United States Nuclear Regulatory Commission Official Hearing Exhibit
In the Matter of: CROW BUTTE RESOURCES, INC.
(License Renewal for the In Situ Leach Facility, Crawford, Nebraska)
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Sept. 8, 2015

Crow Butte License Renewal Hearing
NRC Staff Response to Intervenors' Request for Modeling Information

INTRODUCTION

This document has been prepared by Dr. Elise Striz and Mr. John Saxton of the NRC Staff. Dr. Striz is an NRC Staff witness in the Crow Butte License Renewal proceeding. Mr. Saxton is an NRC hydrogeologist who was enlisted to assist Dr. Striz in order to meet the promised deadline for providing this document to the Board and parties. Dr. Striz and Mr. Saxton have attempted to respond to all of the requests submitted by the intervenors to the best of their ability. However, neither Dr. Striz nor Mr. Saxton were involved in initially developing or running these models. As Dr. Striz testified during the hearing, that work was performed by a person who is no longer with the NRC. For this reason, as discussed in some of the responses below, Dr. Striz and Mr. Saxton have not been able to provide requested justifications for certain choices or decisions made when the models were created.

In order to develop this document, Dr. Striz and Mr. Saxton had to extract information from data embedded in a proprietary software package, the Groundwater Modeling System (GMS). Because of the tremendous quantity of data used to generate, parameterize, run and calibrate the models, and the fact that this data was embedded in proprietary groundwater modeling software, the extraction may be subject to some errors. Dr. Striz and Mr. Saxton have made their best efforts to provide accurate information. In addition, the input and output files for the groundwater flow models are listed in the "REFERENCES" section below and are now publicly available in ADAMS. These files are being submitted as Board Exhibits BRD-007A through BRD-007J, and provide all of the information used to generate, run, and calibrate the Simulation 1 and Simulation 2 groundwater flow models used in the evaluation of the White River structural feature described in the CBR Safety Evaluation Report (SER) (Exhibit NRC-009) and Environmental Assessment (EA) (Exhibit NRC-010).

RESPONSES TO SPECIFIC QUESTIONS

1. Purpose of the model

The purpose of this NRC groundwater modeling effort was to conduct an uncertainty evaluation of several conceptual site models for the groundwater flow system at the Crow Butte Resources (CBR) North Trend Expansion Area (NTEA) using a Bayesian Maximum Likelihood (ML) analysis. This analysis is described in NUREG/CR-6940/PNNL-16396, "Combined Estimation of Hydrogeologic Conceptual Model, Parameter and Scenario Uncertainty with Application to Uranium Transport at the Hanford Site 300 Area" (Reference 12), which is being provided as Exhibit NRC-094 to accompany this document. The conceptual models used for the ML analysis were based on the different possible interpretations of the White River structural feature, specifically as a conductive or non-conductive feature or as not present. To undertake the ML analysis, the NRC staff first developed two different base groundwater flow models (simulations) for the NTEA using MODFLOW as it has been incorporated into a front-end user interface known as the Groundwater Modeling System (GMS). MODFLOW is a widely used finite difference, groundwater flow modeling program developed by the United States Geological Survey (USGS). The staff used MODFLOW 2000, which is the current version incorporated into

the GMS. The two base models, Simulation 1 and Simulation 2, differ in the manner in which they incorporated the White River structural feature. The NRC staff subsequently developed eight groundwater flow model scenarios (four based on each simulation) with variations to the base model to study the effect of a potential flow or no-flow feature on the Basal Chadron Sandstone aquifer flow system. Two models for each simulation assumed that the feature acted as a medium to high conductivity flow boundary, and two models for each simulation assumed that it was a low to very low conductivity (restricted-flow or no-flow) boundary. The staff developed these scenarios by altering the conditions of the southern boundary of the proposed NTEA for Simulation 1 and by altering the hydraulic conductivity of a linear zone in the Basal Chadron Sandstone Aquifer for Simulation 2. Data input included well-boring log data, hydraulic properties of the geologic units down to the Pierre Shale, well water level data, and boundary conditions. Because these models were developed for the NTEA, the staff obtained field data used to develop the model from the NTEA license amendment application (CBR 2007). After model development, the staff calibrated each model using Parameter Estimation (PEST), a parameter estimation and automated calibration software application that is included in the GMS software. Specifically, PEST was used to fit the hydraulic conductivity of the Basal Chadron Sandstone Aquifer and two separate general head boundaries, using the observed head values from the NTEA pumping test conducted in 2006. The ML analysis was conducted using the weighted sum of the squared residuals (WSSRs) and the eigenvalues of the PEST calibration for each model in the Bayes Theorem to determine the posterior probability for each of the models as described in the Safety Evaluation Report (SER) for the CBR license renewal (Exhibit NRC-009).

As discussed above, this groundwater modeling for the interpretation of the White River structural feature was performed to assess the probability of several site conceptual models of the feature to enable the selection of the best conceptual site model. The modeling was not done to develop a deterministic groundwater flow model to be used for a specific purpose such as history matching or future groundwater flow and contaminant transport predictions. Because this effort was only to assess the uncertainty of multiple conceptual site models using a Bayesian Maximum Likelihood analysis and not for deterministic modeling based on one preferred site conceptual model, many of the traditional steps of deterministic groundwater flow modeling (e.g., sensitivity analysis, parameter uncertainty analysis, verification, etc.) were not invoked.

2. Modeling program(s), code(s) used, both public access and private domain

The groundwater flow modeling for each of the simulations developed for the ML analysis of the White River structural feature was conducted using the proprietary Department of Defense Groundwater Modeling System (GMS) software. GMS is available from the Corps of Engineers Coastal Hydraulic Laboratory website for DOD, EPA and NRC users (http://chl.erdc.usace.army.mil/gms). This website describes the GMS as follows:

> The Department of Defense Groundwater Modeling System (GMS) is the most sophisticated groundwater modeling environment available today. The U.S. Army, in partnership with the U.S. Environmental Protection Agency, the U.S. Nuclear Regulatory Commission and academic partners, has developed the DoD Groundwater Modeling System. The GMS provides an integrated and comprehensive computational environment for simulating subsurface flow, contaminant fate/transport, and the efficacy and design of remediation systems.
>
> GMS integrates and simplifies the process of groundwater flow and transport

modeling by bringing together all of the tools needed to complete a successful study. GMS provides a comprehensive graphical environment for numerical modeling, tools for site characterization, model conceptualization, mesh and grid generation, geostatistics, and sophisticated tools for graphical visualization.

Several types of models are supported by GMS. The current version of GMS provides a complete interface for the codes ADH, FEMWATER, MODAEM, MODFLOW, MODPATH, MT3D, and RT3D, SEAM 3D, SEEP2D, UTEXAS, and WASH123D. The parameter estimation code PEST and the geostatistic code T-PROGS are also supported. Additional tools and interfaces for models are being designed in an on-going development process so stay tuned for more features.

3. Map of the model domain with justification for the domain selection

Figure 1 shows the model domain on a basemap for Simulation 1. This domain is the same for all six model layers. Each red square (section) represents 1 square mile. The elevation of the ground surface and bottom of each layer were assigned by interpolation of the layer elevations from the well borings presented in Response 22 below. Table 1 gives the grid and layer assignments for the Simulation 1 models.

Figure 4 shows the model domain on a basemap for Simulation 2. This domain is the same for all six model layers. Each red square (section) represents 1 square mile. The ground surface and bottom layer elevations were assigned as a different constant for each layer based on the average elevation of the layer from the well borings presented in Response 22 below. Table 2 gives the grid and layer assignments for the Simulation 2 models.

The justification for the selection of the model domain is unknown, as the employee who conducted the modeling left the NRC in August 2013.

4. Grid spacing and any irregular grid spacing with explanation/justification for choice

The Simulation 1 models used a 100 by 100 cell grid, bounded by the purple rectangle on Figure 1. Table 1 provides the grid spacing for the model domain of Simulation 1 which was constant for all six layers. The Simulation 2 models used a 137 by 98 cell grid, bounded by the purple rectangle on Figure 2. Table 2 provides the grid spacing for the model domain of Simulation 2 which was variable for all six layers to incorporate a resolution of 25 feet by 25 feet around the pumping test well.

The justification for the selection of the model grid spacing is unknown, as the employee who conducted the modeling left the NRC in August 2013.

5. Initial Input values including head, K, S, porosity, with justification and documentation of the exact source of and reasoning behind these inputs

Table 3 provides the hydraulic conductivity, K, and starting head for each of the model layers in Simulation 1. Table 4 provides the hydraulic conductivity, K, and starting head for each of the model layers for Simulation 2. Storativity was not reported and not used for the steady state calibration. Porosity was reported as 0.30 for all layers in both simulations but is not used in the steady state flow model calibration.

The justification for selection of these values is unknown as the employee who conducted the modeling left the NRC in August 2013.

6. Explicit stress applied to model (e.g. pumping, drains)

All of the Simulation 1 and 2 groundwater models used a pumping well rate of -3100 ft3/day (16.1 gpm). This was the approximately the pumping well rate reported in the NTEA 2006 aquifer pumping test (16.4 gpm).

7. Boundary conditions with numerical values and types (Neumann, Dirichlet, no flow, etc.) with exact locations and reasons for selection

For Simulation 1, the specific site conceptual models and associated input/output (I/O) files were: Baseline (Ex. BRD-007A)); Barrier with low conductivity (BRD-007B); Barrier with very low conductivity (Ex. BRD-007C); Drain with medium conductance (Ex. BRD-007D); Drain with high conductance (Ex. BRD-007E). All of the boundary conditions for all models in Layers 2-6 are Neumann (general head, drain or barrier). The boundary conditions for all models for Layer 1 are Dirichlet (constant head).

The boundary conditions for the Simulation 1 conceptual models are listed on the following pages of the associated I/O files: Baseline model (Ex. BRD-007A at PDF 259-273); Barrier with low conductivity (Ex. BRD-007B at PDF 283-305); Barrier with very low conductivity (Ex. BRD-007C at PDF 281-289); Drain with medium conductance (Ex. BRD-007D at PDF 440-451); and Drain with high conductance (Ex. BRD-007E at PDF 445-456).

The White River structural feature was modeled as the southern boundary condition of the Simulation 1 models as shown in Figures 2 and 3. The type of boundary condition and its assigned value for each of the layers for the White River structural feature is provided in Table 5 for each of the Simulation 1 models.

For Simulation 2, the specific site conceptual models and associated I/O files were: Baseline (Ex. BRD-007F) Barrier with low conductivity (Ex. BRD-007G); Barrier with very low conductivity (Ex. BRD-007H); Drain with medium conductance (Ex. BRD-007I); Drain with high conductance (Ex. BRD-007J). All of the boundary conditions are located along the perimeter for all models in the same grid cells in each layer as shown in Figure 4. In Layers 1-4 the boundaries were Dirichlet (constant head). In Layers 5-6 the boundaries are Neumann (general head).

The boundary conditions for the Simulation 2 conceptual models are listed on the following pages of the associated I/O files: Baseline (Ex. BRD-007F at PDF 395-424); Barrier with low conductivity (Ex. BRD-007G at PDF 398-428; Barrier with very low conductivity (Ex. BRD-007H at PDF 337-367); and Drain with high conductance (Ex. BRD-007J at PDF 396-426). The boundary conditions for Drain with medium conductance in Simulation 2 were not reported in the output file (Ex. BRD-007I).

In Simulation 2, the White River structural feature was modeled as a zone of grid cells as shown in Figure 5 with modified hydraulic conductivity in lieu of a boundary condition in Layers 1-5. Layer 6 did not contain the modified grid cell zone. The hydraulic conductivity assignments for this modified grid cell zone in each layer for each of the Simulation 2 models are provided in Table 6.

The justifications for the selection of the boundary conditions for both Simulation 1 and Simulation 2 models and the modified hydraulic conductivity zone in Simulation 2 are unknown, as the employee who conducted the modeling left the NRC in August 2013.

8. Calibration and recalibration details

Simulations 1 and 2 groundwater flow models were calibrated to the NTEA 2006 pumping test observed head values (shown in Table 7) using a steady state calibration. The details of all calibration or recalibration for both of the simulations are unknown, as the employee who conducted the modeling left the NRC in August 2013.

The calibration statistics for Simulation 1 are listed on the following pages of the associated I/O files: Baseline model (Ex. BRD-007A at PDF 300); Barrier with low conductivity (Ex. BRD-007B at PDF 480); Barrier with very low conductivity (Ex. BRD-007C at PDF 484); Drain with medium conductance (Ex. BRD-007D at PDF 316); Drain with high conductance (Ex. BRD-007E at PDF 331). The weighted sum of the squared residuals (WSSR) for each of the Simulation 1models is provided in Table 8.

The calibration statistics for Simulation 2 are listed on the following pages of the associated I/O files: Baseline (Ex. BRD-007F at PDF 479); Barrier with low conductivity (Ex. BRD-007G at PDF 511); Barrier with very low conductivity (Ex. BRD-007Hat 421); Drain with medium conductance (Ex. BRD-007I at PDF 105; and Drain with high conductance (Ex. BRD-007J at PDF 480). The weighted sum of the squared residuals (WSSR) for each of the Simulation 2 models is provided in Table 9.

9. Validation steps

It is unknown if validation of the Simulation 1 and Simulation 2 groundwater models was performed, as the employee who conducted the modeling left the NRC in August 2013.

10. Sensitivity analysis

It is unknown if a sensitivity analysis of the Simulation 1 and Simulation 2 groundwater models was performed, as the employee who conducted the modeling left the NRC in August 2013.

11. Treatment of heterogeneities, justification, documentation on tilted strata, folds, etc.

The Bayesian Maximum Likelihood analysis method was applied using the calibration statistics from the Simulation 1 and Simulation 2 groundwater site conceptual models to evaluate the probability of a specific structural heterogeneity within the given hydrogeological setting. For each simulation, several different model assignments were used to represent the structural heterogeneity of the White River structural feature.

In Simulation 1, the White River structural feature was defined at the southern boundary of the model as a boundary condition, either a barrier or a drain, using the barrier and drain packages in MODFLOW 2000 in GMS. As stated in Response 7 above, the specific conceptual models were: Barrier with low conductivity; Barrier with very low conductivity; Drain with medium conductance; Drain with high conductance. The specific assignment for the barrier or drain in

these models for Simulation 1 are provided in Table 5.

In Simulation 2, the White River structural feature was represented as a modified hydraulic conductivity zone in layers 1-5 in the southern portion of the model. As stated in Response 7 above, the specific conceptual models were: Barrier with low conductivity; Barrier with very low conductivity; Drain with medium conductance; Drain with high conductance. The specific assignment for the barrier or drain in these models for Simulation 2 are provided in Table 6.

The justification for the assignment of any of the values in Tables 5 and 6 for the Simulation 1 or 2 models for barrier or drain boundaries or modified hydraulic conductivity zones is unknown, as the employee who conducted the modeling left the NRC in August 2013.

12. Residual tolerances

The staff were unable to locate any reported values for residual tolerances for any of the Simulation 1 or Simulation 2 model files.

13. Correlation of weighted residuals with normal order statistics

The correlation of the weighted residuals with normal order statistics for Simulation 1 are listed on the following pages of the associated I/O files: Baseline (Ex. BRD-007A at PDF 57-58); Barrier with low conductivity (Ex. BRD-007B at PDF 52-53); Barrier with very low conductivity (Ex. BRD-007C at PDF 57-58); Drain with medium conductance (Ex. BRD-007D at PDF 59-60); Drain with high conductance (Ex. BRD-007E at PDF 69-70).

The correlation of the weighted residuals with normal order statistics for Simulation 2 are listed on the following pages of the associated I/O files: Baseline (Ex. BRD-007F at PDF 111-112); Barrier with low conductivity (Ex. BRD-007G at PDF 113-114; Barrier with very low conductivity (Ex. BRD-007H at PDF 411-412); Drain with medium conductance (Ex. BRD-007I at PDF 96-97; Drain with high conductance (Ex. BRD-007J at PDF 113-114).

14. Any goodness of fit testing, e.g. Kolmogorov-Smirnov testing

It is unknown if any goodness of fit testing was conducted for any of the Simulation 1 or Simulation 2 models, as the employee who conducted the modeling left the NRC in August 2013.

15. Quantification of uncertainties in inputs, output probabilities, etc.

It is unknown if any quantification of uncertainties in inputs or output probabilities was conducted for any of the Simulation 1 or Simulation 2 models, as the employee who conducted the modeling left the NRC in August 2013.

16. Any chemical modeling assumptions that would change hydraulic parameters (e.g. K, S) with time such as dissolution of fissure fill material/ minerals-not done

All of the conceptual site models only simulated the groundwater flow system. No chemical modeling was conducted for any of the conceptual site models used in either Simulation 1 or Simulation 2 for the Bayesian Maximum Likelihood analysis.

17. Values for vertical surface recharge used, including different inflow scenarios

The value for the vertical surface recharge for Simulation 1 was 0.1 ft/day. The value for the vertical surface recharge in Simulation 2 was zero. The recharge was applied to the highest active layer in all models. The justification for the assignment of the recharge values in the Simulation 1 or 2 models is unknown as the employee who conducted the modeling left NRC in August 2013.

18. Descript ion of the uniqueness of solutions

None of groundwater flow models in Simulation 1 or Simulation 2 are unique. This non-uniqueness is inherent to all groundwater flow models because of uncertainty in the selection of the model features, grid discretization, boundary conditions and paucity of parameters and data used to initialize and calibrate each model.

19. Model numerical stability

All models were solved using the pre-conjugate gradient solver. The features and numerical stability of this solver is described on the USGS MODFLOW 2000 website (http://water.usgs.gov/nrp/gwsoftware/modflow2000/Guide/index.html?pcgn.htm)/

The pre-conjugate gradient solver settings used in the Simulation 1 models are listed on the following pages of the associated I/O files: Baseline (Ex. BRD-007A at PDF 57); Barrier with low conductivity (Ex. BRD-007B at PDF 52); Barrier with very low conductivity (Ex. BRD-007C at PDF 57); Drain with medium conductance (Ex. BRD-007D at PDF 58); Drain with high conductance (Ex. BRD-007E at PDF 68-69).

The pre-conjugate gradient solver settings used in the Simulation 2 models are listed on the following pages of the associated I/O files: Baseline (Ex. BRD-007F at PDF 110-111); Barrier with low conductivity (Ex. BRD-007G at PDF 112); Drain with medium conductance (Ex. BRD-007I at PDF 95); and Drain with high conductance (Ex. BRD-007J at PDF 112). The solver settings for Barrier with very low conductivity were not listed in the I/O file (Ex. BRD-007H)

20. Uncertainties in probability of folds vs. faults

The discussion of the probabilities calculated in the Bayesian Maximum Likelihood analysis of the White River structural feature based on the Simulation 1 and 2 conceptual site modeling results is provided in the final CBR SER on pages 23-28 (Exhibit NRC-009). Additional information on the calculation of these probabilities may be found in NUREG/CR-6940/PNNL-16396, “Combined Estimation of Hydrogeologic Conceptual Model, Parameter and Scenario Uncertainty with Application to Uranium Transport at the Hanford Site 300 Area.”

21. Discussion of model results and implications

The discussion of the model results and implications from the Bayesian Maximum Likelihood analysis of the White River structural feature based on Simulations 1 and 2 is provided in the final CBR SER on pages 23-28 (Exhibit NRC-009).

22. Drill holes (which ones, location) used to populate model

Data from thirty-six drill holes were used to define the layer elevations. The drill hole data (elevation in feet above sea level) used for the interpolation of the elevation of the ground surface and bottom of the layers for Simulation 1 models are provided in Tables 10 to 16. Selection of constant elevations for the surface and bottoms of each layer in the Simulation 2 models are based on averages of the drill hole data in Tables 10 to 16.

REFERENCES

1. CBR 2007, "Application for Amendment of Crow Butte Resources License SUA-1534-North Trend Expansion Area", ADAMS Accession Nos. ML071760343 and ML071730274 (May 30, 2007).

2. NRC 2012, "CROW BUTTE NORTH TREND NT_DRAIN-BAR_BASE _IO_ MODELING FILES", ADAMS Accession No. ML12341A218 (Dec. 6, 2012) (Ex. BRD-007A).

3. NRC 2012, "CROW BUTTE NORTH TREND NT_BARRIER_LOWK_IO_MODELING FILES," ADAMS Accession No. ML12341A208 (Dec. 6, 2012) (Ex. BRD-007B).

4. NRC 2012, "CROW BUTTE NORTH TREND NT_BARRIER_VLOWK_IO_MODELING FILES," ADAMS Accession No. ML12341A210 (Dec. 6, 2012) (Ex. BRD-007C).

5. NRC 2012, "CROW BUTTE NORTH TREND NT_DRAIN_MEDK_IO_MODELING FILES," ADAMS Accession No. ML12341A214 (Dec. 6, 2012) (Ex. BRD-007D).

6. NRC 2012, "CROW BUTTE NORTH TREND NT_DRAIN_HIGHK_IO_MODELING FILES", ADAMS Accession No. ML12341A212 (Dec. 6, 2012) (Ex. BRD-007E).

7. NRC 2012, "Crow Butte NORTH TREND_BASELINE_I-O Modeling FILES", ADAMS Accession No. ML12341A020 (Dec. 6, 2012) (Ex. BRD-007F).

8. NRC 2012, "CROW BUTTE NORTH TREND_WALL_LOWK_I-O Modeling FILES", ADAMS Accession No. ML12341A025 (Dec. 6, 2012) (Ex. BRD-007G).

9. NRC 2012, "CROW BUTTE NORTH TREND_WALL_VLOWK_I-O Modeling Files", ADAMS Accession No. ML12341A030 (Dec. 6, 2012) (Ex. BRD-007H).

10. NRC 2012, "CROW BUTTE NORTH TREND_WALL_MEDK_I-O Modeling FILES", ADAMS Accession No. ML12341A028 (Dec. 6, 2012) (Ex. BRD-007I).

11. NRC 2012, "Crow Butte NORTH TREND_WALL_HIGHK_I-O Modeling FILES", ADAMS Accession No. ML12341A021 (Dec. 6, 2012) (Ex. BRD-007J).

12. NUREG/CR-6940/PNNL-16396, "Combined Estimation of Hydrogeologic Conceptual Model, Parameter and Scenario Uncertainty with Application to Uranium Transport at the Hanford Site 300 Area" (July 2007).

Table 1. Simulation 1 Grid and Layer Definitions

Model Layer	Type of Layer	Hydrogeologic Unit	Grid Dimension x (feet)	Grid Dimension y (feet)
1	Upper Aquifer	Brule	47.35	57
2	Upper Confining Layer	Chadron	47.35	57
3	Middle Aquifer	Chadron	47.35	57
4	Middle Confining Layer	Chadron	47.35	57
5	Production Zone Aquifer	Basal Chadron	47.35	57
6	Lower Confining Layer	Pierre	47.35	57

Table 2. Simulation 2 Grid and Layer Definitions

Model Layer	Type of Layer	Hydrogeologic Unit	Grid Dimension x (feet)	Grid Dimension y (feet)
1	Upper Aquifer	Brule	Linear from 25 feet (at pumping well to 79.5 feet at boundary cell	Linear from 25 feet (at pumping well to 78.8 feet at boundary cell
2	Upper Confining Layer	Chadron		
3	Middle Aquifer	Chadron		
4	Middle Confining Layer	Chadron		
5	Production Zone Aquifer	Basal Chadron		
6	Lower Confining Layer	Pierre		

Table 3. Hydraulic Conductivity, K, Starting Head assignments for each layer in all models in Simulation 1

Model Layer	Type of Layer	Hydrogeologic Unit	Horiz. Hydraulic Conductivity (ft/day)	Kh/Kv	Starting Head (ft)
1	Upper Aquifer	Brule	25	10	3700
2	Upper Confining Layer	Chadron	2.80E-07	10	3607
3	Middle Aquifer	Chadron	2	10	3700
4	Middle Confining Layer	Chadron	2.80E-07	10	3607
5	Production Zone Aquifer	Basal Chadron	10	10	3700
6	Lower Confining Layer	Pierre	2.80E-07	10	3620

Table 4. Hydraulic Conductivity, K, Starting Head assignments for each layer in all models in Simulation 2

Model Layer	Type of Layer	Hydrogeologic Unit	Horiz. Hydraulic Conductivity (ft/day)	Kh/Kv	Starting Head (ft)
1	Upper Aquifer	Brule	1.4	3	3700
2	Upper Confining Layer	Chadron	1.4E-04	3	3700
3	Middle Aquifer	Chadron	1.4E-01	3	3700
4	Middle Confining Layer	Chadron	1.4E-04	3	3700
5	Production Zone Aquifer	Basal Chadron	20	3	3700
6	Lower Confining Layer	Pierre	1.4E-04	3	3700

Table 5. Southern Boundary (White River structural feature) assignments in the Simulation 1 conceptual site models.

Model Layer	Type of Layer	Hydrogeologic Unit	Low Cond Barrier (1/t)	Very Low Cond Barrier (1/t)	Drain with Med Cond (ft^2/d/ft)	Drain with High Cond (ft^2/d/ft)
1	Upper Aquifer	Brule	N/A	N/A	N/A	N/A
2	Upper Confining Layer	Chadron	1.00E-05	1.00E-09	0.12	100.00
3	Middle Aquifer	Chadron	1.00E-05	1.00E-09	0.12	100.00
4	Middle Confining Layer	Chadron	1.00E-05	1.00E-09	0.12	100.00
5	Production Zone Aquifer	Basal Chadron	1.00E-05	1.00E-09	0.12	100.00
6	Lower Confining Layer	Pierre	1.00E-05	1.00E-09	0.12	100.00

Table 6. White River structural feature assignments in the Simulation 2 conceptual site models

Model Layer	Type of Layer	Hydrogeologic Unit	Low Cond Zone (ft/day)	Very Low Cond Zone (ft/day)	Med Cond Zone (ft/day)	High Cond Zone (ft/day)
1	Upper Aquifer	Brule	1.00E-05	1.00E-03	10	1000
2	Upper Confining Layer	Chadron	1.00E-05	1.00E-03	10	1000
3	Middle Aquifer	Chadron	1.00E-05	1.00E-03	10	1000
4	Middle Confining Layer	Chadron	1.00E-05	1.00E-03	10	1000
5	Productio n Zone Aquifer	Basal Chadron	1.00E-05	1.00E-03	10	1000
6	Lower Confining Layer	Pierre	N/A	N/A	N/A	N/A

Table 7. NTEA 2006 Pumping Test Observed Heads used for Simulation 1 and 2 Model Calibration

Model Layer	Well Name	Hydrogeologic Unit	Observed Head (ft)	Days
5	COW-3	Basal Chadron	3706.41	15
5	CPW-2	Basal Chadron	3696.72	15
5	COW-2	Basal Chadron	3700.85	15
5	COW-1	Basal Chadron	3689.73	15
5	COW-4	Basal Chadron	3698.05	15
5	RC-2	Basal Chadron	3702.56	15

Table 8. Simulation 1 Model Calibration WSSR values

Model Name	WSSR
Baseline	27.47
Low K Barrier	27.04
Very Low K Barrier	27.13
Med K Drain	215000
High K Drain	8840000

Table 9. Simulation 2 Model Calibration WSSR values

Model Name	WSSR
Baseline	620.2
Low K Barrier	783.1
Very Low K Barrier	666.3
Med K Drain	916.2
High K Drain	80000

Table 10. Surface Elevations (Simulations 1 and 2)

Well ID	Easting	Northing	Elevation (ft)
A761	220605.00	328059.20	3638.5
A764	221192.80	327908.00	3625
C-167	219917.00	325434.60	3690.3
C-170	220406.60	325420.70	3666
C-237	220481.10	328061.30	3643.8
COW-1	221327.20	326728.00	3631.9
COW-4	219776.00	326790.00	3686
CPW-2	220131.00	325400.60	3675.82
D-107	219553.10	328046.60	3695.5
D-144	220105.30	325678.80	3687.9
D-57	220186.60	327857.10	3665.3
D67	219974.80	328113.80	3661
D69	220196.90	328108.20	3652.8
D-71	220134.40	328283.90	3648.9
FISHER-3	223760.90	326628.80	3590
JRABEN-2	222399.40	326676.30	3570
T-145	220185.20	326135.30	3679.21
T-176	220192.40	326374.90	3678.25
T-189	220143.90	327255.10	3675.38
T-205	220098.20	327554.70	3679.24
T-220	220248.00	326984.10	3674.95
T-46	220000.50	326781.50	3680.2
T-48	220243.30	326771.40	3670.36
T-50	220487.80	326757.80	3659.47
T-82	219732.80	325454.10	3689.51
T-93	220677.20	325451.40	3663.46
T-106	220045.40	325002.60	3660.69
T-109	220069.70	324693.00	3647.2
SO-3	220467.70	323884.20	3655.7
D-140	220717.30	323347.80	3697
D-133	220853.60	322794.00	3723.7
SO-12	219785.80	323653.30	3688.3
SO-13	220232.20	323831.90	3664.1
HA-6	220893.40	323870.90	3663.3
HA-8	221236.50	323831.90	3681.6
MOORE-1	221549.00	323854.00	3640
COW-2	220779.00	324851.00	3652.1
COW-3	219770.00	325299.00	3682.8
COW-5	220522.00	325981.00	3669.24

Table 11. Elevations - Bottom of Layer 1 (Simulations 1 and 2)

Well ID	Easting	Northing	Elevation – Bottom of Layer 1 (ft)
A761	220605.00	328059.20	3573.13
A764	221192.80	327908.00	3593.13
C-167	219917.00	325434.60	3590.12
C-170	220406.60	325420.70	3619.03
C-237	220481.10	328061.30	3568.25
COW-1	221327.20	326728.00	3520.63
COW-4	219776.00	326790.00	3582.5
CPW-2	220131.00	325400.60	3577.725
D107	219553.10	328046.60	3606
D-144	220105.30	325678.80	3573.32
D-57	220186.60	327857.10	3573.605
D67	219974.80	328113.80	3585.38
D69	220196.90	328108.20	3582.88
D-71	220134.40	328283.90	3585.18
FISHER-3	223760.90	326628.80	3525.005
JRABEN-2	222399.40	326676.30	3465
T-145	220185.20	326135.30	3581.84
T-176	220192.40	326374.90	3585.18
T-189	220143.90	327255.10	3580.55
T-205	220098.20	327554.70	3566.66
T-220	220248.00	326984.10	3557.4
T-46	220000.50	326781.50	3573.13
T-48	220243.30	326771.40	3556.25
T-50	220487.80	326757.80	3552.5
T-82	219732.80	325454.10	3588.05
T-93	220677.20	325451.40	3546.75
T-106	220045.40	325002.60	3577.58
T-109	220069.70	324693.00	3569.06
SO-3	220467.70	323884.20	3615.92
D-140	220717.30	323347.80	3609.53
D-133	220853.60	322794.00	3631.84
SO-12	219785.80	323653.30	3628.455
SO-13	220232.20	323831.90	3624.14
HA-6	220893.40	323870.90	3654.31
HA-8	221236.50	323831.90	3654.31
MOORE-1	221549.00	323854.00	3624.14

Table 12. Elevations - Bottom of Layer 2 (Simulations 1 and 2)

Well ID	Easting	Northing	Elevation – Bottom of Layer 2 (ft)
A761	220605.00	328059.20	3401.63
A764	221192.80	327908.00	3413.13
C-167	219917.00	325434.60	3389.815
C-170	220406.60	325420.70	3371.23
C-237	220481.10	328061.30	3400.25
COW-1	221327.20	326728.00	3316.255
COW-4	219776.00	326790.00	3327.5
CPW-2	220131.00	325400.60	3367.095
D107	219553.10	328046.60	3388.5
D-144	220105.30	325678.80	3385.88
D-57	220186.60	327857.10	3393.035
D67	219974.80	328113.80	3459.76
D69	220196.90	328108.20	3404.38
D-71	220134.40	328283.90	3372.2
FISHER-3	223760.90	326628.80	3524.5
JRABEN-2	222399.40	326676.30	3315
T-145	220185.20	326135.30	3381.62
T-176	220192.40	326374.90	3367.57
T-189	220143.90	327255.10	3383.775
T-205	220098.20	327554.70	3397.665
T-220	220248.00	326984.10	3362.94
T-46	220000.50	326781.50	3355.63
T-48	220243.30	326771.40	3357.5
T-50	220487.80	326757.80	3357.5
T-82	219732.80	325454.10	3402.2
T-93	220677.20	325451.40	3336.12
T-106	220045.40	325002.60	3373.1
T-109	220069.70	324693.00	3377.36
SO-3	220467.70	323884.20	3471.08
D-140	220717.30	323347.80	3554.15
D-133	220853.60	322794.00	3572.2
SO-12	219785.80	323653.30	3374.165
SO-13	220232.20	323831.90	3365.54
HA-6	220893.40	323870.90	3512.08
HA-8	221236.50	323831.90	3557.335
MOORE-1	221549.00	323854.00	3623

Table 13. Elevations - Bottom of Layer 3 (Simulations 1 and 2)

Well ID	Easting	Northing	Elevation – Bottom of Layer 3 (ft)
A761	220605.00	328059.20	3370.13
A764	221192.80	327908.00	3371.88
C-167	219917.00	325434.60	3356.775
C-170	220406.60	325420.70	3362.97
C-237	220481.10	328061.30	3379.25
COW-1	221327.20	326728.00	3301.255
COW-4	219776.00	326790.00	3290
CPW-2	220131.00	325400.60	3334.055
D107	219553.10	328046.60	3369.75
D-144	220105.30	325678.80	3373.1
D-57	220186.60	327857.10	3381.46
D67	219974.80	328113.80	3444.76
D69	220196.90	328108.20	3393.88
D-71	220134.40	328283.90	3349.05
FISHER-3	223760.90	326628.80	3524
JRABEN-2	222399.40	326676.30	3296.25
T-145	220185.20	326135.30	3317.72
T-176	220192.40	326374.90	3316.64
T-189	220143.90	327255.10	3369.885
T-205	220098.20	327554.70	3388.405
T-220	220248.00	326984.10	3335.16
T-46	220000.50	326781.50	3299.38
T-48	220243.30	326771.40	3306.875
T-50	220487.80	326757.80	3303.125
T-82	219732.80	325454.10	3369.16
T-93	220677.20	325451.40	3325.795
T-106	220045.40	325002.60	3353.93
T-109	220069.70	324693.00	3356.06
SO-3	220467.70	323884.20	3415.7
D-140	220717.30	323347.80	3537.11
D-133	220853.60	322794.00	3563.68
SO-12	219785.80	323653.30	3320.29
SO-13	220232.20	323831.90	3331.06
HA-6	220893.40	323870.90	3499.15
HA-8	221236.50	323831.90	3548.715
MOORE-1	221549.00	323854.00	3622.5

Table 14. Elevations - Bottom of Layer 4 (Simulations 1 and 2)

Well	Easting	Northing	Elevation – Bottom of Layer 4 (ft)
A761	220605.00	328059.20	3254.63
A764	221192.80	327908.00	3225.63
C-167	219917.00	325434.60	3075.935
C-170	220406.60	325420.70	3065.61
C-237	220481.10	328061.30	3269
COW-1	221327.20	326728.00	3087.505
COW-4	219776.00	326790.00	3085.625
CPW-2	220131.00	325400.60	3057.345
D107	219553.10	328046.60	3238.5
D-144	220105.30	325678.80	3028.04
D-57	220186.60	327857.10	3221.725
D67	219974.80	328113.80	3313.51
D69	220196.90	328108.20	3271.38
D-71	220134.40	328283.90	3247.19
FISHER-3	223760.90	326628.80	3401.255
JRABEN-2	222399.40	326676.30	3108.75
T-145	220185.20	326135.30	3053.6
T-176	220192.40	326374.90	3031.895
T-189	220143.90	327255.10	3159.22
T-205	220098.20	327554.70	3210.15
T-220	220248.00	326984.10	3124.495
T-46	220000.50	326781.50	3093.13
T-48	220243.30	326771.40	3093.125
T-50	220487.80	326757.80	3089.375
T-82	219732.80	325454.10	3096.58
T-93	220677.20	325451.40	3024.305
T-106	220045.40	325002.60	3094.07
T-109	220069.70	324693.00	3091.94
SO-3	220467.70	323884.20	3138.8
D-140	220717.30	323347.80	3388.01
D-133	220853.60	322794.00	3457.18
SO-12	219785.80	323653.30	3018.59
SO-13	220232.20	323831.90	3046.6
HA-6	220893.40	323870.90	3283.65
HA-8	221236.50	323831.90	3402.175
MOORE-1	221549.00	323854.00	3430.19

Table 15. Elevations - Bottom of Layer 5 (Simulations 1 and 2)

Well	Easting	Northing	Elevation - Bottom of Layer 5 (ft)
A761	220605.00	328059.20	3230.13
A764	221192.80	327908.00	3184.38
C-167	219917.00	325434.60	3044.96
C-170	220406.60	325420.70	3024.31
C-237	220481.10	328061.30	3237.5
COW-1	221327.20	326728.00	3074.38
COW-4	219776.00	326790.00	3033.125
CPW-2	220131.00	325400.60	3016.045
D107	219553.10	328046.60	3178.5
D-144	220105.30	325678.80	3002.48
D-57	220186.60	327857.10	3193.945
D67	219974.80	328113.80	3276.01
D69	220196.90	328108.20	3245.13
D-71	220134.40	328283.90	3221.725
FISHER-3	223760.90	326628.80	3391.88
JRABEN-2	222399.40	326676.30	3101.25
T-145	220185.20	326135.30	2998.22
T-176	220192.40	326374.90	3004.115
T-189	220143.90	327255.10	3131.44
T-205	220098.20	327554.70	3166.165
T-220	220248.00	326984.10	3099.03
T-46	220000.50	326781.50	3055.63
T-48	220243.30	326771.40	3068.75
T-50	220487.80	326757.80	3070.625
T-82	219732.80	325454.10	3049.085
T-93	220677.20	325451.40	2983.005
T-106	220045.40	325002.60	3045.08
T-109	220069.70	324693.00	3055.73
SO-3	220467.70	323884.20	3102.59
D-140	220717.30	323347.80	3362.45
D-133	220853.60	322794.00	3427.36
SO-12	219785.80	323653.30	2984.11
SO-13	220232.20	323831.90	3025.05
HA-6	220893.40	323870.90	3255.635
HA-8	221236.50	323831.90	3369.85
MOORE-1	221549.00	323854.00	3378.47

Table 16. Elevations – Bottom of Layer 6 (Simulations 1 and 2)

Well	Easting	Northing	Elevation – Bottom of Layer 6 (ft)
A761	220605.00	328059.20	2030.13
A764	221192.80	327908.00	1984.38
C-167	219917.00	325434.60	1844.96
C-170	220406.60	325420.70	1824.31
C-237	220481.10	328061.30	2037.5
COW-1	221327.20	326728.00	1874.38
COW-4	219776.00	326790.00	1833.125
CPW-2	220131.00	325400.60	1816.045
D107	219553.10	328046.60	1978.5
D-144	220105.30	325678.80	1802.48
D-57	220186.60	327857.10	1993.945
D67	219974.80	328113.80	2076.01
D69	220196.90	328108.20	2045.13
D-71	220134.40	328283.90	2021.725
FISHER-3	223760.90	326628.80	2191.88
JRABEN-2	222399.40	326676.30	1901.25
T-145	220185.20	326135.30	1798.22
T-176	220192.40	326374.90	1804.115
T-189	220143.90	327255.10	1931.44
T-205	220098.20	327554.70	1966.165
T-220	220248.00	326984.10	1899.03
T-46	220000.50	326781.50	1855.63
T-48	220243.30	326771.40	1868.75
T-50	220487.80	326757.80	1870.625
T-82	219732.80	325454.10	1849.085
T-93	220677.20	325451.40	1783.005
T-106	220045.40	325002.60	1845.08
T-109	220069.70	324693.00	1855.73
SO-3	220467.70	323884.20	1902.59
D-140	220717.30	323347.80	2162.45
D-133	220853.60	322794.00	2227.36
SO-12	219785.80	323653.30	1784.11
SO-13	220232.20	323831.90	1825.05
HA-6	220893.40	323870.90	2055.635
HA-8	221236.50	323831.90	2169.85
MOORE-1	221549.00	323854.00	2178.47

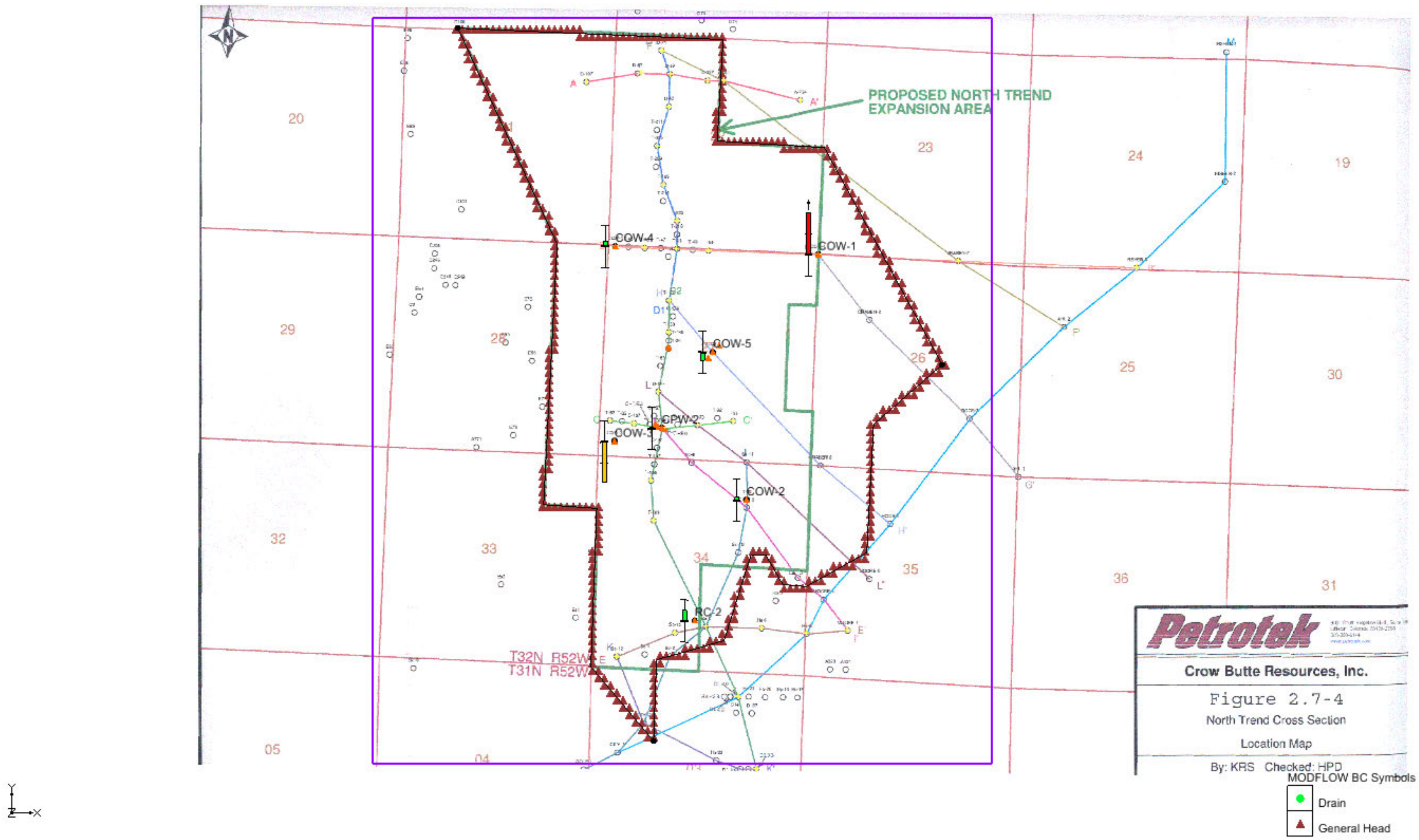

Figure 1. Basemap for Simulation 1 baseline groundwater flow model, showing model grid border (in purple), location of general head boundaries (rust) and aquifer pumping test observation wells in Layer 5.

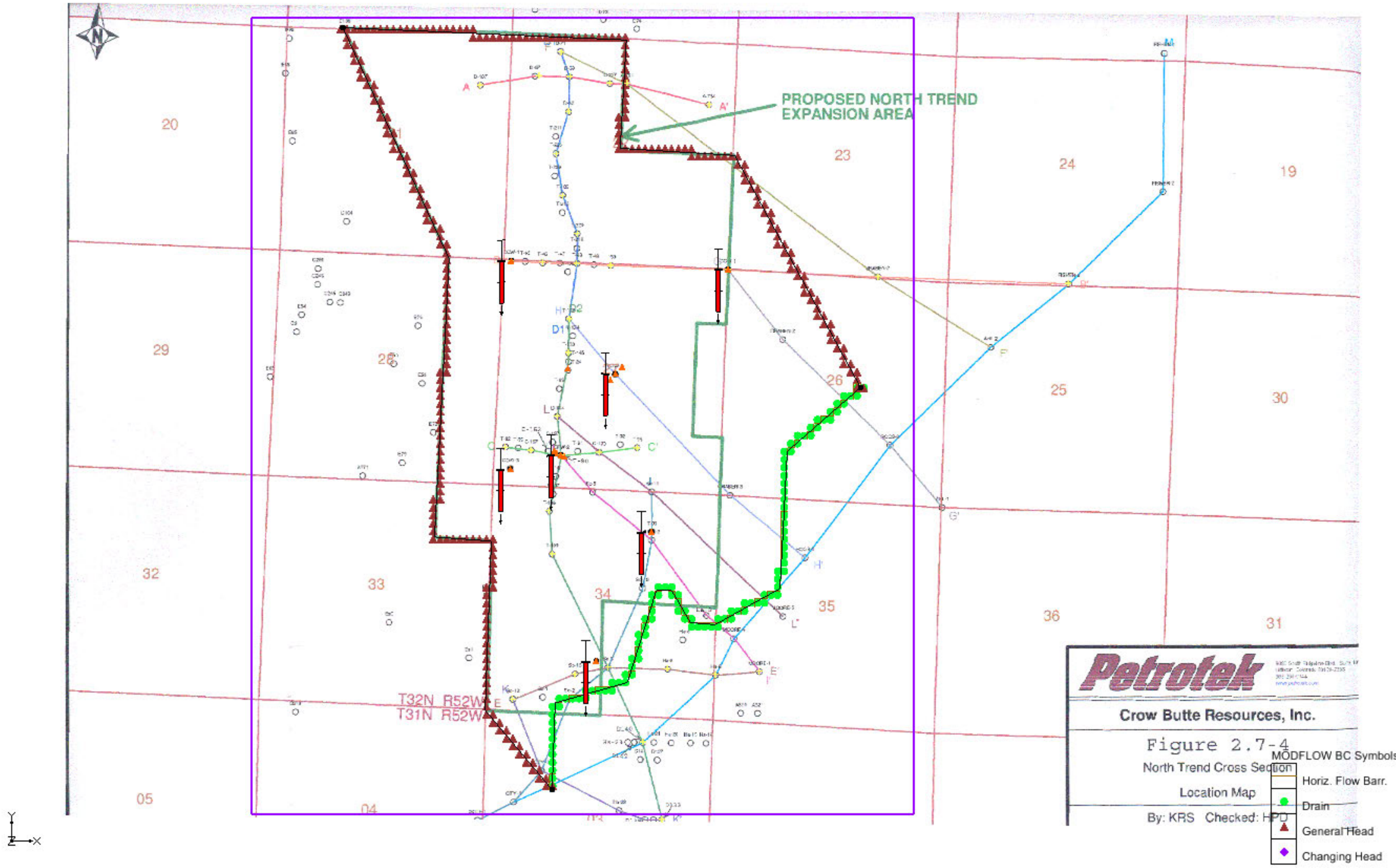

Figure 2. Basemap for all Simulation 1 drain groundwater flow models, showing model grid border (in purple), location of general head boundaries (rust), White River structural feature as drain boundary (green) and aquifer pumping test observation wells in Layer 5.

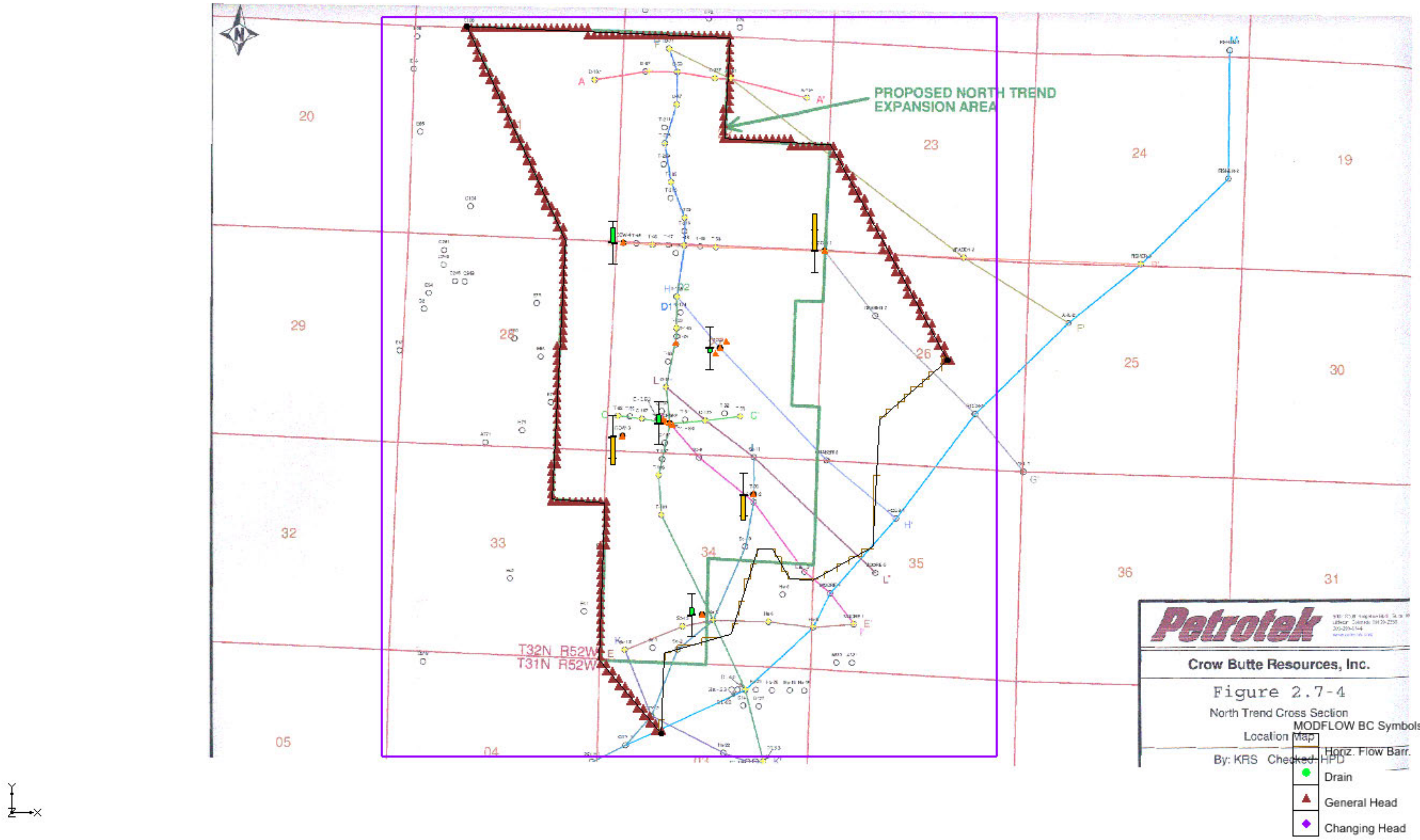

Figure 3. Basemap for all Simulation 1 horizontal barrier groundwater flow models, showing model grid border (in purple), location of general head boundaries (rust), White River structural feature as horizontal barrier boundary (brown) and aquifer pumping test observation wells in Layer 5.

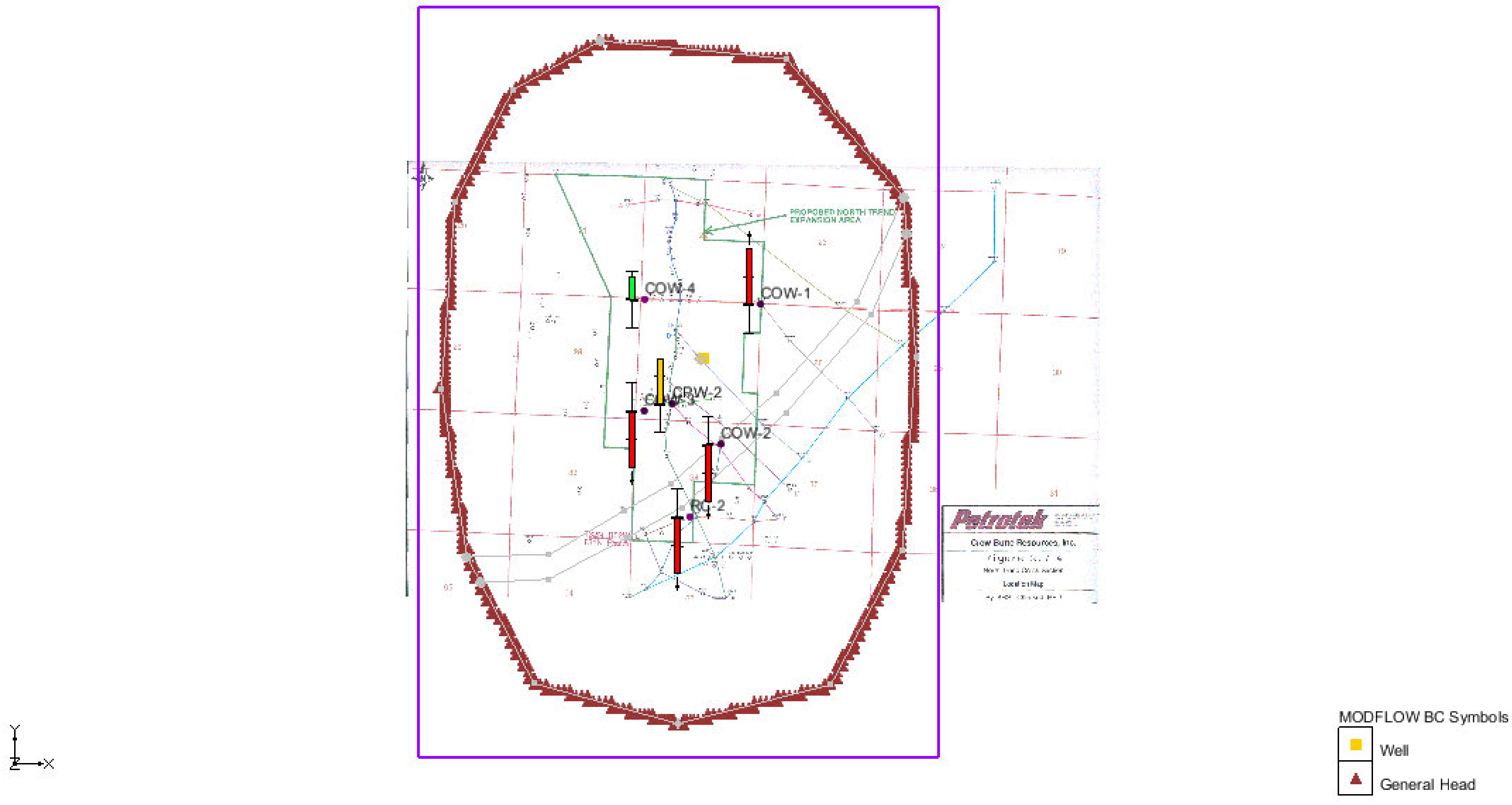

Figure 4. Basemap for Simulation 2 baseline groundwater flow model, showing model grid border (in purple), location of general head boundaries (rust) and aquifer pumping test observation wells in Layer 5.

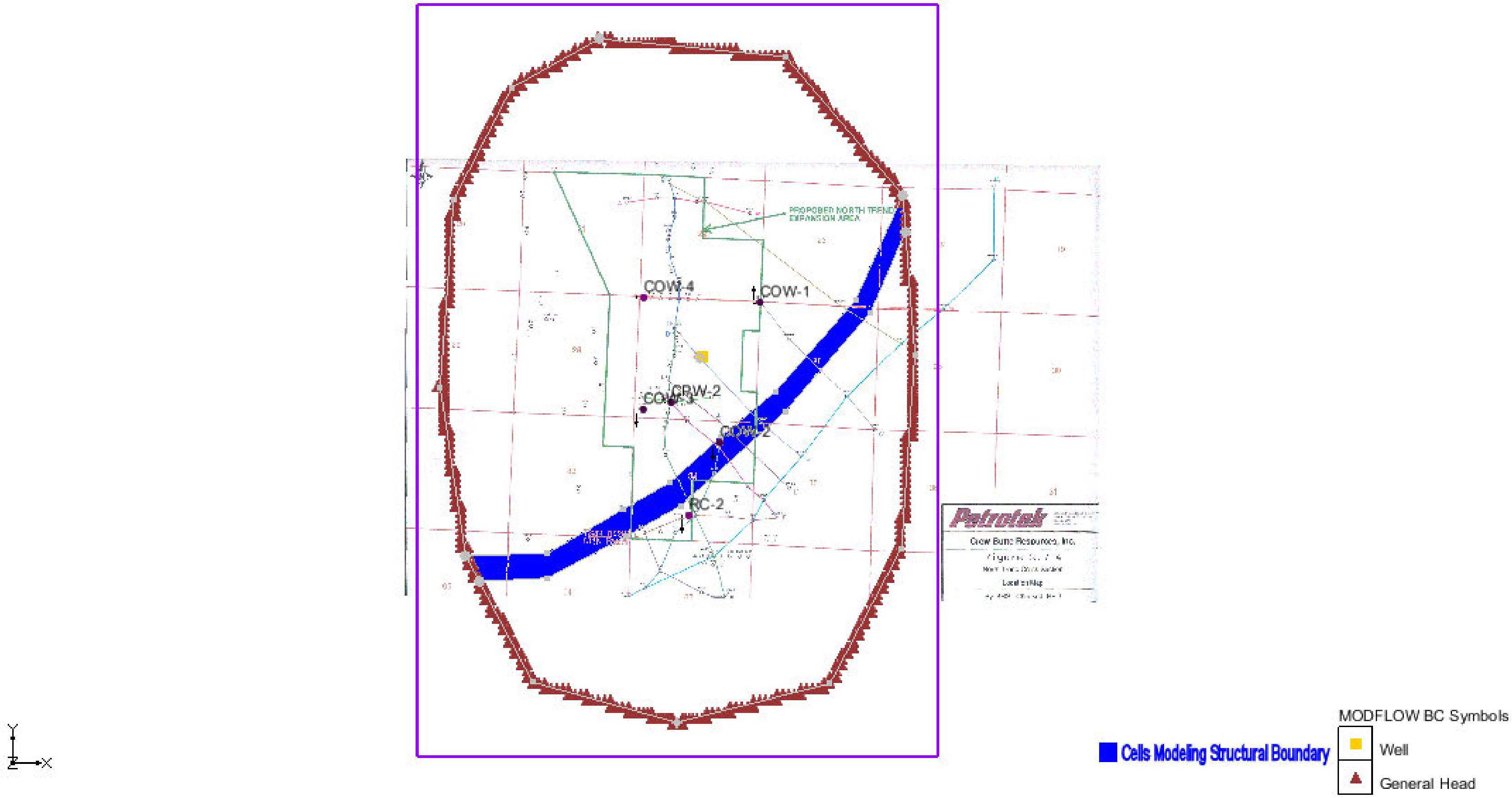

Figure 5. Basemap for Simulation 2 groundwater flow models with White River structural feature, showing model grid border (in purple), location of modified conductivity zone (blue), location of general head boundaries (rust) and aquifer pumping test observation wells in Layer 5.