF/y compared to Scenario 3.
- Stream leakance decreased by an average of 1,169 AF/y.
- The volume of groundwater flow laterally leaving the R9 Ranch increased by an average of 597 AF/y.
- The outflow from storage decreased by an average of 38 AF/y, indicating the total volume of groundwater in storage was greater than it was in Scenario 3.

Figure 4-7 was created by subtracting the water levels at the end of Scenario 3 from the water levels at the end of Scenario 5. Comparison of the drawdown at the end of Scenario 5 and Scenario 3 illustrates the differences between projected municipal operations pumping from the R9 Ranch and irrigation pumping averaging 4,054 AF/y over the same time frame. As can be seen in Figure 4-7, comparing operations pumping with 1991 to 2007 irrigation pumping resulted in higher water levels over most of the R9 Ranch and surrounding area. On average, water levels were approximately 0.5 feet higher at the end of the 51-year period at the R9 Ranch boundary to the north and east.

Scenario 5 water levels are slightly lower at the southwest end of the R9 Ranch. As previously discussed, this lower water level is due to the lack of irrigation pumping in the southwest area from 1991 to 2007. The minimal irrigation pumping from 1991 to 2007 on the southwest portion of the property does not reflect irrigation pumping from earlier time periods when the southwest portion of the R9 Ranch was actively farmed and irrigated, nor does it reflect the significantly greater quantities approved for withdrawal for irrigation use by the Cities' water rights.



Legend

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

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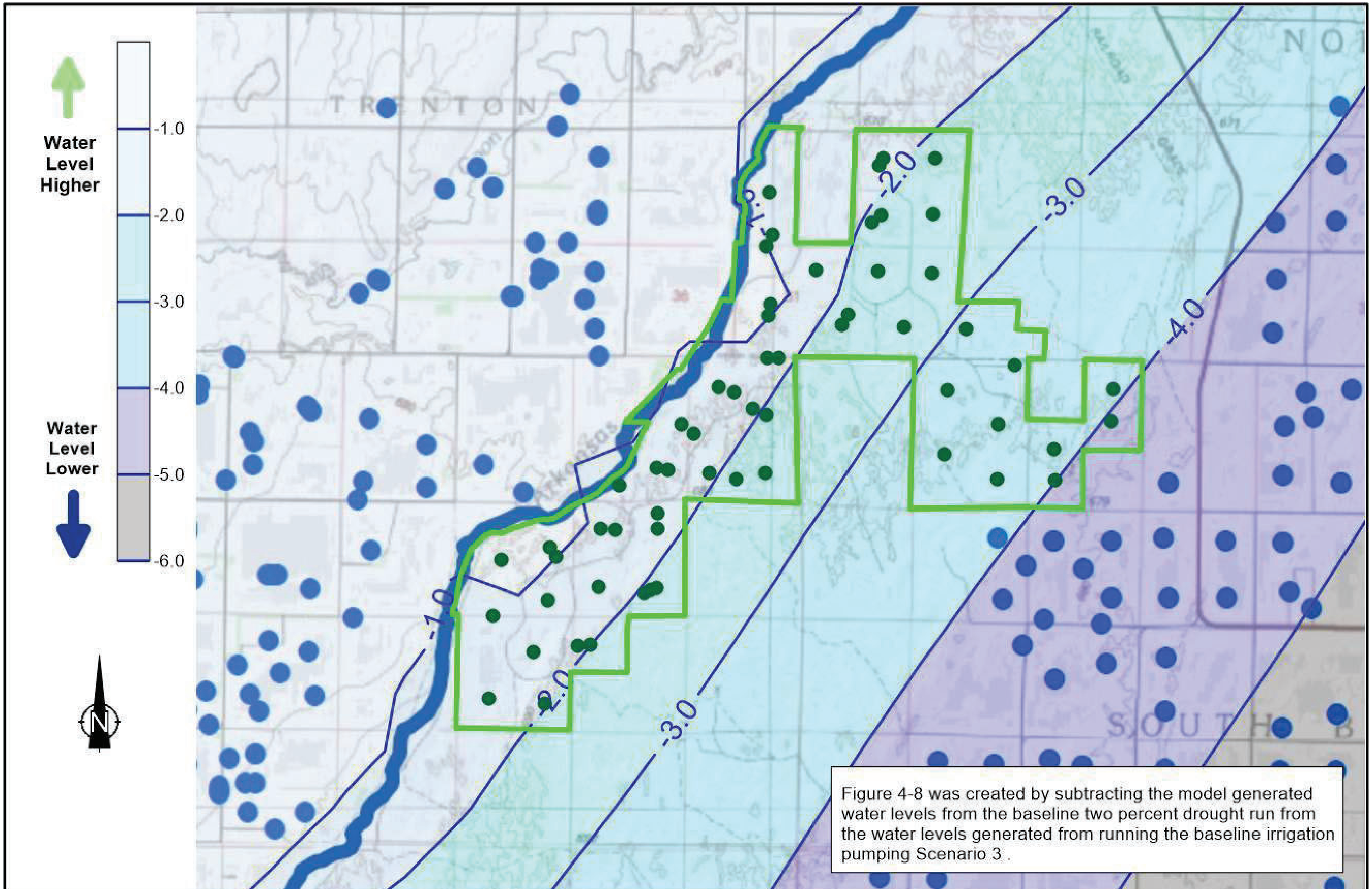
0 1500 3000 4500 6000
Scale in Feet

Figure 4-7

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

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Hays Water Resources Department

0 1500 3000 4500 6000
Scale in Feet

Figure 4-8

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

4.4 Long-Term Drought Scenarios

At DWR's request, BMcD completed an additional predictive scenario to evaluate the impact of a drought. Kansas regulations define a two-percent drought as the equivalent to the drought of record, which occurred from 1952 to 1957. To simulate a two percent drought in the 51-year runs, BMcD extracted the recharge and ET data from the BGW Model for the time periods representing 1952 through 1957 and used it in place of the recharge and ET data in the predictive run for years 35 through 39. This places the drought two-thirds of the way through the 51-year model simulation, at a point in time when projected municipal demands have increased.

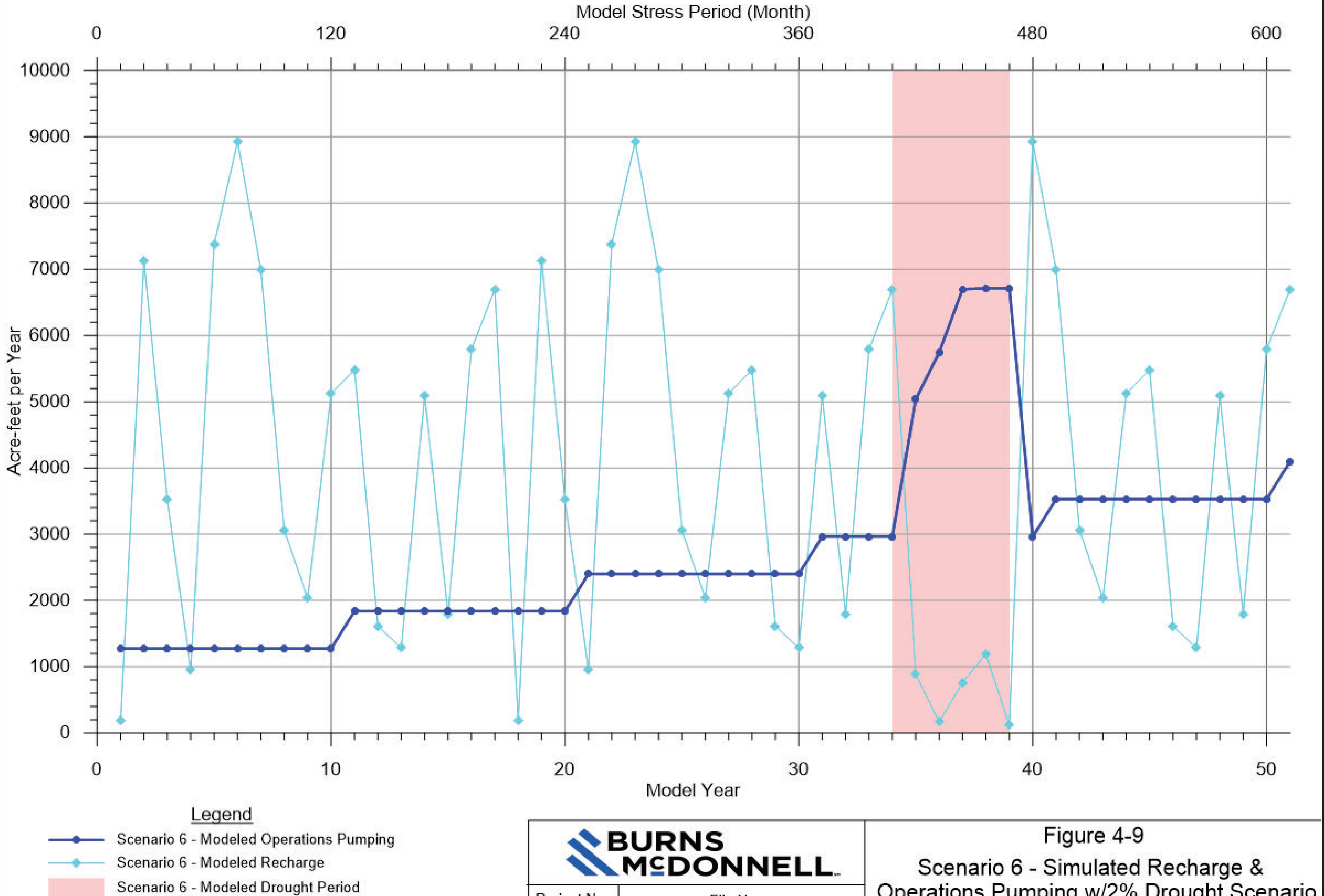
To establish a basis for comparison to the drought conditions, a 51-year run to duplicate the Long-Term Baseline Irrigation Scenario was completed utilizing the drought recharge and ET data. This run calculated baseline water levels for the area using the reduced recharge values from the simulated drought in conjunction with the documented quantities pumped for irrigation use from 1991 to 2007. Figure 4-8 was generated to illustrate the difference between the model-predicted baseline water levels from Scenario 3 with the model-predicted baseline water levels with a two percent drought at the end of the 51-year model run. As expected, adding the two percent drought conditions resulted in lower water levels throughout the area, including water levels that were over five feet lower in the area east of the R9 Ranch at the end of the 51-year period.

4.4.1 *Scenario 6 – Long-Term Operations with Two Percent Drought*

Scenario 6 was developed to simulate the potential effects of municipal water use from the R9 Ranch during a two percent drought. Figure 4-9 is a graph that shows the simulated recharge, the average pumped quantity, and highlights the period of drought for this scenario.

Scenario 6 is a 51-year model run that incorporates the two modifications to the Arkansas River inputs discussed in Section 4.2; removal of the upstream flow component after year 16, and holding the streambed elevation constant. The pumping inputs were also modified for this scenario by removing the R9 Ranch historic irrigation and irrigation return wells. The 14 proposed municipal wells were added and assigned pumping quantities similar to Scenario 5, with variations during the simulated drought.

For the operations scenario, flow was initially distributed among proposed Wells A through H. Pumping quantities were increased in June, July and August of each year to reflect increased demand during the hot summer months. In later years, as simulated demands increased, pumping rates were increased and additional wells (I through N) were added to deliver the required yield. During the drought years, pumping was increased to reflect a higher reliance on the R9 Ranch wellfield to supply water due to the



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Project No. 123193	File Name: Fig 4-9 R9 Drought Operations.gpj

Figure 4-9

Scenario 6 - Simulated Recharge & Operations Pumping w/2% Drought Scenario loss of the less drought-resilient Smoky Hill Wellfield and Big Creek sources. 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 4-6: Summary of Scenario 6 Water Budget Results & Comparison to Scenarios 3, 4 & 5

	Long-Term Scenarios[4]			
Scenario Results *Average Net Model Mass Balance Parameters*	**Scenario 3** **Baseline Irrigation**	**Scenario 4** **Maximum Average**	**Scenario 5** **Projected Operations**	**Scenario 6** **Projected Operations w/2% Drought**
Inflow to the R9 R9 aquifer system				
Recharge	4,732	4,732	4,732	4,390
Stream Leakance	1,579	1,990	410	625
Total Inflow	***6,311***	***6,722***	***5,142***	***5,015***
Outflow from the R9 R9 aquifer system				
Pumping	4,054	4,793	2,426	2,741
Evapotranspiration	646	610	488	412
Lateral Groundwater Flow	1,909	1,670	2,506	2,206
Total Outflow	***6,609***	***7,073***	***5,420***	***5,359***
Change in Storage[1]	**-319**	**-367**	**-281**	**-352**
Remainder[2]	21	16	3	8
Model Accuracy[3]	99.68%	99.77%	99.94%	99.85%
Wells in Pumping Scenario	Irrigation & Return Wells	Proposed Municipal Wells	Proposed Municipal Wells	Proposed Municipal Wells

All units are acre-feet per year.

[1] *Negative values indicate an outflow from storage, positive values indicate water added to storage*

[2] *Remainder is the difference between Inflow and Outflow*

[3] *Model Accuracy is calculated by dividing the remainder by the larger of Inflow or Outflow*

[4] *1991-2007 data repeated three times. Assumes zero flow in Ark River after year 16.*

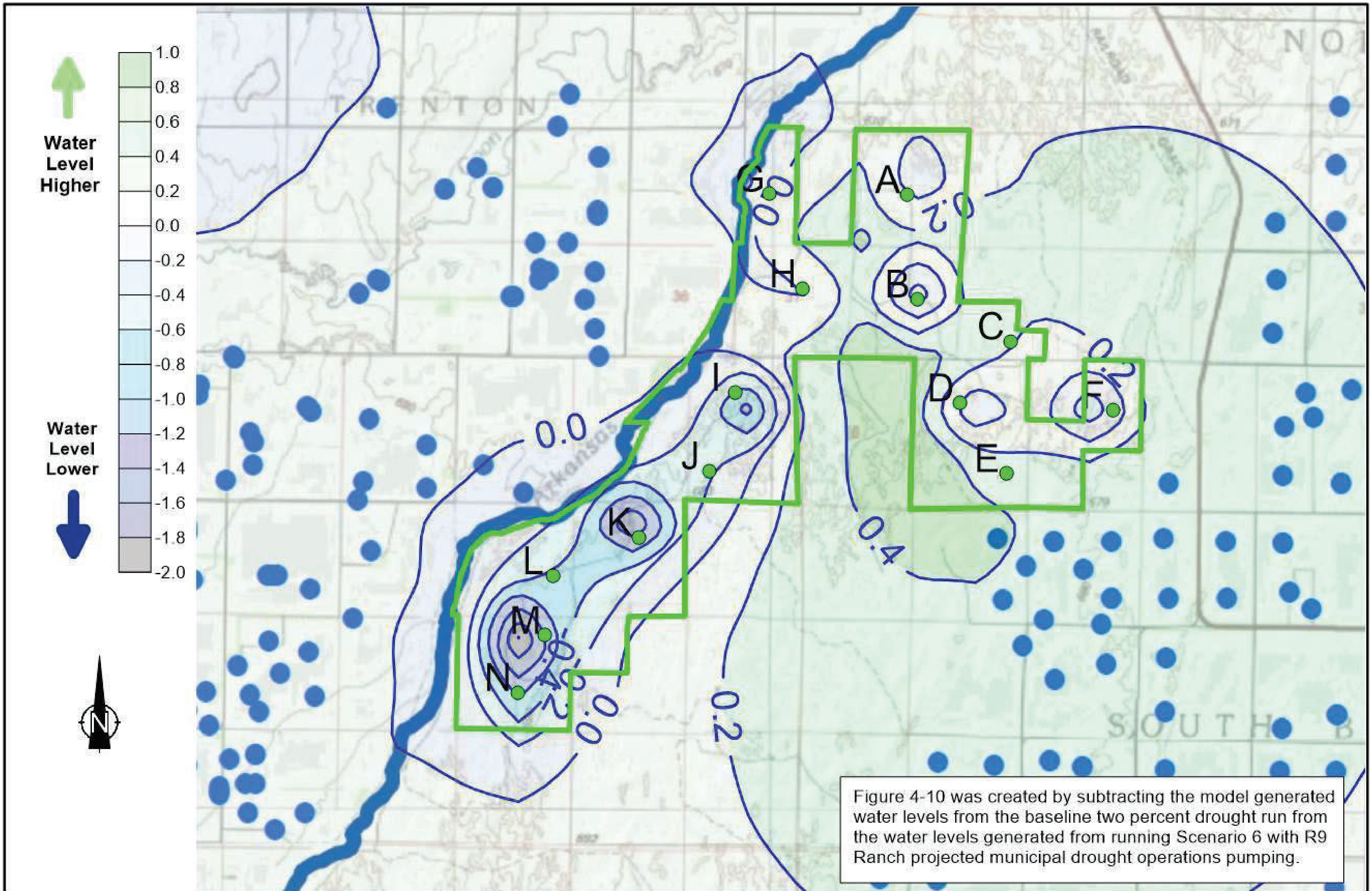
Table 4-6 provides a numerical summary comparing the results of Scenario 6 with Scenarios 3, 4 and 5. Evaluating the differences between the Scenario results:

- Recharge decreased significantly during the simulated 2% drought from years 35 through 39, resulting in an average reduction of approximately 340 AF/y for the entire period of the model.
- The average net pumping quantity of 2,741 AF/y in this scenario was lower than Scenarios 3 and 4, but higher than Scenario 5.

- Average ET losses of 412 AF/y in Scenario 6 were less than in Scenarios 3, 4, and 5.
- Stream leakance averaged 625 AF/y, indicating more water on average flowed into the River from the aquifer under the R9 Ranch than in Scenario 5, but less than in Scenarios 3 and 4.
- An average of approximately 2,206 AF/y of groundwater flowed laterally off of the R9 Ranch. This volume is less than in Scenario 5 but more than in Scenarios 3 and 4.
- The average volume taken from storage 352 AF/y, which was more than in Scenario 3 and 5, but less than in Scenario 4.

Figure 4-10 was created by subtracting the model generated water levels from the baseline two percent drought run using the documented 1991 to 2007 irrigation pumping quantities 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 4-10, drought operations pumping resulted in higher water levels throughout most of the R9 Ranch and surrounding area, compared to historic irrigation pumping water levels. Water levels were approximately 0.4 feet higher on average at the R9 Ranch boundary to the north and east at the end of the 51-year period. Water levels differences at the southwest end of the R9 Ranch are again slightly greater because recorded irrigation pumping was minimal in that area from 1991 to 2007.



Legend

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

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0 1500 3000 4500 6000
Scale in Feet

Figure 4-10

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

5.0 SUMMARY AND CONCLUSIONS

The Cities' intent in developing a municipal water supply wellfield on the R9 Ranch is to provide a long-term viable and drought-resistant raw water resource for the future. The BGW Model was developed and has been used by GMD5 and DWR for years to evaluate alternative water management scenarios like the Cities' planned use of the R9 Ranch as a municipal water source. The data and the hydrogeologic framework created for the BGW Model were used to develop short-term and long-term simulations to evaluate the proposed municipal pumping on the R9 Ranch.

The BGW Model was run using irrigation pumping from the period of 1991 to 2007 for a preliminary evaluation of the effects of municipal pumping on the R9 Ranch as compared to irrigation pumping during that timeframe. Evaluation of the water levels at various pumping rates through an iterative process resulted in a determination that 4,800 AF/y is a sustainable long-term pumping rate for municipal use. Scenario 2 verified that this rate was sustainable for a 17-year period and quantified the differences between the maximum possible municipal pumping and documented 1991 to 2007 irrigation pumping for that period. It should be noted that the quantities pumped on the R9 Ranch from 1991 to 2007 were less than the quantities diverted during the 1970s and 1980s, and more than 3,500 AF/y less than the maximum quantity permitted by the R9 Ranch irrigation water rights.

The framework and data from the 1991 to 2007 period of the BGW Model was replicated for use in predicting future water level changes over a simulated 51-year period of time. Scenarios 3, 4, 5 and 6 simulate the long-term effects of municipal pumping for this period on the water levels on the R9 Ranch as compared to documented 1991 to 2007 irrigation pumping. Pumping the proposed municipal wells at a maximum quantity of 4,800 AF/y demonstrates that a long-term average yield of 4,800 AF/y is sustainable with a reasonable change in water levels. After 51 years of continuous pumping of 4,800 AF/y, water levels at the boundary of the R9 Ranch decreased by approximately 0.4 feet as compared to irrigation pumping at 1991 to 2007 quantities. This is a change of approximately one-half of one percent of the average saturated thickness of the aquifer under the R9 Ranch.

Actual projected operations on the R9 Ranch after conversion to municipal use were modeled in Scenario 5 to simulate more realistic anticipated pumping than the maximum quantity scenario. Scenario 5 results indicate that an average reduction of more than 1,300 AF/y in pumping on the R9 Ranch, as compared to the documented 1991 to 2007 irrigation usage, will result in water levels that are approximately 0.5 feet higher at the boundary of the R9 Ranch after 51 years of pumping.

The R9 Ranch is also intended to provide drought tolerance for the Cities' water supply. Scenario 6 was included at the request of the Chief Engineer 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 caused by pumping at the projected operational rates would be approximately 0.4 feet higher at the boundary of the R9 Ranch as compared to 1991 to 2007 irrigation quantities.

Table 5-1 summarizes the mass balance water budget results from all six scenarios discussed in this Report. Comparison of the results from the various scenarios illustrates the effects of changes to the pumping, recharge, and streamflow influences and their effects on the flow from various contributing sources.

Based on the model results, 4,800 AF/y of municipal pumping was calculated to be the long-term sustainable 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.

Table 5-1: Modeled Scenarios Water Budget Summary

Scenario Results *Average Net Model Mass Balance Parameters*	Short-Term Scenarios: Scenario 1 Baseline Irrigation	Short-Term Scenarios: Scenario 2 Maximum Average	Long-Term Scenarios[4]: Scenario 3 Baseline Irrigation	Long-Term Scenarios[4]: Scenario 4 Maximum Average	Long-Term Scenarios[4]: Scenario 5 Projected Operations	Long-Term Scenarios[4]: Scenario 6 Projected Operations w/2% Drought
Inflow to the R9 R9 aquifer system						
Recharge	4,732	4,732	4,732	4,732	4,732	4,390
Stream Leakance	1,313	1,766	1,579	1,990	410	625
Total Inflow	***6,045***	***6,498***	***6,311***	***6,722***	***5,142***	***5,015***
Outflow from the R9 R9 aquifer system						
Pumping	4,054	4,793	4,054	4,793	2,426	2,741
Evapotranspiration	1,098	1,074	646	610	488	412
Lateral Groundwater Flow	1,346	1,157	1,909	1,670	2,506	2,206
Total Outflow	***6,498***	***7,024***	***6,609***	***7,073***	***5,420***	***5,359***
Change in Storage[1]	**-465**	**-553**	**-319**	**-367**	**-281**	**-352**
Remainder[2]	12	27	21	16	3	8
Model Accuracy[3]	99.82%	99.62%	99.68%	99.77%	99.94%	99.85%
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] *Negative values indicate an outflow from storage, positive values indicate water added to storage*

[2] *Remainder is the difference between Inflow and Outflow*

[3] *Model Accuracy is calculated by dividing the remainder by the larger of Inflow or Outflow*

[4] *1991-2007 data repeated three times. Assumes zero flow in Ark River after year 16.*

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