BURNS McDONNELL

Groundwater Flow Model Report
Cimarron Remediation Site

Cimarron Environmental Response Trust

Project No. 142089

Revision 0
10/7/2022

Groundwater Flow Model Report
Cimarron Remediation Site

prepared for

Cimarron Environmental Response Trust

Crescent, Oklahoma

Project No. 142089

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prepared by

Burns & McDonnell Engineering Company, Inc.
Enter City, State of Office Location

TABLE OF CONTENTS

EXECUTIVE SUMMARY

LIST OF TABLES

LIST OF FIGURES

Page No.

LIST OF ABBREVIATIONS

Abbreviation	Term/Phrase/Name
ARM	Absolute Residual Mean
BA1	Burial Area #1
Burns & McDonnell	Burns & McDonnell Engineering Company, Inc.
EPM	Environmental Properties Management LLC
ft	Feet
ft/day	Feet per Day
GHB	MODFLOW General Head Boundary
GPM	Gallon per Minute
K	Hydraulic Conductivity
MNW2	MODFLOW Multi-Node Well package
RMS	Root Mean Square
Site	Cimarron Site
Trust	Cimarron Environmental Response Trust
U>DCGL	Uranium Greater Than the DCGL Area
VDU	Vertical Distribution of Uranium
WAA	Western Alluvial Area

1.0 INTRODUCTION

On behalf of Environmental Property Management LLC (EPM), Trustee for the Cimarron Environmental Response Trust, Burns & McDonnell Engineering Company, Inc. (Burns & McDonnell) submits this 2022 Groundwater Flow Model Report for the Cimarron site (the Site), located at 100 N. Highway 74, Guthrie, Oklahoma. During this report existing groundwater flow models were updated to evaluate groundwater remediation alternatives for the Western Alluvial Area (WA) and Burial Area #1 (BA1) located on the Site.

The WAA and BA1 groundwater models were originally developed in 2006 (ENSR October, 2006), and have been periodically updated to reflect newly available data and various remedial alternatives:

- Groundwater Flow Modeling Report (ENSR October, 2006)
- Groundwater Flow Model Update, (Burns & McDonnell, 2014)
- 2016 Groundwater Flow Model Update (Burns & McDonnell, 2017a).
- 2020 Groundwater Flow Model Review (Burns & McDonnell, 2020)

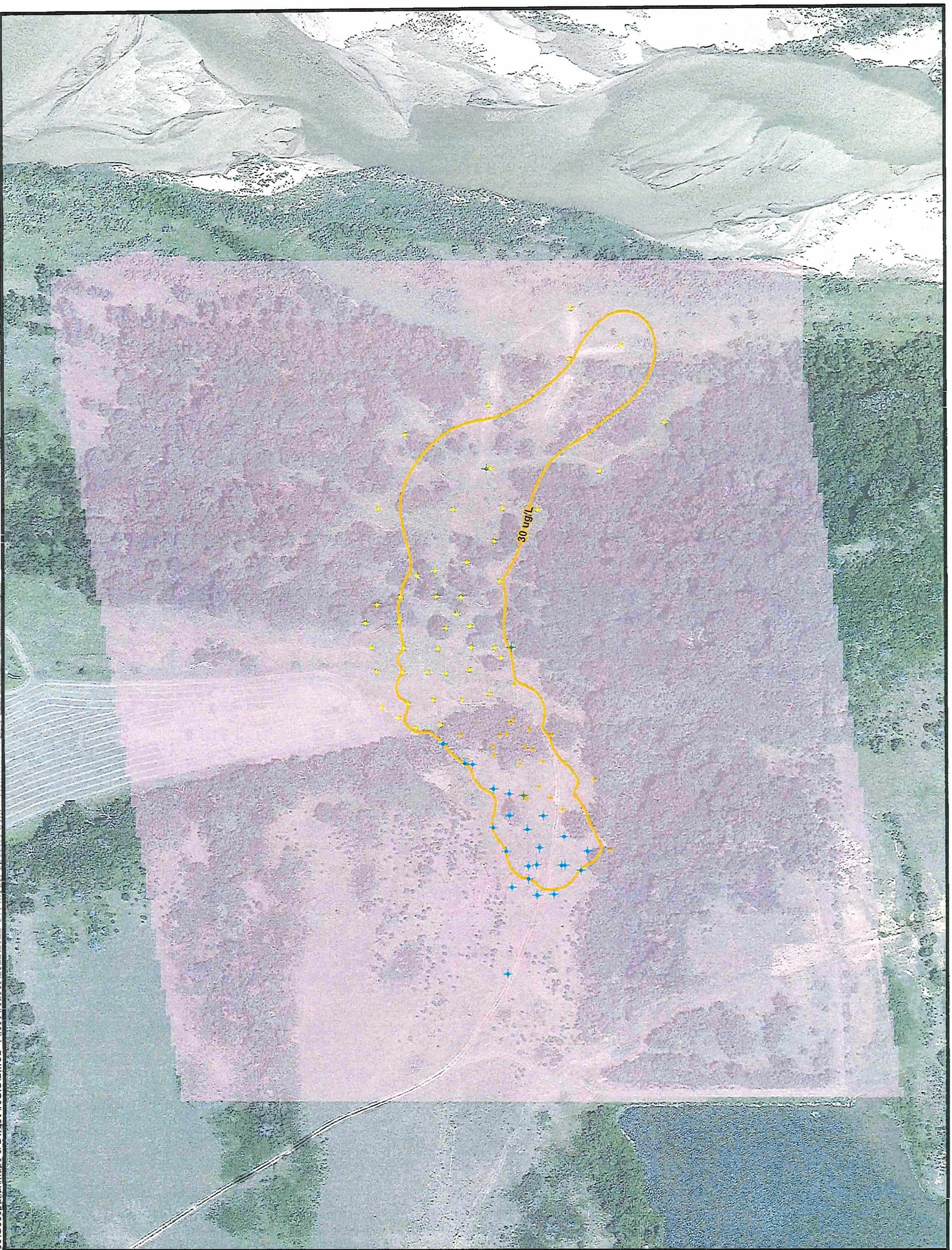
The purpose of this report is to document the construction, calibration, and remedial alternative simulations of the WAA groundwater flow model and the BA1 groundwater flow model in support of the Site Facility Decommissioning Plan (Revision 3). Consistent with previous iterations of the CERT groundwater models, MODFLOW-2000 (Harbaugh et al., 2000), a three-dimensional, finite difference groundwater flow computer code, was used for the update to the groundwater models. Model construction and the evaluation of model-predicted output were completed using Groundwater Vistas Version 8. Groundwater Vistas® is a pre- and post-processing software package that was used to create standard format MODFLOW file sets from graphically input data. Model outputs were evaluated using Groundwater Vistas®, ArcGIS Pro® (ESRI) and Microsoft Office programs. Groundwater Vistas was used to provide contoured model-predicted results (model predicted heads and drawdown) and numerical data output. Additional data contouring and evaluation was completed using ArcGIS Pro®. All model units for length are in feet, and all model units for time are in days.

2.0 BA1 GROUNDWATER FLOW MODEL CONSTRUCTION

The BA1 2020 Groundwater Flow Model Review (Burns & McDonnell, 2020) was used as the starting point for revisions of the BA1 groundwater flow model documented in this report. The two improvements made to the BA1 2020 Groundwater Flow Model include decreasing the uniform cell size from ten feet to five feet and updates to the distribution of lithology zones. A reduction in cell size was performed to allow for more accurate analysis of groundwater flow near boundary conditions such as infiltration and extraction trenches. The second improvement included updates of lithology zones and associated hydraulic conductivity within the valley of the BA1 transition zone. The Environmental Sequence Stratigraphy (ESS) and Porosity Analysis (Burns & McDonnell, 2018) was used as the basis for an improved representation of varying lithology and specifically the isolated sand channels within the BA1 transition zone.

2.1 Groundwater Model Domain

The same model domain of the BA1 2020 Groundwater Flow Model Review (Burns & McDonnell, 2020) was used for reconstruction of the groundwater flow model in this report (Figure 2-1). The northern extent of the model domain intersects the boundary of the Cimarron River. Groundwater flow is primarily northward toward the Cimarron River. The eastern and western extents of the model domain were developed at adequate distance to limit impact to flow fields within the BA1 transition area. The southern extent of the model boundary was selected to be upgradient of the BA1 transition area and is oriented along an east-west line approximately parallel to the Reservoir #2 dam (ENSR, 2006).



LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- ACTIVE MODEL DOMAIN

NOTES

1) GROUNDWATER ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (NORTH AMERICAN VERTICAL DATUM OF 1988).

2) BASEMAP: GOOGLE EARTH 2017

0 230 460
SCALE IN FEET

N

FIGURE 2-1
BA1 GROUNDWATER FLOW MODEL
ACTIVE MODEL DOMAIN
SITE FACILITY DECOMMISSIONING PLAN
(REVISION 3)

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environmental properties management, LLC

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2.2 Groundwater Model Discretization

The BA1 2020 Groundwater Flow Model Review (Burns & McDonnell, 2020) was used as the starting point for revisions to the BA1 groundwater flow model documented in this report. The BA1 2020 Groundwater Flow Model (Burns & McDonnell, 2020) featured a uniform square cell size of ten feet by ten feet. Re-discretization to a smaller uniform square cell size of five feet by five feet was achieved by splitting each ten feet by ten feet MODFLOW cell into four equal cells. The revised grid model domain consists of 340 rows, 340 columns, 12 layers, 1,387,200 total cells, and 1,126,246 active cells. ArcGIS Pro was utilized to assign the properties of the higher-resolution model grid based upon a spatial location match to the attributes of the BA1 2020 Groundwater Flow Model (Burns & McDonnell, 2020). This approach allowed for model re-discretization while maintaining established layer geometry (layer top and bottom elevations), boundary conditions, and hydrogeologic attributes (hydraulic conductivity, porosity) from the active model domain of the BA1 2020 Groundwater Flow Model (Burns & McDonnell, 2020).

2.3 Groundwater Model Layering

Twelve layers are used to simulate the geology of the BA1 area. The upper eight model layers are generally used to simulate the alluvial aquifer, which is approximately 20 feet thick in most of the model domain, and the lower four layers primarily contain bedrock with lower permeability. The model layers are generally uniform with individual layer thicknesses typically between two to three feet. No adjustments were made to the number of layers or model layer elevations within the active model domain during this model update. The original model layering system setup is further described in the 2006 Groundwater Flow Modeling Report (ENSR, 2006).

2.4 Model Perimeter Boundary Conditions

Model perimeter boundary conditions are used to simulate the conceptual flow into and out of the model domain along the outer perimeter of the active model domain. Model perimeter boundary conditions were developed to mirror those implemented in the BA1 2020 Groundwater Flow Model (Burns & McDonnell, 2020) and include the use of no flow cells, the MODFLOW river package, and general head boundaries. The location of model perimeter boundary conditions is illustrated in (Figure 2-2).

2.4.1 No Flow Boundaries

Outside of the active domain are no flow cells that define the western and eastern boundary of the model domain. Starting water levels for all steady-state model solutions were assigned as being one foot below the top of model Layer 1. The high starting water levels allow for the MODFLOW steady-state solution to start cells within the active model domain as saturated and therefore active. Model cells will then remain active unless calculated by MODFLOW to be dry during a final solution.

LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS
- ACTIVE MODEL DOMAIN

NOTES

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0 230 460

SCALE IN FEET

N

FIGURE 2-2
BA1 GROUNDWATER MODEL
PERIMETER BOUNDARY CONDITIONS
SITE FACILITY DECOMMISSIONING PLAN
(REVISION 3)

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2.4.2 General Head Boundaries

General Head Boundaries (GHB) were utilized to simulate upgradient flux into the aquifer along the southern extent of the model domain and model Layer 12 consistent with previous the BA1 2020 Groundwater Flow Model (Burns & McDonnell, 2020). The assigned head and conductance terms assigned to general head boundaries within the model are equal to the BA1 2020 Groundwater Flow Model (Burns & McDonnell, 2020).

2.4.3 River Boundaries

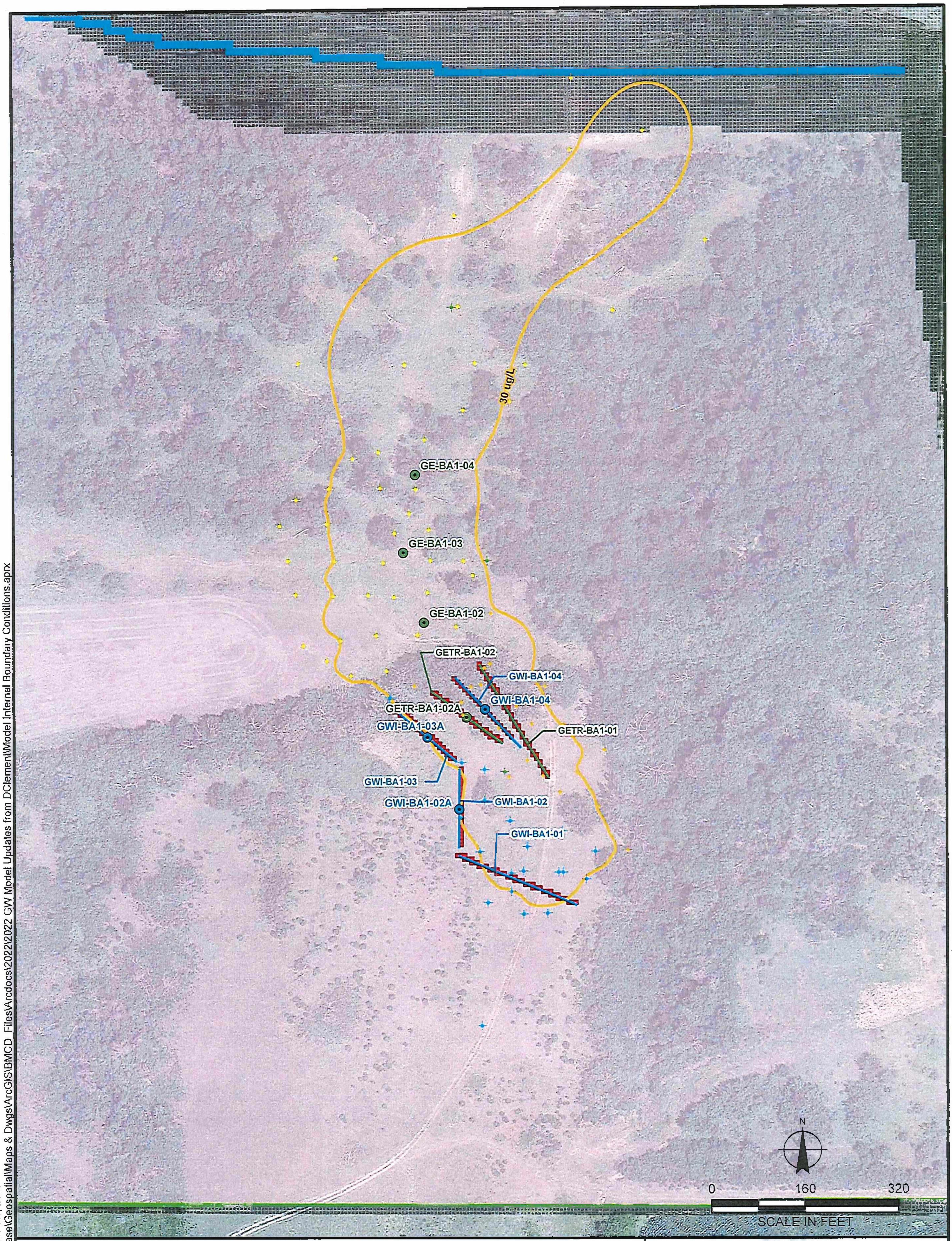
The river package was used to simulate the surface water and groundwater interaction of the Cimarron River as a regional groundwater discharge point within model layers 3 through 6. River boundary cells are based upon the location of river cells within the 2020 BA1 Groundwater Flow Model. Values for assigned river heads, boundary conductance, and riverbed elevation were also maintained at those established by the 2020 BA1 Groundwater Flow Model (Burns & McDonnell, 2020).

2.5 Internal Model Boundary Conditions

Internal model boundary conditions are used to simulate internal sources and sinks including recharge, remedial infiltration trenches, remedial extraction trenches, and pumping wells (Figure 2-3).

2.5.1 Aquifer Recharge

Recharge to groundwater is simulated using the MODFLOW recharge package. The recharge package is used to represent the fraction of precipitation that enters the subsurface as rainfall recharge directly to the groundwater table. The model domain is small enough that significant variability in precipitation is not anticipated, therefore recharge is applied uniformly across the model domain. For the steady-state simulation of groundwater flow the recharge package was used to apply a uniform constant recharge rate of 2.4 inches per year (approximately 8% of annual precipitation) consistent with previous steady-state model values (ENSR, 2006) (Burns & McDonnell, 2020).



LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- EXTRACTION WELL/SUMP
- INJECTION WELL
- GROUNDWATER EXTRACTION TRENCH
- GROUNDWATER INJECTION TRENCH
- BA1 URANIUM CONTOUR (30 UG/L)
- ACTIVE MODEL DOMAIN
- GENERAL HEAD BOUNDARY CELLS
- RIVER BOUNDARY CELLS
- NO FLOW BOUNDARIES
- TRENCH MODEL CELLS

NOTES

1) GROUNDWATER ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (NORTH AMERICAN VERTICAL DATUM OF 1988).

2) BASEMAP: GOOGLE EARTH 2017

FIGURE 2-3
BA1 GROUNDWATER FLOW MODEL INTERNAL BOUNDARY CONDITIONS
SITE FACILITY DECOMMISSIONING PLAN
(REVISION 3)

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2.5.2 Groundwater Wells MNW2 Well Package

The updated groundwater model simulates extraction wells with discrete, short screen intervals, using the Multi-Node Well (MNW2) Package (Konikow, et. al. 2009). In the MNW2 Package, a single well screen can occur at any position within a model layer if the user specifies the elevation of the top and bottom of the well screen. The MNW2 package uses the specified top and bottom of the screen intervals to distribute the prescribed well pumping rate within the cell and to calculate the additional head loss in the pumping well that occurs due to partial penetration effects. All extraction wells simulated in the BA1 model were simulated with ten-foot screen sections.

2.5.3 Injection and Extraction Trenches

The Site Facility Decommissioning Plan (Revision 3) includes several proposed groundwater injection and extraction trenches. Injection and extraction trenches were simulated utilizing the MODFLOW well package by assigning individual well boundary conditions to model cells which overlapped the linear extent of each infiltration or extraction trench. Injection or extraction rates were then assigned to individual cells based upon the total simulated flow rate for the trench, divided by the number of cells in the well package simulating each trench.

2.6 Injection and Extraction Trenches

The hydrogeologic properties specified within the model are horizontal hydraulic conductivity (K_{xy}), vertical hydraulic conductivity (K_z), and porosity. All modeling simulations were run under steady-state conditions, which do not require specification of aquifer storage coefficients (specific storage or specific yield).

Hydraulic conductivity is a measure of a material's capacity to transmit water and is defined as a constant of proportionality relating the specific discharge of a porous medium under a unit hydraulic gradient. The units for hydraulic conductivity within this report are provided as feet per day (feet/day). Hydraulic conductivity values are required to describe the permeability of each cell in the MODFLOW model. The BA1 model represents a complicated layering system of unconsolidated deposits underlain by semi-permeable bedrock (ENSR, 2006). The distribution of hydraulic conductivity within the model is based upon hydraulic conductivity zones which correlate to a specific lithology type.

Distribution of hydraulic conductivity values for this model update began with utilizing values established by the 2020 BA1 Groundwater Flow Model (Burns & McDonnell, 2020). The intended use of this model update is additional examination of groundwater flow and transport conditions, specifically within the BA1 transition zone under the remedial conditions of the Site Facility Decommissioning Plan (Revision 3). In 2018 an ESS and porosity analysis (Burns & McDonnell, 2018) was performed which developed a high-resolution three-dimensional interpretation of the lithology within the BA1 transition zone (Appendix B). This ESS analysis included three-dimensional interpolation of specific lithology zones which include:

- Cimarron River Floodplain Deposits – Clay, silt, and interbedded fine-grained sand corresponding to floodplain deposits of the Cimarron River. Includes sands as overbank splays deposited during flood-stages.
- Cimarron River Channel Deposits – Fine to coarse grained, cross-bedded sand deposited as point-bars by the Cimarron River.
- Cimarron River Clay Plug Deposits: Clay and silt with some thin sands, deposited in abandoned stretches of Cimarron River channels (oxbow lakes).
- Upper Gully Fill - Silt and silty sand with interbedded clayey sand and silty sand deposited as gully-wash by streamflow during flash flood events. Contains minor sand-rich streamflow deposits.
- Lower Gully Fill: Clay-rich deposits including gully-wall failure (slump, slide, and debris-flow) features. Chaotic, may include minor re-worked streamflow deposits.
- Intra-gully Stream Deposits: Sand and silty sand deposited by streamflow within gully system.
- Garber Sandstone Bedrock (undifferentiated).

Using ArcGIS Pro® and Groundwater Vistas 8®, the three-dimensional distribution of lithology zones within the ESS model was incorporated into the groundwater model using a nearest neighbor merge of the MODFLOW cell nodes to the three-dimensional ESS lithology coverage. Each of the unconsolidated sediment lithologies defined by ESS was assigned a distinct zone within the model so that model hydraulic conductivity and porosity attributes are grouped by lithology zone. The final distribution of lithology zones is provided within Table 2-1 and illustrated within Appendix A.

Table 2-1: Model Lithology Zones and Hydrogeologic Properties

Lithology	Groundwater Model Lithology Zone Number	K_x	K_y	K_z	Porosity
Cimarron River Floodplain Deposits Clay/Silt traces sand	101	3	3	0.3	0.2
Cimarron River Deposits - Upper Alluvial Aquifer Sands	2 and 102	117.5	117.5	11.75	0.3
Cimarron River Deposits - Lower Alluvial Aquifer Sands	12	352.5	352.5	35.25	0.3
River Clay Plug Deposits	103	2.77	2.77	0.277	0.2
Uppermost Gulley Fill Unit	5	1.28	1.28	0.128	0.2
Upper Gully Fill	104	15	15	1.5	0.2
Lower Gully Fill	105	3	3	0.3	0.2
Intra Gully Stream Deposits (Sand Body)	106	50	50	5	0.3
Clay	10	0.5	0.5	0.05	0.2
Silt	3	0.283	0.283	0.0283	0.2
Siltstone	6, 8, and 9	8.43	8.43	0.422	0.01
Sandstone A	4	40	40	2	0.05
Sandstone B	7	5	5	0.25	0.05
Sandstone C	11	3	3	0.15	0.05

3.0 BA1 GROUNDWATER FLOW MODEL CALIBRATION

After updating model discretization and lithology zones, validation of model calibration was evaluated by comparing observed and simulated groundwater elevations, groundwater flow contours, and water budgets. The calibration goals for the numerical model are based upon industry standards and previous BA1 modeling efforts which are defined as:

- A less than one (1) percent water balance error, which is considered appropriate for a calibrated groundwater model (Anderson and Woessner, 1992). The water balance error is defined as the total inflow minus the total outflow, divided by either the inflow or outflow, whichever yields the highest error.
- A Normalized Root Mean Square error (NRMS) of less than ten (10) percent. A NRMS of less than ten (10) percent is generally considered appropriate for a calibrated groundwater model (Anderson and Woessner, 1992). A lower NRMS indicates a better statistical model calibration.
- An Absolute Residual Mean (ARM) of less than ten percent the observed head change value across the model domain. The ARM can be described as the average error of the absolute value of the residuals.
- A qualitative match of model simulated potentiometric surface and observed potentiometric surface, evaluated by visually comparing contours. When calibrated, the model should be able to reproduce the direction and magnitude of the hydraulic gradient observed within the boundary.

3.1 Verification of Model After Grid Re-Discretization

The groundwater flow model was updated to a smaller uniform square grid cell size of five feet by five feet. Prior to any other model changes, the calculated groundwater heads from the updated grid model were then compared to the heads obtained from the 2020 groundwater flow model. The comparison found that the heads in the updated grid model and the 2020 groundwater flow model were nearly identical. The near identical heads confirm that model grid refinement and the re-import of model attributes did not significantly influence model calibration.

3.2 Simulated versus Observed Groundwater Heads

As documented in the model construction portion of this report, updates to the distribution of lithology zones were completed after refinement of the groundwater model grid. After completing the modifications to the distribution of lithology zones, water level measurements collected in August 2016 were compared to the model calculated head values. The calibration data set and the model calculated heads reflect non-pumping conditions prior to implementation of any remedial alternatives. The calibration dataset included 68 wells with a range in observed water level elevations of 17.48 feet. The model simulated heads and observed heads used for the calibration dataset are within Table 3-1.

The calibration statistics for the updated model indicate a mass balance error of 0.0012 percent, NRMS of 0.059 (5.9 percent), and ARM of 0.64 feet which meet the established model calibration goals. As an additional evaluation for the model calibration, the simulated versus observed groundwater level data for the calibrated steady state model is provided as Figure 3-1 and indicates a good fit between simulated and observed head data. The resulting flow field of the calibrated groundwater model and distribution of residuals are illustrated Figure 3-2. The updated model calibration is an improvement of the calibration statistics from the 2016 Groundwater Flow Model Update which achieved a NRMS of 0.069 (6.9 percent) and ARM of 0.7 feet (Burns & McDonnell, 2017a).

Figure 3-1: 2022 BA1 Calibrated Steady State Model – Modeled vs Observed Heads (feet)

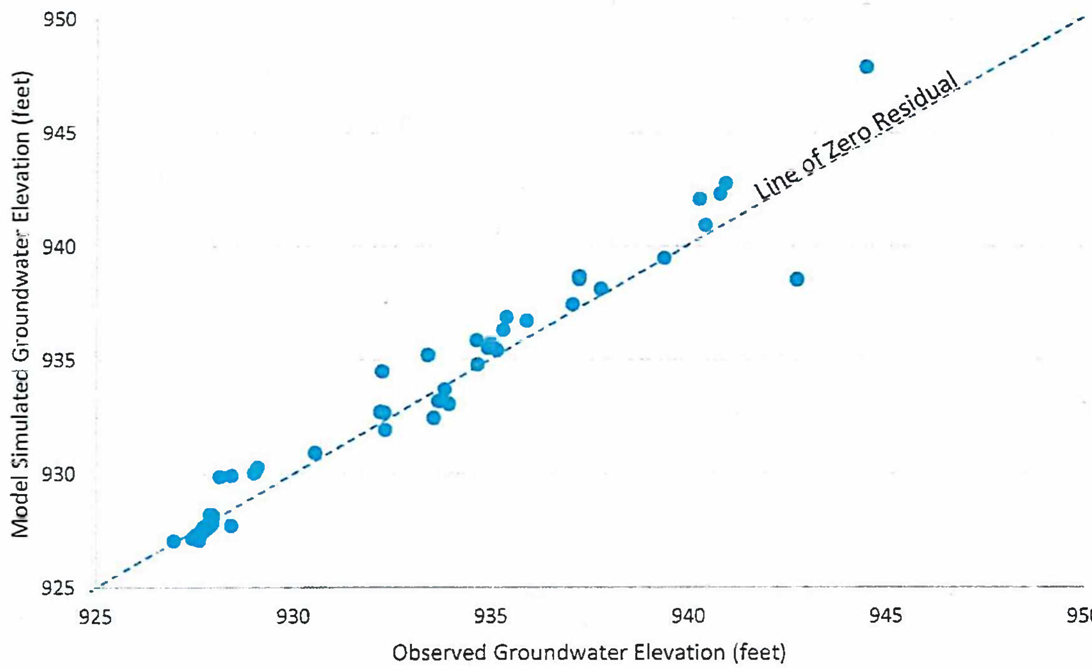


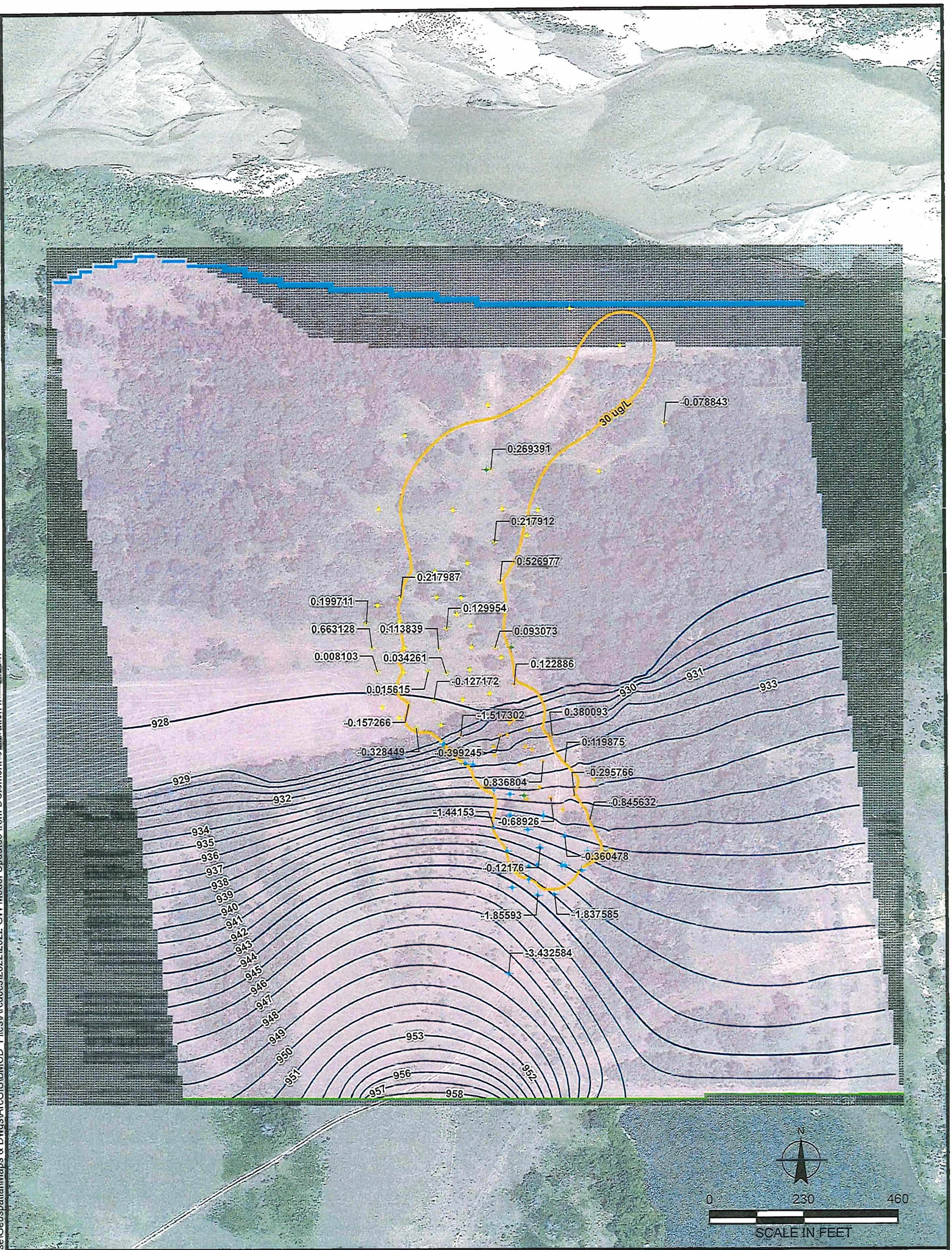
Table 3-1: Model Computed versus Observed Heads

Observation Well Name	X Coordinate	Y Coordinate	Model Layer	Observed Head (ft)	Computed Head (ft)	Residual (ft)
02W02	2095455	322885	6	930.53	930.93	-0.40
02W03	2095375	322885	5	928.42	929.94	-1.52
02W04	2095335	322905	6	927.88	928.24	-0.36
02W05	2095315	322955	5	927.88	928.01	-0.13
02W06	2095305	323005	7	927.87	927.85	0.02
02W07	2095345	323005	7	927.87	927.84	0.03
02W08	2095395	323015	7	927.85	927.78	0.07
02W09	2095595	322765	6	935.13	935.43	-0.30
02W10	2095575	322825	6	933.81	933.69	0.12
02W11	2095445	323055	8	927.74	927.65	0.09
02W12	2095455	323035	8	927.73	927.68	0.05
02W13	2095475	322985	8	927.93	927.81	0.12
02W14	2095395	323055	8	927.76	927.68	0.08
02W15	2095285	322895	5	927.91	928.24	-0.33
02W16	2095265	322945	6	927.90	928.06	-0.16
02W17	2095255	323005	7	927.86	927.87	-0.01
02W18	2095345	323095	8	927.74	927.61	0.13
02W19	2095325	323055	7	927.82	927.71	0.11
02W21	2095195	323055	8	928.41	927.75	0.66
02W22	2095215	322935	6	927.89	928.10	-0.21
02W23	2095205	323005	8	927.89	927.88	0.01
02W24	2095265	323055	8	927.83	927.73	0.10
02W26	2095625	322715	5	935.88	936.73	-0.85
02W27	2095395	322825	6	932.18	932.72	-0.54
02W28	2095535	322835	6	933.91	933.07	0.84
02W29	2095555	322755	5	934.99	935.68	-0.69
02W30	2095475	322765	7	934.91	935.52	-0.61
02W31	2095505	322855	6	933.53	932.45	1.08
02W32	2095435	322965	7	927.87	927.90	-0.03
02W33	2095255	322915	6	927.96	928.16	-0.20
02W34	2095185	323105	8	927.84	927.64	0.20
02W35	2095255	323155	8	927.75	927.53	0.22
02W36	2095255	323105	8	927.78	927.62	0.16
02W37	2095325	323155	7	927.69	927.51	0.18
02W38	2095395	323095	8	927.70	927.59	0.11
02W39	2095575	322735	5	935.29	936.32	-1.03
02W40	2095525	322665	7	939.37	939.49	-0.12
02W41	2095575	322685	6	937.77	938.13	-0.36

Observation Well Name	X Coordinate	Y Coordinate	Model Layer	Observed Head (ft)	Computed Head (ft)	Residual (ft)
02W42	2095475	322725	7	937.06	937.45	-0.39
02W43	2095325	323205	8	927.66	927.43	0.23
02W44	2095375	323155	8	927.65	927.49	0.16
02W45	2095285	323195	8	927.69	927.46	0.23
02W46	2095465	322905	6	929.07	930.29	-1.22
02W47	2095525	322625	7	940.39	940.92	-0.53
02W50	2095525	322565	7	940.91	942.77	-1.86
02W52	2095555	322565	7	940.25	942.09	-1.84
02W53	2095385	322825	6	932.28	932.68	-0.40
02W62	2095205	323145	8	927.77	927.56	0.21
1314	2095465	322415	8	944.45	947.88	-3.43
1344	2095775	323505	7	926.97	927.05	-0.08
1361	2095435	323265	8	927.53	927.31	0.22
1362	2095455	323185	10	927.61	927.08	0.53
1315R	2095505	322755	7	934.62	935.87	-1.25
1316R	2095435	322775	7	933.38	935.21	-1.83
TMW-01	2095505	322695	7	942.72	938.53	4.19
TMW-02	2095505	322595	7	940.77	942.31	-1.54
TMW-05	2095555	322885	7	932.30	931.92	0.38
TMW-06	2095635	322795	4	934.64	934.80	-0.16
TMW-08	2095535	322725	6	935.37	936.89	-1.52
TMW-09	2095485	322825	6	933.65	933.19	0.46
TMW-13	2095375	322955	6	927.90	927.96	-0.06
TMW-17	2095495	322765	12	932.22	934.50	-2.28
TMW-18	2095335	322865	6	928.12	929.89	-1.77
TMW-19	2095335	322865	4	928.99	930.06	-1.07
TMW-21	2095435	322705	6	937.22	938.66	-1.44
TMW-24	2095435	323405	7	927.44	927.17	0.27
TMW-25	2095625	322655	5	937.22	938.57	-1.35

3.3 BA1 Model Limitations and Uncertainty

All models are a simplified representation of the physical aquifer system. Use of the updated groundwater model documented in this report is appropriate for the development of the conclusions provided within this report. Site conditions and hydrogeologic properties have been estimated through extrapolation of measured or estimated properties based on existing site information and professional judgment. Use of the groundwater model is currently limited to steady-state analyses which are intended to represent long-term static groundwater elevations or specific remedial alternatives. Additional specification of aquifer storage terms would be required for implementation of transient MODFLOW solutions.



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- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- NON-PUMPING HEAD CONTOURS (1 FT) FROM LAYER 7
- ACTIVE MODEL DOMAIN
- GENERAL HEAD BOUNDARY CELLS
- RIVER BOUNDARY CELLS
- NO FLOW BOUNDARIES

NOTES

1) GROUNDWATER ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (NORTH AMERICAN VERTICAL DATUM OF 1988).

2) BASEMAP: GOOGLE EARTH 2017

FIGURE 3-2
BA1 GROUNDWATER FLOW MODEL
CALIBRATED MODEL HEADS / RESIDUALS
SITE FACILITY DECOMMISSIONING PLAN
(REVISION 3)

BURNS McDONNELL
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Preparer: BELOCKWOOD	Date: 9/20/2022
Reviewer: DCLEMENT	Date: 9/20/2022

Coordinate System
WGS 1984 Web Mercator Auxiliary Sphere

4.0 BA1 REMEDIATION SIMULATIONS

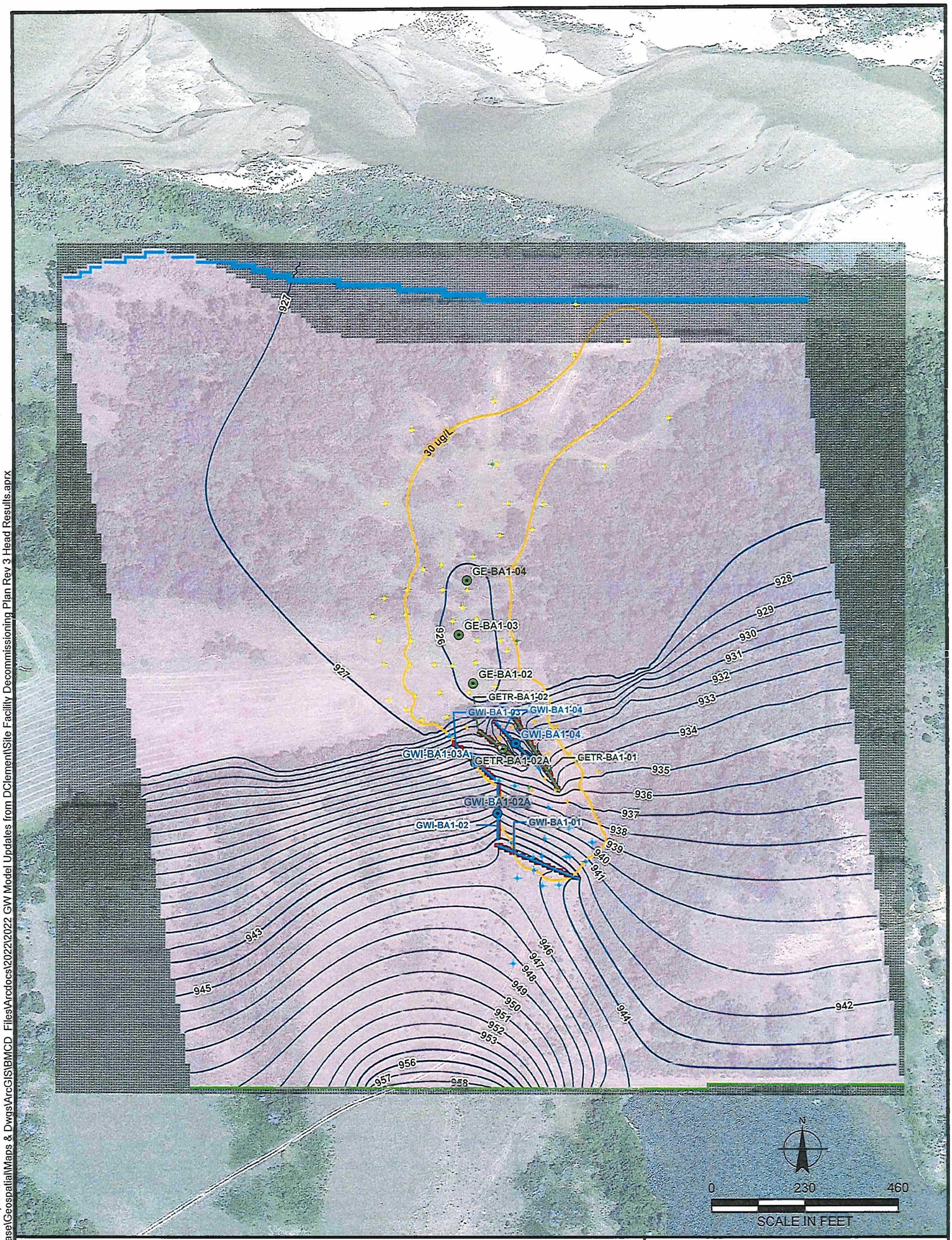
For this groundwater model update, particle tracking was completed under the nominal extraction and injection rates proposed in the current BA1 Site Facility Decommissioning Plan (Revision 3). Infiltration trench GWI-BA1-04 was added to address the potential for dewatering of the coarse grained intra gully sand deposits between GETR-BA1-01 and GETR-BA1-02. Implementing infiltration trench GWI-BA1-04 will raise groundwater levels and provides additional flushing of the pore space in the unconsolidated sediments between GETR-BA1-01 and GETR-BA1-02. The nominal rates used to simulate the extraction and injection infrastructure within the model are summarized in Table 4-1.

A simulated flow rate of ten gallons per minute (gpm) was selected for GW1-BA1-04. This flow rate was determined based upon iteratively increasing the flow rate to GWI-BA1-04 until achieving near zero drawdown across the extent of the sands of the intra-gully stream deposits within model Layer 7. The resulting groundwater heads for the steady-state MODFLOW solution based upon the injection and extraction rates within Table 4-1 are illustrated within Figure 4-1.

The groundwater heads and cell flux information from the MODFLOW solution were then input into a 30-year MODPATH particle tracking simulation (Pollock, 1989). MODPATH utilizes the results of the MODFLOW model along with specified porosity values and user-specified starting particle locations to calculate a three-dimensional pathline. Particles are tracked individually through the simulated flow system using the calculated distribution of velocity throughout the flow system. MODPATH was selected for this modeling study because of its applicability and simple linkage with MODFLOW. Particles were placed in or near each cell representing an injection trench and near the outer boundaries of the uranium plume. MODPATH particle tracking results for the BA1 uranium plume remediation area is presented in Figure 4-2. Particle tracking results near infiltration trench GWI-BA1-04 indicate that particles are either captured by the adjacent infiltration trench or flushed to the nearest downgradient extraction well (Figure 4-3).

Table 4-1: BA1 Model Simulated Rates for Remedial Wells and Trenches

Trench or Well Name	Extraction or Injection	Extraction or Injection Rate (GPM)
GWI-BA1-01	Injection Trench	10
GWI-BA1-02	Injection Trench	4
GWI-BA1-03	Injection Trench	4
GWI-BA1-04	Injection Trench	10
GETR-BA1-01	Extraction Trench	7
GETR-BA1-02	Extraction Trench	7
GE-BA1-02	Extraction Well	31
GE-BA1-03	Extraction Well	24
GE-BA1-04	Extraction Well	31



LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- EXTRACTION WELL/SUMP
- INJECTION WELL
- GROUNDWATER EXTRACTION TRENCH
- GROUNDWATER INJECTION TRENCH
- PUMPING HEAD CONTOURS (1 FT)
- BA1 URANIUM CONTOUR (30 UG/L)
- ACTIVE MODEL DOMAIN
- GENERAL HEAD BOUNDARY CELLS
- RIVER BOUNDARY CELLS
- NO FLOW BOUNDARIES
- TRENCH MODEL CELLS

NOTES

1) GROUNDWATER ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (NORTH AMERICAN VERTICAL DATUM OF 1988).

2) BASEMAP: GOOGLE EARTH 2017

FIGURE 4-1
BA1 GROUNDWATER FLOW MODEL
SITE FACILITY DECOMMISSIONING PLAN
(REVISION 3) CALCULATED HEADS

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Reviewer: DCLEMENT	Date: 9/20/2022

Coordinate System
WGS 1984 Web Mercator Auxiliary Sphere

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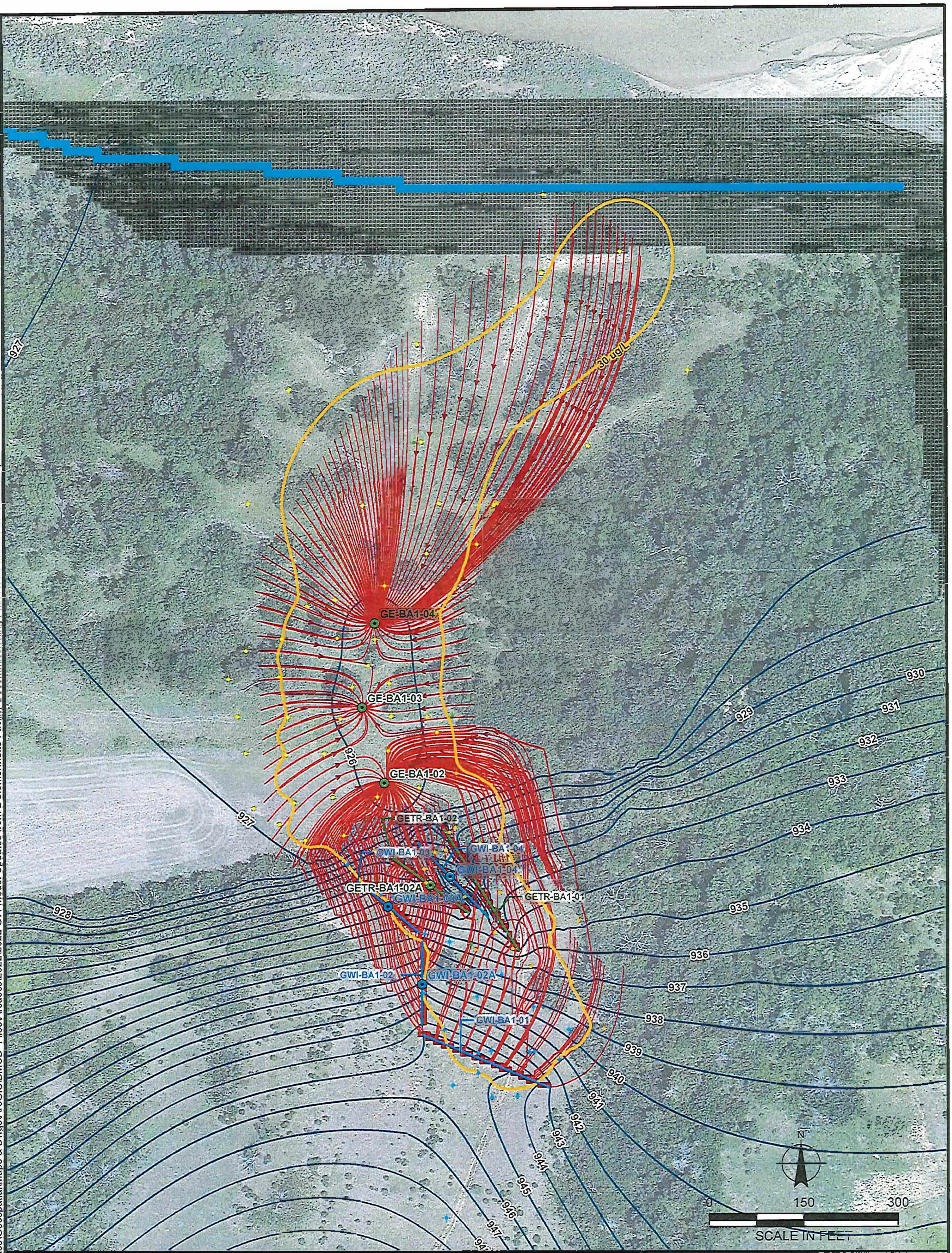

LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- EXTRACTION WELL/SUMP
- INJECTION WELL
- GROUNDWATER EXTRACTION TRENCH
- GROUNDWATER INJECTION TRENCH
- PARTICLE FLOW DIRECTION ARROWS
- PARTICLE TRACKING
- PUMPING HEAD CONTOURS (1 FT)
- BA1 URANIUM CONTOUR (30 UG/L)
- GENERAL HEAD BOUNDARY CELLS
- RIVER BOUNDARY CELLS
- NO FLOW BOUNDARIES
- TRENCH MODEL CELLS

NOTES

1) GROUNDWATER ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (NORTH AMERICAN VERTICAL DATUM OF 1988).

2) BASEMAP: GOOGLE EARTH 2017

FIGURE 4-2
BA1 GROUNDWATER FLOW MODEL
MODPATH PARTICLE TRACKING RESULTS
SITE FACILITY DECOMMISSIONING PLAN
(REVISION 3)

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Preparer: BELOCKWOOD	Date: 9/20/2022
Reviewer: DCLEMENT	Date: 9/20/2022

Coordinate System
WGS 1984 Web Mercator Auxiliary Sphere

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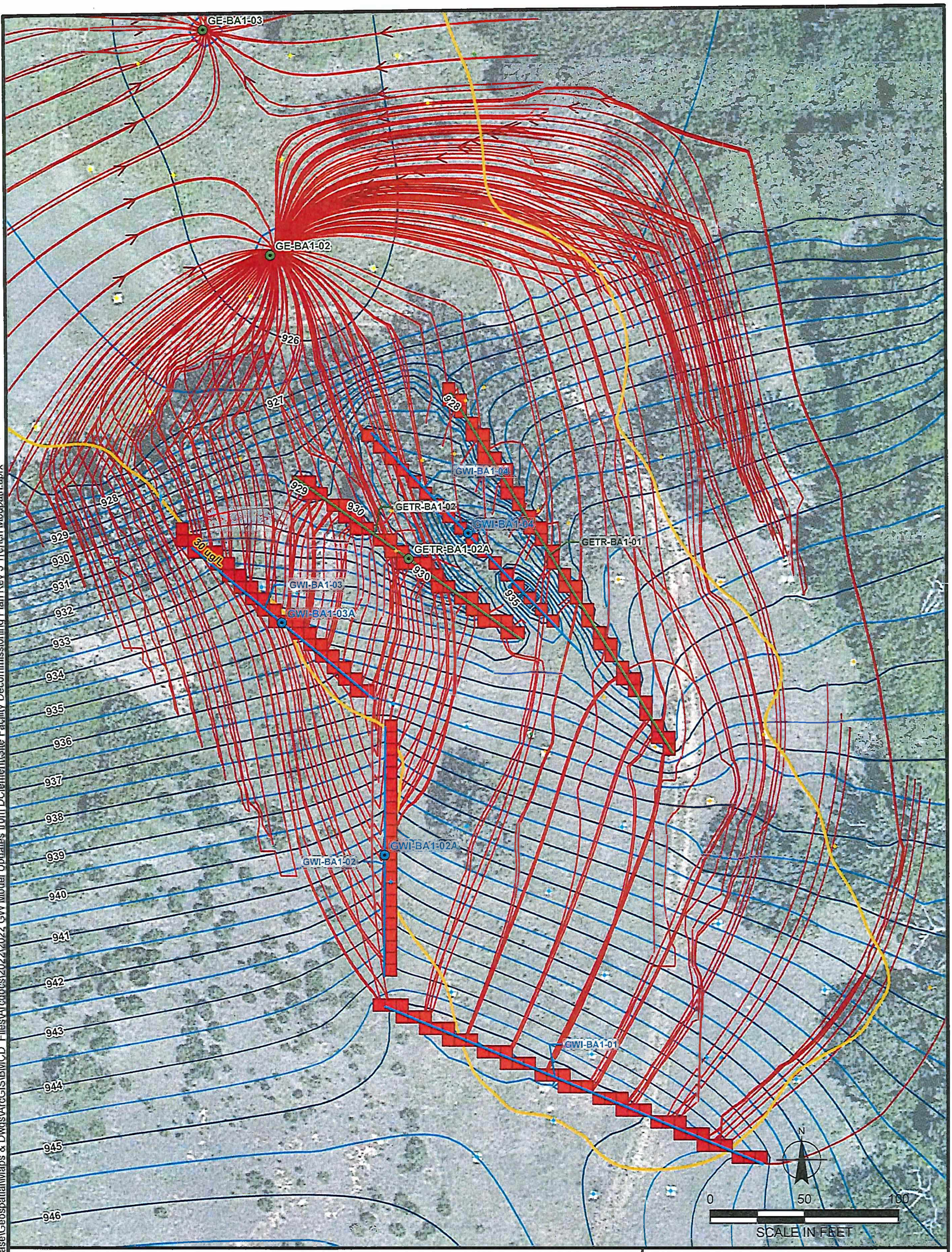

LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- EXTRACTION WELL/SUMP
- INJECTION WELL
- GROUNDWATER EXTRACTION TRENCH
- GROUNDWATER INJECTION TRENCH
- BA1 URANIUM CONTOUR (30 UG/L)
- PARTICLE TRACKING
- PARTICLE FLOW DIRECTION ARROWS
- PUMPING HEAD CONTOURS (1 FT)
- PUMPING HEAD CONTOURS (0.5 FT)
- TRENCH MODEL CELLS

NOTES

1) GROUNDWATER ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (NORTH AMERICAN VERTICAL DATUM OF 1988).

2) BASEMAP: GOOGLE EARTH 2017

FIGURE 4-3
BA1 GROUNDWATER FLOW MODEL
MODPATH PARTICLE TRACKING RESULTS
NEAR TRENCHES
SITE FACILITY DECOMMISSIONING PLAN (REVISION 3)

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Reviewer: DCLEMENT	Date: 9/20/2022

Coordinate System
WGS 1984 Web Mercator Auxiliary Sphere

Path: Z:\Clients\ENS\CERT_Clientinfo\Sites\Database\Geospatial\Maps & Dwgs\ArcGIS\BMCD_Files\Arcdocs\2022\2022 GW Model Updates from DClement\Site Facility Decommissioning Plan Rev 3 Trench Modpath.aprx

5.0 WAA GROUNDWATER FLOW MODEL CONSTRUCTION

The WAA Groundwater Flow Model described by (Burns & McDonnell, 2020) was used as the model for remedial alternative simulations. The sections below document model construction.

5.1 Groundwater Model Domain and Discretization

The same model domain of the 2020 Groundwater Flow Model Update (Burns & McDonnell, 2020) was used for construction of the groundwater flow model in this report. The model domain for the WA area was set up to include the area from the escarpment to the south to the Cimarron River to the north and east and west to distances to have a negligible effect on groundwater flow conditions within the interior of the model domain (Figure 5-1). The model was developed with 402 rows, 412 columns, and three layers for which grid cells are approximately 10 feet square in the X-Y plane. This results in 496,872 total cells with 407,245 cells within the active model domain.

5.2 Model Perimeter Boundary Conditions

Model perimeter boundary conditions are used to simulate the conceptual flow into and out of the model domain along the outer perimeter of the active model domain. Model perimeter boundary conditions are the same as those described by the 2020 Groundwater Flow Model (Burns & McDonnell, 2020) and include the use of no flow cells, the MODFLOW river package, and general head boundaries. The location of model perimeter boundary conditions is illustrated in (Figure 5-2).

5.2.1 No Flow Boundaries

Outside of the active domain are no flow cells that define the western and eastern boundary of the entire model domain. Starting water levels for all steady-state model solutions were assigned as being one foot below the top of model Layer 1. The high starting water levels allow for the MODFLOW steady-state solutions to start cells within the active model domain as saturated and therefore active. Model cells will then remain active unless calculated by MODFLOW to be dry during a final solution.

5.2.2 Constant Head Boundaries

The impact of leakage to groundwater from Reservoir 3 on the groundwater elevations within the WAA model is simulated utilizing a coverage of constant head boundary cells. The constant head boundaries are assigned an elevation of 958 feet msl. The assigned head elevation based on prior investigations (Burns & McDonnell, 2017a).

FIGURE 5-1
WAA GROUNDWATER FLOW MODEL DOMAIN
FACILITY DECOMMISSIONING PLAN
REVISION 3

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE A
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- ACTIVE MODEL DOMAIN

NOTES

1) Groundwater elevations in feet above mean sea level (North American Vertical datum of 1988).

0 550 1,100
SCALE IN FEET

N

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Coordinate System
NAD 1983 StatePlane Oklahoma North FIPS 3501 Feet

Service Layer Credits: Imagery: Maxar

Z:\Clients\ENS\CERT_ClientInfo\Sites\Database\Geospatial\Maps & Dwgs\ArcGIS\BMCD_Files\Arcdocs\2020\2022 - Decommissioning Plan\Figure 1 - GW Model Domain

FIGURE 5-2
WAA GROUNDWATER FLOW MODEL
PERIMETER BOUNDARY CONDITIONS
FACILITY DECOMMISSIONING PLAN
REVISION 3

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE A
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- ACTIVE MODEL DOMAIN
- NO FLOW BOUNDARIES
- CONSTANT HEAD BOUNDARIES
- RIVER BOUNDARIES CELLS
- GENERAL HEAD BOUNDARY CELLS

NOTES

1) Groundwater elevations in feet above mean sea level (North American Vertical datum of 1988).

0 550 1,100
SCALE IN FEET

N

	Rev No: 0
Preparer: DHORNE	Date: 10/6/2022
Reviewer: DCLEMENT	Date: 10/6/2022

Coordinate System
NAD 1983 StatePlane Oklahoma North FIPS 3501 Feet

Service Layer Credits: Imagery: Maxar

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5.2.3 General Head Boundaries

General Head Boundaries (GHB) were utilized to simulate upgradient flux into the aquifer along the southern extent of the model domain (Layer 2), and flux from underlying bedrock (Layer 3). The locations, assigned heads, and conductance terms allocated to general head boundaries within the model are equal to the 2020 Groundwater Flow Model (Burns & McDonnell, 2020).

5.2.4 River Boundaries

The river package was used to simulate the surface water and groundwater interaction of the Cimarron River as a regional groundwater discharge point within model Layers 1 and 2. River boundary cells are based upon the location of river cells within the 2020 Groundwater Flow Model Review (Burns & McDonnell, 2020). Values for assigned river heads, boundary conductance, and riverbed elevation were also maintained at those established by the 2020 Groundwater Flow Model Review.

5.3 Internal Model Boundary Conditions

Internal model boundary conditions are used to simulate internal sources and sinks including recharge, remedial infiltration trenches, remedial extraction trenches, and pumping wells (Figure 5-3).

5.3.1 Aquifer Recharge

Recharge to groundwater is simulated using the MODFLOW recharge package. The recharge package is used to represent the fraction of precipitation that enters the subsurface as rainfall recharge directly to the groundwater table. The model domain is small enough that significant variability in precipitation is not anticipated, therefore recharge is applied uniformly across the model domain. For the steady-state simulation of groundwater flow the recharge package was used to apply a uniform constant recharge rate of 2.4 inches per year (approximately 8% of annual precipitation) consistent with previous steady-state model values (ENSR, 2006) (Burns & McDonnell, 2020).

5.3.2 Groundwater Extraction Wells and Trenches

The Site Facility Decommissioning Plan (Revision 3) includes several proposed groundwater extraction wells and trenches. The WAA groundwater model simulates extraction wells, extraction trenches, and injection trenches utilizing the MODFLOW well package. Extraction trench GETR-WU-01A was simulated utilizing the MODFLOW well package by assigning individual well boundary conditions to model cells which overlapped the linear extent of the trench. Flux from infiltration trench GWI-WU-01A reaching the end of nearby interceptor trench and piping is simulated as a group of MODFLOW well package cells near the downhill termination of the interceptor collection.

FIGURE 5-3
WAA GROUNDWATER FLOW MODEL
INTERNAL BOUNDARY CONDITIONS
FACILITY DECOMMISSIONING PLAN
REVISION 3

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LEGEND
- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE A
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- EXTRACTION WELL
- INJECTION WELL
- GROUNDWATER EXTRACTION TRENCH
- GROUNDWATER INJECTION TRENCH
- ACTIVE MODEL DOMAIN
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- WELL PACKAGE CELLS
- CONSTANT HEAD BOUNDARIES
- GENERAL HEAD BOUNDARY CELLS

NOTES
1) Groundwater elevations in feet above mean sea level (North American Vertical datum of 1988).

0 550 1,100
SCALE IN FEET
N

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Coordinate System
NAD 1983 StatePlane Oklahoma North FIPS 3501 Feet

Z:\Clients\ENS\CERT_ClientInfo\Sites\Database\Geospatial\Maps & Dwgs\ArcGIS\BMCD_Files\Arcdocs\2020\2022 - Decommissioning Plan\Figure 3 - Internal Boundary Conditions

5.4 Hydrogeologic Properties

The hydrogeologic properties specified within the model are horizontal hydraulic conductivity (K_{xy}), vertical hydraulic conductivity (K_z), and porosity. All modeling simulations were run under steady-state conditions, which do not require specification of aquifer storage coefficients (specific storage or specific yield). The WAA model represents a layering system of unconsolidated deposits underlain by semi-permeable bedrock (ENSR, 2006). The distribution of hydraulic conductivity within the model is based upon hydraulic conductivity zones which correlate to a specific lithology type. Distribution of hydraulic conductivity is based upon values established by the 2020 Groundwater Flow Model Review (Burns & McDonnell, 2020). The final distribution of lithology zones is provided within Table 5-1 and illustrated within Appendix C.

Table 5-1: Model Lithology Zones and Hydrogeologic Properties

Lithology	Groundwater Model Lithology Zone Number	K_x	K_y	K_z	Porosity
Cimarron River Deposits Upper Alluvial Aquifer Sands	5	117.5	117.5	11.75	0.3
Cimarron River Deposits Lower Alluvial Aquifer Sands	2	117.5	117.5	11.75	0.3
Sandstone	4	3	3	0.15	0.05

6.0 WAA GROUNDWATER FLOW MODEL CALIBRATION

Validation of the WAA model calibration was evaluated by comparing observed and simulated groundwater elevations, groundwater flow contours, and water budgets. The calibration goals for the numerical model are based upon industry standards and previous WAA modeling efforts which are defined as:

- A less than one (1) percent water balance error, which is considered appropriate for a calibrated groundwater model (Anderson and Woessner, 1992).
- A Normalized Root Mean Square error (NRMS) of less than ten (10) percent.
- An Absolute Residual Mean (ARM) of less than ten percent the observed head change value across the model domain.
- A qualitative match of model simulated potentiometric surface and observed potentiometric surface, evaluated by visually comparing contours.

6.1 Simulated versus Observed Groundwater Heads

Water level measurements collected in August 2016 were compared to the model calculated head values as part of model calibration. The calibration data set and the model calculated heads reflect non-pumping conditions prior to implementation of any remedial alternatives. The calibration dataset included 70 wells with a range in observed water level elevations of 26.03 feet.

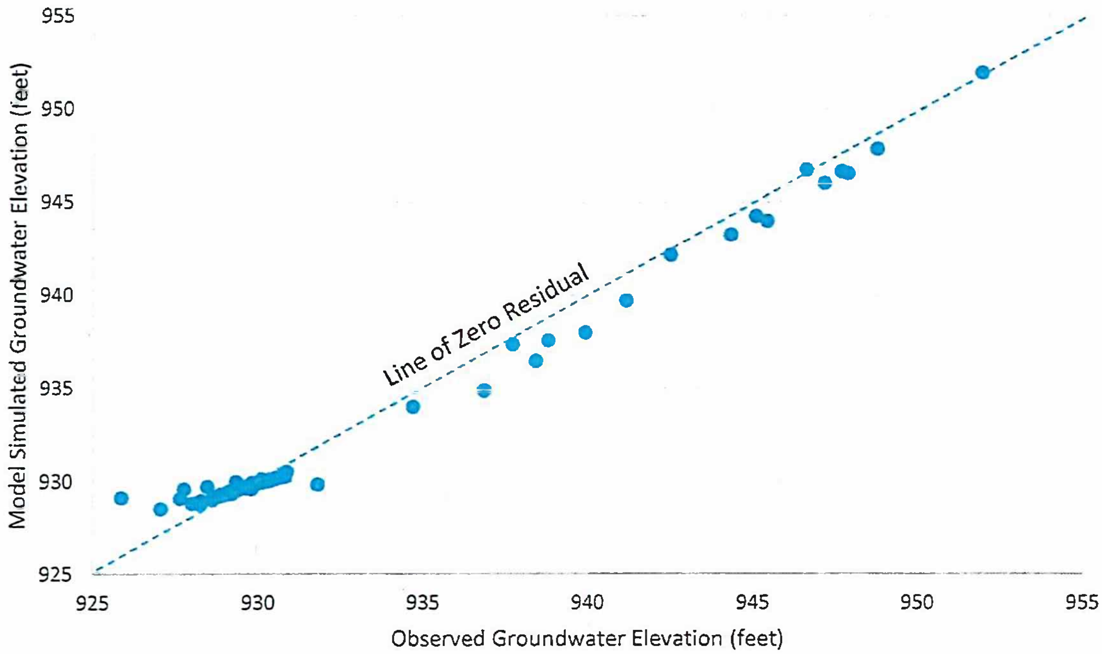
The model simulated heads and observed heads used for the calibration dataset are within Table 6-1. The calibration statistics for the WAA model indicate a mass balance error of 0.0034 percent, NRMS of 0.033 (3.3 percent), and ARM of 0.62 feet which meet established model calibration goals. As an additional evaluation for the model calibration, the simulated versus observed groundwater level data for the calibrated steady state model is provided as Figure 6-1 and indicates a good fit between simulated and observed head data. The resulting flow field of the calibrated groundwater model and distribution of residuals are illustrated Figure 6-2.

Table 6-1: WAA Model Computed versus Observed Heads

Observation Well Name	X Coordinate	Y Coordinate	Observed Head (ft)	Computed Head (ft)	Residual (ft)
T-51	2091962	322775	929.40	929.59	-0.19
T-52	2092407	321938	929.33	929.99	-0.66
T-53	2092659	322773	929.20	929.45	-0.26
T-54	2092871	321928	929.90	929.89	0.01
T-55	2093120	322070	928.46	929.74	-1.28
T-56	2093378	322211	927.75	929.61	-1.86
T-57	2092461	321788	930.23	930.05	0.18
T-58	2092165	321742	930.42	930.13	0.29
T-59	2092955	322774	929.18	929.40	-0.22
T-60	2093282	322774	929.20	929.36	-0.16
T-61	2093610	322774	929.03	929.34	-0.31
T-62	2091853	321471	930.69	930.28	0.41
T-63	2091977	321623	930.50	930.20	0.30
T-64	2091691	321342	930.85	930.53	0.32
T-65	2091814	321569	930.65	930.24	0.41
T-66	2091842	321712	930.53	930.19	0.34
T-67	2091743	321657	930.61	930.22	0.39
T-68	2091713	322052	930.25	930.04	0.20
T-69	2091872	321962	930.35	930.07	0.27
T-70R	2091626	321578	930.72	930.26	0.46
T-72	2091717	321899	930.40	930.12	0.28
T-73	2091492	321771	930.53	930.19	0.34
T-74	2091531	321541	930.80	930.28	0.52
T-75	2091598	321911	930.08	930.12	-0.04
T-76	2091731	321776	930.52	930.17	0.34
T-77	2091578	322010	930.29	930.08	0.21
T-78	2091494	321897	930.39	930.14	0.25
T-79	2091582	322213	930.07	929.97	0.10
T-81	2091476	321994	930.29	930.09	0.20
T-82	2091569	322414	931.77	929.86	1.91
T-83	2091501	322297	929.80	929.93	-0.13
T-84	2091869	322295	929.92	929.89	0.03
T-85	2092243	322346	929.81	929.79	0.01
T-86	2092647	322374	929.63	929.69	-0.06
T-87	2092979	322422	929.40	929.58	-0.19
T-88	2093384	322464	929.10	929.50	-0.40
T-89	2093072	323042	928.73	929.22	-0.49
T-90	2092830	323042	928.85	929.25	-0.40

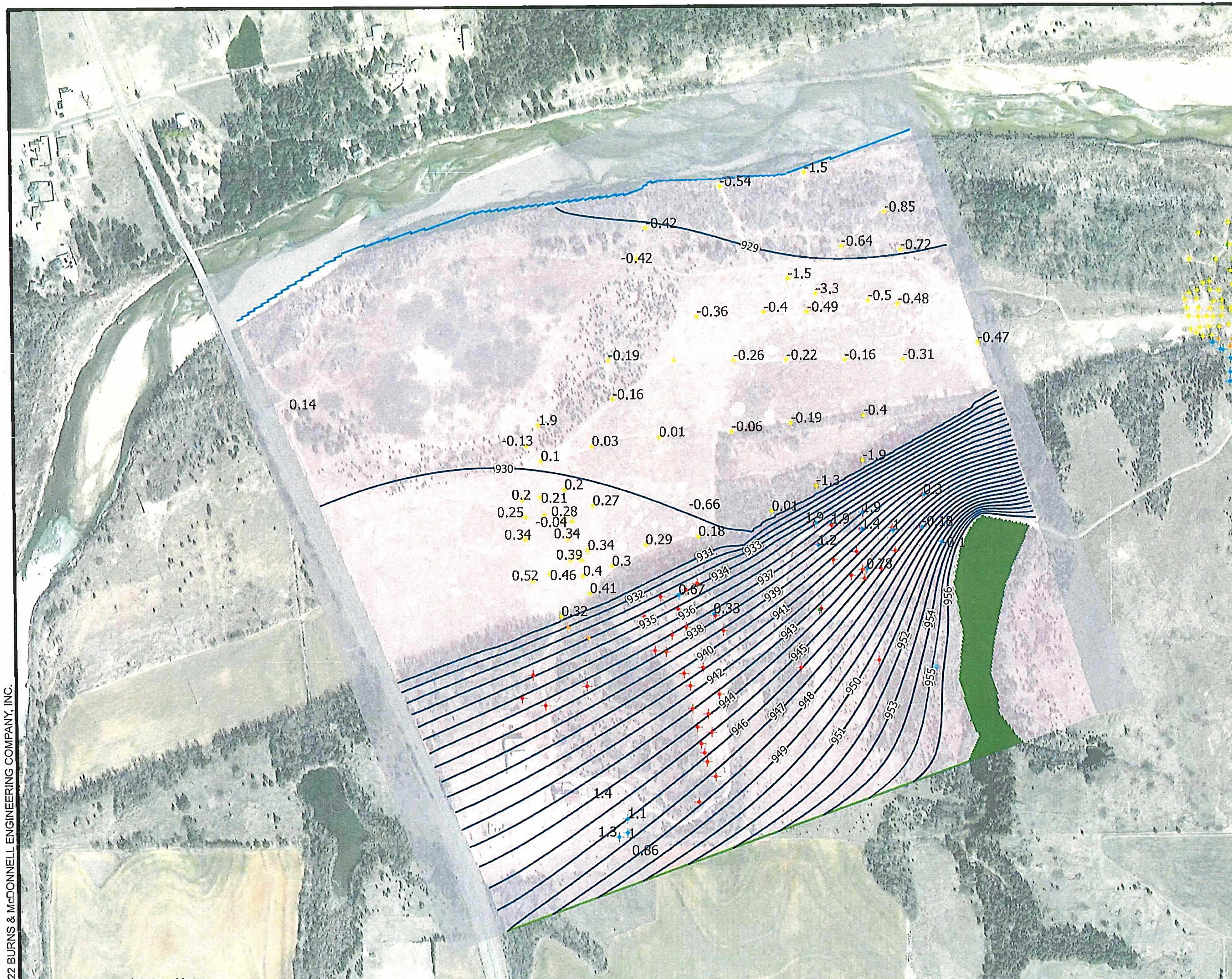
Observation Well Name	X Coordinate	Y Coordinate	Observed Head (ft)	Computed Head (ft)	Residual (ft)
T-91	2092966	323228	927.63	929.10	-1.48
T-92R	2093121	323143	925.85	929.15	-3.30
T-93	2093414	323104	928.66	929.16	-0.50
T-94	2093267	323409	928.31	928.95	-0.64
T-95	2092458	323019	928.98	929.34	-0.36
T-96	2091985	322557	929.56	929.72	-0.16
T-97	2092039	323318	928.78	929.20	-0.42
T-98	2092176	323514	928.61	929.03	-0.42
T-99	2092590	323746	928.25	928.79	-0.54
T-100	2093060	323821	927.05	928.54	-1.49
T-101	2093508	323599	927.99	928.84	-0.85
T-102	2093581	323085	928.69	929.17	-0.48
T-103	2094028	322867	928.86	929.33	-0.47
1319B-1	2092053	320128	947.62	946.62	0.99
1319B-2	2092078	320000	948.71	947.85	0.86
1319B-3	2092005	320105	947.82	946.51	1.31
1319B-4	2092053	320207	947.11	946.01	1.10
1319B-5	2091860	320322	945.37	943.99	1.38
1338	2093546	321819	944.27	943.25	1.02
1341	2092542	321355	937.68	937.36	0.33
1345	2092347	321461	934.66	933.99	0.67
1346	2093200	321854	938.38	936.47	1.91
1382	2093128	321736	938.76	937.56	1.20
1384	2093399	321602	945.03	944.25	0.78
1386	2093376	321918	939.89	938.00	1.89
1388	2093710	321837	946.55	946.73	-0.18
1390	2093720	322017	942.47	942.17	0.30
1391	2093820	321752	951.88	951.98	-0.10
1392	2093115	321861	936.82	934.88	1.94

Figure 6-1: WAA Calibrated Steady State Model – Modeled vs Observed Heads (feet)



6.2 WAA Model Limitations and Uncertainty

All models are a simplified representation of the physical aquifer system. Use of the updated groundwater model documented in this report is appropriate for the development of the conclusions provided within this report. Site conditions and hydrogeologic properties have been estimated through extrapolation of measured or estimated properties based on existing site information and professional judgment. Use of the groundwater model is currently limited to steady-state analyses which are intended to represent long-term static groundwater elevations or specific remedial alternatives. Additional specification of aquifer storage terms would be required for implementation of transient MODFLOW solutions.



Z:\Clients\ENS\CERT_ClientInfo\Sites\Database\Geospatial\Maps & Dwgs\ArcGIS\BMCD_Files\Arcdocs\2020\2022 - Decommissioning Plan\Figure 7 - Calibration Model

FIGURE 6-2
WAA GROUNDWATER FLOW MODEL CALIBRATED HEADS / REDIDUALS FACILITY DECOMMISSIONIONG PLAN (REVISION3)

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environmental properties management, LLC

LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE A
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- ACTIVE MODEL DOMAIN
- NO FLOW BOUNDARIES
- CONSTANT HEAD BOUNDARIES
- RIVER BOUNDARIES CELLS
- GENERAL HEAD BOUNDARY CELLS
- CALIBRATION HEAD CONTOURS (FEET)

NOTES

1) Groundwater elevations in feet above mean sea level (North American Vertical datum of 1988).

0 550 1,100

SCALE IN FEET

N

	Rev No: 0
Preparer: DHORNE	Date: 10/6/2022
Reviewer: DCLEMENT	Date: 10/6/2022

Coordinate System
NAD 1983 StatePlane Oklahoma North FIPS 3501 Feet

7.0 WAA REMEDIATION SIMULATIONS

For this groundwater model update, particle tracking was completed under the nominal extraction and injection rates proposed in the current Site Facility Decommissioning Plan (Revision 3). The nominal rates used to simulate the extraction and injection infrastructure within the model are summarized in Table 7-1. The resulting groundwater heads for the steady-state MODFLOW solution based upon the injection and extraction rates within Table 7-1 are illustrated within Figure 7-1.

Table 7-1: WAA Model Simulated Rates for Remedial Wells and Trenches

Trench or Well Name	Extraction or Injection	Extraction or Injection Rate (GPM)
GE-WAA-04	Extraction Well	20
GE-WAA-05	Extraction Well	25
GE-WAA-02	Extraction Well	30
GE-WAA-03	Extraction Well	24
GETR-WU-01A	Extraction Trench	8
GWI-WU-01	Infiltration Trench	8

The groundwater heads and cell flux information from the MODFLOW solution were then input into a 30-year MODPATH particle tracking simulation (Pollock, 1989). MODPATH utilizes the results of the MODFLOW model along with specified porosity values and user-specified starting particle locations to calculate a three-dimensional pathline. Particles are tracked individually through the simulated flow system using the calculated distribution of velocity throughout the flow system. MODPATH was selected for this modeling study because of its applicability and simple linkage with MODFLOW. Particles were placed near the outer boundaries of the remediation area. MODPATH particle tracking results for the remediation area is presented in Figure 7-2. Particle tracking indicate that all particles are captured by the proposed extraction wells.

FIGURE 7-1
WAA SITE FACILITY DECOMMISSIONING PLAN (REV 3) MODEL CALCULATED HEADS

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE A
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- ACTIVE MODEL DOMAIN
- NO FLOW BOUNDARIES
- CONSTANT HEAD BOUNDARIES
- WA 2022 Nominal Q Head Contours
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS

NOTES

1) Groundwater elevations in feet above mean sea level (North American Vertical datum of 1988).

0 550 1,100

SCALE IN FEET

N

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Coordinate System
NAD 1983 StatePlane Oklahoma North FIPS 3501 Feet

Z:\Clients\ENS\CERT_ClientInfo\Sites\Database\Geospatial\Maps & Dwgs\ArcGIS\BMCD_Files\Arcdocs\2020\2022 - Decommissioning Plan\Figure 8 - DPlan Rev 3 Head Results

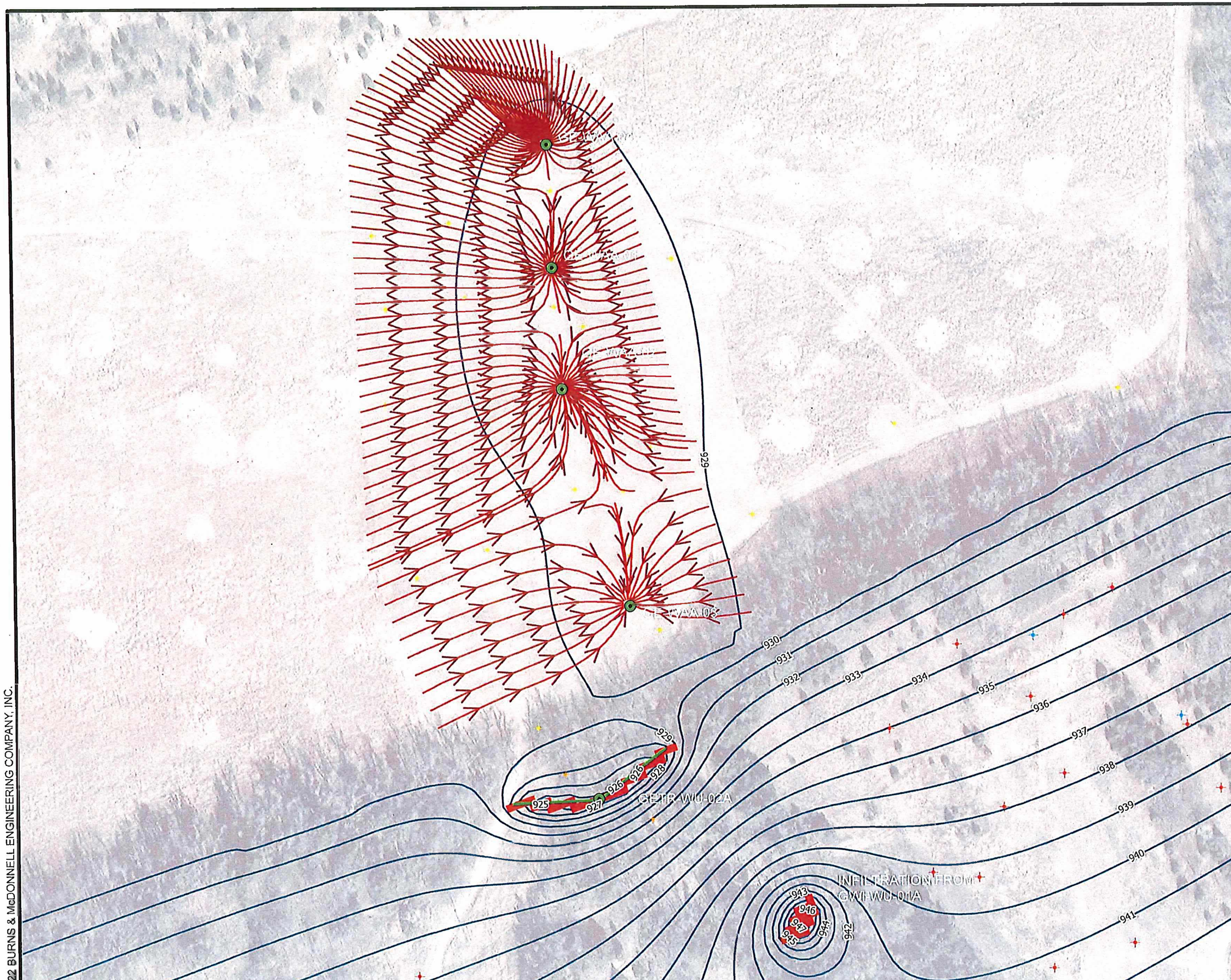

FIGURE 7-2
WAA SITE FACILITY DECOMMISSIONING PLAN (REV 3) MODPATH PARTICLE TRACKING RESULTS

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE A
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- EXTRACTION WELL
- INJECTION WELL
- GROUNDWATER EXTRACTION TRENCH
- GROUNDWATER INJECTION TRENCH
- ACTIVE MODEL DOMAIN
- NO FLOW BOUNDARIES
- CONSTANT HEAD BOUNDARIES
- NOMINAL HEAD CONTOURS
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS
- PARTICLE TRACKING
- PARTICLE FLOW DIRECTION ARROWS
- WELL PACKAGE CELLS

NOTES

1) Groundwater elevations in feet above mean sea level (North American Vertical datum of 1988).

0 130 260
SCALE IN FEET

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Coordinate System
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Z:\Clients\ENS\CERT_ClientInfo\Sites\Database\Geospatial\Maps & Dwgs\ArcGIS\BMCD_Files\Arcdocs\2020\2022 - Decommissioning Plan\Figure 10 - DPlan Rev 3 Modpath Results Pumping

8.0 SUMMARY AND CONCLUSIONS

This groundwater flow model report documents the construction, calibration, and remedial alternative simulations of the WAA groundwater flow model and the BA1 groundwater flow model in support of the Site Facility Decommissioning Plan (Revision 3).

The BA1 groundwater flow model from the 2020 Groundwater Flow Model Review (Burns & McDonnell, 2020) was improved by decreasing the uniform MODFLOW cell size from ten feet to five feet and through updates of lithology zones within the valley of the BA1 transition zone. The reduction in cell size allows for more accurate analysis of groundwater flow near boundary conditions such as infiltration and extraction trenches. The lithology update improved upon the distribution of lithology zones based on the Environmental Sequence Stratigraphy (ESS) and Porosity Analysis (Burns & McDonnell, 2018), which incorporated the distribution of isolated sand channels within the gulley fill of the BA1 transition zone (Appendix A). After verifying the BA1 groundwater model calibration, the model was used to simulate the resulting groundwater flow field under the proposed nominal extraction and infiltration rates of the current Site Facility Decommissioning Plan (Revision 3). This included simulation of a new infiltration trench GWI-BA1-04 to address the potential for dewatering of the coarse-grained, intra-gully sand deposits between GETR-BA1-01 and GETR-BA1-02. Implementing infiltration trench GWI-BA1-04 raises groundwater levels and provides additional flushing of the pore space in the unconsolidated sediments between GETR-BA1-01 and GETR-BA1-02. Based upon the resulting steady state groundwater flow field from MODFLOW, particle tracking was performed utilizing MODPATH forward particle analysis for a period of 30 years. The results indicate groundwater capture for the BA1 remediation area. Particle tracking also indicates that particles between GETR-BA1-01 and GETR-BA1-02 are either captured by these two infiltration trenches or flushed from the additional flux of GWI-BA1-04 to downgradient extraction wells.

The WAA groundwater flow is primarily based upon the groundwater flow model described by the 2020 Groundwater Flow Model Review (Burns & McDonnell, 2020). After verifying the WAA groundwater model calibration, the model was used to simulate the resulting groundwater flow field under the proposed nominal extraction and infiltration rates of the current Site Facility Decommissioning Plan (Revision 3). Based upon the resulting steady state groundwater flow field from MODFLOW, particle tracking was performed utilizing MODPATH forward particle analysis for a period of 30 years. The results indicate groundwater capture for the WAA remediation area.

9.0 REFERENCES

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APPENDIX A - 2022 BA1 GROUNDWATER FLOW MODEL LITHOLOGY DISTRIBUTION BY MODFLOW LAYER

LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS
- (101) CIMARRON RIVER FLOODPLAIN DEPOSITS CLAY/SILT TRACES SAND - KX/KY: 3
- (2 & 102) CIMARRON RIVER DEPOSITS - UPPER ALLUVIAL AQUIFER SANDS - KX/KY: 117.5
- (5) UPPERMOST GULLEY FILL UNIT - KX/KY: 1.28
- (104) UPPER GULLY FILL - KX/KY: 15
- (3) SILT - KX/KY: 0.283
- (6,8, & 9) SILTSTONE - KX/KY: 8.43
- (4) SANDSTONE A - KX/KY: 40

APPENDIX A
BA1 GROUNDWATER FLOW MODEL
LAYER 3 - LITHOLOGIC ZONES
SITE FACILITY DECOMMISSIONING PLAN (REVISION 3)

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Coordinate System
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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS

- (101) CIMARRON RIVER FLOODPLAIN DEPOSITS CLAY/SILT TRACES SAND - KX/KY: 3
- (2 & 102) CIMARRON RIVER DEPOSITS - UPPER ALLUVIAL AQUIFER SANDS - KX/KY: 117.5
- (5) UPPERMOST GULLEY FILL UNIT - KX/KY: 1.28
- (104) UPPER GULLY FILL - KX/KY: 15
- (105) LOWER GULLY FILL - KX/KY: 3
- (106) INTRA GULLY STREAM DEPOSITS (SAND BODY) - KX/KY: 50
- (3) SILT - KX/KY: 0.283
- (6,8, & 9) SILTSTONE - KX/KY: 8.43
- (4) SANDSTONE A - KX/KY: 40
- (7) SANDSTONE B - KX/KY: 5

APPENDIX A
BA1 GROUNDWATER FLOW MODEL
LAYER 2 - LITHOLOGIC ZONES
SITE FACILITY DECOMMISSIONING PLAN (REVISION 3)

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS
- (101) CIMARRON RIVER FLOODPLAIN DEPOSITS CLAY/SILT TRACES SAND - KX/KY: 3
- (2 & 102) CIMARRON RIVER DEPOSITS - UPPER ALLUVIAL AQUIFER SANDS - KX/KY: 117.5
- (104) UPPER GULLY FILL - KX/KY: 15
- (105) LOWER GULLY FILL - KX/KY: 3
- (106) INTRA GULLY STREAM DEPOSITS (SAND BODY) - KX/KY: 50
- (3) SILT - KX/KY: 0.283
- (6,8, & 9) SILTSTONE - KX/KY: 8.43
- (4) SANDSTONE A - KX/KY: 40
- (7) SANDSTONE B - KX/KY: 5

FIGURE X
HYDRAULIC CONDUCTIVITY ZONES - L3
FACILITY DECOMMISSIONING PLAN
REVISION 3

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS
- (101) CIMARRON RIVER FLOODPLAIN DEPOSITS CLAY/SILT TRACES SAND - KX/KY: 3
- (2 & 102) CIMARRON RIVER DEPOSITS - UPPER ALLUVIAL AQUIFER SANDS - KX/KY: 117.5
- (104) UPPER GULLY FILL - KX/KY: 15
- (105) LOWER GULLY FILL - KX/KY: 3
- (106) INTRA GULLY STREAM DEPOSITS (SAND BODY) - KX/KY: 50
- (10) CLAY - KX/KY: 0.5
- (6) SILTSTONE - KX/KY: 8.43
- (7) SANDSTONE B - KX/KY: 5

APPENDIX A
BA1 GROUNDWATER FLOW MODEL
LAYER 4 - LITHOLOGIC ZONES
SITE FACILITY DECOMMISSIONING PLAN (REVISION 3)

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS
- (101) CIMARRON RIVER FLOODPLAIN DEPOSITS CLAY/SILT TRACES SAND - KX/KY: 3
- (2 & 102) CIMARRON RIVER DEPOSITS - UPPER ALLUVIAL AQUIFER SANDS - KX/KY: 117.5
- (12) CIMARRON RIVER DEPOSITS - LOWER ALLUVIAL AQUIFER SANDS - KX/KY: 352.5
- (103) RIVER CLAY PLUG DEPOSITS - KX/KY: 2.77
- (5) UPPERMOST GULLEY FILL UNIT - KX/KY: 1.28
- (104) UPPER GULLY FILL - KX/KY: 15
- (105) LOWER GULLY FILL - KX/KY: 3
- (106) INTRA GULLY STREAM DEPOSITS (SAND BODY) - KX/KY: 50
- (10) CLAY - KX/KY: 0.5
- (6) SILTSTONE - KX/KY: 8.43
- (7) SANDSTONE B - KX/KY: 5
- (11) SANDSTONE C - KX/KY: 3

APPENDIX A
BA1 GROUNDWATER FLOW MODEL
LAYER 5 - LITHOLOGIC ZONES
SITE FACILITY DECOMMISSIONING PLAN (REVISION 3)

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS

- (101) CIMARRON RIVER FLOODPLAIN DEPOSITS CLAY/SILT TRACES SAND - KX/KY: 3
  (2 & 102) CIMARRON RIVER DEPOSITS - UPPER ALLUVIAL AQUIFER SANDS - KX/KY: 117.5
  (12) CIMARRON RIVER DEPOSITS - LOWER ALLUVIAL AQUIFER SANDS - KX/KY: 352.5
- (104) UPPER GULLY FILL - KX/KY: 15
- (105) LOWER GULLY FILL - KX/KY: 3
- (106) INTRA GULLY STREAM DEPOSITS (SAND BODY) - KX/KY: 50
- (10) CLAY - KX/KY: 0.5
- (6) SILTSTONE - KX/KY: 8.43
- (7) SANDSTONE B - KX/KY: 5
- (11) SANDSTONE C - KX/KY: 3

APPENDIX A
BA1 GROUNDWATER FLOW MODEL
LAYER 6 - LITHOLOGIC ZONES
SITE FACILITY DECOMMISSIONING PLAN (REVISION 3)

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- EXTRACTION WELL/SUMP
- INJECTION WELL
- GROUNDWATER EXTRACTION TRENCH
- GROUNDWATER INJECTION TRENCH
- BA1 URANIUM CONTOUR (30 UG/L)
- TRENCH MODEL CELLS
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS

- (2 & 102) CIMARRON RIVER DEPOSITS - UPPER ALLUVIAL AQUIFER SANDS - KX/KY: 117.5
- (12) CIMARRON RIVER DEPOSITS - LOWER ALLUVIAL AQUIFER SANDS - KX/KY: 352.5
- (103) RIVER CLAY PLUG DEPOSITS - KX/KY: 2.77
- (104) UPPER GULLY FILL - KX/KY: 15
- (105) LOWER GULLY FILL - KX/KY: 3
- (106) INTRA GULLY STREAM DEPOSITS (SAND BODY) - KX/KY: 50
- (10) CLAY - KX/KY: 0.5
- (6) SILTSTONE - KX/KY: 8.43
- (7) SANDSTONE B - KX/KY: 5
- (11) SANDSTONE C - KX/KY: 3

APPENDIX A
BA1 GROUNDWATER FLOW MODEL
LAYER 7 - LITHOLOGIC ZONES
SITE FACILITY DECOMMISSIONING PLAN (REVISION 3)

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS
- (2 & 102) CIMARRON RIVER DEPOSITS - UPPER ALLUVIAL AQUIFER SANDS - KX/KY: 117.5
- (12) CIMARRON RIVER DEPOSITS - LOWER ALLUVIAL AQUIFER SANDS - KX/KY: 352.5
- (103) RIVER CLAY PLUG DEPOSITS - KX/KY: 2.77
- (105) LOWER GULLY FILL - KX/KY: 3
- (106) INTRA GULLY STREAM DEPOSITS (SAND BODY) - KX/KY: 50
- (10) CLAY - KX/KY: 0.5
- (6) SILTSTONE - KX/KY: 8.43
- (7) SANDSTONE B - KX/KY: 5
- (11) SANDSTONE C - KX/KY: 3

APPENDIX A
BA1 GROUNDWATER FLOW MODEL
LAYER 8 - LITHOLOGIC ZONES
SITE FACILITY DECOMMISSIONING PLAN (REVISION 3)

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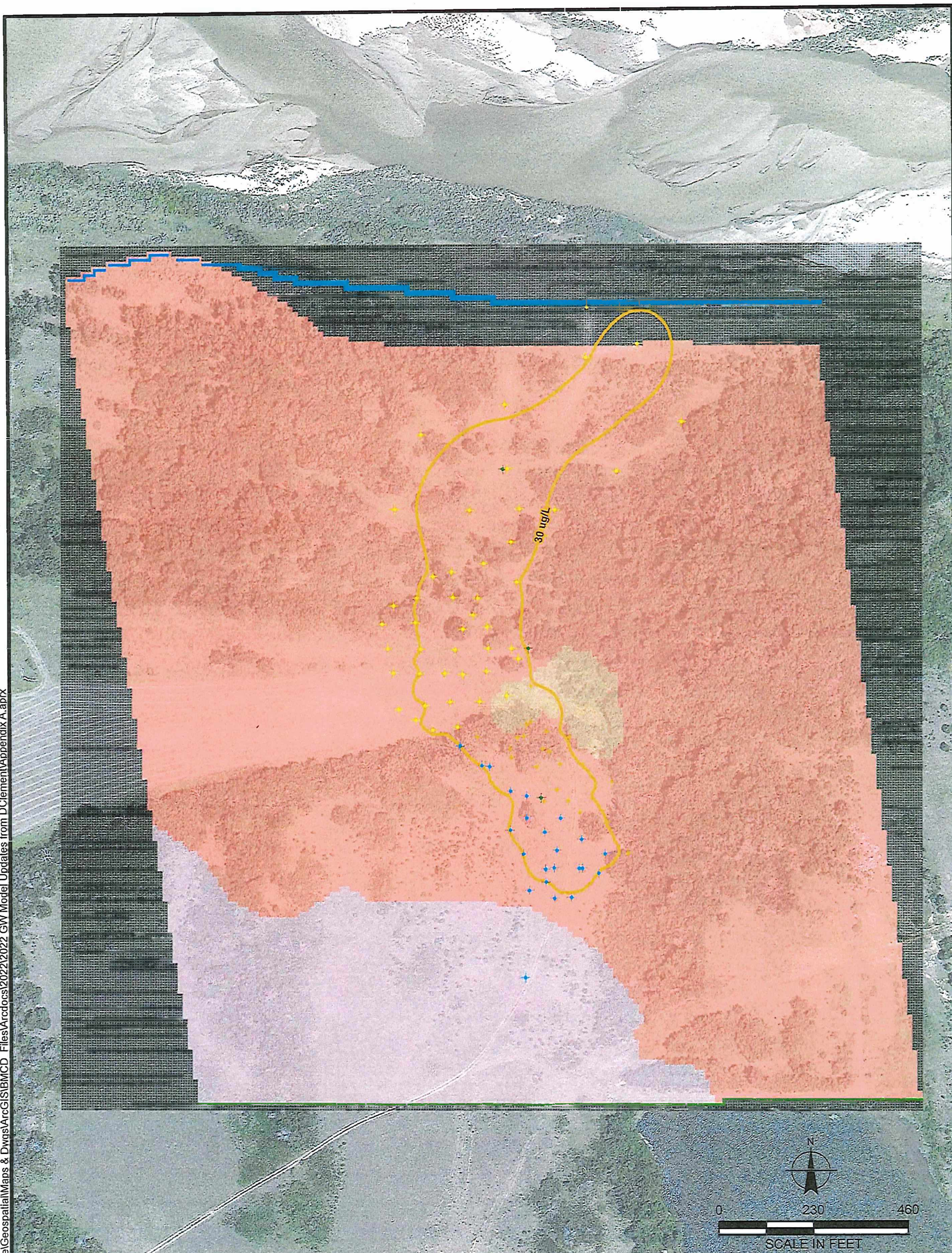

LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS
- (6) SILTSTONE - KX/KY: 8.43
- (7) SANDSTONE B - KX/KY: 5
- (11) SANDSTONE C - KX/KY: 3

APPENDIX A
BA1 GROUNDWATER FLOW MODEL
LAYER 9 - LITHOLOGIC ZONES
SITE FACILITY DECOMMISSIONING PLAN (REVISION 3)

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- BA1 URANIUM CONTOUR (30 UG/L)
- NO FLOW BOUNDARIES
- RIVER BOUNDARY CELLS
- GENERAL HEAD BOUNDARY CELLS
- (11) SANDSTONE C - KX/KY: 3

APPENDIX A
BA1 GROUNDWATER FLOW MODEL
LAYER 10 THROUGH 12 - LITHOLOGIC ZONES
SITE FACILITY DECOMMISSIONING PLAN
(REVISION 3)

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APPENDIX B - ENVIRONMENTAL SEQUENCE STRATIGRAPHY (ESS) AND POROSITY ANALYSIS

Memorandum

BURNS & McDONNELL

Date: April 6, 2018

To: Jeff Lux, P.E.

From: Mike Shultz, PhD

Subject: Environmental Sequence Stratigraphy (ESS) and Porosity Analysis, Burial Area 1, Cimarron Former Nuclear Fuel Production Facility

The ESS analysis described herein includes reviews of existing subsurface data and reformatting of grain size information provided in existing lithologic logs to elucidate trends in grain size. These trends can be interpreted by a stratigrapher in the context of the depositional environments in which aquifer materials were originally laid down. This process yields an updated conceptual site model (CSM) and provides insight into preferential pathways for groundwater migration and contaminant fate and transport. The work products resulting from the ESS analysis consist of:

1. A network of cross-sections through the Transition Zone (TZ) and out onto the Cimarron River floodplain (Cross-Sections A-A' through H-H');
2. An interpretive isopach map of more permeable deposits within the TZ saturated zone;
3. A calculated estimate of the transmissive fraction of the saturated interval within the TZ; and,
4. This technical memorandum.

Figure 1A shows the geologic cross-section locations and Figure 1B is provided as a legend for the cross-section symbology. Cross-Sections A-A' through H-H' are included as Figures 2A through 2H. Isopach maps, included as Figures 3A through 3C, show relatively permeable strata thickness with cross-section transects, potentiometric surface, and uranium isopleths, respectively. With the exception of monitor wells 02W29 and 02W46, monitor well water levels presented on the cross-sections were recorded on November 6, 2017. The 02W29 and 02W46 water levels presented on the cross-sections were recorded on July 31, 2017, because water levels recorded at these wells in November 2017 were outside typical historical ranges.

Geologic Setting

The BA-1 area consists of a bedrock bench of Permian-age deltaic channel sands and interbedded claystone (Garber Sandstone) upon which the burial trenches were sited (see Figure 1A). An erosional gully partially filled with primarily low-permeability material is present to the north and east of the bedrock ridge, and this gully area has been referred to as the "Transition Zone" between the bedrock escarpment and the sand-rich deposits of the Cimarron River alluvium present to the north of the burial area.

Environmental Sequence Stratigraphy Analysis

The TZ represents a gully eroded into the underlying bedrock which has been partially filled with predominantly fine-grained deposits. The eastern margin of the gully cannot be defined due to the lack of lithologic logs; no borings have been advanced in that area to date. The gully fill can be subdivided into a basal clay-rich unit (Lower Gully Fill [LGF]), and an upper silt-rich unit (Upper Gully Fill [UGF]). A relatively sandy deposit marks the base of the UGF unit. An isopach (equal-thickness) map of the sandy zone (relatively permeable strata) at the base of the UGF has been interpreted as part of the ESS analysis (see Figures 3A through 3C). The lateral connectivity of this deposit cannot be fully defined by existing lithologic information. Thus, the isopach map interpreted herein represents a sum of the interpreted permeable thickness and should not necessarily be taken to indicate a "channel" in the sense of a wholly continuous layer of sandy material. However, the consistent position of the sandy deposit at the contact of the UGF and the LGF suggests that it may in fact be hydraulically connected to a certain degree and that a disproportionate percentage of groundwater flow and contaminant mass flux likely occurs within this thin zone. Figure 3B illustrates the groundwater flow directions and geometry of the potentiometric surface as groundwater flows from the upland deposits through the TZ into the alluvial floodplain deposits.

The LGF likely represents slope failure (slump and debris-flow deposits) derived from soil horizons developed atop the bedrock in the immediate vicinity during initial phases of gully development. Flash flood events periodically removed portions of this material in an iterative process of erosion and deposition. With time, as the gully widened and headward erosion of the gully proceeded, the gully captured a greater area and greater volumes of surface water flowed through the gully during rain events. The area of investigation in the TZ was transformed into an alluvial valley and the setting changed from slope failure-dominated deposition to streamflow-dominated deposition. An erosional surface was carved into the underlying LGF by streams, likely during flash flood events. As described above, residual sands at the base of the UGF mark this transition. From this point on, the gully fill is dominated by thin sand channel deposits and silts of the UGF deposited by waning flow after flood events.

Isoconcentration contours of uranium in groundwater are plotted on the isopach map included as Figure 3C. As shown on this figure, the distribution of uranium in the subsurface seems to correlate well with the interpretive isopach map of the permeable material, with the plume extending northwest from the burial trenches, following the gully sand channel deposits through the TZ and out to the alluvial aquifer in the floodplain. In the upper reaches of the gully, the contaminant distribution appears to be controlled by the location and orientation of the burial trenches, the source of contamination. In this area, the permeable TZ materials appear to split into an eastern and a western zone (e.g., Cross-Section G-G'). Contamination appears to be limited to the western permeable unit in this area, likely due to the proximity of the burial trenches. From a CSM perspective, it appears that contaminated groundwater emanating from the BA-1 burial trenches percolates downward through the bedrock and TZ sediments (depending on burial trench location), is discharged into the western arm of the sandy deposits at the UGF/LGF contact, travels northwest within this interval down-gully, and then discharges primarily to the Upper Point Bar (UPB) deposit of the Cimarron River sands.

Estimate of Transmissive Porosity within BA1 Transition Zone
Boring logs for TZ wells were critically examined as part of the ESS analysis and cross-section creation. Thickness of the sandy unit at the base of the UGF was tabulated for each well and imported into Earth Volumetric Studio® (EVS) for calculation of total saturated sand channel volume within the uranium-impacted portion of the TZ (44,458 cubic feet [ft^3]). This value was multiplied by an assumed effective porosity for fine silty sand (20%), based on reference values obtained from *Applications of Environmental Chemistry – A Practical Guide for Environmental Professionals*[1], to calculate the transmissive pore volume for saturated sand channel deposits located within the effected BA1 TZ (8,892 ft^3).

EVS was also used to calculate the total saturated volume within the uranium-impacted portion of the TZ (511,425 ft^3). This volume is comprised of the saturated, uranium-impacted UGF volume (189,137 ft^3), the saturated, uranium-impacted LGF volume (277,830 ft^3), and the saturated, uranium-impacted sand channel volume (44,458 ft^3). The saturated, uranium-impacted UGF and LGF volumes were each multiplied by a conservatively assumed effective porosity for silty-clay (10%), based on reference values[1], to calculate the corresponding transmissive pore volume for these fine-grained deposits – 18,914 ft^3 for the UGF and 27,783 ft^3 for the LGF. Finally, all three transmissive pore volumes were added together and divided by the bulk volume of impacted, saturated TZ material (511,425 ft^3) to calculate the transmissive porosity for the effected BA1 TZ (11%).

The calculation conducted to estimate the transmissive fraction of the saturated interval within the uranium-impacted TZ is presented in Table 1 and two-dimensional (2D) and three-dimensional (3D) renderings of the EVS volume calculations are presented on Figures 4 through 7. This work suggests that approximately 9% of the overall TZ saturated thickness is sandy and therefore constitutes a porous interval with the potential to transmit groundwater and contaminant mass. The estimates presented above and in Table 1 assume that the sand channel deposits are in fact permeable and somewhat connected, and that the clay- and silt-rich LGF and UGF are significantly less transmissive.

As stated above, EVS was used to model 3D volumetric 'bodies' for the saturated, uranium-impacted sand channel, UGF, and LGF TZ deposits. Figure 4 provides a plan view rendering of the volumetric analysis domain. In the horizontal dimension, the northwest domain boundary represents the BA1 TZ/alluvium boundary, the northeast and southeast domain boundaries represent the approximate extent of BA1 uranium groundwater impacts, and the southeast domain boundary (annotated black line) represents the saturated TZ deposit/bedrock interface (at the water table). In the vertical dimension, the water table (depicted as the blue surface on Figure

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[1] Weiner, Eugene R, *Applications of Environmental Chemistry – A Practical Guide for Environmental Professionals*, Taylor & Francis Group, LLC, CRC Press, 2000.

5) serves as the upper boundary of the volumetric analysis domain, and the basal TZ/bedrock interface (see Figure 5) serves as the lower boundary. Figure 5 provides an orthogonal view of the volumetric analysis domain and the sand channel deposit 'body', with the UGF and LGF deposits hidden in the model. Figure 6 provides the same orthogonal view shown in Figure 5, with the UGF deposits shown and the LGF and sand channel deposits hidden. Finally, Figure 7 provides the same orthogonal view with the LGF deposits shown and the UGF and sand channel deposits hidden.

Cimarron River Deposits

Sand-rich point bar and overlying floodplain deposits of the Cimarron River to the north interfinger with the gully fill deposits (e.g., Cross-Section A-A'). Individual point-bar deposits of the Cimarron River are approximately 5' thick, and in the BA1 investigation area there are two stacked point bar deposits (UPB and Lower Point Bar [LPB]). A sharp grain size increase marks the base of the UPB, and this contact surface is well-displayed in Cross-Sections A-A', B-B', and C-C'. This contact is indicated by a thin zone of increased conductivity in the electrical conductivity (EC) log for 02W32 (Cross-Section D-D'), probably related to a slight increase in clay content in the upper foot of the lower point bar. This contact is also indicated by a color change described in the boring log for 02W32. Depth-discrete sampling at 02W32 (see Cross-Section D-D') suggests that the majority of contaminant mass flux is occurring within the UPB deposit within the Cimarron River sands. Cross-section A-A' shows a connection to the UPB deposits with the sandy unit present at the base of the UGF, suggesting that this is the pathway from the gully fill to the UPB Deposits. The relatively higher concentration within the UPB may be explained by this connection.

Data Gaps and Recommendations

While it is likely that channel sand deposits at the UGF/LGF interface represents the primary pathway for contaminants in the TZ, there are no data related to the vertical distribution of uranium within the TZ gully fill deposits. Attempts at depth-discrete groundwater sampling in TZ material have been unsuccessful due to the low-permeability nature of the gully fill sequence. Vertical profiling of groundwater flow and chemistry within existing wells via dye tracer systems offered by the United States Geological Survey (USGS) and/or BESST, Inc. may provide data to support the CSM presented herein, and the results may be useful in refining the BA1 remedial action implementation plans. In addition, other means of obtaining depth-discrete high-resolution vertical profiling of uranium should be investigated.

Attachments:

Figure 1A:	Cross-Section Location Map
Figure 1B:	Cross-Section Legend
Figures 2A-2H:	Cross-Sections A-A' through H-H'
Figure 3A:	Isopach Map of Relatively Permeable Deposits of the

	Transition Zone
Figure 3B:	Isopach Map of Relatively Permeable Deposits of the Transition Zone with Potentiometric Surface Contours
Figure 3C:	Isopach Map of Relatively Permeable Deposits of the Transition Zone with Uranium Isopleth Contours
Table 1:	Transmissive Porosity Calculation for Saturated and Contaminated BA1 Transition Zone
Figure 4:	Plan View of Transition Zone Saturated Bedrock and Intra-Gully Stream Deposits – Burial Area 1
Figure 5:	Orthogonal View of Saturated Intra-Gully Stream Deposits and Bedrock – Burial Area 1
Figure 6:	Orthogonal View of Saturated Upper Gully Fill Deposits and Bedrock – Burial Area 1
Figure 7:	Orthogonal View of Saturated Lower Gully Fill Deposits and Bedrock – Burial Area 1

cc: John Hesemann
Jeff Binder
Bill Halliburton

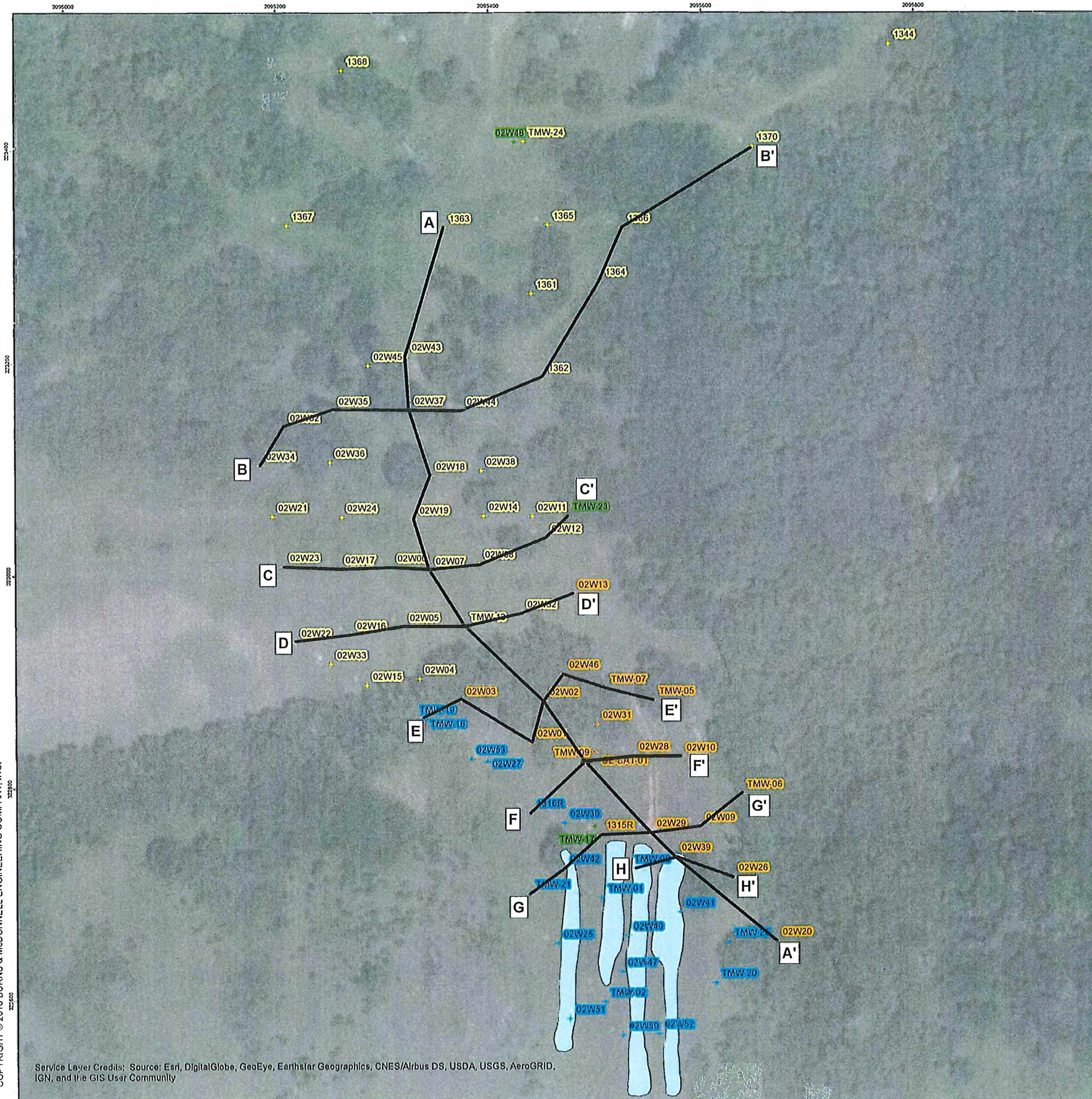


FIGURE 1A
CROSS-SECTION LOCATION MAP
BURIAL AREA 1
CIMARRON SITE, OKLAHOMA

BURNS McDONNELL. environmental

Legend

- MONITORING WELL IN TRANSITION ZONE
- MONITORING WELL IN ALLUVIUM
- MONITORING WELL IN SANDSTONE A
- MONITORING WELL IN SANDSTONE B
- MONITORING WELL IN SANDSTONE C
- WASTE DISPOSAL TRENCH
- CROSS-SECTION LINE

0 50 100 200 Feet N

Source: ESRI and Burns & McDonnell Engineering.
COORDINATES : (NAD 83) STATE PLANE OKLAHOMA NORTH FEET
DATE : AERIAL PHOTO - 2010 / MAP PRODUCED - 4/6/2018

Path: Z:\Clients\ENS\CERT_ClientInfo\Sites\Database\Geospatial\Maps & Dwgs\ArcGIS\BMCD_Files\Arcdocs\2018\ESS Tech Memo\Basemap.mxd

Cimarron River Floodplain Deposits: Clay, silt, and interbedded fine-grained sand corresponding to floodplain deposits of the Cimarron River. Sands as overbank splays deposited during flood-stages.

Cimarron River Channel Deposits: Fine to coarse-grained, trough cross-bedded sand deposited as point-bars by the Cimarron River. Minor intraclast or extrabasinal conglomerate lags define bases of individual point-bar sequences

Cimarron River Clay Plug Deposits: Clay and silt, some thin sands, deposited in abandoned stretches of Cimarron River channels (oxbow lakes).

Upper Gully Fill: Silt and silty sand with interbedded clayey sand and silty sand deposited as gully-wash by stream-flow during flash flood events. Contains minor sand-rich streamflow deposits.

Lower Gully Fill: Clay-rich deposits including gully-wall failure (slump, slide, and debris-flow). Chaotic, may include minor re-worked streamflow deposits.

Intra-gully Stream Deposits: Sand and silty sand deposited by streamflow within gully system.

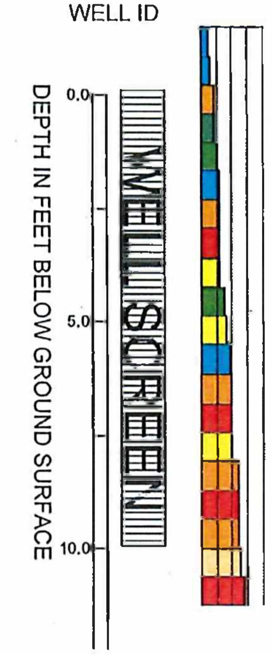
Estimated Intra-gully Stream Deposits: Sand and silty sand deposited by streamflow within gully system.

Garber Sandstone Bedrock (undifferentiated).

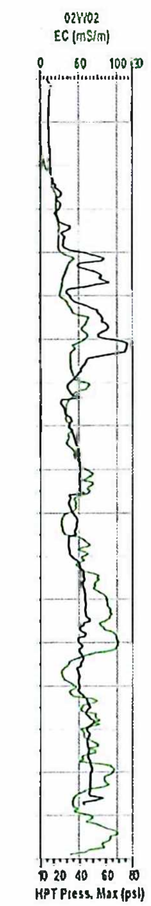
Schematic point bar lateral accretion surface.

Waste Disposal Trench (approximate)

LOG LEGEND



EC/HPT LOG



mS/m - MILLISIEMENS PER METER

psi - POUNDS PER SQUARE INCH

EC - ELECTRICAL CONDUCTIVITY

HPT - HYDRAULIC PROFILING TOOL

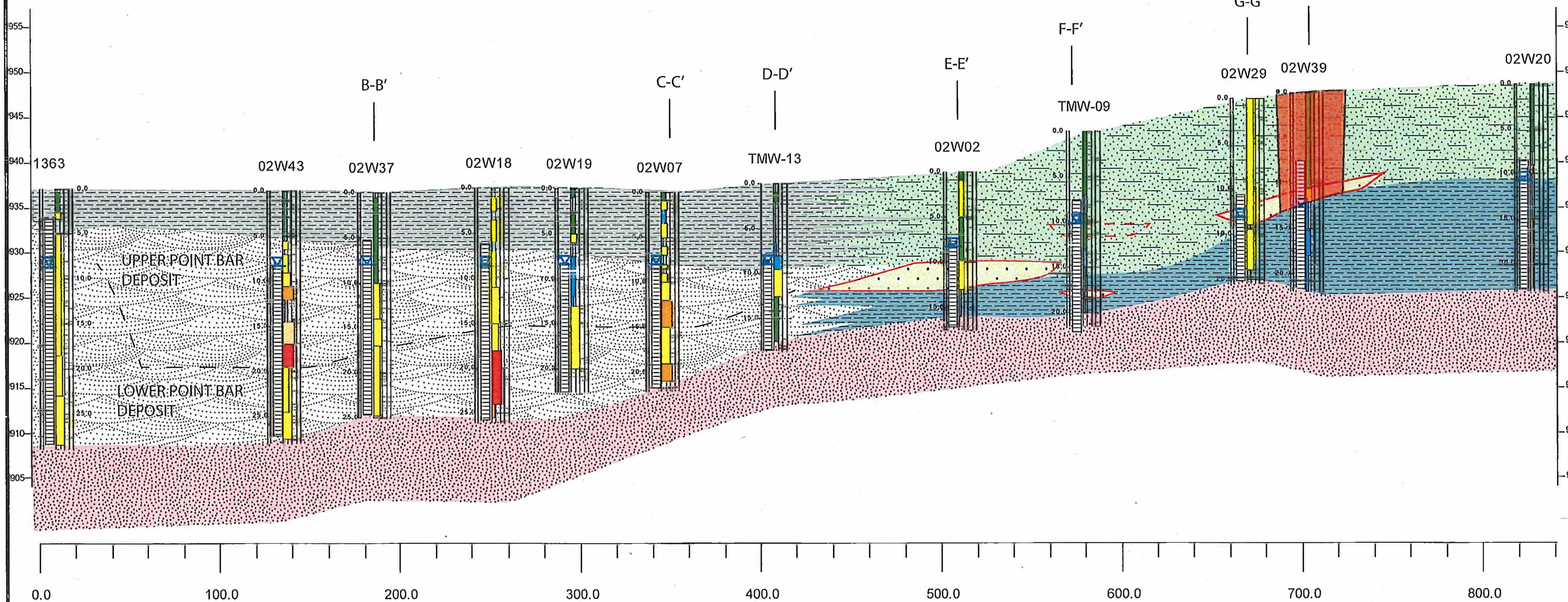
▽ - OBSERVED WATER LEVEL

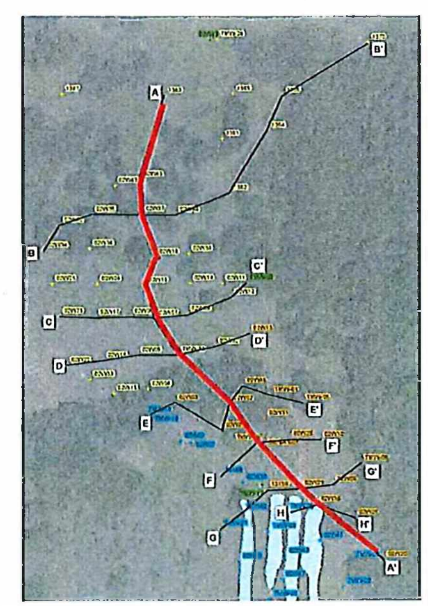
BURNS McDONNELL

Figure 1B

CROSS-SECTION LEGEND
BURIAL AREA 1
CIMMARON SITE, OKLAHOMA

Cross-Section A-A'





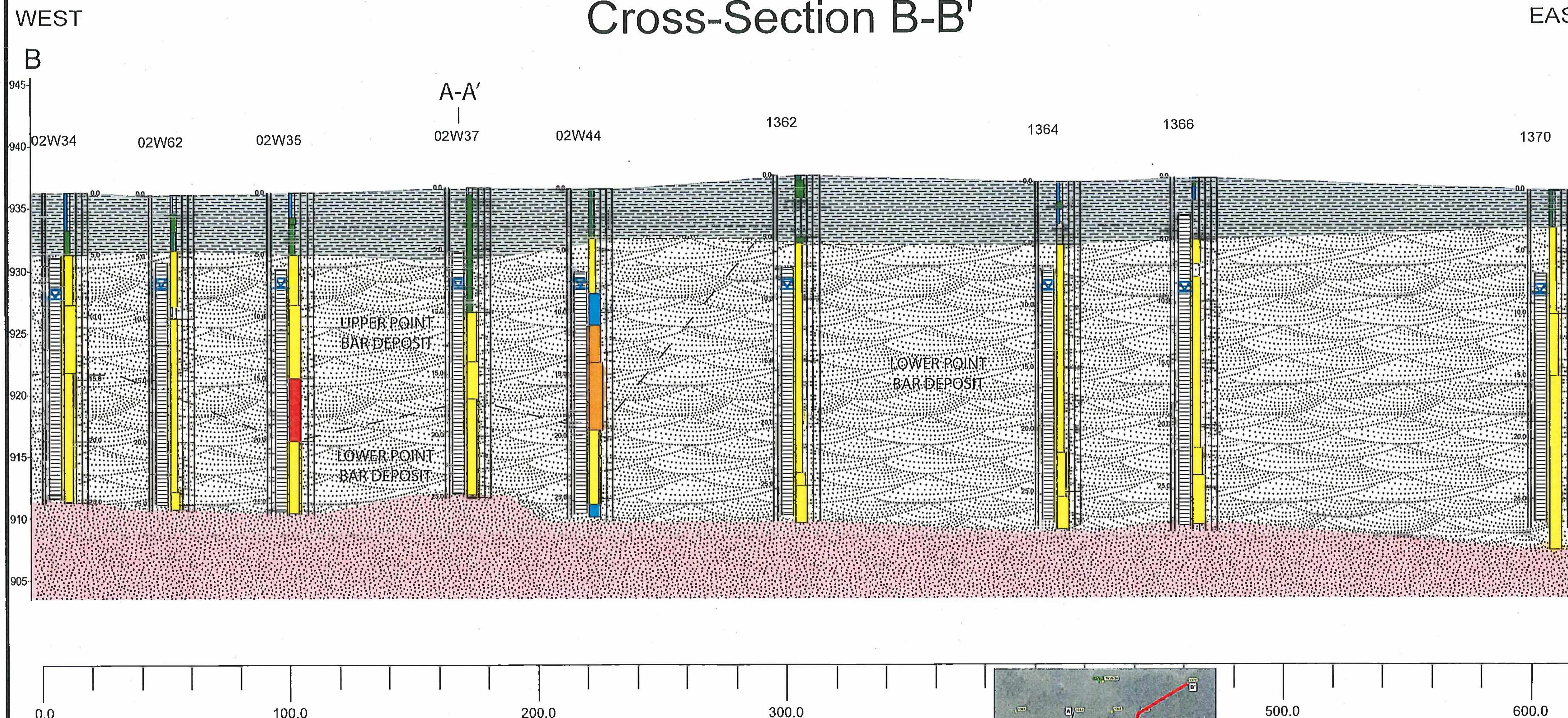
NOTES
1) Y-AXIS MEASURED IN FEET ABOVE MEAN SEA LEVEL (NORTH AMERICAN VERTICAL DATUM 1983)
2) X-AXIS MEASURED IN FEET
3) ALL CROSS-SECTION SYMBOLS ARE DEFINED ON FIGURE 1B
4) HORIZONTAL AND VERTICAL SCALES ARE APPROXIMATE
5) SURFACE TOPOGRAPHY IS APPROXIMATE
6) GROUNDWATER ELEVATIONS MEASURED NOVEMBER 6, 2017, EXCEPT 02W29 (MEASURED JULY, 31 2017)
7) CORRELATION OF UNITS IS AN INTERPRETATION AND NOT NECESSARILY A DELINEATION OF ACTUAL EXTENT AND THICKNESS OF EACH INDIVIDUAL UNIT

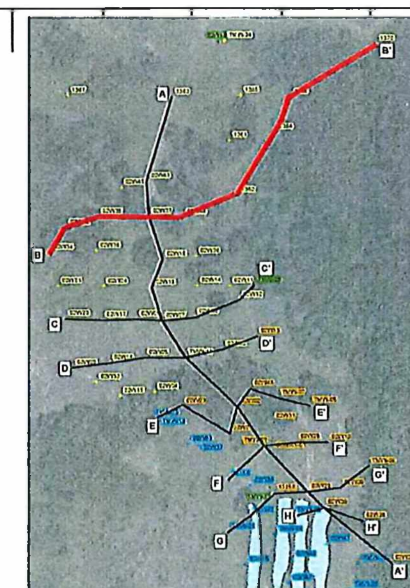
BURNS McDONNELL

Figure 2A

CROSS-SECTION A-A′
BURIAL AREA 1
CIMMARON SITE, OKLAHOMA

Cross-Section B-B'





NOTES
1) Y-AXIS MEASURED IN FEET ABOVE MEAN SEA LEVEL (NORTH AMERICAN VERTICAL DATUM 1983)
2) X-AXIS MEASURED IN FEET
3) ALL CROSS-SECTION SYMBOLS ARE DEFINED ON FIGURE 4-1
4) HORIZONTAL AND VERTICAL SCALES ARE APPROXIMATE
5) SURFACE TOPOGRAPHY IS APPROXIMATE
6) GROUNDWATER ELEVATIONS MEASURED NOVEMBER 6, 2017
7) CORRELATION OF UNITS IS AN INTERPRETATION AND NOT NECESSARILY A DELINEATION OF ACTUAL EXTENT AND THICKNESS OF EACH INDIVIDUAL UNIT

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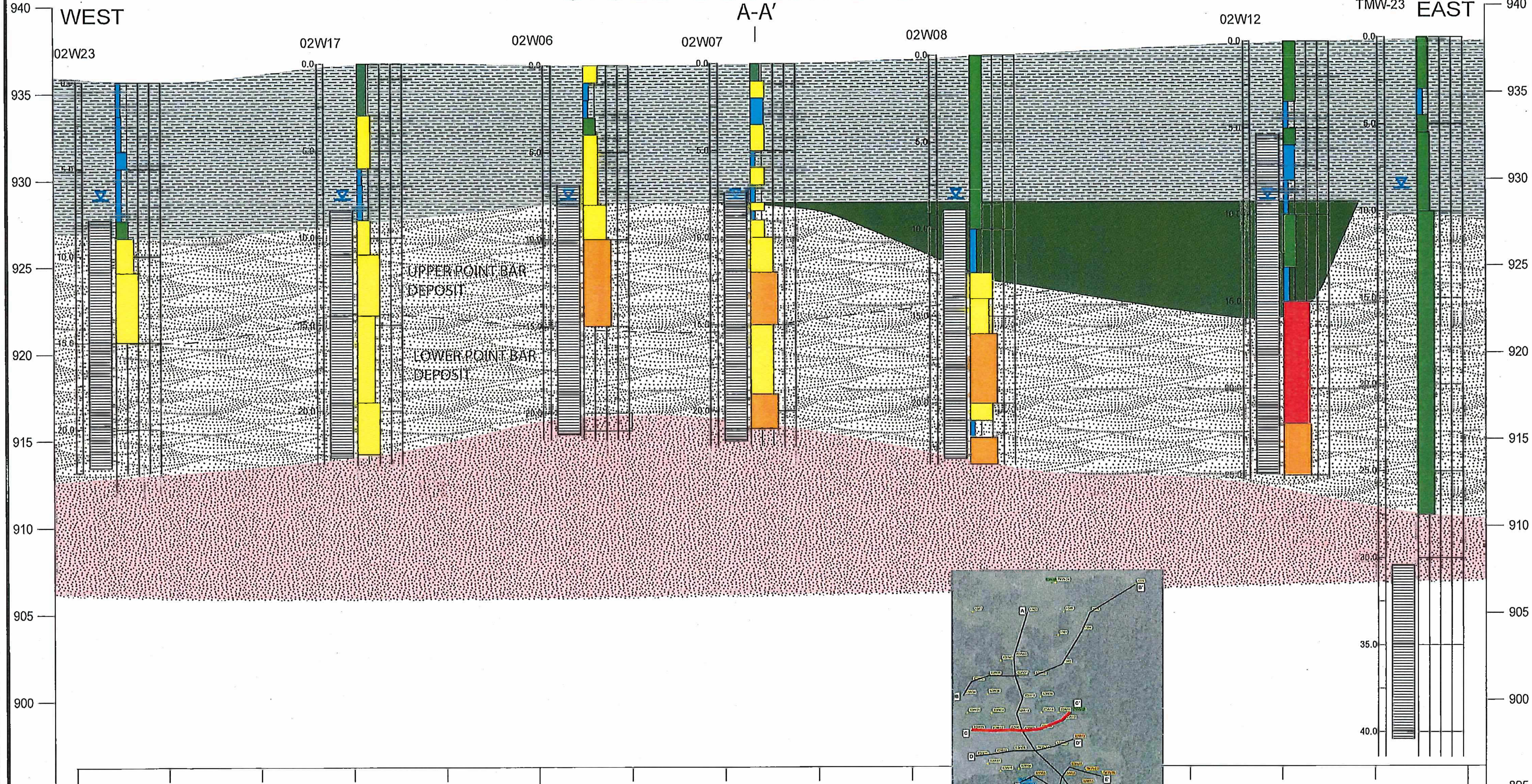
Figure 2B

CROSS-SECTION B-B'
BURIAL AREA 1
CIMMARON SITE, OKLAHOMA

Cross-Section C-C'



NOTES
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2) X-AXIS MEASURED IN FEET
3) ALL CROSS-SECTION SYMBOLS ARE DEFINED ON FIGURE 4-1
4) HORIZONTAL AND VERTICAL SCALES ARE APPROXIMATE
5) SURFACE TOPOGRAPHY IS APPROXIMATE
6) GROUNDWATER ELEVATIONS MEASURED NOVEMBER 6, 2017
7) CORRELATION OF UNITS IS AN INTERPRETATION AND NOT NECESSARILY A DELINEATION OF ACTUAL EXTENT AND THICKNESS OF EACH INDIVIDUAL UNIT

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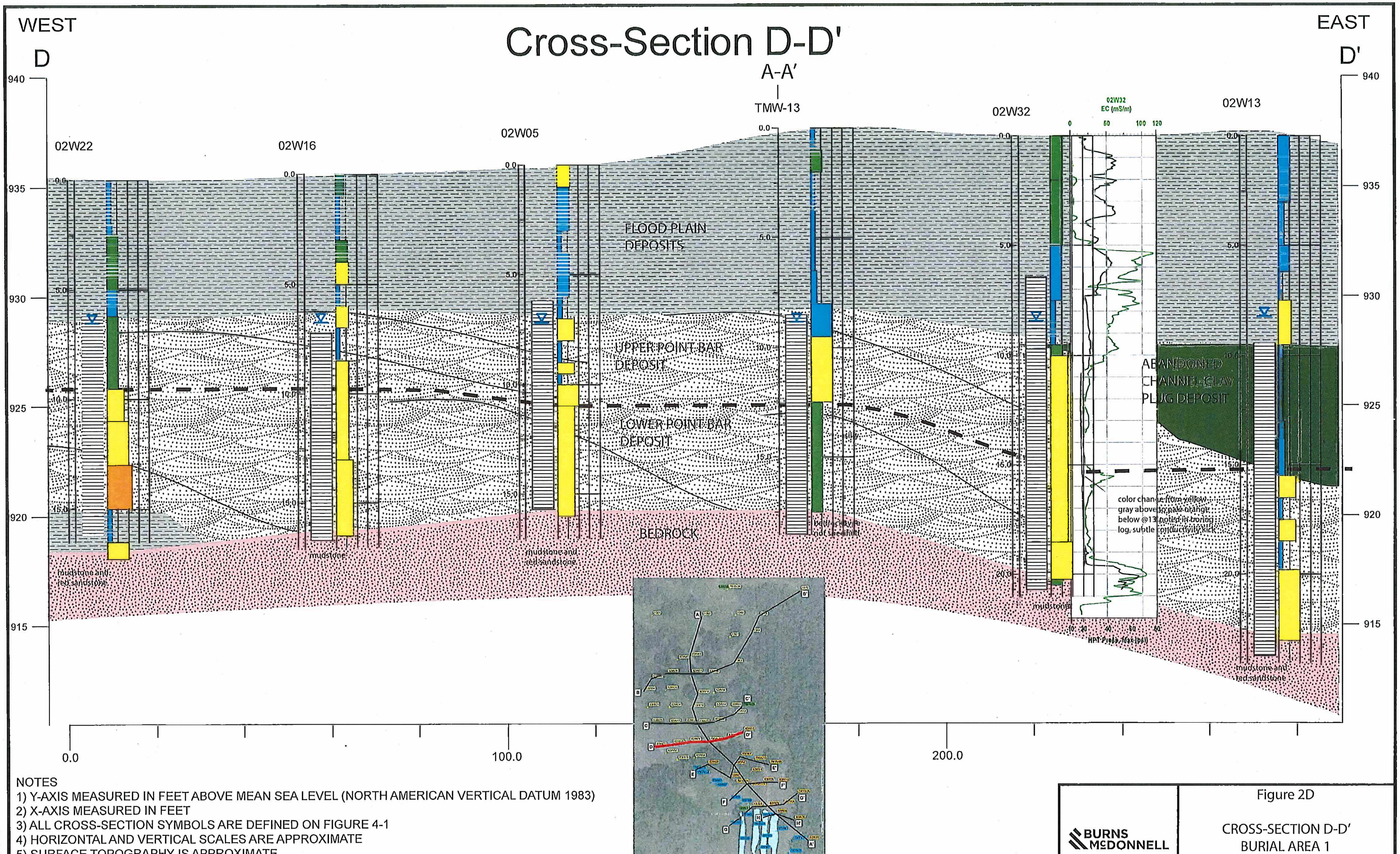
Figure 2C

CROSS-SECTION C-C'
BURIAL AREA 1
CIMMARON SITE, OKLAHOMA



NOTES
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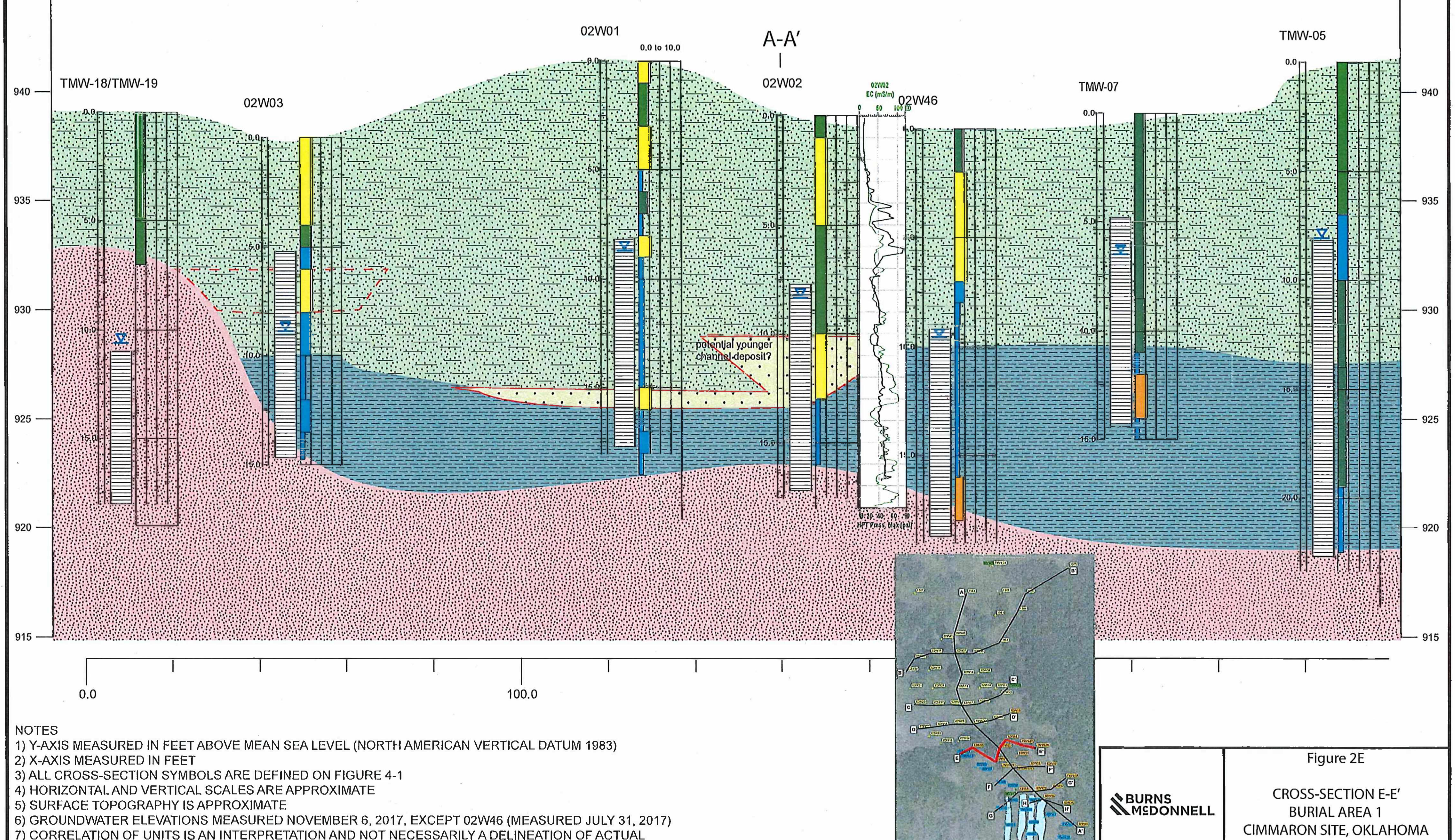
2) X-AXIS MEASURED IN FEET
3) ALL CROSS-SECTION SYMBOLS ARE DEFINED ON FIGURE 4-1
4) HORIZONTAL AND VERTICAL SCALES ARE APPROXIMATE
5) SURFACE TOPOGRAPHY IS APPROXIMATE
6) GROUNDWATER ELEVATIONS MEASURED NOVEMBER 6, 2017
7) CORRELATION OF UNITS IS AN INTERPRETATION AND NOT NECESSARILY A DELINEATION OF ACTUAL EXTENT AND THICKNESS OF EACH INDIVIDUAL UNIT

BURNS McDONNELL

Figure 2D

CROSS-SECTION D-D'
BURIAL AREA 1
CIMMARON SITE, OKLAHOMA

Cross-Section E-E'



NOTES
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2) X-AXIS MEASURED IN FEET
3) ALL CROSS-SECTION SYMBOLS ARE DEFINED ON FIGURE 4-1
4) HORIZONTAL AND VERTICAL SCALES ARE APPROXIMATE
5) SURFACE TOPOGRAPHY IS APPROXIMATE
6) GROUNDWATER ELEVATIONS MEASURED NOVEMBER 6, 2017, EXCEPT 02W46 (MEASURED JULY 31, 2017)
7) CORRELATION OF UNITS IS AN INTERPRETATION AND NOT NECESSARILY A DELINEATION OF ACTUAL EXTENT AND THICKNESS OF EACH INDIVIDUAL UNIT

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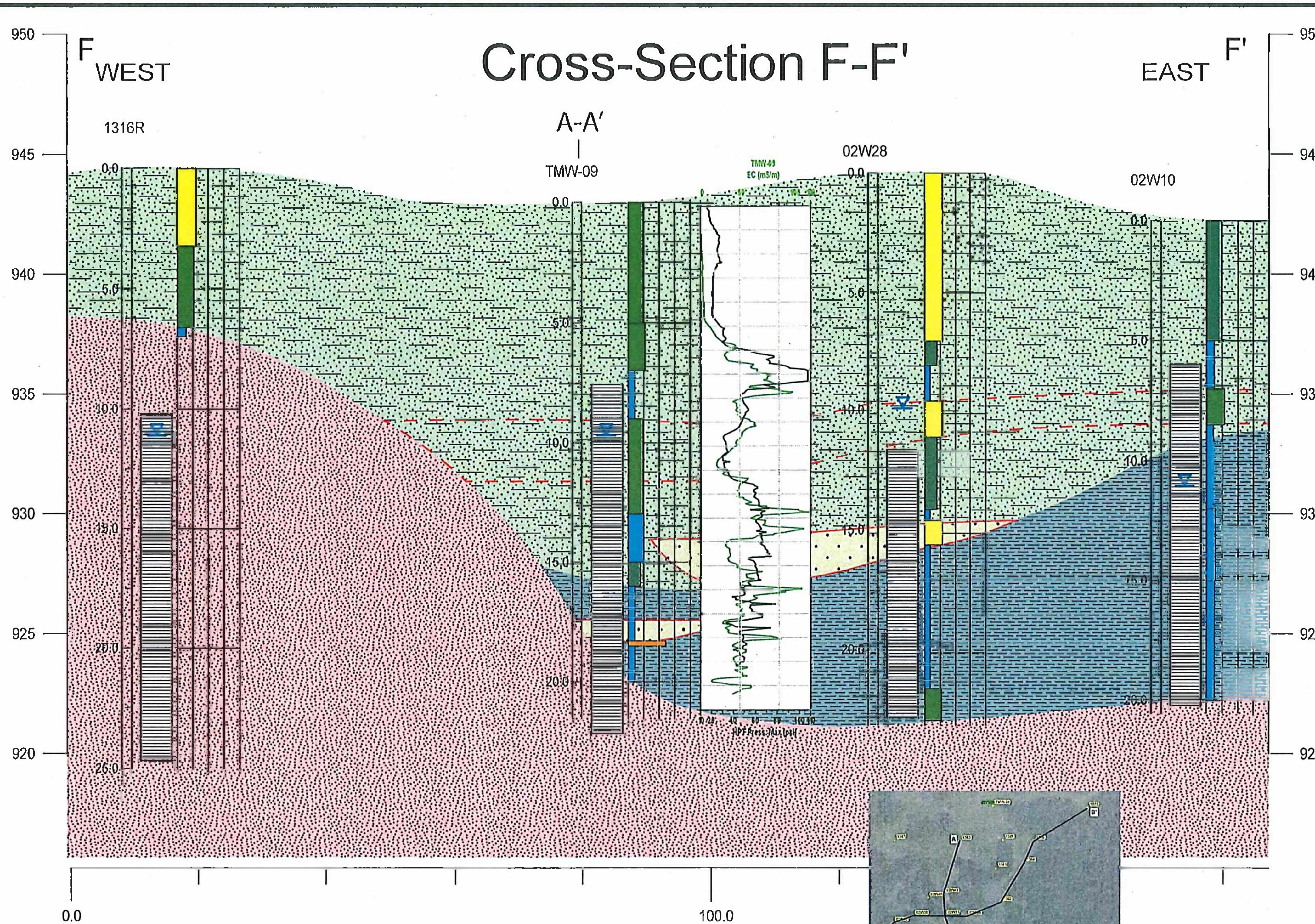
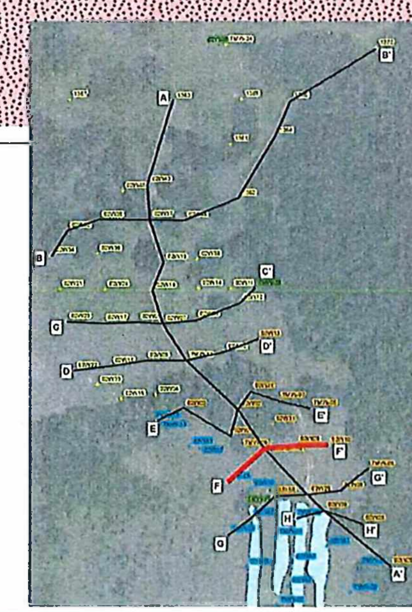
Figure 2E

CROSS-SECTION E-E'
BURIAL AREA 1
CIMMARON SITE, OKLAHOMA





NOTES
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4) HORIZONTAL AND VERTICAL SCALES ARE APPROXIMATE
5) SURFACE TOPOGRAPHY IS APPROXIMATE
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7) CORRELATION OF UNITS IS AN INTERPRETATION AND NOT NECESSARILY A DELINEATION OF ACTUAL EXTENT AND THICKNESS OF EACH INDIVIDUAL UNIT

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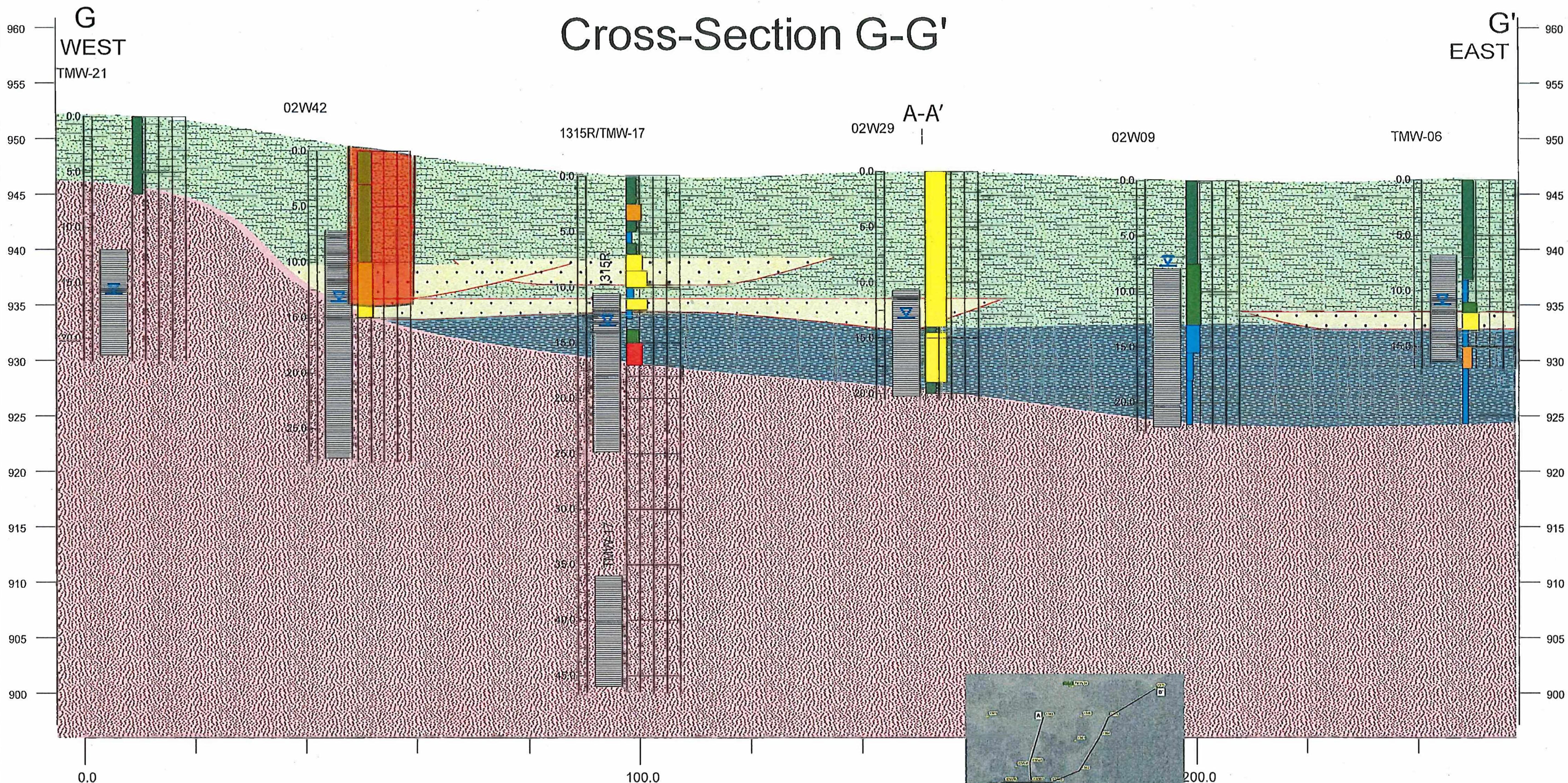
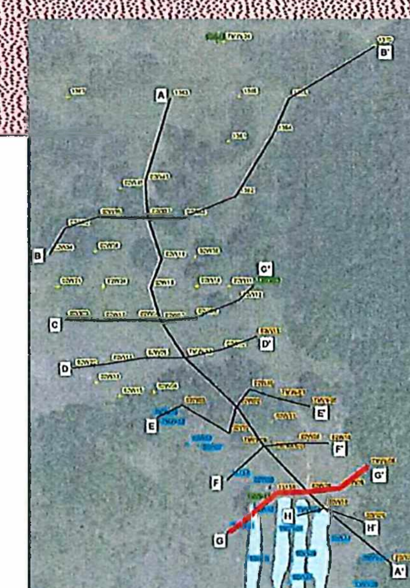
Figure 2F

CROSS-SECTION F-F'
BURIAL AREA 1
CIMMARON SITE, OKLAHOMA

Cross-Section G-G'





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2) X-AXIS MEASURED IN FEET
3) ALL CROSS-SECTION SYMBOLS ARE DEFINED ON FIGURE 4-1
4) HORIZONTAL AND VERTICAL SCALES ARE APPROXIMATE
5) SURFACE TOPOGRAPHY IS APPROXIMATE
6) GROUNDWATER ELEVATIONS MEASURED NOVEMBER 6, 2017, EXCEPT 02W29 (MEASURED JULY, 31 2017)
7) CORRELATION OF UNITS IS AN INTERPRETATION AND NOT NECESSARILY A DELINEATION OF ACTUAL EXTENT AND THICKNESS OF EACH INDIVIDUAL UNIT

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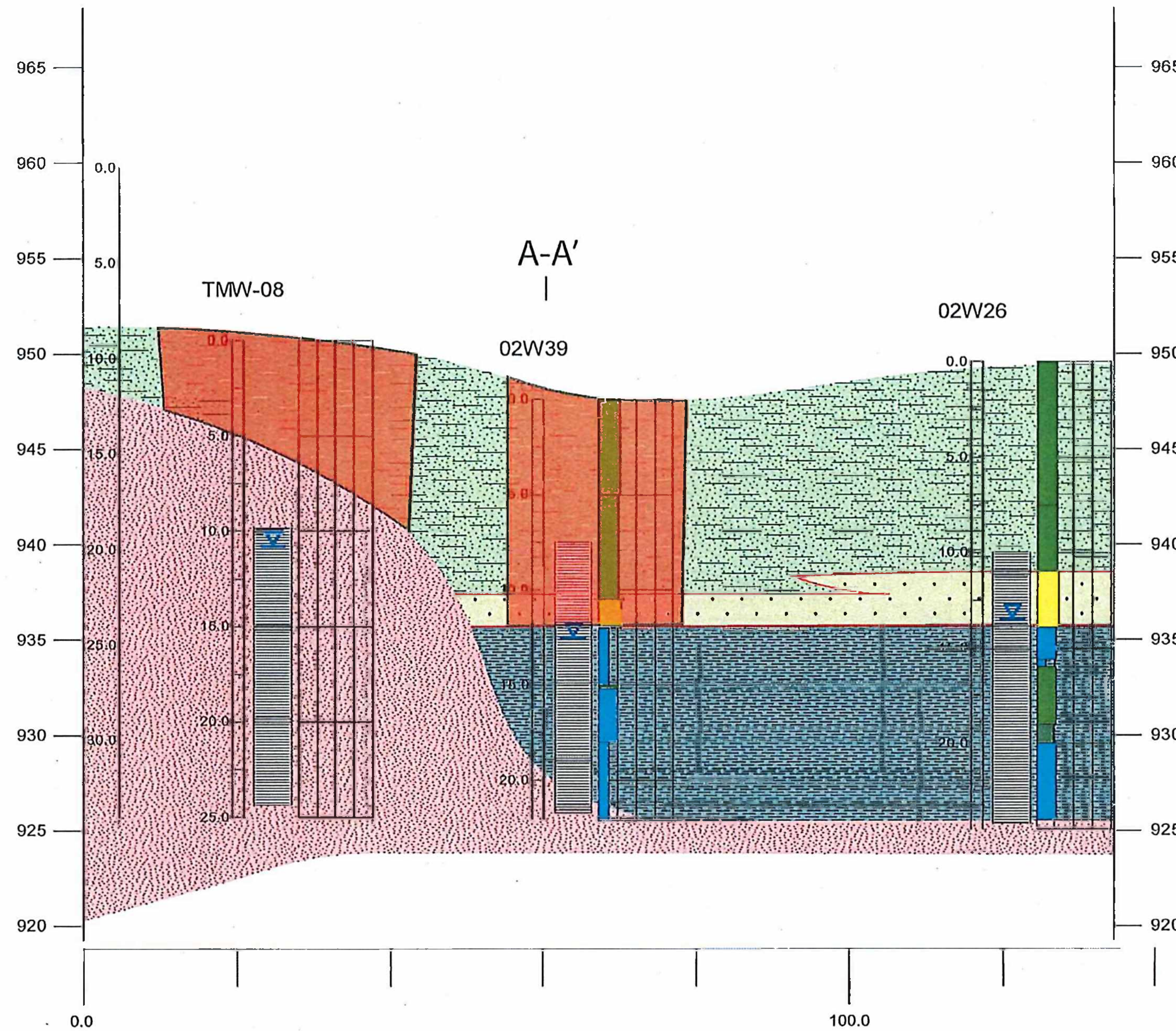
Figure 2G

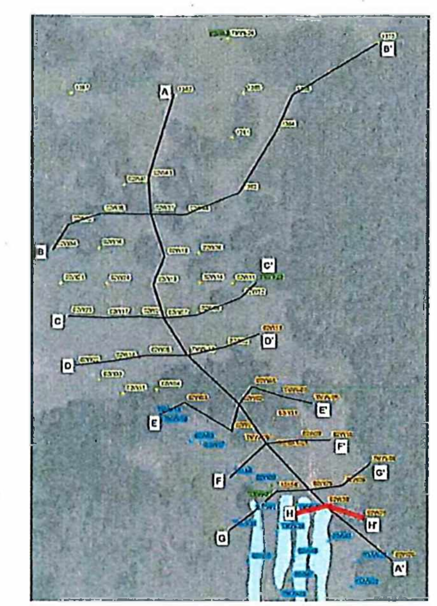
CROSS-SECTION G-G'
BURIAL AREA 1
CIMMARON SITE, OKLAHOMA

Cross-Section H-H'

WEST
H

EAST
H'





NOTES
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2) X-AXIS MEASURED IN FEET
3) ALL CROSS-SECTION SYMBOLS ARE DEFINED ON FIGURE 4-1
4) HORIZONTAL AND VERTICAL SCALES ARE APPROXIMATE
5) SURFACE TOPOGRAPHY IS APPROXIMATE
6) GROUNDWATER ELEVATIONS MEASURED NOVEMBER 6, 2017
7) CORRELATION OF UNITS IS AN INTERPRETATION AND NOT NECESSARILY A DELINEATION OF ACTUAL EXTENT AND THICKNESS OF EACH INDIVIDUAL UNIT

BURNS McDONNELL

Figure 2H

CROSS-SECTION H-H'
BURIAL AREA 1
CIMMARON SITE, OKLAHOMA

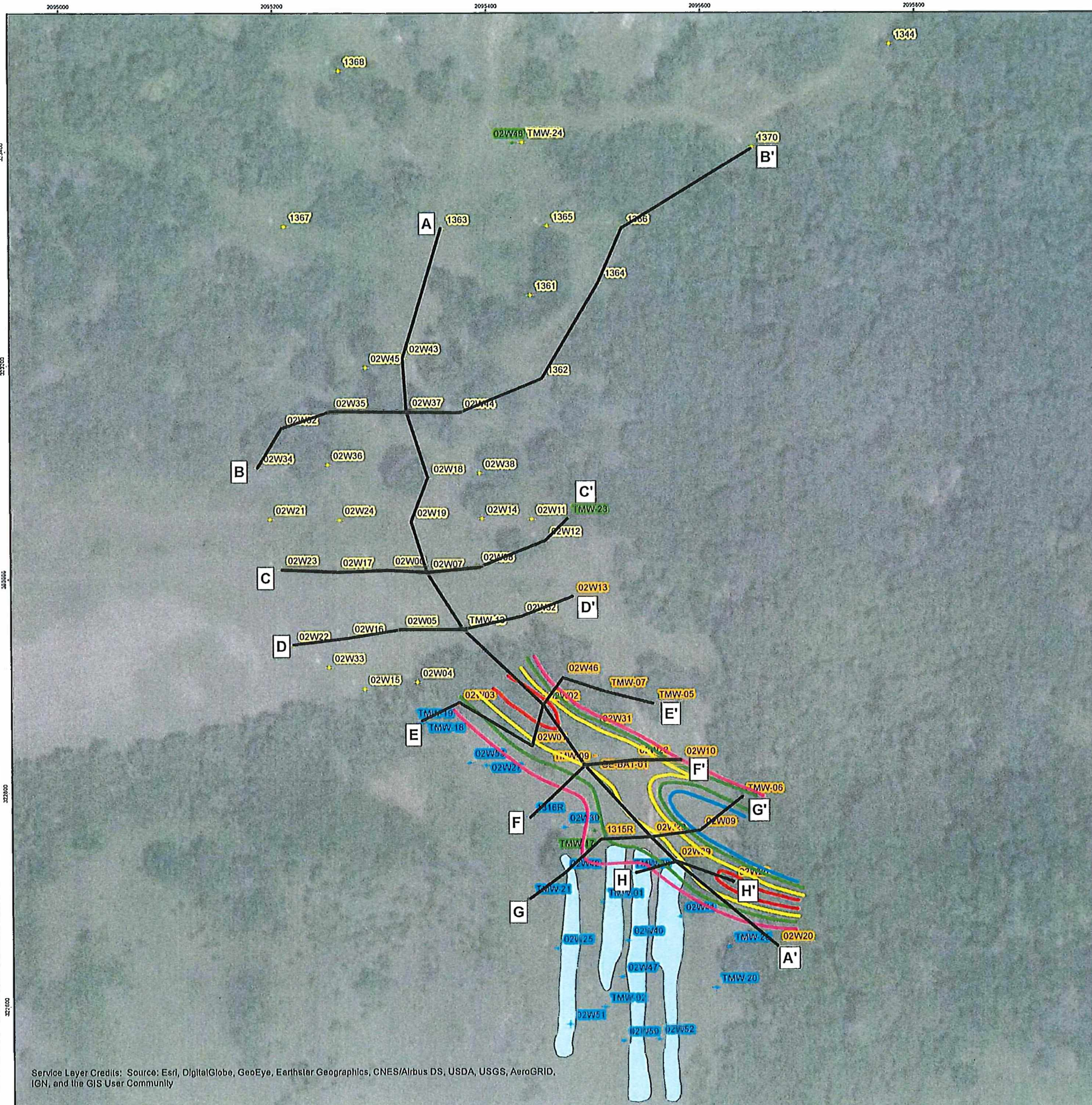

FIGURE 3A
ISOPACH CONTOURS
BURIAL AREA 1
CIMARRON SITE, OKLAHOMA

BURNS McDONNELL. environmental

Legend

- MONITORING WELL IN TRANSITION ZONE
- MONITORING WELL IN ALLUVIUM
- MONITORING WELL IN SANDSTONE A
- MONITORING WELL IN SANDSTONE B
- MONITORING WELL IN SANDSTONE C
- WASTE DISPOSAL TRENCH
- CROSS-SECTION LINE

ESTIMATED THICKNESS OF RELATIVELY PERMEABLE STRATA

- ZERO EDGE
- ONE FOOT
- TWO FEET
- THREE FEET

NOTES:

ISOPACH THICKNESS CONTOUR LINES APPROXIMATED. LINES BASED ON BASAL, SATURATED, INTRA-GULLY STREAM DEPOSITS.

0 50 100 200 Feet N

Source: ESRI and Burns & McDonnell Engineering.
COORDINATES: (NAD 83) STATE PLANE OKLAHOMA NORTH FEET
DATE: AERIAL PHOTO - 2010 / MAP PRODUCED - 4/6/2018

Path: Z:\Clients\ENS\CERT_ClientInfo\Sites\Database\Geospatial\Maps & Dwgs\ArcGIS\BMCD_Files\Arcdocs\2018\ESS Tech Memo\Isopach Map.mxd

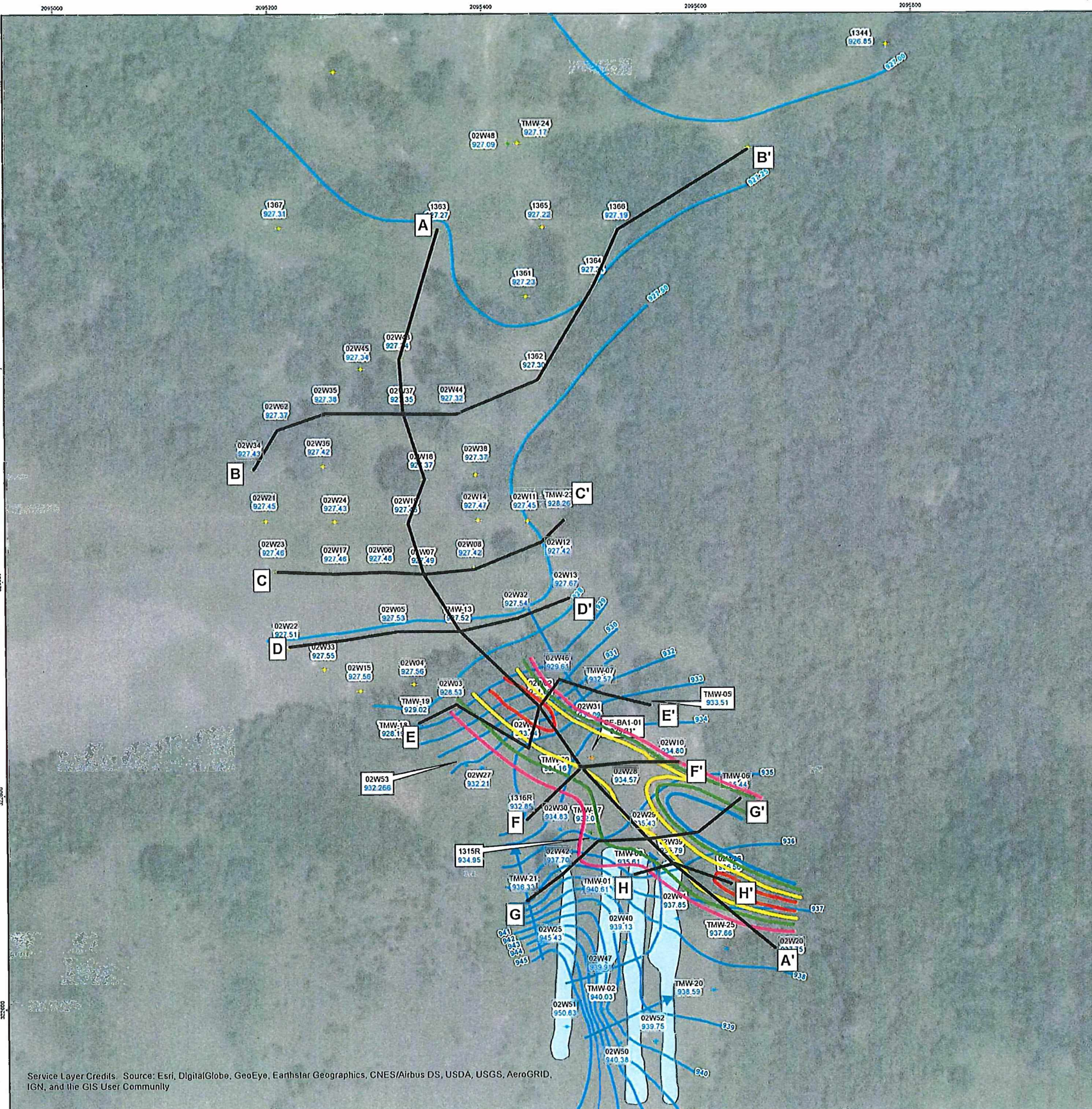

FIGURE 3B
ISOPACH CONTOURS WITH POTENTIOMETRIC SURFACE
BURIAL AREA 1
CIMARRON SITE, OKLAHOMA

BURNS McDONNELL. environmental

Legend

- MONITORING WELL IN TRANSITION ZONE
- MONITORING WELL IN ALLUVIUM
- MONITORING WELL IN SANDSTONE A
- MONITORING WELL IN SANDSTONE B
- MONITORING WELL IN SANDSTONE C
- GROUNDWATER FLOW DIRECTION
- ALLUVIUM DEPOSITS GW CONTOURS
- SANDSTONE B GW CONTOURS
- WASTE DISPOSAL TRENCH
- CROSS-SECTION LINE

ESTIMATED THICKNESS OF RELATIVELY PERMEABLE STRATA

- ZERO EDGE
- ONE FOOT
- TWO FEET
- THREE FEET

NOTES:

GROUNDWATER ELEVATION DATA COLLECTED MARCH 18, 2015

ELEVATIONS ARE IN FEET ABOVE MEAN SEA LEVEL (NORTH AMERICAN VERTICAL DATUM 1988)

*DATA FROM GE-BA1-01 NOT USED IN CONTOURING

ISOPACH CONTOUR LINES APPROXIMATED. LINES BASED ON BASAL, SATURATED, INTRA-GULLY STREAM DEPOSITS.

GW - GROUNDWATER

0 50 100 200 Feet N

Source: ESRI and Burns & McDonnell Engineering.
COORDINATES : (NAD 83) STATE PLANE OKLAHOMA NORTH FEET
DATE : AERIAL PHOTO - 2010 / MAP PRODUCED - 4/6/2018

FIGURE 3C
ISOPACH CONTOURS WITH URANIUM ISOPLETHS BURIAL AREA 1 CIMARRON SITE, OKLAHOMA

BURNS McDONNELL. environmental

Legend

- MONITORING WELL IN TRANSITION ZONE
- MONITORING WELL IN ALLUVIUM
- MONITORING WELL IN SANDSTONE A
- MONITORING WELL IN SANDSTONE B
- MONITORING WELL IN SANDSTONE C
- URANIUM CONTOURS IN UG/L
- WASTE DISPOSAL TRENCH
- CROSS-SECTION LINE

ESTIMATED THICKNESS OF RELATIVELY PERMEABLE STRATA

- ZERO EDGE
- ONE FOOT
- TWO FEET
- THREE FEET

NOTES:

UG/L - MICROGRAMS PER LITER

ISOPACH CONTOUR LINES APPROXIMATED. LINES BASED ON BASAL, SATURATED, INTRA-GULLY STREAM DEPOSITS.

URANIUM COTOURS ARE BASED ON 95% UCL FROM DATA COLLECTED 2011 THROUGH 2ND QUARTER 2017.

0 50 100 200 Feet N

Source: ESRI and Burns & McDonnell Engineering.

COORDINATES : (NAD 83) STATE PLANE OKLAHOMA NORTH FEET

DATE : AERIAL PHOTO - 2010 / MAP PRODUCED - 4/6/2018

Path: Z:\Clients\ENS\CERT_Client\Info\Sites\Database\Geospatial\Maps & Dwgs\ArcGIS\BMCD_Files\Arcdocs\2018\ESS Tech Memo\Isopach U Conc Map.mxd

Table 1
Transmissive Porosity Calculation for Saturated and Contaminated Burial Area #1 Transition Zone
Cimarron Environmental Response Trust

Aquifer Zone	Aquifer Material	Bulk Aquifer Volume (ft^3)[1]	Assumed Effective Porosity[2]	Transmissive Pore Volume (ft^3)	Total Bulk Aquifer Volume (ft^3)[1]	Total Transmissive Pore Volume (ft^3)	Calculated Effective Porosity
Impacted TZ UGF Deposits	silt and silty sand with interbedded clayey sand and silty sand	189,137	10%	18,914	511,425	55,588	11%
Impacted TZ Sand Channel Deposits	sand and silty-sand streamflow deposits	44,458	20%	8,892			
Impacted TZ LGF Deposits	clay-rich channel wall failure deposits	277,830	10%	27,783			

<u>Notes:</u>
TZ - Transition Zone
UGF -Upper Gully Fill
LGF - Lower Gully Fill
ft^3 - cubic feet

[1]Calculated using Earth Volumetric Studio® software application. Sediment and groundwater depths imported into EVS were taken from TZ borings depicted on cross-sections A-A' through E-E'. Highest groundwater surface elevations depicted on cross-sections were used to determine saturated thickness and volume. Calculated bulk saturated volume within the uranium-impacted portion of the TZ is 609,606 ft^3.

[2]Material-specific effective porosity values based on reference values obtained from *Applications of Environmental Chemistry – A Practical Guide for Environmental Professionals* (Weiner, 2000).

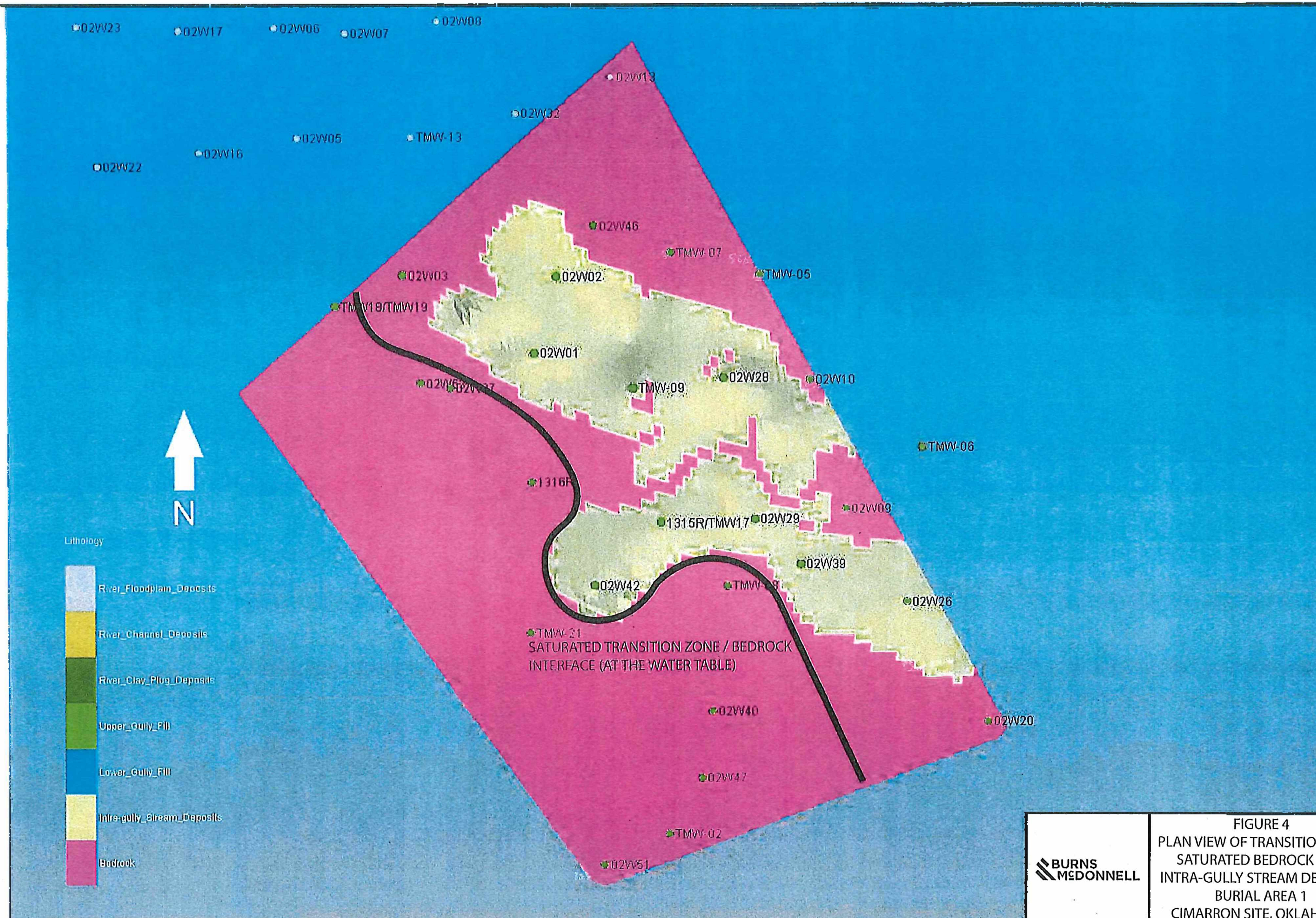

FIGURE 4
PLAN VIEW OF TRANSITION ZONE
SATURATED BEDROCK AND
INTRA-GULLY STREAM DEPOSITS
BURIAL AREA 1
CIMARRON SITE, OKLAHOMA

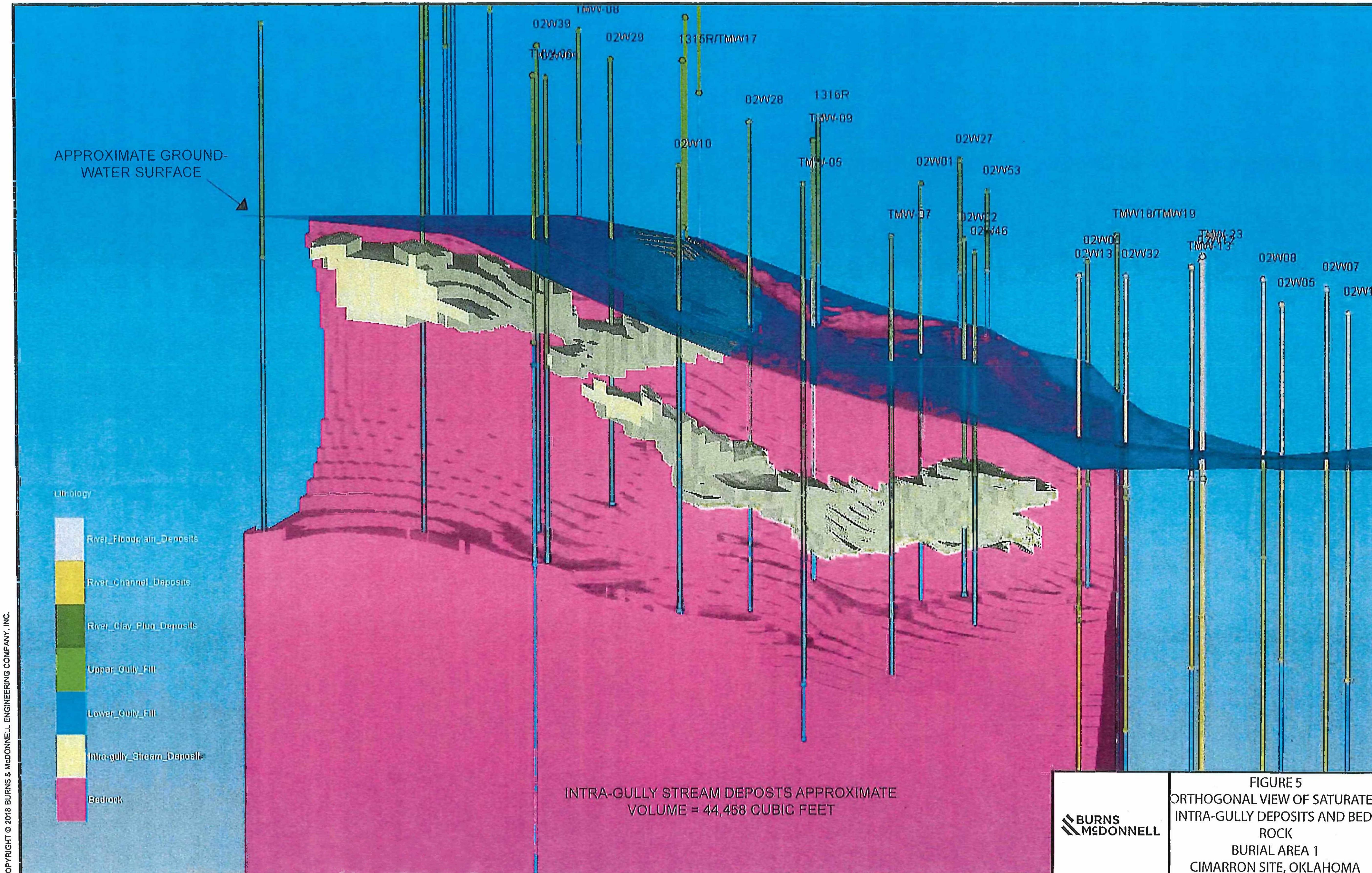

FIGURE 5
ORTHOGONAL VIEW OF SATURATED INTRA-GULLY DEPOSITS AND BED-ROCK
BURIAL AREA 1
CIMARRON SITE, OKLAHOMA

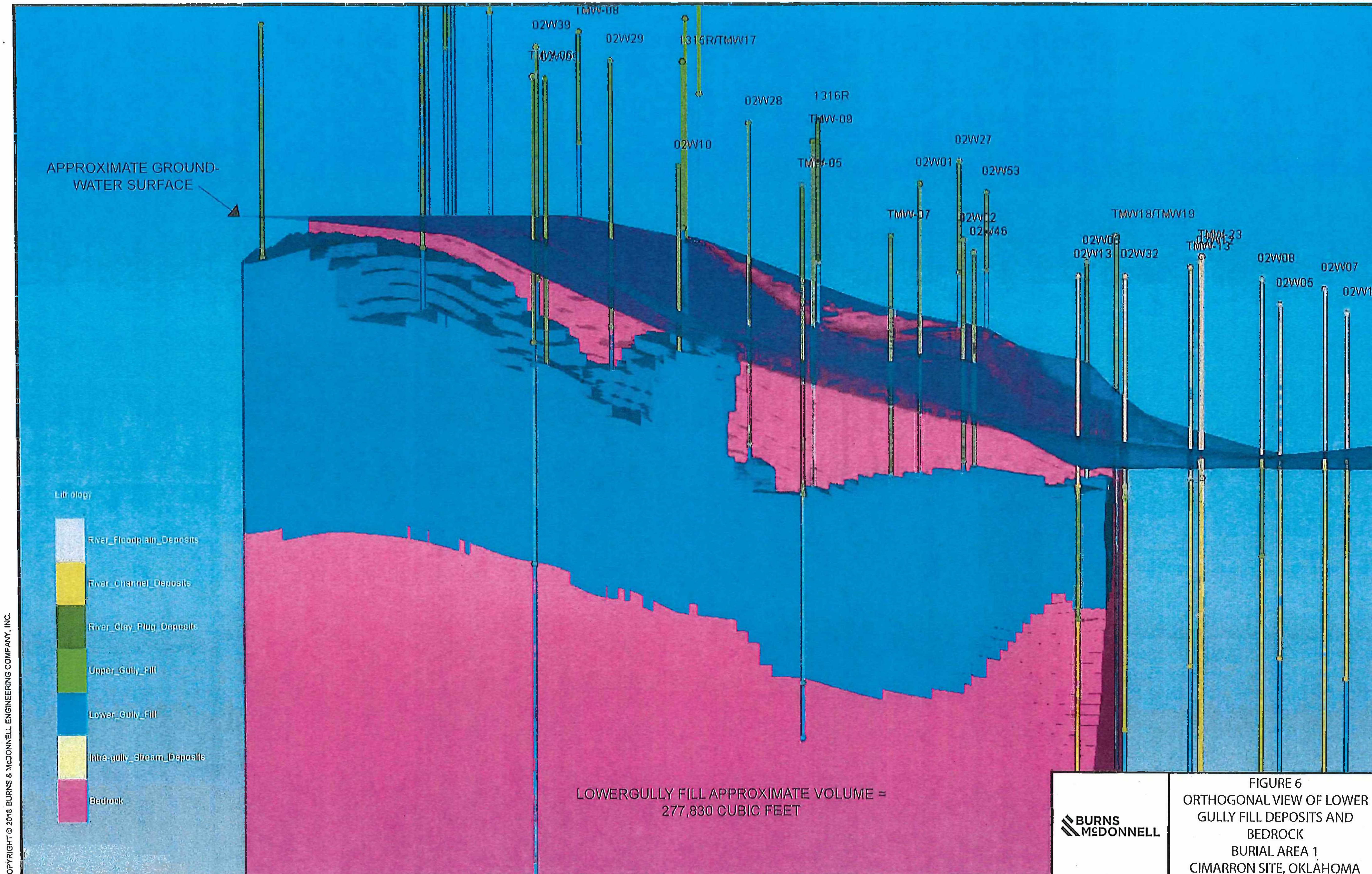

FIGURE 6
ORTHOGONAL VIEW OF LOWER GULLY FILL DEPOSITS AND BEDROCK
BURIAL AREA 1
CIMARRON SITE, OKLAHOMA

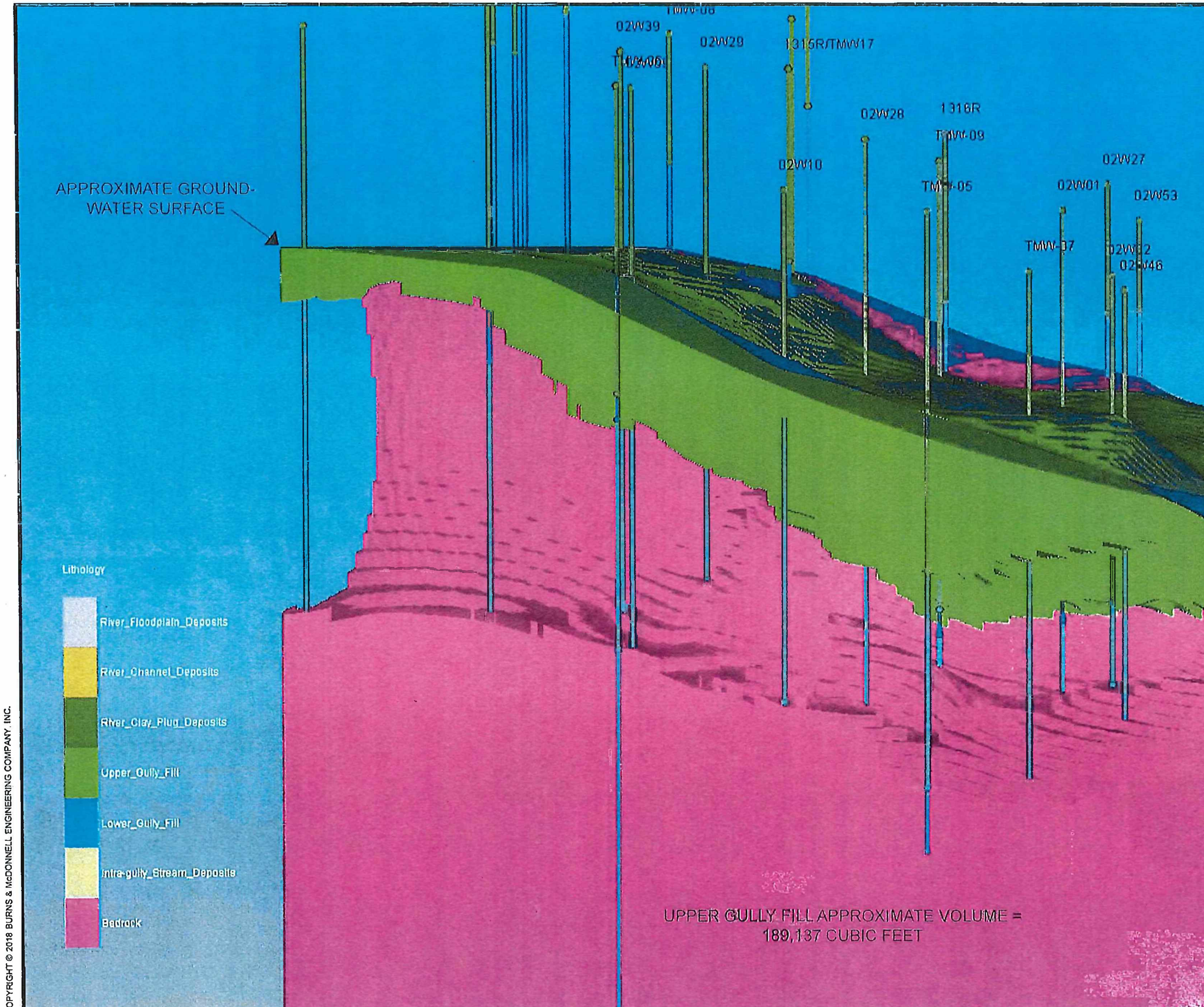

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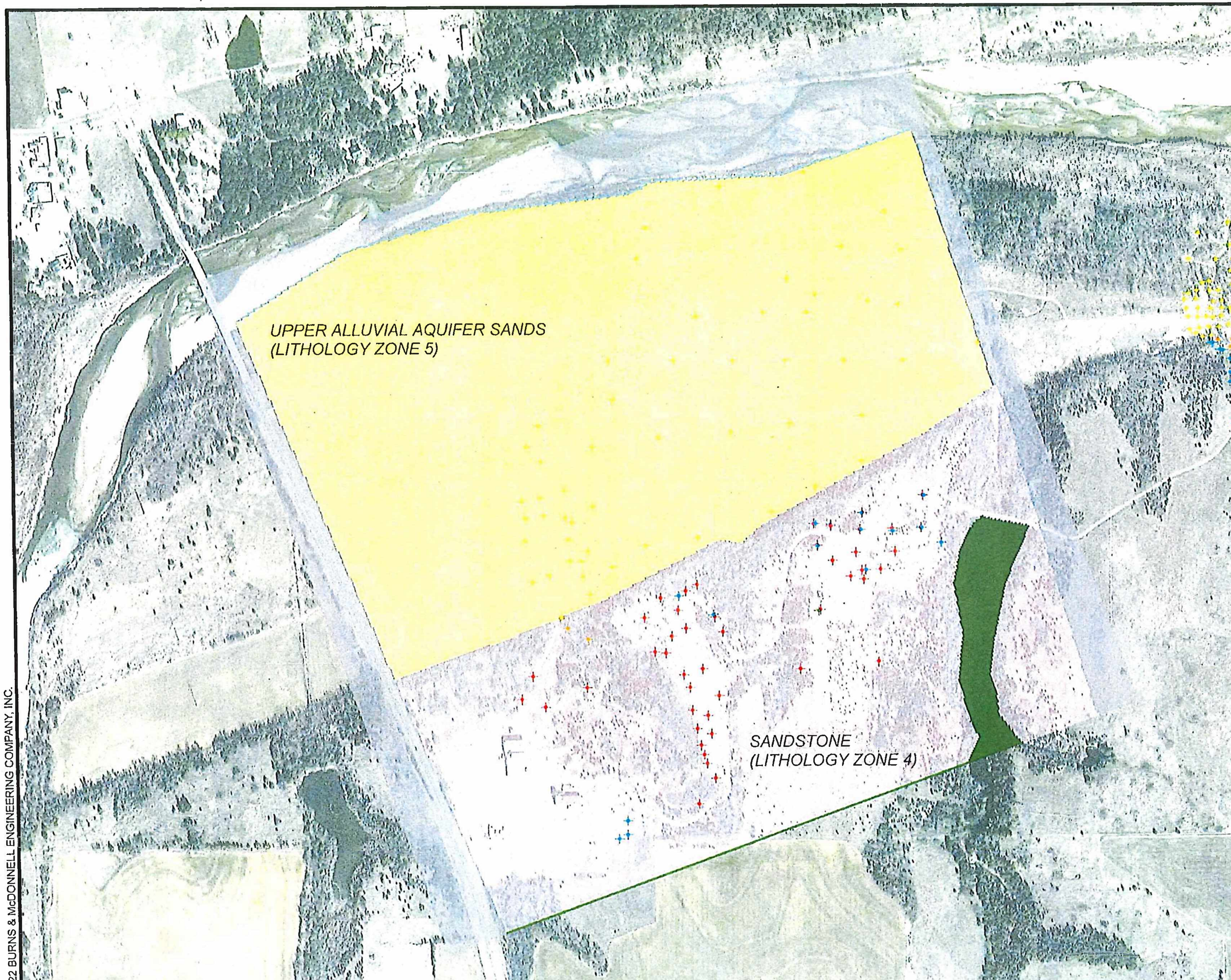
FIGURE 7
ORTHOGONAL VIEW OF UPPER GULLY FILL DEPOSITS AND BEDROCK
BURIAL AREA 1
CIMARRON SITE, OKLAHOMA

APPENDIX C - 2022 WAA GROUNDWATER FLOW MODEL LITHOLOGY DISTRIBUTION BY MODFLOW LAYER



APPENDIX C
WAA GROUNDWATER FLOW MODEL
LITHOLOGY ZONES - MODEL LAYER 1

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environmental properties management, llc

LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE A
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- ACTIVE MODEL DOMAIN
- NO FLOW BOUNDARIES
- CONSTANT HEAD BOUNDARIES
- RIVER BOUNDARIES CELLS
- GENERAL HEAD BOUNDARY CELLS
- UPPER ALLUVIAL AQUIFER SANDS (LITHOLOGY ZONE 5)
- SANDSTONE (LITHOLOGY ZONE 4)

NOTES

1) Groundwater elevations in feet above mean sea level (North American Vertical datum of 1988).

0 550 1,100
SCALE IN FEET

N

	Rev No: 0
Preparer: DHORNE	Date: 10/6/2022
Reviewer: DCLEMENT	Date: 10/6/2022

Coordinate System
NAD 1983 StatePlane Oklahoma North FIPS 3501 Feet

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APPENDIX C
WAA GROUNDWATER FLOW MODEL
LITHOLOGY ZONES - MODEL LAYER 2

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE A
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- ACTIVE MODEL DOMAIN
- NO FLOW BOUNDARIES
- CONSTANT HEAD BOUNDARIES
- RIVER BOUNDARIES CELLS
- GENERAL HEAD BOUNDARY CELLS
- LOWER ALLUVIAL AQUIFER SANDS (LITHOLOGY ZONE 5)
- SANDSTONE (LITHOLOGY ZONE 4)

NOTES

1) Groundwater elevations in feet above mean sea level (North American Vertical datum of 1988).

0 550 1,100
SCALE IN FEET
N

	Rev No: 0
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Coordinate System
NAD 1983 StatePlane Oklahoma North FIPS 3501 Feet

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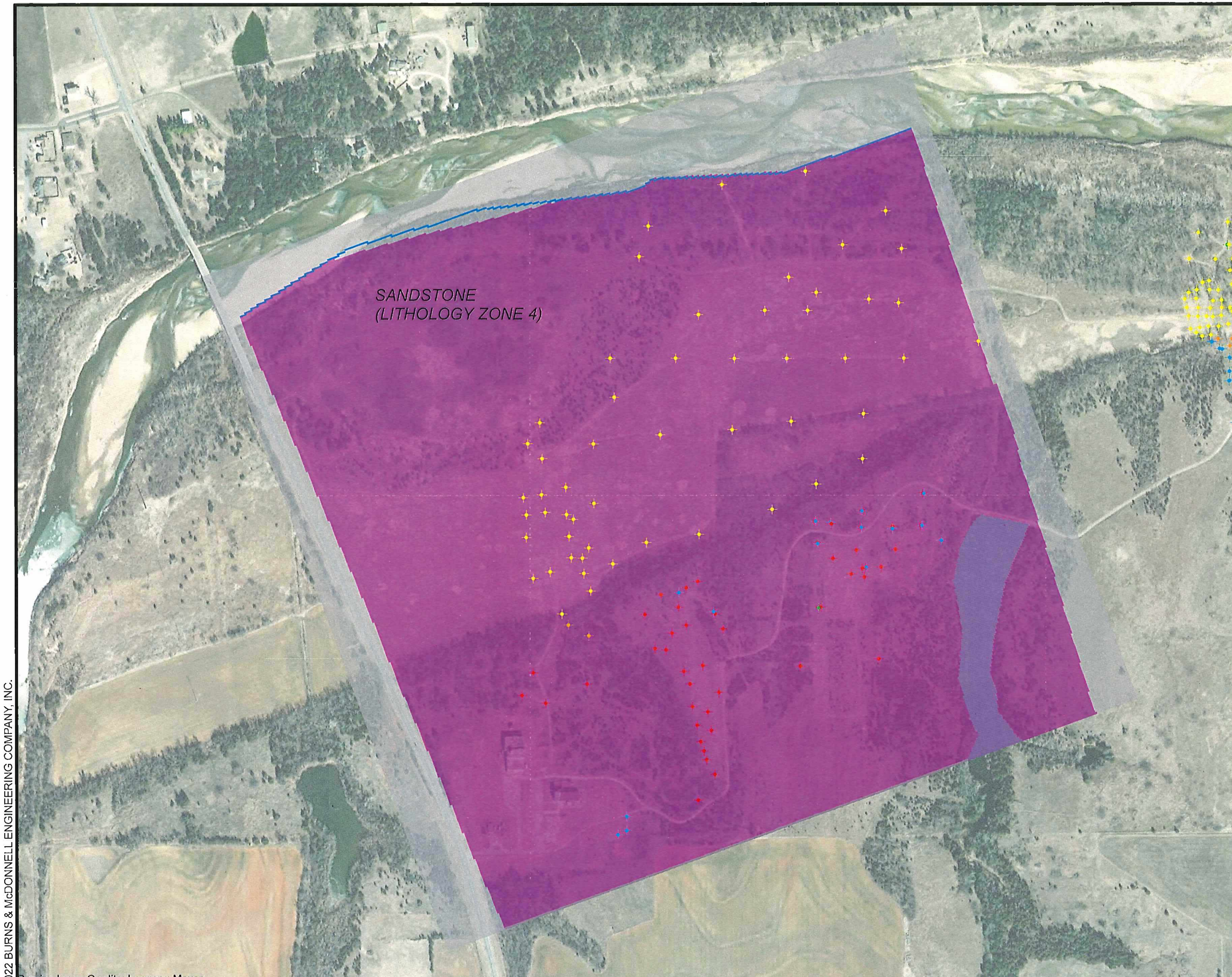

APPENDIX C
WAA GROUNDWATER FLOW MODEL
LITHOLOGY ZONES - MODEL LAYER 3

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LEGEND

- MONITOR WELL IN ALLUVIUM
- MONITOR WELL IN SANDSTONE A
- MONITOR WELL IN SANDSTONE B
- MONITOR WELL IN SANDSTONE C
- MONITOR WELL IN TRANSITION ZONE
- ACTIVE MODEL DOMAIN
- NO FLOW BOUNDARIES
- CONSTANT HEAD BOUNDARIES
- RIVER BOUNDARIES CELLS
- GENERAL HEAD BOUNDARY CELLS
- SANDSTONE (LITHOLOGY ZONE 4)

NOTES

1) Groundwater elevations in feet above mean sea level (North American Vertical datum of 1988).

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CREATE AMAZING.

Burns & McDonnell World Headquarters
9400 Ward Parkway
Kansas City, MO 64114
O 816-333-9400
F 816-333-3690
www.burnsmcd.com