APPENDIX D
Numerical Groundwater Model Report

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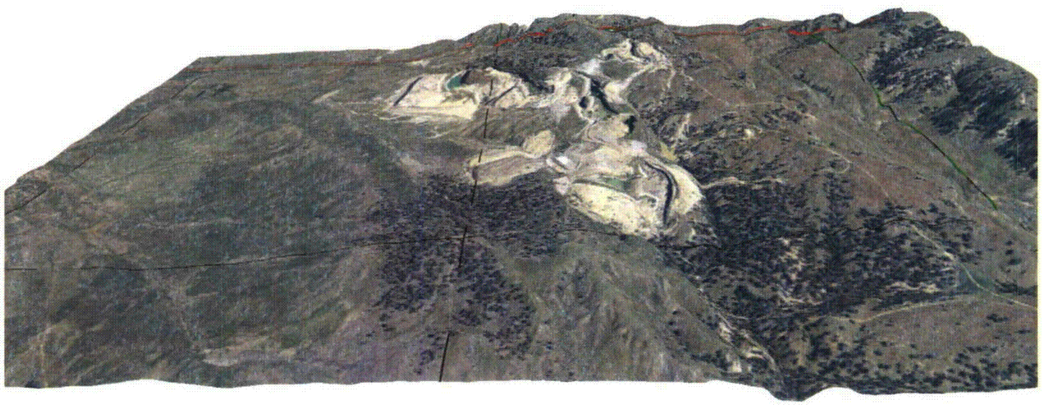
Petrotek

NUMERICAL MODELING OF HYDROGEOLOGIC CONDITIONS
DEWEY-BURDOCK PROJECT
SOUTH DAKOTA



POWERTECH DEWEY-BURDOCK PROJECT
FALL RIVER AND CUSTER COUNTIES, SD
February 2012

Petrotek Engineering Corporation
10288 West Chatfield Avenue, Suite 201
Littleton, Colorado 80127
Phone: (303) 290-9414
Fax: (303) 290-9580

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DEWEY-BURDOCK PROJECT
SOUTH DAKOTA

1 Introduction

Powertech USA (Powertech) has submitted an application to the U.S. Nuclear Regulatory Commission (NRC) for a Uranium Recovery License (URL) to conduct in-situ recovery (ISR) of uranium from the Dewey-Burdock Project in South Dakota. The target ore zones are the Fall River Formation (Fall River) and the Chilson Member (Chilson) of the Lakota Formation, both included within the Inyan Kara Group. The target ore zones are separated by the Fuson Shale, a low permeability confining unit.

A numerical groundwater flow model was developed using site-specific data to evaluate hydraulic responses of the Fall River and Chilson aquifers to ISR production and restoration operations at the site. This report describes the development of the numerical model and summarizes the results of numerical simulations used to predict aquifer drawdown and recovery from ISR operations in the Inyan Kara aquifer system.

2 Purpose and Objectives

The numerical groundwater flow model was developed to support Powertech in planning and operation of the uranium ISR project. The numerical model is used to assess hydraulic response of the Fall River and Chilson aquifers to ISR uranium extraction.

Objectives of the numerical model included the following:

- Enhance understanding of the Fall River and Chilson aquifer systems with respect to:
    - regional and local flow patterns
    - recharge and discharge boundaries
    - overall water budget (available and sustainable resources)
- Evaluate potential hydraulic impacts (e.g. drawdown and potential dewatering) from production and restoration operations on both the local and regional scale;
- Assess potential communication (if any) between the Fall River and Chilson aquifers during production and restoration activities;
- Compare hydraulic impacts of variable bleed rates and production rates on the Fall River and Chilson aquifers;
- Determine the level of interference between wellfields that could occur with simultaneous production and restoration operations;

- Evaluate the potential impacts of ISR operations to an open pit mine located within the Project Area that intercepts Fall River groundwater;
- Assess the potential hydraulic impacts that would result from a breccia pipe recharge to the Fall River and Chilson aquifers (as hypothesized by Gott et al [1974]) within the Project Area.

3 Conceptual Model

Detailed description of the geology and hydrogeology of the Project Area can be found in the Dewey-Burdock Project Application for NRC URL Technical Report (Dewey-Burdock TR) prepared by Powertech. The conceptual hydrologic model for the Dewey-Burdock Project Area is summarized below.

The Dewey-Burdock Project Area lies on the southwest flank of the Black Hills Uplift; a large structural feature of Laramide age. Igneous and metamorphic Precambrian-age rocks are exposed in the core of the uplift and are surrounded by outward-dipping Paleozoic and Mesozoic rocks. The Dewey Fault, a northeast to southwest trending fault zone, is present approximately one mile north of the Dewey-Burdock Project Area. The Dewey Fault is a steeply dipping to vertical normal fault with the north side uplifted approximately 350 feet by a combination of vertical and horizontal displacement. The Project Area lies near the eastern limit of the Powder River Basin. Locally, the Barker Dome Anticline, present east of the Project Area, creates geologic dip to the west-southwest in the subsurface strata.

The target ore zones are the Fall River Formation and the Chilson Member of the Lakota Formation within the Cretaceous Inyan Kara Group. The Inyan Kara consists of interbedded sandstone, siltstone and shale and averages approximately 350 feet thick in the Dewey-Burdock Project Area. To the northeast, toward the Black Hills Uplift, the Inyan Kara is largely eroded away. Where exposed at the surface, infiltration of precipitation and runoff provides recharge to the Inyan Kara aquifers. The Inyan Kara is confined below by the Jurassic Morrison Formation and above by the Cretaceous Graneros Group except for the areas to the north and east where the Inyan Kara is exposed in outcrop.

Groundwater flow within the Inyan Kara, based on regional studies conducted by the U.S. Geological Survey in the 1990s (Strobel et al 2000), is generally away from the Black Hills Uplift, toward the south and west. Within the Black Hills area, the transmissivity of the Inyan Kara aquifers is highly variable, ranging from 1 to 6,000 ft^2/day. The Inyan Kara is capable of yielding large volumes of water (Driscoll et al 2002). For example, an aquifer test conducted near the Project Area by Tennessee Valley Authority (TVA) averaged nearly 500 gpm over an 11 day pumping period (Boggs 1983).

The Fall River Formation is the uppermost unit within the Inyan Kara Group. It is composed of carbonaceous interbedded siltstone and sandstone, channel sandstone and a sequence of interbedded sandstone and shale. The Fall River ranges from 120 to 160 feet thick within the Project Area. The Fall River Formation dips southwesterly at 2 to 6 degrees and is present in outcrop near the eastern and northern edges of the Project Area. A structure map of the top of the Fall River is provided as Plate 2.6-5 in the Dewey-Burdock TR.

Overlying the Fall River Formation is the Graneros Group, a sequence of dark shales that reaches over 500 feet thick in the northwestern portion of the Project Area. This unit is eroded away along the eastern edge of the Project Area where the Fall River is exposed in outcrop. Where present, the Graneros Group provides an upper confining unit to the Fall River Formation. Evidence of the confining characteristics of the Graneros Group can be seen in the large artesian heads present in many of the Inyan Kara wells in the western portion of the Project Area.

The Lakota Formation is locally subdivided into the Fuson, the Minnewaste Limestone and the Chilson Members. The Minnewaste Limestone is not present in the Project Area. The Fuson Shale is differentiated from the Fuson Member for purposes of characterizing site geology. The Fuson Shale consists of low permeability shales and clays which generally occur at or near the base of the Fuson Member. An isopach of the Fuson, based on over 3,000 boreholes, indicates the thickness of this unit ranges from about 20 to 80 feet as shown on Plate 2.6-8 of the Dewey-Burdock TR. The Fuson Shale is a confining unit between the Fall River and Chilson.

The Chilson consists of fluvial channel sandstone and associated laterally finer-grained overbank deposits and varies from 100 to 240 feet thick. It also is present in outcrop, slightly farther north and east than the Fall River, and is readily observed along the sides of Bennett Canyon. The Chilson also dips to the southwest at between 2 and 6 degrees. A structure map of the top of the Chilson is provided as Plate 2.6-3 in the Dewey-Burdock TR.

Hydrologic properties for these hydrostratigraphic units have been estimated from a number of pumping tests, core analyses and water level measurements. Figure 3-1 shows the location of pumping tests.

The Fall River aquifer is partially saturated in the eastern portion of the Project Area, becoming fully saturated to the west-southwest. Flowing artesian conditions exist across the western portion of the site. The potentiometric surface of the Fall River across the Project Area has a hydraulic gradient of approximately 0.005 to 0.006 ft/ft (26 to 32 ft/mile) toward the southwest. The potentiometric surface of the Fall River based on average water level elevations collected in 2010 and 2011, is shown on Figure 3-2. Water level data used to construct the potentiometric map are included in Table 3-1. Transmissivity of the

Fall River ranges from about 50 to 330 ft^2/d (375 to 2,500 gpd/ft) based on reports of the pumping tests conducted by TVA in 1979 and Knight-Piesold in 2008. The transmissivity values were approximately three to four times higher in the test conducted near the Dewey location compared to the test near Burdock. Storativity estimated from the pumping tests ranged from 1.0 E-05 to 5.0 E-05. Hydraulic conductivity calculated from pumping tests ranged from 1.5 to 2.0 ft/d in the northwest test (Knight-Piesold 2008) and around 0.5 ft/d in the southeast test (Boggs 1983).

The Chilson is fully saturated across the most of the site. There are areas along the eastern margin of the Project Area where water level data from monitor wells indicate that the potentiometric head is below the top of the Chilson. In that area, the Chilson does contain a clay unit that separates the upper and lower Chilson sand units locally. The upper unit is partially saturated but the lower unit is fully saturated. The target ore zone in the eastern portion of the Project Area is the lower, fully confined Chilson unit.

The potentiometric surface of the Chilson across the Project Area has a hydraulic gradient of approximately 0.002 to 0.004 ft/ft (10.5 to 16 ft/mile) toward the southwest. The potentiometric surface of the Chilson, determined from average water level elevations collected in 2010 and 2011, is shown on Figure 3-3. Water level data used to construct the potentiometric map are included in Table 3-1. The transmissivity and hydraulic conductivity of the Chilson are slightly higher than those of the Fall River, based on the available data. Transmissivity of the Chilson ranges from about 150 to 600 ft^2/d (1,125 to 4,500 gpd/ft) based on reports of the pumping tests conducted by TVA in 1982 and Knight-Piesold in 2008. The transmissivity values for the Chilson were approximately four times higher in the test conducted near the Dewey location compared to the test near Burdock, consistent with the results for the Fall River tests. Storativity estimated from the pumping tests ranged from 1.0 E-04 to 2.0 E-04. Hydraulic conductivity calculated from pumping tests ranged from 3.1 ft/d in the northwest test (Boggs 1983) to around 0.9 ft/d in the southeast test (Knight-Piesold 2008).

Total porosity of the Fall River and Chilson is estimated at 30 percent (Dewey-Burdock TR Section 6.1.6).

Data regarding aquifer properties of the Fuson Shale are derived from core permeability analyses and pumping test data. Vertical permeability ranges from about 7.8 E-09 to 2.2 E-07 cm/sec (2.2 E-05 to 6.2 E-04 ft/d) from core data. An estimate of the vertical permeability of the Fuson Shale from the 1979 pumping tests in the Fall River and Chilson was reported by TVA as 4.6 E-08 to 1.0 E-07 cm/sec (1.4E-04 to 2.8E-04 ft/d), which is consistent with the values from the core tests.

Core data from the Skull Creek Shale (of the Graneros Group) that is overlying the Fall River indicate a vertical permeability of 1.5 E-05 ft/d (Knight-Piesold 2008).

Underlying the Chilson is the Morrison Formation. The Morrison Formation averages 100 feet in thickness in the Project Area and is composed of waxy, calcareous, non-carbonaceous, massive shale with numerous limestone lenses and a few thin fine-grained sandstones. Core sample analyses indicate the vertical permeability of the Morrison clays to be very low, in the range of 3.9 E-09 to 4.2 E-08 cm/sec (1.1 E-05 to 1.1 E-04 ft/d) (Dewey-Burdock TR). Because of the low permeability and continuity beneath the Dewey-Burdock area, the Morrison Formation is considered the lowermost confining unit for the proposed ISR operations. No impacts from ISR activities are anticipated below the Morrison Formation.

Within the Project Area, the Fall River and Chilson are generally bounded above and below by low permeability clays and silts that act as confining units. Water level differences between the Fall River and the Chilson are variable but can be in excess of 40 feet. In the northern portion of the site, the potentiometric head of the Fall River is generally from 8 to 16 feet higher than the Chilson. Toward the central western portion of the site, the potentiometric head of the Chilson is 35 to 40 feet higher than the Fall River. Close to the outcrop area of the Fall River on the east side of the Project Area the potentiometric heads are nearly equal. There are numerous flowing artesian wells throughout the area both in the Fall River and Chilson aquifers, providing an indication that there is an overall upward gradient across much of the area, particularly away from recharge areas where the Fall River crops out. Figure 3-4 indicates the general relationship of hydraulic head between the Fall River and Chilson aquifers.

Recharge occurs to the Fall River from a combination of infiltration of precipitation over outcrop areas and from infiltration of overland flow. In the fall of 2011, Petrotek personnel conducting a site visit observed flow in the Pass Creek drainage near the northern boundary of the Project Area infiltrate into the ground over a distance of a few hundred feet. The observed flow was estimated on the order of 100 gpm within a few hundred feet of where the drainage became dry.

The Fall River crops out to the east and north of the Project Area. The Chilson crops out slightly farther east and north of the Fall River outcrop area. These are areas of direct recharge to the aquifers. Geologic dip and hydraulic gradient are both toward the southwest. Therefore a portion of groundwater passing through the Fall River and Chilson beneath the Project Area most likely originates from recharge from the outcrop areas to the north and east. A number of private wells either pump water from the Fall River and Chilson aquifers or allow water to flow under natural artesian conditions. Estimates of the current level of discharge from these wells, based on a recent survey conducted by Powertech, are on the order of 100 to 150 gpm and are summarized in Table 3-2. There must be sufficient

recharge occurring to the Fall River and Chilson aquifers to sustain the artesian water levels observed in wells in the area.

An approximation of groundwater flux across the Project Area can be calculated for the Fall River and Chilson using the following equation:

$$Q = K\,i\,a$$

where Q = groundwater flux in ft^3/d
K = hydraulic conductivity in ft/d
i = hydraulic gradient in ft/ft
a = cross-sectional area perpendicular to flow.

The following parameter estimates are used in the calculation. The cross-sectional distance from the northwest corner of the Project Area to the southeast corner (approximately parallel to the potentiometric contours) is approximately 37,500 feet. For the Fall River, an average thickness of 140 feet, a hydraulic conductivity of 1 ft/d and a hydraulic gradient of 0.005 ft/ft are used to calculate a flux of 26,250 ft^3/d or 136 gpm. For the Chilson, an average thickness of 180 feet, a hydraulic conductivity of 2 ft/d and a hydraulic gradient of 0.003 ft/ft are used to calculate a flux of 40,500 ft^3/d or 210 gpm. The recharge rate updip of the Project Area must be approximately equivalent to this flux in order to maintain present water levels. These estimates are on the low side because the recharge must also account for the private well discharge of 100 to 150 gpm.

Average groundwater velocity under the aquifer conditions stated above for each of the aquifers and an estimated porosity of 0.30 would be 0.017 ft/d (6.1 ft/yr) for the Fall River aquifer and 0.02 ft/d (7.3 ft/yr) for the Chilson aquifer.

Annual precipitation in the Black Hills area generally ranges from 12 to 28 inches. In the Dewey-Burdock area, the average precipitation is approximately 16.5 inches.

As previously indicated, the Fall River and Chilson are the primary hosts of uranium mineralization within the Dewey-Burdock Project Area. These two units, and the Fuson Shale confining unit between them, will be the focus of the modeling effort.

Average ore zone thickness between the Fall River and Chilson is estimated at 4.6 feet (Dewey-Burdock TR Section 6.1.6). Anticipated production rates will be 20 gpm per well pattern, all of which will be reinjected with the exception of a net 0.5 to 1.0 percent bleed (overproduction) as indicated in the Dewey-Burdock TR.

4 Model Development

The model code used to simulate the Dewey-Burdock ISR project was MODFLOW-2000 (Harbaugh et al 2000). MODFLOW-2000 is a public domain computer code developed by the U.S. Geological Survey that numerically solves the groundwater flow equation for a porous medium using a finite difference method. MODFLOW-2000 is an enhanced version of the widely used MODFLOW code that has been updated several times (McDonald and Harbaugh 1988, and Harbaugh and McDonald 1996). Like its predecessors, MODFLOW 2000 simulates groundwater flow using a block-centered, finite-difference approach that is capable of a wide array of boundary conditions. The code can simulate aquifer conditions as unconfined, confined, or a combination of the two. MODFLOW-2000 also supports variable thickness layers (i.e. variable aquifer bottoms and tops). Documentation of all aspects of the MODFLOW-2000 code is provided in the users manuals (Harbaugh et al 2000).

The pre/post-processor Groundwater Vistas (Environmental Simulations, Version 6, 2011) was used to assist with input of model parameters and output of model results. Groundwater Vistas serves as a direct interface with MODFLOW-2000, and MODPATH. Groundwater Vistas provides an extensive set of tools for developing, modifying and calibrating numerical models and allows for ease of transition between the groundwater flow and particle tracking codes. Full description of the Groundwater Vistas program is provided in the Users Guide to Groundwater Vistas, Version 6.0 (Environmental Simulations Inc. 2011).

4.1 Model Domain and Grid

The model domain encompasses an area of nearly 360 square miles with north-south and east-west dimensions of 100,000 ft (18.9 miles). The Project Area is located in the northeastern quadrant of the model domain. As described in the conceptual model discussion, north and east of the Project Area the Fall River Formation and the Chilson Member have been eroded away. The northern and eastern extent of the model domain represents the natural updip termination of saturated conditions within the Inyan Kara aquifer system in the vicinity of the Project Area due to the absence of the Fall River and Chilson hydrologic units. The south and west boundaries of the model extend at least 10 miles beyond the Project Area. The extent of the model domain is illustrated in Figure 4-1.

The model grid was designed to provide adequate spatial resolution within the Project Area in order to simulate response of the aquifer to typical extraction and injection rates anticipated for the Dewey-Burdock uranium project. The model domain was extended a considerable distance from the wellfield boundaries to minimize impacts of exterior boundary conditions on the model solution in the area of interest.

Cell dimensions within the vicinity of the Project Area are 100 feet by 100 feet. Cell dimensions are gradually increased to a maximum size of 400 feet by 400 feet near the edges of the model. The model consists of 525 rows and 523 columns with 4 layers and contains 1,098,300 cells.

The four layers of the model represent, from shallowest to deepest, the Graneros Group, the Fall River Formation, the Fuson Shale and the Chilson Member of the Lakota Formation. The Morrison Formation beneath the Chilson is considered an aquitard for the region and is represented as a no flow boundary in the model. The Graneros Group is also considered an aquitard in the region but was included in the model to provide a reference point for water level elevations within the Fall River and Chilson aquifers relative to ground surface. Figure 4-2 shows the relationship of the model layers. Ground surface elevation corresponds to the top of the model, and the bottom of the Chilson corresponds to the base of the model. The data within the Project Area are based on site borings. Outside of the Project area, geologic picks are largely based on available oil and gas well logs. The geologic dips of the surfaces are projected out to the model limits.

4.2 Boundary Conditions

Boundary conditions imposed on a numerical model define the external geometry of the groundwater flow system being studied as well as internal sources and sinks. Boundary conditions assigned in the model were determined from observed conditions. Descriptions of the types of boundary conditions that can be implemented with the MODFLOW code are found in McDonald and Harbaugh (1988). Boundary conditions used to represent hydrologic conditions at the Dewey-Burdock Project Area included general-head (GHB), areal recharge and wells and no-flow boundaries (NFB). The locations of the NFB, GHB and recharge boundary conditions within the model are illustrated in Figure 4-1. Discussion of the placement and values for these boundary conditions is provided below. The well boundaries are described in the discussion of calibration and operation simulations.

The NFB was used to represent areas where groundwater flow was not hydraulically connected to the site or where the aquifer was absent, as in the case where the Fall River has been eroded away north and east of the site. The Dewey Fault system has sufficient offset such that there is a break in the continuity of the Fall River and Chilson units. Therefore, the assumption used in the development of the model is that there is no flow across the fault in either the Fall River or Chilson aquifers. The model domain north of the Dewey Fault system is simulated using the NFB condition.

Geologic maps of the area (Braddock 1963) were used to identify where the Fall River has been eroded away. The NFBs were used to represent that condition. To simplify some of the modeling effort, it was assumed that the underlying

Fuson Shale was also absent in the same area as the Fall River. Similarly, geologic maps were used to identify areas were the Chilson was absent or very thin and those areas were also simulated using the NFBs.

The GHB was used in the Dewey-Burdock Project Area model to account for inflow and outflow from the model domain. GHBs were assigned along the edges of the model domain where available water-level data suggest the aquifer is being recharged from, or discharging to, a source external to the model domain. GHBs were used because the groundwater elevation at those boundaries can change in response to simulated stresses. In the Dewey-Burdock Project Area model, GHBs were assigned to the west, south and southeast boundaries of the model to represent outflow from the model domain as groundwater moves away from the Project Area out into the Powder River Basin (to the west) and down the Cheyenne River Valley (to the south and southeast). The values of head assigned to the GHBs on the west edge of the model ranged from 5445 to 5560 ft amsl from south to north. Along the south edge of the model GHB values ranged from 5445 to 5550 ft amsl.

Pass Creek recharges the underlying Fall River and Chilson aquifer systems north of the Project Area. GHBs were used to simulate the recharge occurring in the area of Pass Creek. Some GHBs were also placed along the eastern edge of the model to account for some underflow through the Chilson from areas outside the model domain. The heads in the GHBs near the Project Area were adjusted to achieve calibration of the model.

The GHB condition was also used to simulate the presence of a surface depression that appears to intercept groundwater. The Triangle Pit located in the east portion of the Project Area, is a former uranium open mine pit. The depth of the pit and the projection of the potentiometric surface at that location suggest that this depression intercepts the water table in the Fall River. The elevation of water in the Pit is approximately 3670 ft amsl. The base of the other former open pit mine workings located further to the southeast are above the potentiometric surface of the Fall River and Chilson aquifers and are not included in the model simulations. A detailed discussion of the former mine pits and the relationship to groundwater is provided in the Dewey-Burdock TR.

The Fall River crops out north and east of the Project Area. This is an area of direct recharge to the aquifer. Recharge to the Fall River and Chilson aquifers upgradient of the Project Area must be approximately equal to the flux across the Project boundary. The flux across the Fall River and Chilson aquifers was previously calculated as 136 gpm and 210 gpm, respectively across a 37,500 ft cross-sectional length. In addition to the GHBs that were applied north of the Project Area to represent recharge from Pass Creek, zones of recharge were applied along the east edge of the model domain to represent infiltration recharge to the Fall River in the area where the unit crops out or is very close to ground surface. The recharge was extended further east than the mapped limits

of the Fall River to allow for infiltration recharge to enter the Chilson in the areas where that unit outcrops or is close to the ground surface. Recharge rates were limited during calibration to not exceed 10 percent of the average precipitation rate for the Project Area. In the final calibration, the rates were substantially lower than that at approximately 0.0001 ft/d or 0.44 in/yr. That value is less than 3 percent of the average annual precipitation rate. The location of the recharge zones is illustrated in Figure 4-3.

Groundwater Vistas allows the option of simulating wells using either the MODFLOW well package or as analytical elements. MODFLOW simulation of the wells using either method of input, is the same. The analytical elements method was selected for this model mainly for the ease of interactively shifting well locations on the viewer screen and for importing large numbers of wells into the model from spreadsheets. Analytical element wells were used to simulated pumping and/or artesian flow from private wells in the area. Table 3-2 summarizes the flow rates used for private wells in the model. It was assumed for purposes of the model that these flow rates represent average continuous rates and are therefore simulated as steady state boundary conditions.

Analytical element wells were also used to simulate well patterns of the ISR project. A single well is used to represent the net extraction that occurs within each well pattern. The total number of well patterns per wellfield ranges from 9 to 120 (Table 6-1). Each well pattern is approximately 100 feet on a side which coincides with the cell size in the area of the wellfields. Extraction rates applied to the wells varied according to the production/restoration schedule applied to the various operational simulations and are described under that section of this report.

The model domain was extended a suitable distance from the location of the proposed production wellfields to minimize perimeter boundary effects on the interior of the model where the hydraulic stresses were applied.

4.3 Aquifer Properties

Input parameters used in the model to simulate aquifer properties are consistent with site-derived data including; top and bottom elevations of the Fall River, Fuson and Chilson, hydraulic gradient, hydraulic conductivity, and specific storage.

The top and bottom elevations of the Fall River and Chilson within the Project Area were determined from picks in several hundred borings provided by Powertech and outside of the Project Area from well logs obtained from the South Dakota Department of Environment and Natural Resources, the Wyoming State Engineer's Office or the Wyoming Oil and Gas Commission. Gridded contour maps were generated using the contouring program Surfer, Version 9.0 (Golden Software, 2009). The maps were imported into Groundwater Vistas to

represent the top and bottom elevations of the Fall River and Chilson (Figure 4-4 through 4-7).

During model construction, there was difficulty in maintaining integrity between the various layers of the model. Based on projection of the available data, some of the layers intersected each other in space. This occurred primarily because the data sets were not entirely consistent, (i.e. not all well reports contained geologic picks for each of the modeled units). The decision was made during model development to utilize the top of the Fall River and Chilson layers as mapped from the available data and to simulate the Fuson as a uniform layer 45 thick with the bottom corresponding to the top of the Chilson. As previously noted, the Fuson ranges from 20 to 80 feet thick across the Project Area (Dewey-Burdock TR), therefore, a simulated thickness of 45 feet is a reasonable approximation for purposes of the model.

The initial potentiometric surfaces of the Fall River and Chilson were estimated from average water level measurements collected from baseline monitor wells in 2010 and 2011 (Table 3-1).

Hydraulic conductivity determined from recently conducted site pumping tests ranged from 0.5 to 2.0 ft/d for the Fall River and 0.9 to 3.1 ft/d for the Chilson. Zones of hydraulic conductivity were set up to facilitate calibration of the model. Parameter values were maintained within the general range exhibited in the pumping tests. However it is recognized that those pump tests may not capture the full range of aquifer properties that exist at the site. The final calibrated hydraulic conductivity zones for Model Layers 2, 3 and 4 are shown on Figures 4-8, 4-9 and 4-10, respectively. Layer 1 was simulated with a uniform value for horizontal hydraulic conductivity of 2.0 E-04 ft/d and vertical hydraulic conductivity of 2.0 E-05 ft/d.

Specific storage is also an aquifer property of interest with respect to the response of an aquifer to extraction or injection. Specific storage is a measure of the water released from storage due to compaction of the aquifer and expansion of water in response to a decline in head. Specific storage is the storage term used for confined aquifers, where lowering of the potentiometric surface in response to pumping does not result in physical dewatering of the aquifer. Specific storage multiplied by the saturated thickness of an aquifer is referred to as storativity or storage coefficient. Storativity of a confined (fully saturated) aquifer system is typically in the range of 5.0 E-03 to 1.0 E-06 or less. The range of storativity calculated from site pumping tests was from 1.5 E-05 to 1.5 E-04. Zones of specific storage were set up to facilitate calibration of the model to various pumping tests. The final calibrated specific storage values were as follows:

Layer 1 (Graneros) = 3.2 E-07

Layer 2 (Fall River) = 3.1 E-07

Layer 3 (Fuson) = 3.2 E-07

Layer 4 (Chilson = 1.0 E-06

The storativity of the aquifer is determined by multiplying the specific storage by the saturated thickness of the aquifer.

Porosity of the aquifer is used in the model to estimate groundwater velocity. Groundwater velocity is calculated from the Darcy equation as follows:

$$v = ki/n$$

where

v = average interstitial groundwater velocity
k = hydraulic conductivity
i = hydraulic gradient
n = porosity (effective)

The porosity for the Fall River and Chilson is estimated from site data as 30 percent (Dewey-Burdock TR).

5 Model Calibration

Groundwater flow model calibration is an integral component of groundwater modeling applications. Calibration of a numerical groundwater flow model is the process of adjusting model parameters to obtain a reasonable match between field measured values and model predicted values of heads and fluxes (Woessner and Anderson 1992). The calibration procedure is generally performed by varying estimates of model parameters (hydraulic properties) and/or boundary condition values from a set of initial estimates until an acceptable match of simulated and observed water levels and/or flux is achieved. Calibration can be accomplished using trial and error methods or automated techniques (often referred to as inverse modeling).

The focus of this model is on the response of the aquifer to hydraulic stresses imposed on a wellfield scale. The model was initially calibrated to current conditions (which incorporated the pumping rates and artesian discharge rates estimated from the previously referenced survey by Powertech). Because of the uncertainty in the discharge rates from the pumping and artesian wells, the calibration is considered to be more of a representative steady state than a true steady state calibration. The variables that were used to calibrate the model to the representative steady state conditions included recharge along the north and east edges of the model domain, heads and conductivity of the GHBs on all model borders, and both the vertical and hydraulic conductivity zone values and distribution. The calibration targets were the average water level data collected in 2010 and 2011. A secondary calibration target was the calculated flux term for the Fall River and Chilson aquifers of 136 and 210 gpm, respectively.

The adequacy of model calibration is judged by examining model residuals. A residual, as defined for use in this modeling report, is the difference between the observed change in groundwater elevation and the change in groundwater elevation predicted by the model. The objective of model calibration should be the minimization of the residual mean, residual standard deviation, and residual sum of squares (RSS) (Duffield et al 1990). The mean residual is the arithmetic average of all the differences between observed and computed water levels. A positive sign indicates that the model has underpredicted the observed drawdown level and a negative sign indicates overprediction. The residual standard deviation quantifies the spread of the differences between observed and predicted drawdown around the mean residual. The ratio of residual standard deviation to the total head change across the model domain should be small, indicating the residual errors are only a small part of the overall model response (Woessner and Anderson 1992). The RSS is computed by adding the square of each residual and is another measure of overall variability. The overall objective during the calibration process is to minimize the residuals and the statistics based on the residual while maintaining aquifer properties within the range of reasonably expected values. .

5.1 Steady-State Calibration

Calibration was achieved by comparing field-measured (observed) water levels in the baseline monitor wells with heads predicted by MODFLOW-2000 for the same wells under simulated steady state conditions of the Fall River and Chilson aquifers. The hydraulic conductivity zones, recharge values and GHB heads were adjusted until the best fit to the average potentiometric surface observed in the baseline monitor wells was achieved. The final distribution and values for hydraulic conductivity zones for model layers representing the Fall River, Fuson and Chilson are shown on Figures 4-8, 4-9 and 4-10, respectively. The values are generally within the ranges determined from site pumping tests. The final distribution and values for the recharge zones are shown on Figure 4-3.

The potentiometric surfaces of that simulation for the Fall River and Chilson are shown in Figures 5-1 and 5-2. Calibration residuals are presented in Figure 5-3 and 5-4, respectively. Calibration statistics from that simulation are listed in Table 5-1. A plot of the observed versus simulated heads is provided in Figure 5-5.

5.2 Transient Calibration

Once a steady-state calibration was achieved, the model was calibrated to the two pumping tests conducted by Knight-Piesold in 2008. The Fall River pump test, conducted near Dewey for 3.1 days at an average rate of 30.2 gpm, was simulated using the initially calibrated model in transient mode. Because the minimum cell size in the model is 100 feet by 100 feet, the drawdown in the pumping well was not included in the calibration statistics. Factors such as well

inefficiency and the steepness of the drawdown cone in the immediate vicinity of the well would make inclusion of the pumping well drawdown of negligible value.

Calibration was achieved by varying the specific storage zone values and then revising the hydraulic conductivity zones. Whenever changes were made to hydraulic conductivity zones, the initial steady-state model was rerun to determine if additional changes had to be made to that base model. The process was repeated until a satisfactory calibration was achieved. Results of the calibration to the Fall River pump test are shown on Figure 5-6 and included in Table 5-2.

The calibration process was then repeated for the 2008 Chilson pump test conducted near Burdock. A 3.0 day pump test, also at 30.2 gpm was simulated. Results of that calibration are provided in Figure 5-7 and the statistics are shown on Table 5-2.

5.3 Model Verification

As a final check to verify that the model provides a reasonable prediction of response to significant hydraulic stress, the calibrated model was used to simulate the TVA test conducted in 1982 in the Chilson, near the north end of the Project Area. That test was run for a period of 11 days at an average rate of 495 gpm. In addition to several Chilson monitoring wells located near the pumping well, a Fuson monitor well and three Fall River monitor wells were observed during the test. The drawdown in the Fuson was over 20 feet at the end of the test. Several feet of drawdown were also measured in the Fall River monitor wells during the test.

The simulated drawdown in the Chilson is generally within 10 percent of the observed drawdown, indicating a reasonable calibration (Figure 5-8). The calibrated model was also able to simulate the drawdown in the overlying Fuson Shale unit fairly closely. It should be noted that the drawdown in the pumping well was over 300 ft during the test so it is expected that there would be drawdown within the Fuson directly above the pumping well even though the hydraulic conductivity of the Fuson is several orders of magnitude lower than the Chilson.

The model was unable to replicate drawdown in the Fall River on the scale of what was observed during the test despite extensive efforts to do so. It is possible that the drawdown observed in the Fall River during the 495 gpm pumping test in the Chilson was the result of improperly completed wells or exploration boreholes that provided a hydraulic connection between the two units.

Additional testing and monitoring will be conducted on the wellfield scale prior to operating the ISR project to determine if the response of the Fall River during the

1982 test was leakage through the Fuson Shale or communication through the wells or boreholes.

The results of the calibration for this simulation are presented in Figure 5-8 and the statistics are provided in Table 5-3. Comparison of the simulated drawdown to the observed drawdown from the 1982 Chilson pumping test confirms that the model adequately replicates response of the Chilson aquifer and the overlying Fuson confining unit to a large hydraulic stress. In fact, the net extraction rate at which the well was pumped (495 gpm) is significantly greater (3 to 12 times) than the net extraction during any period of the proposed production/restoration mine schedule as described in Section 6 of this report.

5.4 Groundwater Flux Comparison

As a final check on the representativeness of the model, the simulated groundwater flux from the calibration model was compared to the previously calculated flux described under the conceptual model discussion. Figure 5-9 shows the location of the cross section through which the flux was originally calculated and described under the conceptual model discussion and was then extracted from the calibration simulation.

Flux through the cross-sectional area in the Fall River was simulated at 25,442 ft^3/d or 132 gpm. Flux through the cross-sectional area in the Chilson was simulated at 41,214 ft^3/d or 214 gpm. These values are in close agreement to the calculation previously described. Additionally, the final recharge rate for the calibration simulation was 1.1 E-04 ft/d or 0.482 in/yr which is approximately 3 percent of the average annual precipitation rate of 16.5 in/yr.

5.5 Sensitivity Analysis

The process of model calibration is intended to estimate parameter values that provide the "best fit" to the selected observational data. As previously described, the hydraulic conductivity, specific storage and recharge zone values and the GHB head and conductance values were adjusted during the calibration process to achieve that fit. Although each of these terms has significant impact on the model solution and calibration, the groundwater flux through the Project Area is of critical importance as this determines whether the proposed ISR production and restoration rates are sustainable throughout operation of the mine. The rate of recharge applied to the model and the head and conductance of the GHBs immediately north of the Project Area largely control the groundwater flux through the area of the proposed wellfields. Because of the importance of these terms, and the fact that they are applied relatively close to the area of the wellfields, a sensitivity analysis was performed to evaluate impacts on model flux and model calibration.

The sensitivity analysis was accomplished by varying the value of the recharge rate and the head and conductance of the GHBs located north of the Project Area in the Fall River and the Chilson. Figure 5-10 shows the locations of the features included in the sensitivity analysis. The values used for each sensitivity analysis simulation and the resulting calibration and groundwater flux through the same cross-sectional area previously described are included in Table 5-4.

Results of the sensitivity analysis indicate that for recharge, the calibration, as measured by the RSS term, was best at the base value of 1.1 E-04 ft/d (indicated by the 1.0 multiplier on Figure 5-11). Reducing the recharge rate by an order of magnitude did not significantly alter the flux through either the Fall River or Chilson in the central portion of the Project Area. Increasing the recharge by an order of magnitude resulted in large increases in the Fall River and Chilson simulated flux and in the RSS. The analysis indicates that the model is not particularly sensitive to decreases in the recharge term but is highly sensitive to increasing that value.

The GHBs representing flux into the Fall River in the area of Pass Creek were evaluated by varying the head and the conductance terms. The conductance assigned to the GHBs representing recharge to the Fall River in the vicinity of Pass Creek ranged from 99 to 366 ft^3/d in the calibration simulation. The sensitivity simulations indicate that varying the conductance even by an order of magnitude up or down results in negligible changes to the flux within the Fall River and Chilson (less than 3 percent of the original calibrated value (Figure 5-12). The head assigned to the GHBs representing recharge to the Fall River in the vicinity of Pass Creek ranged from 3767.2 to 3790.8 ft in the calibration simulation. Increases in head for the Fall River GHB result in increased flux in the Fall River, but decreased flux in the Chilson (Figure 5-13). The opposite also holds true in that decreasing the head results in decreased flux in the Fall River and increased flux in the Chilson. As a result, the combined flux of the Fall River and Chilson stays relatively consistent (within about 3 percent of the calibrated value) but the RSS shows large fluctuation in response to changes in head of the Fall River GHB.

The conductance assigned to the GHBs representing recharge to the Chilson in the vicinity of Pass Creek ranged from 47 to 112 ft^3/d in the calibration simulation. Varying the conductance of the GHBs representing flux into the Chilson in the vicinity of Pass Creek results in negligible change to the flux of the Fall River and Chilson (less than 1 percent of the calibrated values) (Figure 5-14). The head assigned to the GHBs representing recharge to the Chilson in the vicinity of Pass Creek ranged from 3725.0 to 4004.5 ft in the calibration simulation. Changing the head in the Chilson GHBs has the same effect as for the Fall River GHBs. Increasing the head results in increased flux in the Chilson and decreased flux in the Fall River and vice versa (Figure 5-15). The net change in total flux varies by less than 7 percent even with a change of 50 ft in the GHB head.

In summary, changes to the conductance and head of the GHBs in the vicinity of Pass Creek do not appreciably alter the flux of the Fall River and Chilson aquifers across the Project Area, but do result in significant increases to the RSS, indicating a generally poorer calibration. Increasing the recharge rate also changes the calibration substantially and causes large increases in the flux of both the Fall River and Chilson. Decreasing the recharge has negligible effect on either flux or calibration.

6 Operational Simulations

This numerical groundwater flow model was developed to evaluate the effects of ISR operations on the Fall River and Chilson during projected ISR operations. Simulations were performed using the numerical model to address requests for additional information posed by the NRC in response to the original URL Application. The simulations described in this section provide:

- Demonstration of the hydraulic effects that the ISR operation will have on the Fall River and Chilson aquifers, including the sustainability of anticipated production and restoration rates;
- Comparison of hydraulic effects of variable bleed rates and production rates on the Fall River and Chilson aquifers;
- Assessment of the level of interference between wellfields that could occur with simultaneous production and restoration operations; and,
- Evaluation of potential hydraulic effects of ISR operation with respect to an open pit mine located on the eastern portion of the Project Area.

6.1 Initial Conditions

The initial condition for the simulations was based on the potentiometric surface determined from the calibration simulation. As previously stated, the hydraulic conductivity, specific storage and recharge values and the GHB heads were adjusted to provide a reasonable match to potentiometric surface data representative of steady-state conditions and to drawdown data from three separate pumping tests. The final calibrated model was then used to simulate operating conditions for the Dewey-Burdock uranium ISR project. The potentiometric surfaces for the Fall River and Chilson, shown on Figures 5-1 and 5-2, respectively, were used as initial conditions for each of the operational runs described below.

6.2 Simulation of ISR Operations

Model simulations were run to represent the full cycle of ISR production and restoration under a wide range of operating conditions. Fourteen wellfields were simulated, ten in the Burdock Production Area and four in the Dewey Production

Area. Figure 6-1 shows the location of the proposed Fall River and Chilson wellfields. The outlines shown on the figure represent the monitor well ring boundaries which extend out approximately 400 feet from the ore bodies. Note that many of the wellfields have adjoining boundaries and some actually overlap. The areas of overlap are locations where ore zones may be present in subunits within the Fall River or Chilson. For purposes of this modeling effort, the Fall River and Chilson are not subdivided and are each simulated as a single layer within the model.

The model cell size within the Project Area is 100 ft by 100 ft. It is assumed that this is also the dimension of a single 5-spot pattern. The number of well patterns simulated for each wellfield was determined by placing a well within each of the cells where ore is indicated. The number of well patterns per wellfield simulated in the model approximates, but is not exactly the same as, the number projected in the Dewey-Burdock TR. Figure 6-1A shows an example of the placement of wells (representing well patterns) within the outline of the ore body.

The target production rate for Dewey-Burdock Project is 4,000 gpm (Dewey-Burdock TR). The projected production rate at any one time for the 4,000 gpm scenario is 2,400 gpm for the Burdock wellfields and 1,600 gpm for the Dewey wellfields. The production rate per well pattern is assumed to be 20 gpm for the 4,000 gpm production case. For purposes of modeling, and to reflect actual operating conditions, only the net loss, or consumption of water, was simulated for each well pattern. For instance, under a scenario of a 1 percent bleed, a single well pattern is simulated at a rate of 0.2 gpm (20 gpm x 0.01). For simulating the Burdock wellfields at the target production rate of 2,400 gpm with a net bleed of 1 percent, the net extraction rate for the Burdock area would be 24 gpm.

To evaluate the sensitivity of the model to hydraulic stress, simulations were also run using an 8,000 gpm production rate. For the 8,000 gpm simulations, the targets for the Burdock and Dewey Production areas were 4,800 gpm and 3,200 gpm, respectively. The production rate per well pattern is assumed to be 40 gpm for the 8,000 gpm production simulations. Multiplying the total well pattern rate by the bleed rate gives the model rate per well pattern for each simulation.

Simulations were run at the 4,000 and 8,000 gpm production rate at variable bleed rates and restoration rates. The simulations were all run for a period of 8.5 years over 12 stress periods and included restoration after production of each wellfield.

Wellfield restoration was simulated under two separate scenarios. The first scenario involves extraction of groundwater during restoration and reinjection of the majority of that water into the wellfield along with makeup water sufficient to maintain a 1 percent net aquifer restoration bleed. The second scenario utilizes 1 Pore Volume (PV) of Groundwater Sweep (GWS) in addition to the 1 percent

bleed during restoration. GWS is used to hydraulically capture groundwater within the affected area of the wellfield and is totally consumptive during a portion of the restoration (that is, none of the extracted water is returned to the aquifer). The extraction rates applied during simulation of restoration under both scenarios are based on the PV of each wellfield. A PV is calculated as follows:

$$PV = A \times B \times n \times WF$$

where A = area of the wellfield (feet^2)
B = average ore body thickness (feet)
n = porosity (unitless)
WF = wellfield flare (combined vertical and horizontal flare factor)

Assumptions used in calculating the PV are that the average ore body thickness is 4.6 feet, porosity for the Fall River and Chilson is 30 percent, and the wellfield flare factor is 1.44. The calculation of a PV for each wellfield is included in Table 6-1.

The net-extraction rates used in these restoration simulations conform with both the restoration methods described in the Dewey-Burdock TR that include:
-Groundwater treatment with Reverse Osmosis (RO)
-Groundwater sweep with clean make-up water re-injection (no RO)

It is assumed that a total of 6 PVs will be removed from each wellfield during the restoration phase. The restoration phase simulated for the wellfields ranged from 183 days up to 549 days. The flow rate required to remove 6 PVs within the simulated restoration phase was calculated for each wellfield (Table 6-1). For each wellfield the flow rate was less than 500 gpm. As previously described, a maximum one percent bleed of the operational capacity (5 gpm) is assumed for the restoration process without groundwater sweep (No GWS). This maximum rate (5 gpm net extraction) was conservatively applied to each of the wellfields for simulation of restoration. The actual net extraction rate would be less than 5 gpm from any of the wellfields, as previously described. The 5 gpm is equally divided into the number of wells within the wellfield during the simulation of restoration.

For the GWS scenario, it is assumed that an additional 1 PV is extracted during restoration and is not reinjected. GWS is applied concurrently with the one percent restoration bleed. The extraction rate used for the simulation of the GWS scenario was calculated by dividing 1 PV by the number of days in the restoration period. The resulting rate was then equally divided by the number of wells in each wellfield to determine the rate per well pattern for the simulation that represents GWS. The one percent restoration bleed rate of 5 gpm was also applied as stated for the previous simulation of restoration with no GWS.

For computational efficiency, some of Burdock wellfields that are "stacked" within the Chilson production zone were simulated as operating at the same time. This

was the case for wellfields BWF5 and BWF9 and also for wellfields BWF2 and BWF3. Wellfields BWF9 and BWF3 are relatively small in comparison to the other wellfields and make up a small proportion (less than 10 percent) of the total production rate for any model simulations. Similarly, Dewey wellfields DWF2 and DWF4 overlie each other.

One of the Dewey wellfields, DWF1 was divided into two wellfields for purposes of modeling production and restoration, because of its large size. Figure 6-1A represents the division of wellfield DWF1 into two components, DWF1A and DWF1B. As previously noted, the figure also provides an illustration of how the well patterns are simulated as single 100 ft by 100 ft cells within the ore body.

The anticipated ISR operational rates for the Dewey-Burdock Project are for the case of 4,000 gpm production with 0.875 percent net bleed and without GWS (Dewey-Burdock TR). However, the same operational scenario with GWS will result in greater hydraulic effects with respect to drawdown and the simulation of that case is shown in detail. Figure 6-2 illustrates the sequence and rates used in the simulation of 4,000 gpm production with a net bleed of 0.875 percent and restoration with GWS. The sequence of wellfield production and restoration in the simulation is provided to illustrate a possible schedule that may be used to operate the Dewey-Burdock Project. The actual schedule and sequence for operating the Dewey-Burdock Project may differ substantially from that simulated. Regardless of the sequence of wellfield operation, hydraulic containment of production and restoration fluids will be a primary objective throughout the Dewey-Burdock Project operations. Figures 6-3 through 6-14 illustrate the drawdown in the Fall River at the end of each of the 12 stress periods for that simulation. The figures indicate which wellfields were in production or restoration and what the simulated rates were for each stress period.

The first Fall River wellfield in production in the simulation (DWF1) is one of the larger wellfields and is divided into two components for modeling (DWF1A and DWF1B). At the end of the first stress period, simulating 730 days of production at a total rate of 1600 gpm (net loss of 14 gpm), drawdown is centered around wellfield DWF1 (Figure 6-3). The drawdown cone continues to gradually expand through stress periods 2 and 3, which have the same extraction rate as the first stress period (Figures 6-4 and 6-5). Stress periods 4 and 5 simulate concurrent production and restoration from wellfield DWF1B and DWF1A at respective net rates of 14.0 and 29.2 gpm (Figures 6-6 and 6-7). The maximum drawdown outside of the Project Area within the Fall River at the end of this period is slightly greater than 8 feet. The full extent of drawdown in the Fall River across the model domain for this stress period is shown on Figure 6-7A. This stress period represents the maximum hydraulic impact on the Fall River because the largest net extraction from the Fall River (43.2 gpm) for the simulation is applied during this period. Although some drawdown is indicated several miles west and southwest of the Project Area, the amount is negligible considering that large

artesian heads exist within the Fall River in those areas. For purposes of comparison, drawdown for the anticipated actual operating scenario, simulation of 4,000 gpm production with 0.875 percent net bleed without GWS, is shown in Figure 6-7B.

Figures 6-8 and 6-9 represent drawdown in the Fall River at the end of stress periods 6 and 7 when only wellfield DWF1B is in production (net extraction of 14 gpm). Simulation of the restoration phase of DWF1B through stress periods 8 and 9 (net extraction of 29.2 gpm) is shown on Figures 6-10 and 6-11. Figure 6-12 exhibits the drawdown resulting from production of wellfield DWF3 at a rate of 300 gpm (net 2.6 gpm bleed) in stress period 10. Wellfield BFW10 (the only Burdock wellfield anticipated to produce from the Fall River) is added in stress period 10 but at very low rates (180 gpm production, 1.6 gpm net bleed) because of its small size (Figure 6-12). Those two wellfields continue in production through stress period 11 (Figure 6-13). The final stress period simulates restoration of wellfields DWF3 and BWF10 and the resulting drawdown is shown on Figure 6-14.

Figures 6-15 through 6-26 illustrate the drawdown in the Chilson at the end of each of the 12 stress periods for the 4,000 gpm, 0.875 percent bleed, with GWS simulation. The figures indicate which wellfields were in production or restoration and what the simulated rates were for each stress period.

The first Chilson wellfield in production in the simulation is BWF1. At the end of the first stress period, simulating 730 days of production at a total rate of 2400 gpm (net bleed of 21 gpm), drawdown in the Chilson is centered around wellfield BWF1 (Figure 6-15). The second and third stress periods simulate concurrent production from three wellfields (BWF5, BWF8 and BWF9) at a combined production rate of 2,380 gpm (net bleed of 20.8 gpm) and restoration from wellfield BWF1 at a net extraction rate of 26.7 gpm (Figures 6-16 and 6-17).

Stress periods 4 and 5 simulate Chilson production of wellfield BWF6 at 2400 gpm (net bleed of 21.0 gpm) and restoration of wellfields BWF5, BWF8 and BWF9 at a combined net extraction rate of 38.0 gpm (Figures 6-18 and 6-19). Figure 6-20 shows the drawdown at the end of stress period 6 which simulates only production from wellfield BWF6 at 2,400 gpm (net bleed of 21.0 gpm). Drawdown during the restoration of wellfield BWF6 (net extraction rate of 20.9 gpm) combined with production at Wellfields BWF2 and BWF3 (net bleed of 14.0 gpm) is simulated as stress period 7 (Figure 6-21).

Stress period 8 simulates the initial Chilson production from the Dewey Production Area in wellfield DWF2 at 1600 gpm (net bleed of 14 gpm) (Figure 6-22). Restoration of wellfields BWF2, BWF3 and BWF6 is included in that stress period at a net extraction rate of 48.4 gpm. Maximum drawdown that occurs outside the Project Area in the simulation is approximately 8 feet. Figure 6-22A shows the hydraulic effect in the Chilson aquifer across the entire domain at the

end of stress period 8. Stress period 8 has the highest extraction rate (Figure 6-2) simulated for the Chilson. The simulation indicates that drawdown extends several miles outside the Project Area but that the total impact is only a few feet, which is negligible considering the large artesian heads that exist in the Chilson west and southwest of the site. For purposes of comparison, drawdown for the anticipated actual operating scenario, simulation of 4,000 gpm production with 0.875 percent net bleed without GWS, is included in Figure 6-22B.

Figure 6-23 shows the drawdown resulting from stress period 9 which simulates continued production of wellfield DWF2 and restoration of wellfield BWF2 (net extraction of 18.9 gpm) and adds production of wellfield BWF7 at 1,040 gpm (net bleed of 9.1 gpm). Note that the drawdown around wellfield BWF7 appears limited because the Chilson in this area is simulated as partially saturated and is also near the active recharge zone for the Chilson. The ore in this portion of the Project Area is within the lower Chilson member and localized low permeability confining units are present above the ore zone in that area (Dewey-Burdock TR). The hydraulic response of wellfield BWF7 will be evaluated further once additional hydrologic characterization is performed, prior to finalizing the hydrogeologic wellfield data package for BWF7.

Chilson wellfields BWF4 and DWF4 come into production in stress period 10 at rates of 1,200 gpm (net bleed of 10.5 gpm) and 500 gpm (net bleed of 4.4 gpm), respectively (Figure 6-24). Wellfield BW7 continues production through this stress period and wellfield DWF2 goes into restoration at a net extraction rate of 20.9 gpm. Stress period 11 simulates the continuation of the previous production except that wellfield BW7 goes into restoration at a net extraction of 16.7 gpm (Figure 6-25). The final stress period simulates restoration of wellfields BWF4 and DWF4 at net extraction rates of 24.1 gpm and 7.4 gpm, respectively (Figure 6-26).

Results of the simulation of the fourteen anticipated wellfields indicate that wellfield interference can be effectively managed through appropriate scheduling and balancing of the production and restoration phases of the wellfields. Wellfield interference between concurrently operating wellfields can be reduced by maximizing distance and balancing net extraction between the wellfields. The simulated scenario does not represent the only acceptable or even a preferred sequence of production and restoration and only serves to illustrate that hydraulic containment can be maintained during simultaneous operation of multiple wellfields in the Dewey-Burdock Project. The Dewey-Burdock model simulates entire wellfields operating during a single stress period. In actual operation, wellfields are produced and restored on the scale of header houses and individual well patterns and monitored accordingly. Use of a numerical model can assist in this effort. However, real time monitoring of water levels during operations and adjustment of flow rates in response to water level changes provides the best engineering control to minimize wellfield interference.

6.3 Fall River and Chilson Hydraulic Head Assessment

Monitor points were placed at strategic locations within the Project Area to illustrate the changes that occur to the potentiometric surface during the life of production and restoration operations and during post mining recovery (Figure 6-27). Monitor points were selected at the Project Area boundary downgradient of the Dewey and Burdock Production Areas and within the wellfields for both Production Areas. Hydrographs are provided for both the Fall River and Chilson at each location.

The hydrographs for the Dewey Production Area downgradient monitor point (D-1) are shown on Figure 6-28A. Hydrographs for monitor point D-1 indicate that the maximum drawdown simulated during ISR operations is less than 10 feet at the edge of the Project Area and that the hydraulic head stays several hundred feet above the top of the Fall River (at 3,079 ft amsl). One year after termination of all production and restoration operations, the water level at that location recovers to within one foot of pre-ISR levels (Figure 6-28A).

The hydrographs for the Burdock Production Area downgradient monitor point (B-1) are shown on Figure 6-28B. The hydrographs for monitor location B-1 indicate that the potentiometric surface of both the Fall River and Chilson stay above ground surface (at 3,592 ft amsl) for the duration of the ISR operations. Figure 6-28B also shows the recovery of water levels to near pre-ISR levels within the first year following termination of all production and restoration operations.

The hydrographs for the Dewey Production Area wellfield monitor point (D-2) are shown on Figure 6-29A. The monitor point is located in the middle of wellfield DWF1 which is where the greatest amount of drawdown occurred during the production/restoration simulation. The hydrographs for monitor location D-2 indicate that the maximum drawdown in the Fall River is less than 10 feet during the simulation and approximately 15 feet in the Chilson.

The hydrographs for the Burdock Production Area wellfield monitor point (B-2) are shown on Figure 6-29B. The monitor point is located in the area where wellfields BWF1, BWF2 and BWF3 overlap which is where the greatest amount of drawdown occurred during the production/restoration simulation. The hydrographs for monitor location B-2 indicate that the maximum drawdown in the Fall River is less than 3 feet during the simulation and approximately 25 feet in the Chilson.

Note that although there is minimal production in the Fall River in the Burdock Production Area there is a noticeable drawdown response in that aquifer at location B-2. Some of that drawdown is induced by the Fall River extraction occurring in the Dewey Production Area. To further evaluate the amount of

drawdown occurring within the Fall River that is directly attributable to ISR operations in the Chilson, a simulation was run in which all Fall River wellfields were shut-in (not operating) but the Chilson wellfields were operating under the same rates as in the 4,000 gpm production, 0.875 percent net bleed with groundwater sweep simulation. The head difference in the Fall River at location B-2 between those two simulations is shown on Figure 6-29C. The difference is the effective drawdown in the Fall River induced by Chilson ISR operation under the stated conditions. As shown on the figure, that drawdown is less than 1.4 feet at any time during the simulation. Although there is a slight decrease in the Fall River hydraulic head during the ISR simulation, the head within the Chilson remains lower throughout the simulation, indicating there would be no groundwater flow from the Chilson into the Fall River.

6.4 Recovery Simulation and Assessment

Recovery of the Fall River and Chilson following termination of ISR operations was simulated by extending the model out an additional one year with no production or restoration. Results of the simulations show that residual drawdown has largely dissipated in both the Fall River and Chilson aquifers within that time period (Figures 6-30 and 6-31). The hydrographs presented in Figures 6-28A, 6-28B, 6-29A and 6-29B also illustrate the recovery of the Fall River and Chilson aquifers to near pre-ISR levels within one year after termination of ISR operations.

6.5 Triangle Pit Assessment

The Triangle Pit location is indicated in each of the figures that illustrate drawdown in the Fall River during the simulation of the 4,000 gpm production-0.875 percent bleed with GWS (Figure 6-3 through 6-15). As previously described, the base of Triangle Pit is beneath the top of the Fall River and it is apparent that water in the pit is connected to groundwater. A component of this evaluation is to assess potential hydraulic impacts to the Triangle Pit as a result of ISR operations at the rates proposed for the Dewey-Burdock Project. The Fall River drawdown figures indicate that the area of the Triangle Pit will have less than one foot of drawdown throughout the operational period of the mine. Multiple factors have a bearing on the limited drawdown simulated by the model. First, with the exception of wellfield BWF10, all of the Fall River production occurs at a distance of over 2 miles from the Triangle Pit. The Triangle Pit is located approximately 3,300 feet from wellfield BWF10 but the net extraction from that wellfield is simulated (and anticipated to be) at less than 3 gpm at any time during mining operations. Second, the Triangle Pit is located near an area where the Fall River is exposed at or near the surface. The conceptual hydrologic model is that active recharge is occurring in the area where the Fall River is present in outcrop. Third, the Triangle Pit is located in an area where the Fall River is partially saturated and is the water table aquifer. Drawdown resulting from pumping from a well or wells that is/are hydrologically unconfined is typically

much less than would occur from a well in a fully saturated (hydrologically confined) system when pumping at the same rate.

6.6 Variable Operational Rate Simulations

Additional simulations were run using the same schedule of wellfield production/restorations previously presented but with variable production rates, net bleed percentages and restoration rates. The 4,000 and 8,000 gpm cases were each simulated using a net bleed (overproduction) of 0.5, 0.875 and 1 percent of the production rate. Additionally, the two restoration cases previously described (No GWS and with GWS) were run for each production rate/net bleed simulation. Table 6-2 summarizes the rates and parameters for each of the simulations. Table 6-3 shows the total flow rate over time for each of the simulations. Table 6-4 indicates the net extraction rates over time for each of the operational simulations. Comparisons of the effect of varying these operational parameters are described below.

Figure 6-32 compares the relative drawdown in the Fall River between the 0.5, 0.875 and 1.0 percent bleed for the 4,000 gpm production, with GWS simulations. The figure shows the drawdown at the end of stress period 5 which is when the maximum drawdown occurs because the extraction rates are largest during that period. The same comparison is made for the Chilson in Figure 6-33 at the end of stress period 8 when the maximum production is occurring in that unit. As anticipated, the increase in the bleed percentage results in slightly greater drawdown at the end of the stress period.

Figure 6-34 is a comparison of the drawdown in the Fall River at the end of stress period 5 from the 4,000 and 8,000 gpm production simulations with 1.0 percent bleed and GWS. Figure 6-35 is a comparison of the drawdown in the Chilson for the same simulation and stress period. Although the drawdown is greater for the 8,000 gpm simulation in both cases, the overall hydraulic effect to the Fall River and Chilson is still negligible compared to the total available head in those aquifers.

Figure 6-36 is a comparison of the drawdown in the Fall River at the end of stress period 5 from the 4,000 gpm for the 0.875 percent bleed simulation with and without GWS. The simulation of GWS increases the drawdown in the Fall River because of the higher net restoration extraction rate of 29.2 gpm compared to 5.0 gpm for the simulation of only RO. Figure 6-37 is a comparison of the drawdown in the Chilson for the same simulation for stress period 8. The drawdown in the Chilson is greater for the simulation of GWS because of the increase in the net restoration extraction rate from 15.0 gpm to 48.4 gpm.

The maximum drawdown for all of the simulations was under the 8,000 gpm case with a 1 percent bleed and application of GWS. The maximum drawdown occurred at the end of stress period 5 for the Fall River and the end of stress

period 8 for the Chilson. Figure 6-38 and 6-39 represent the drawdown from that simulation for the Fall River and Chilson, respectively. Maximum drawdown outside the Project area during the simulation was slightly greater than 12 feet within the Fall River and approximately 10 feet in the Chilson.

7 Evaluation of a Hypothetical Breccia Pipe

Gott et al. (1974) hypothesized that breccia pipes sourced from the underlying Paleozoic formations may discharge into overlying geologic units. Concerns have been expressed by interested parties that there may be breccia pipe releases into either the Fall River or Chilson aquifers within the Dewey-Burdock Project Area and that such a release could conceivably compromise proposed ISR operations. Powertech has extensively surveyed the Project Area and has found no direct evidence of a breccia pipe or breccia pipe release in that area. There is no direct evidence from either visual observation or water level data of the presence of a breccia pipe release into the Fall River or Chilson aquifers within the Project Area.

The calibrated numerical model developed for the Dewey-Burdock ISR Project was used to assess the potential hydraulic impacts of a hypothetical breccia pipe release. A breccia pipe release into the Fall River and or Chilson was simulated by placing an injection well into the model layers representing those hydrostratigraphic units and running a steady state simulation. A value of 200 gpm was selected for the simulations. Much higher flow rates have been documented at known breccia pipe locations. Discharge rates much lower than 200 gpm would probably have minimal impact on ISR operations and could be controlled using engineering practices.

The result of the simulation of a hypothetical breccia pipe discharge into the Fall River within the Project Area is shown on Figure 7-1. The potentiometric surface shows a large recharge mound resulting from the hypothetical discharge. A hydraulic profile showing the potentiometric surface resulting from the hypothetical breccia pipe discharge is shown on Figure 7-2. The simulation of a breccia pipe discharge into the Chilson is shown on Figures 7-3 and 7-4. A large recharge mound occurs within the Chilson in this simulation.

Because of the large change in the potentiometric surface, the occurrence of discharge from a breccia pipe into either the Fall River or Chilson should be observable with the existing monitor well network and would definitely be noticed once a monitor ring has been installed around a proposed production unit. No such recharge mound has been observed to date. If a breccia pipe release were identified during additional characterization for the wellfield, engineering controls could be applied to ensure that the discharge did not compromise the ISR operations.

8 Summary

A numerical model was developed to evaluate the response of the Fall River and Chilson aquifers to hydraulic stresses imposed by operation of the Dewey-Burdock ISR uranium project. The model was developed using site-specific data regarding top and bottom aquifer elevations, saturated thickness, potentiometric surface and hydraulic gradient, hydraulic conductivity, specific yield, storativity and porosity of the Fall River and Chilson aquifers. The model was calibrated to existing conditions and to three pumping tests.

The calibrated model was used to simulate the complete operational cycle of the Dewey-Burdock ISR uranium project, from production through restoration, of fourteen delineated wellfields and recovery after the conclusion of restoration. Simulations were run using a range of production/restoration rates and net bleeds ranging from 0.5 to 1.0 percent. Results of the modeling indicated the following:

- Simulated production at the projected rates of up to 8,000 gpm (40 gpm per well pattern) with a 0.5 to 1.0 percent bleed for a period of 8.5 years did not result in dewatering of the aquifer;
- Maximum drawdown outside of the Project Area was simulated as less than 12 feet throughout the entire life cycle of the ISR project;
- Restoration using RO at the projected rates of up to 500 gpm per wellfield with a 1 percent reject rate can be sustained throughout the restoration cycle of 6 PVs of removal;
- Groundwater sweep simulated at rates to remove one PV within 6 to 18 months per wellfield did not result in localized dewatering of the aquifer;
- Wellfield interference can be managed for the simulated production/restoration and net bleed rates through sequencing of wellfields to maximize distance between concurrently operating units;
- Model simulations indicate limited drawdown will occur within the Fall River as a result of ISR operations within the Chilson;
- Simulated hydraulic impact (drawdown) at the Triangle Pit was less than 1 foot;
- Simulation of a hypothetical breccia pipe discharge to the Fall River or Chilson results in large changes in the potentiometric surface such that existing and proposed monitoring would detect such an occurrence; and,
- Water levels recover to near pre-operational elevations within 1 year after ISR operation cease.

9 References

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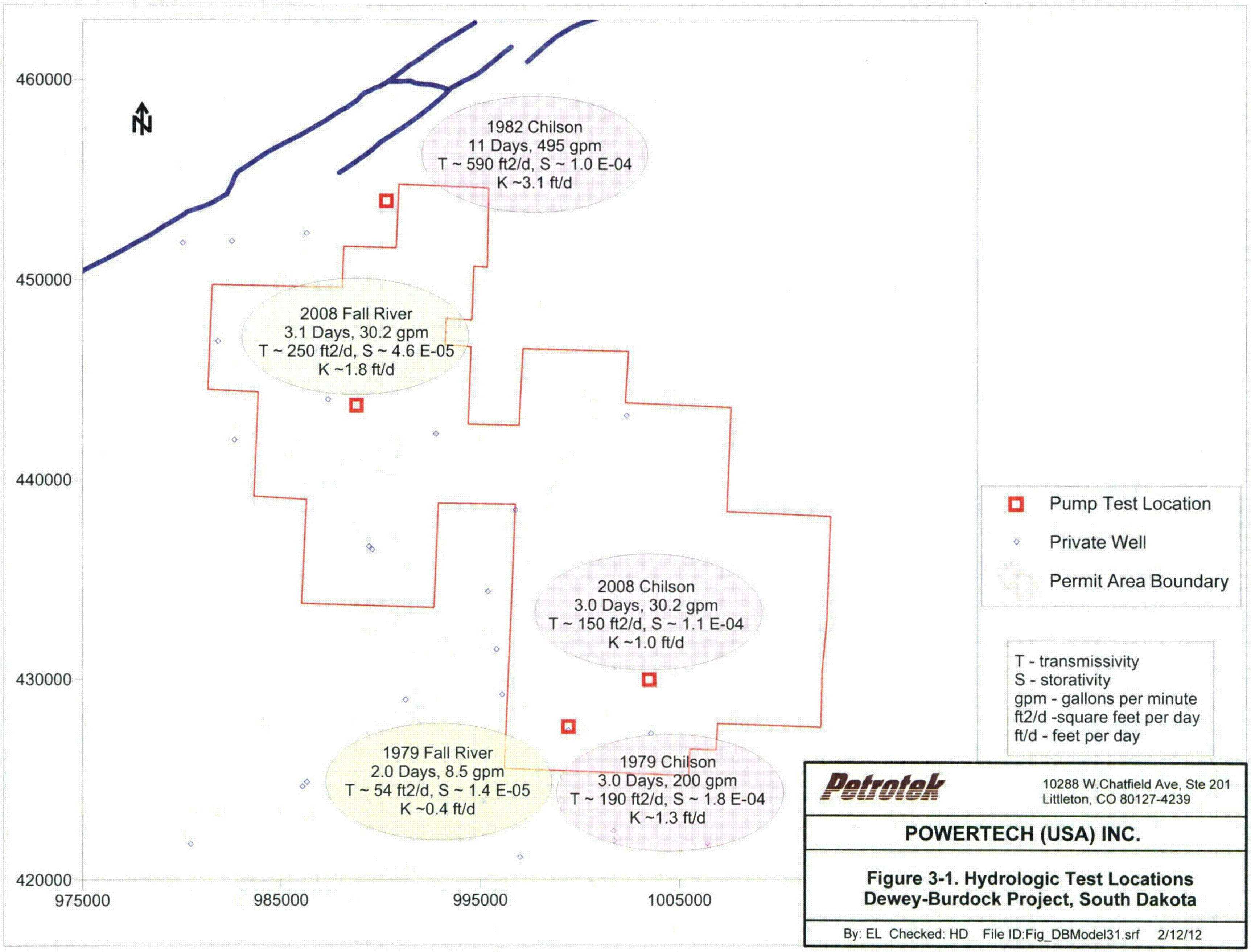
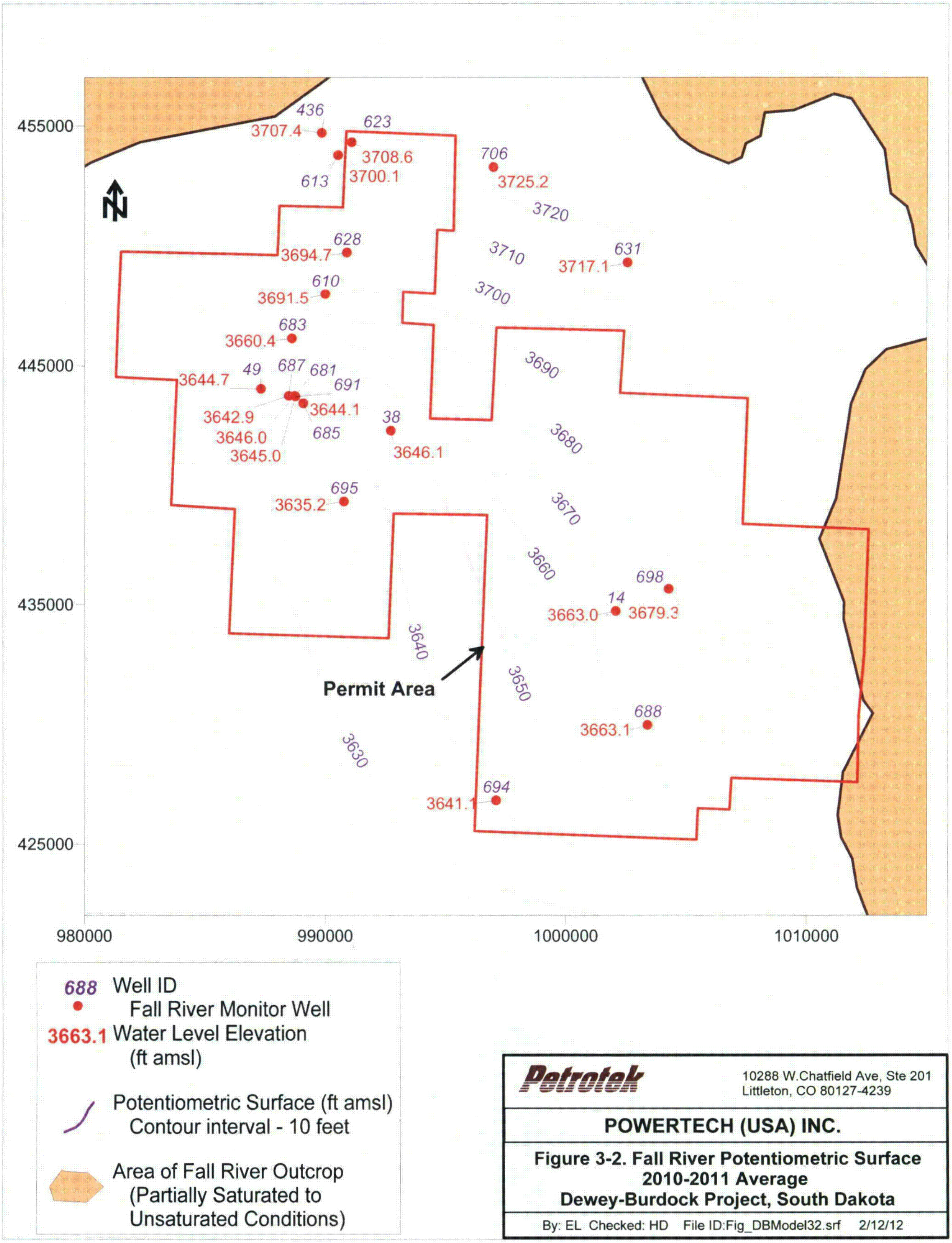


Figure 3-1. Hydrologic Test Locations
Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel31.srf 2/12/12


455000
445000
435000
425000
980000
990000
1000000
1010000
436
3707.4
623
3708.6
613
3700.1
706
3725.2
3720
628
3694.7
3710
631
3717.1
610
3691.5
3700
683
3660.4
3690
49
687
681
691
3644.7
3642.9
3644.1
3646.0
685
3645.0
38
3646.1
3680
695
3635.2
3670
3660
698
14
3663.0
3679.3
3640
Permit Area
3650
688
3663.1
3630
694
3641.1
N
688 Well ID
Fall River Monitor Well
3663.1 Water Level Elevation (ft amsl)
Potentiometric Surface (ft amsl) Contour interval - 10 feet
Area of Fall River Outcrop (Partially Saturated to Unsaturated Conditions)
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Littleton, CO 80127-4239
POWERTECH (USA) INC.
Figure 3-2. Fall River Potentiometric Surface
2010-2011 Average
Dewey-Burdock Project, South Dakota
By: EL Checked: HD File ID:Fig_DBModel32.srf 2/12/12

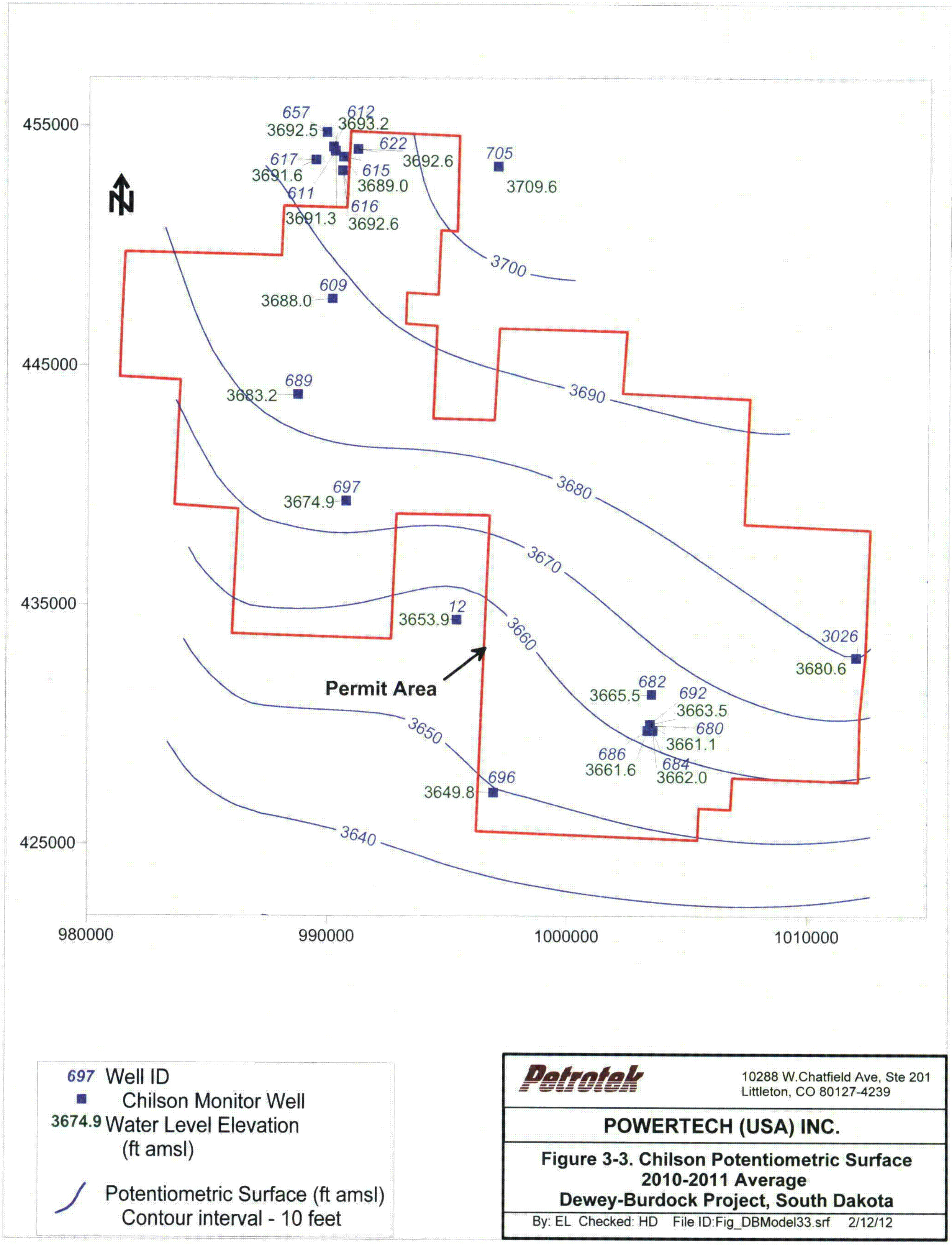

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Figure 3-3. Chilson Potentiometric Surface 2010-2011 Average Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel33.srf 2/12/12

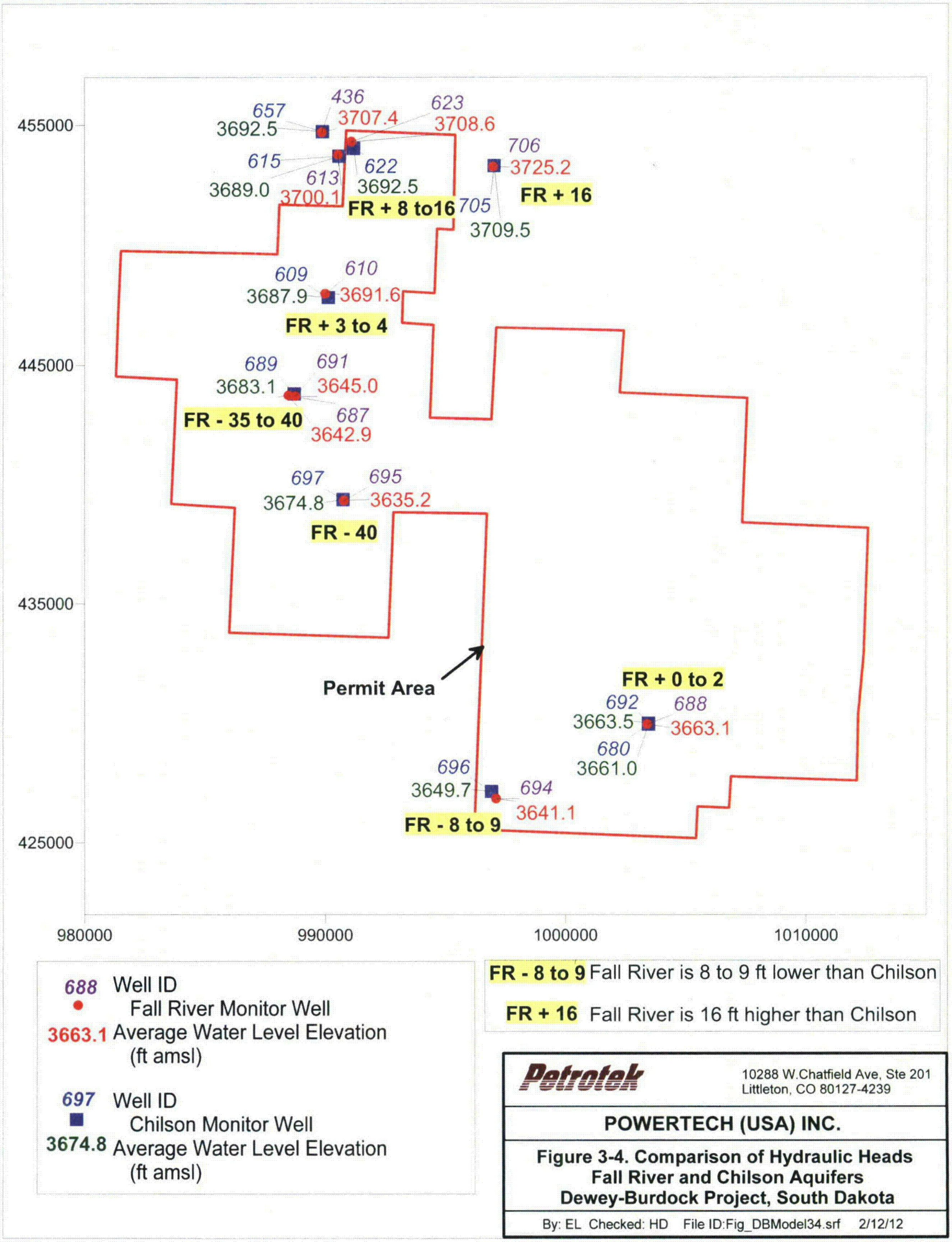

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Figure 3-4. Comparison of Hydraulic Heads Fall River and Chilson Aquifers Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel34.srf 2/12/12

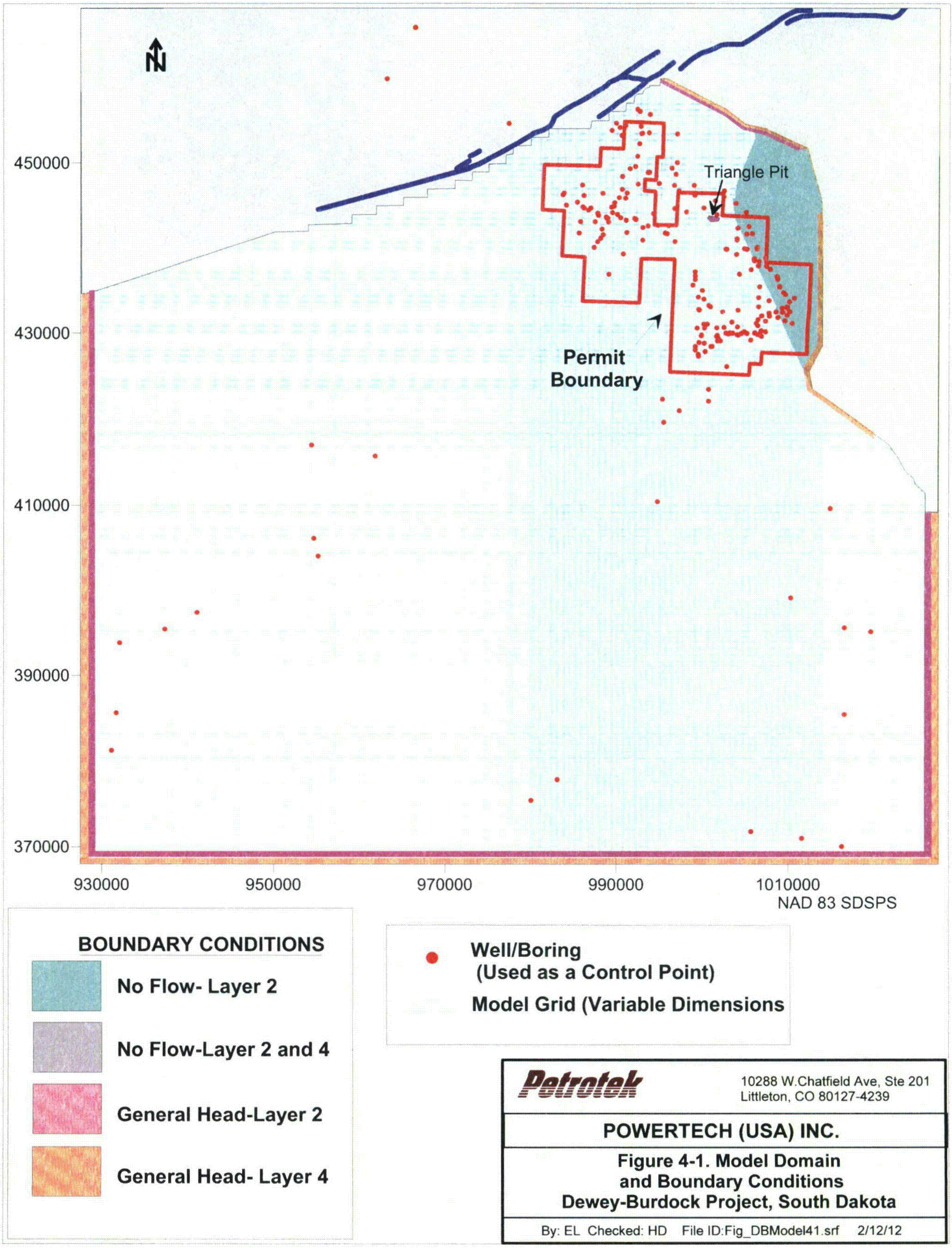

Figure 4-1. Model Domain and Boundary Conditions Dewey-Burdock Project, South Dakota

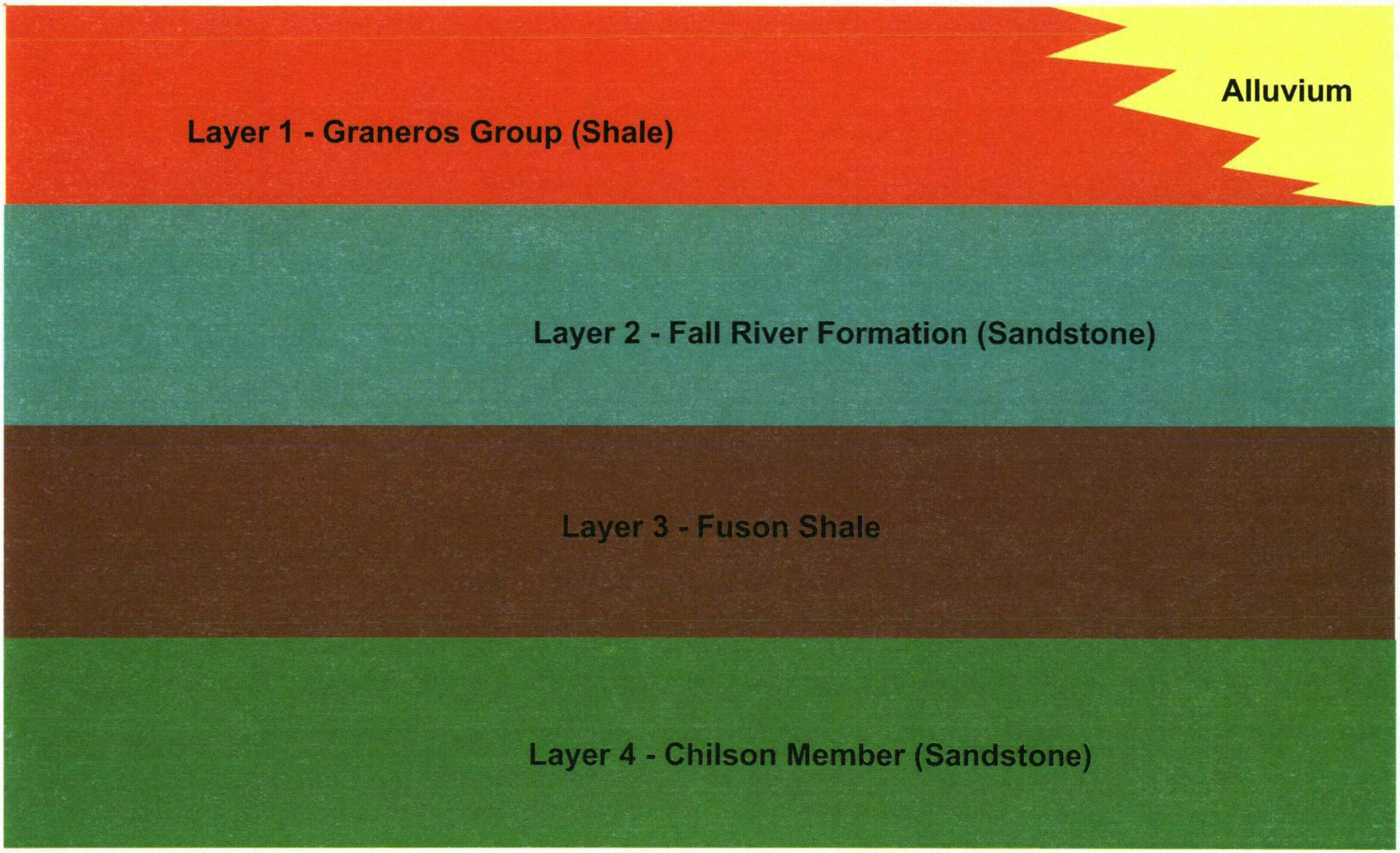

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Figure 4-2. Schematic Diagram of Model Layers Dewey-Burdock Project, South Dakota

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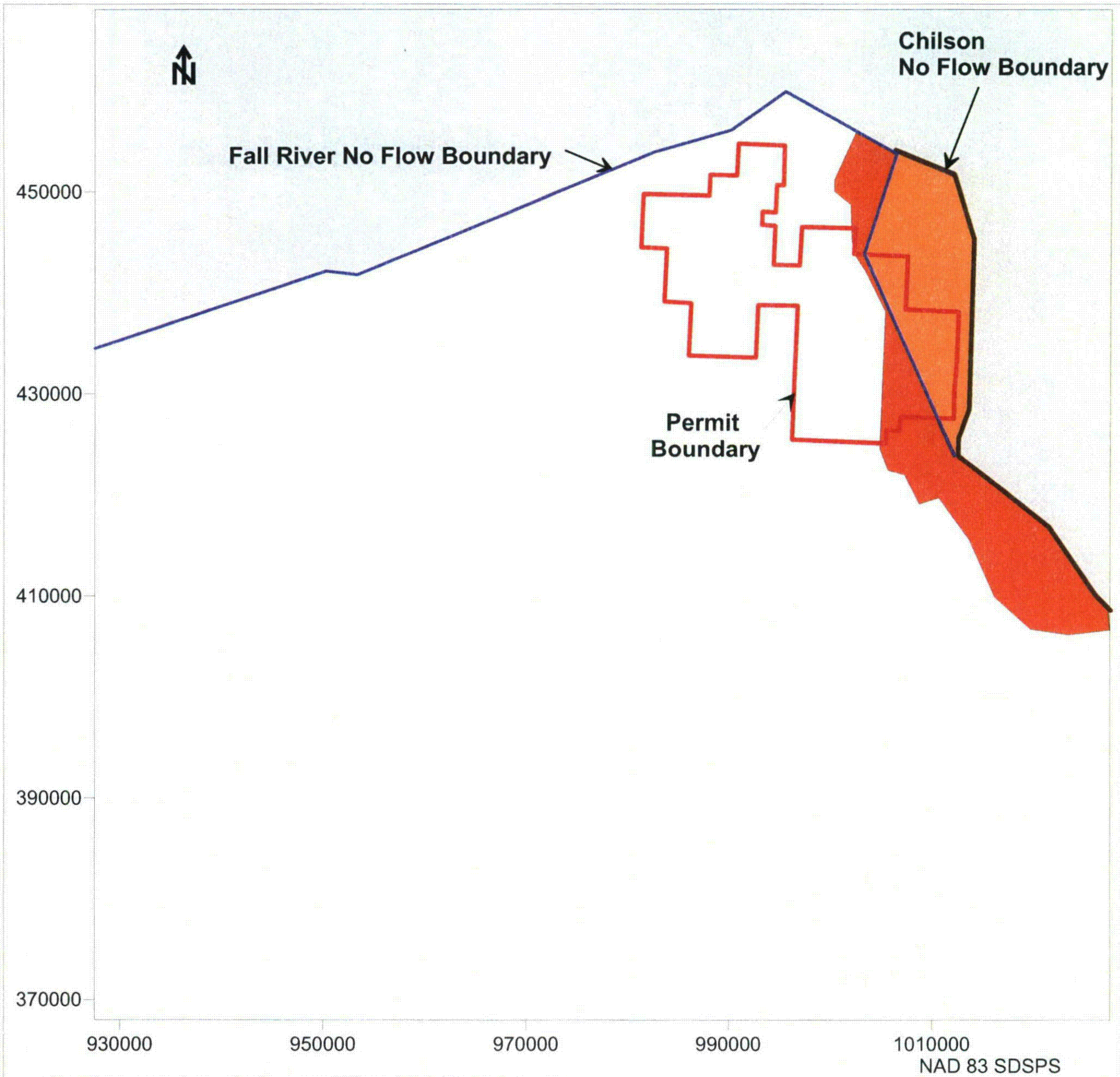

Recharge Zone
Rate = 1.1 E-04 feet/day
Applied to uppermost active layer

Recharge to Fall River

Recharge to Chilson

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Figure 4-3. Recharge Zones
Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel43.srf 2/12/12

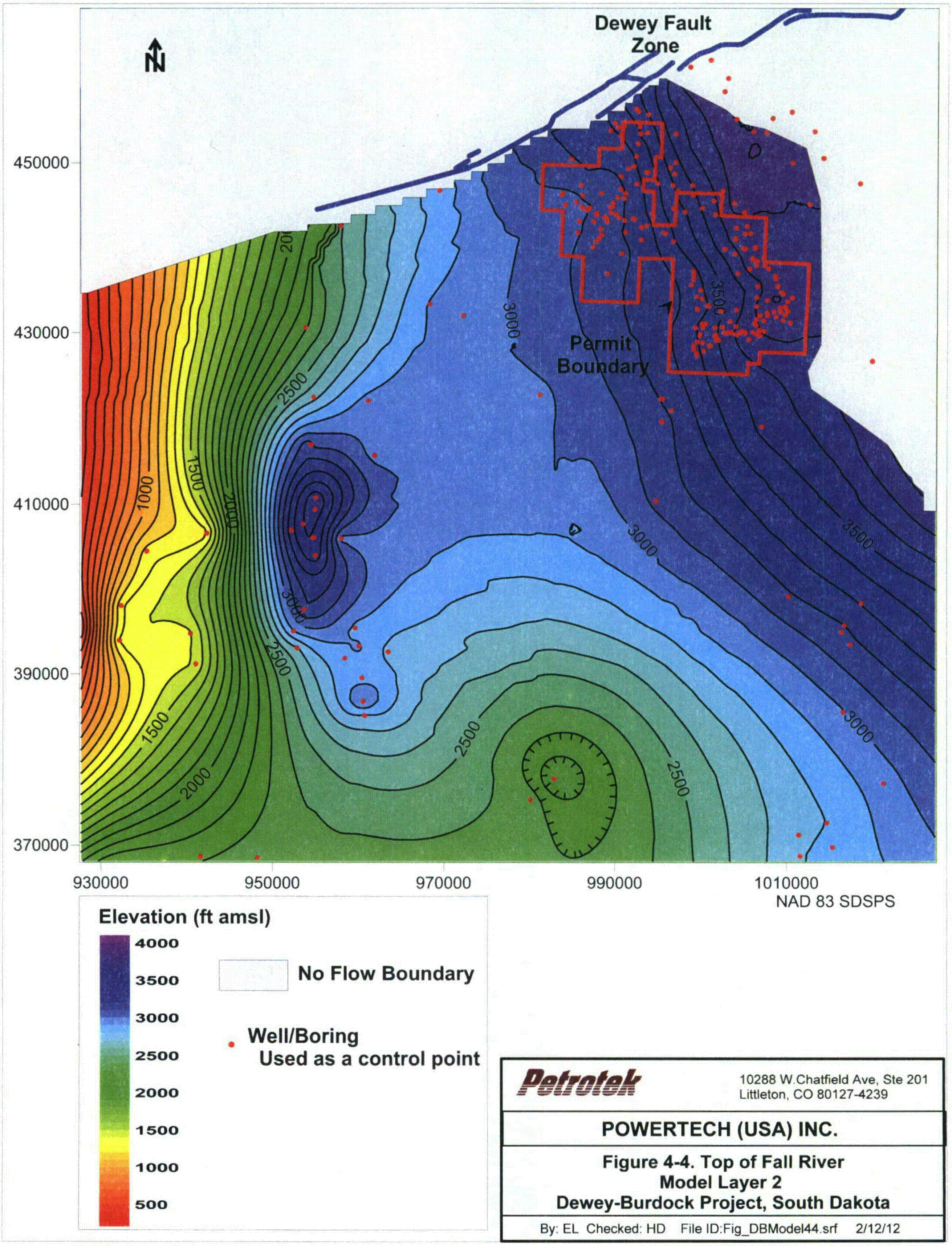

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Figure 4-4. Top of Fall River Model Layer 2 Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel44.srf 2/12/12

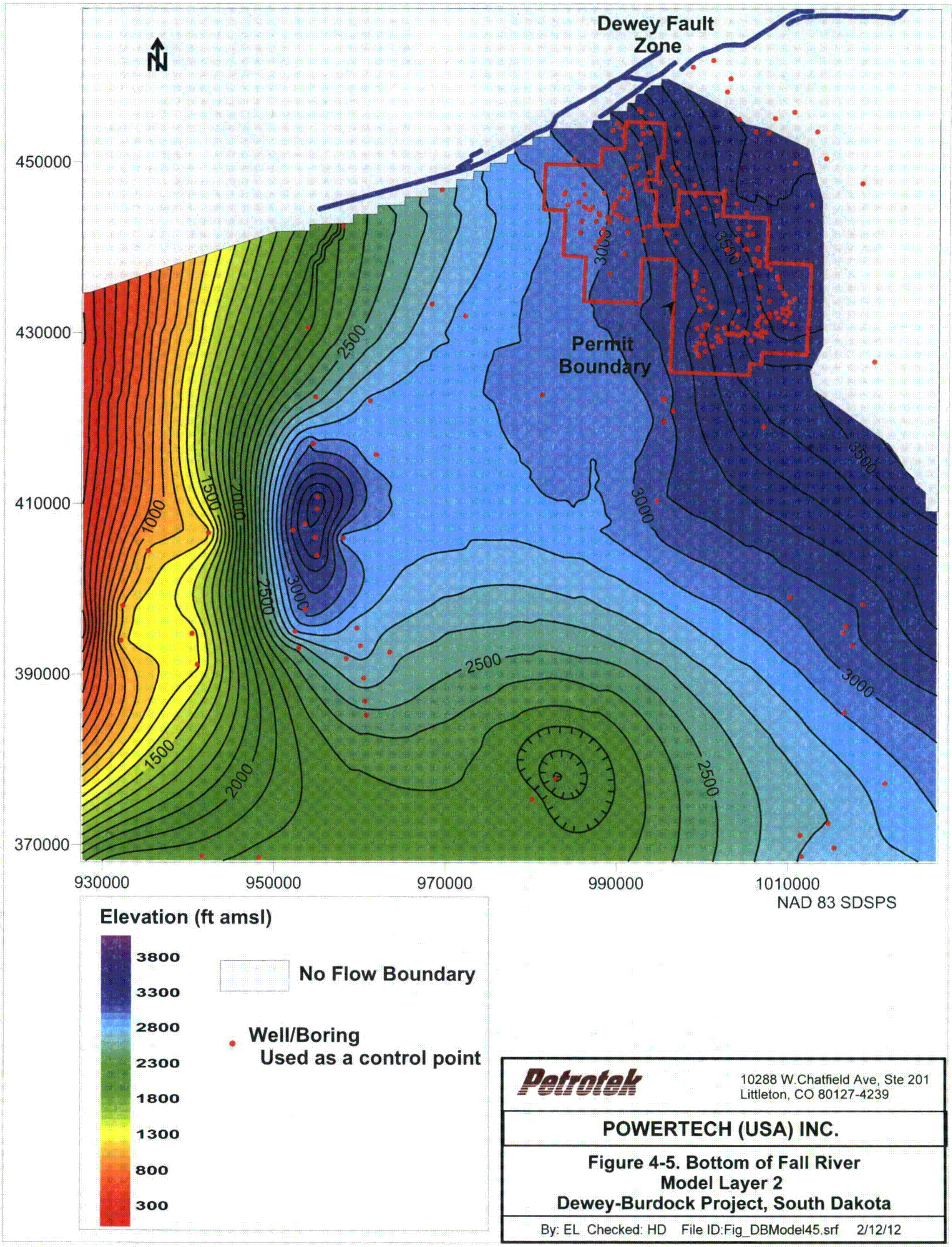
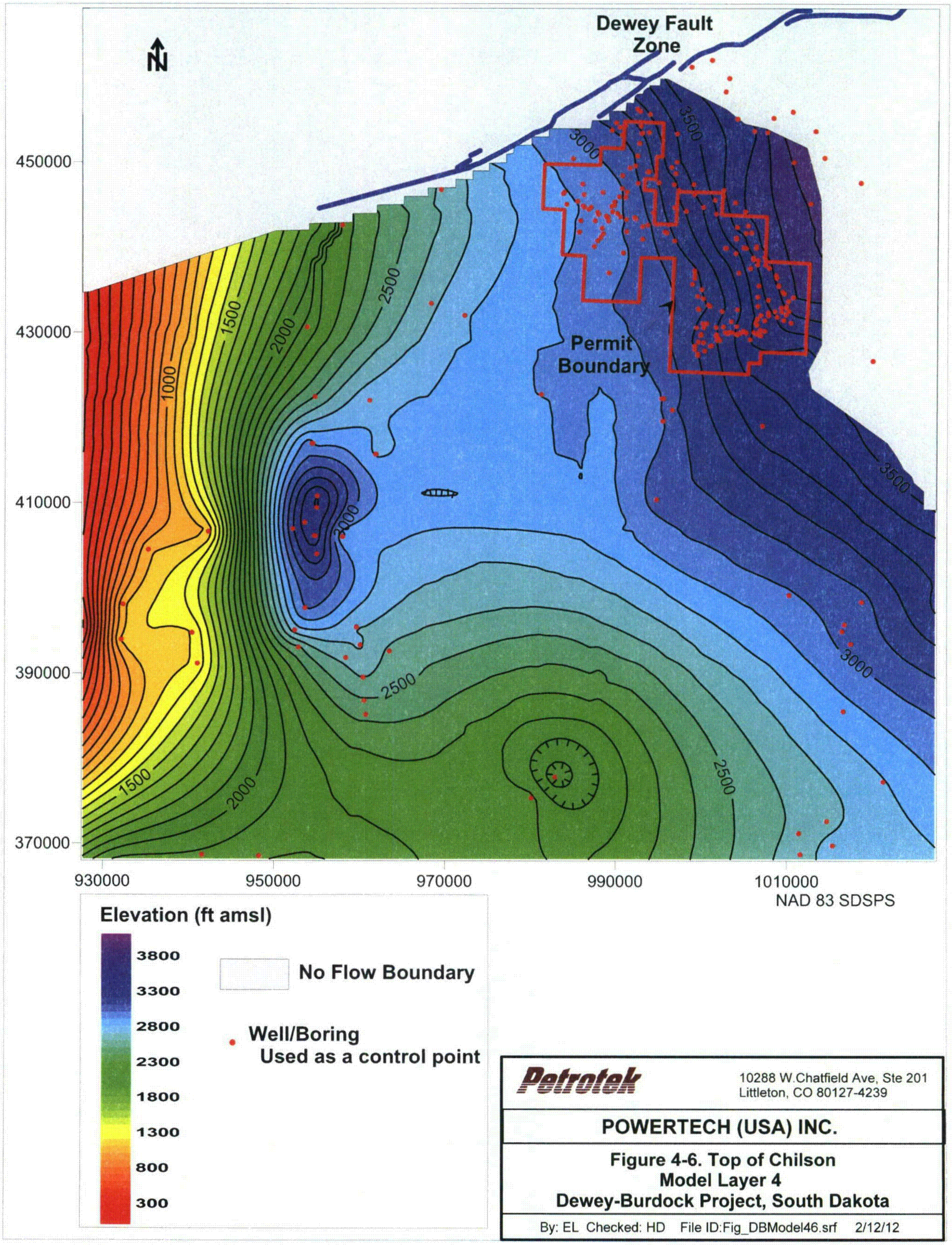


Figure 4-5. Bottom of Fall River Model Layer 2 Dewey-Burdock Project, South Dakota



Dewey Fault Zone
N
Permit Boundary
450000
430000
410000
390000
370000
930000
950000
970000
990000
1010000
NAD 83 SDSPS
3000
3500
2500
2000
1500
1000
Elevation (ft amsl)
3800
3300
2800
2300
1800
1300
800
300
No Flow Boundary
Well/Boring
Used as a control point
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Figure 4-6. Top of Chilson
Model Layer 4
Dewey-Burdock Project, South Dakota
By: EL Checked: HD File ID:Fig_DBModel46.srf 2/12/12

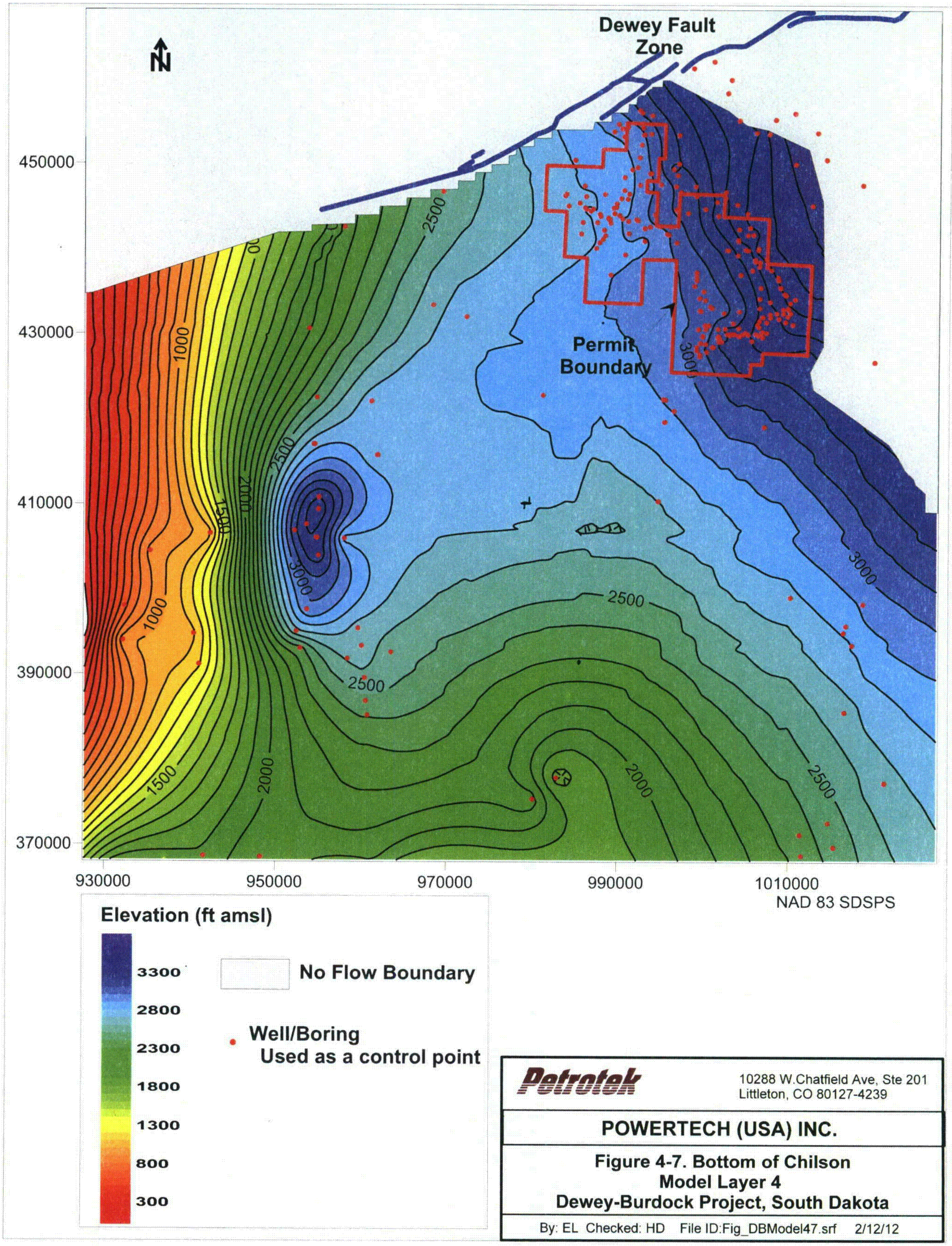
Dewey Fault Zone
N
Permit Boundary
450000
430000
410000
390000
370000
930000
950000
970000
990000
1010000
NAD 83 SDSPS
2500
3000
2000
1500
1000
Elevation (ft amsl)
3300
2800
2300
1800
1300
800
300
No Flow Boundary
Well/Boring Used as a control point
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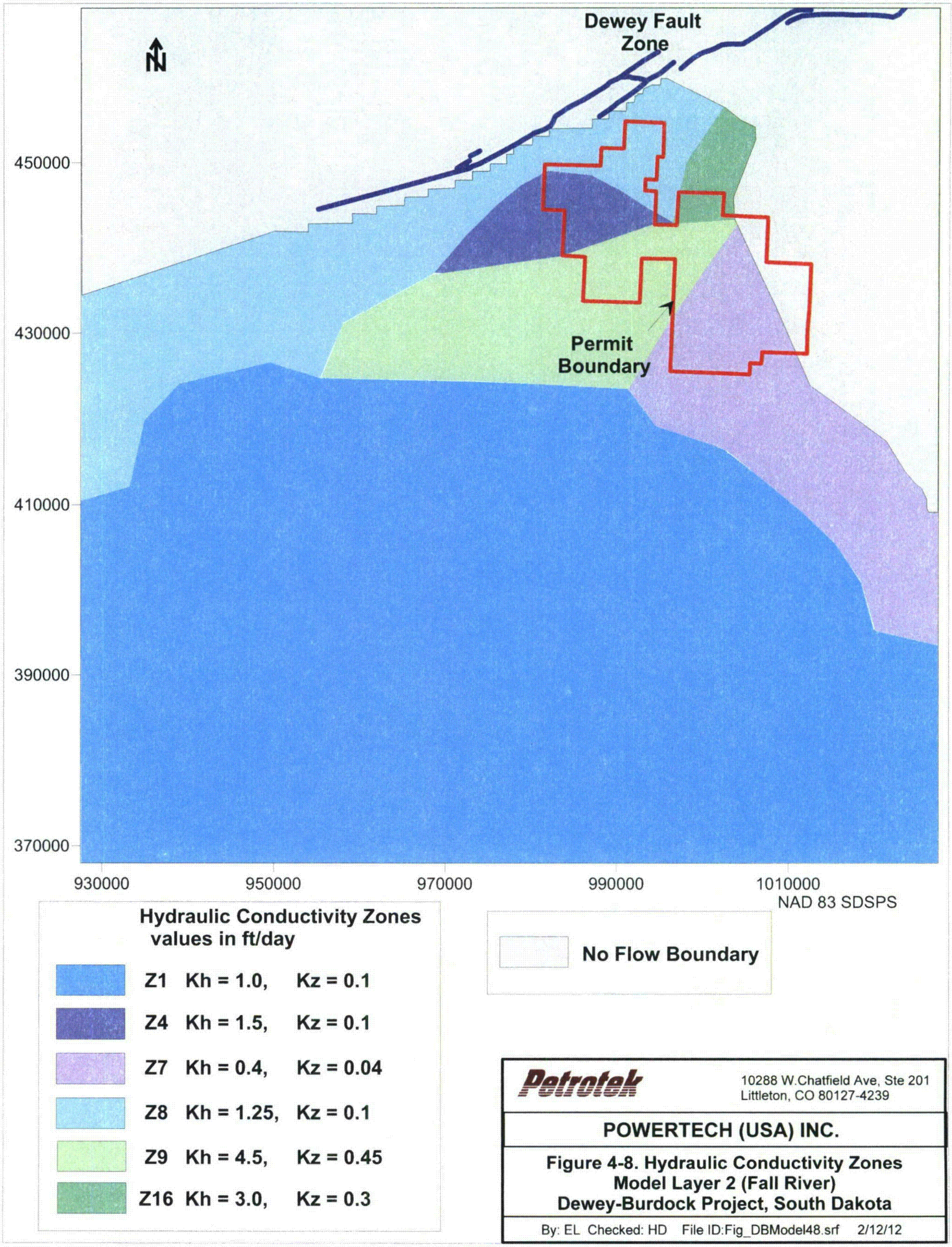
Figure 4-7. Bottom of Chilson
Model Layer 4
Dewey-Burdock Project, South Dakota
By: EL Checked: HD File ID:Fig_DBModel47.srf 2/12/12



Dewey Fault Zone
N
Permit Boundary
450000
430000
410000
390000
370000
930000
950000
970000
990000
1010000
NAD 83 SDSPS
Hydraulic Conductivity Zones values in ft/day
Z1 Kh = 1.0, Kz = 0.1
Z4 Kh = 1.5, Kz = 0.1
Z7 Kh = 0.4, Kz = 0.04
Z8 Kh = 1.25, Kz = 0.1
Z9 Kh = 4.5, Kz = 0.45
Z16 Kh = 3.0, Kz = 0.3
No Flow Boundary
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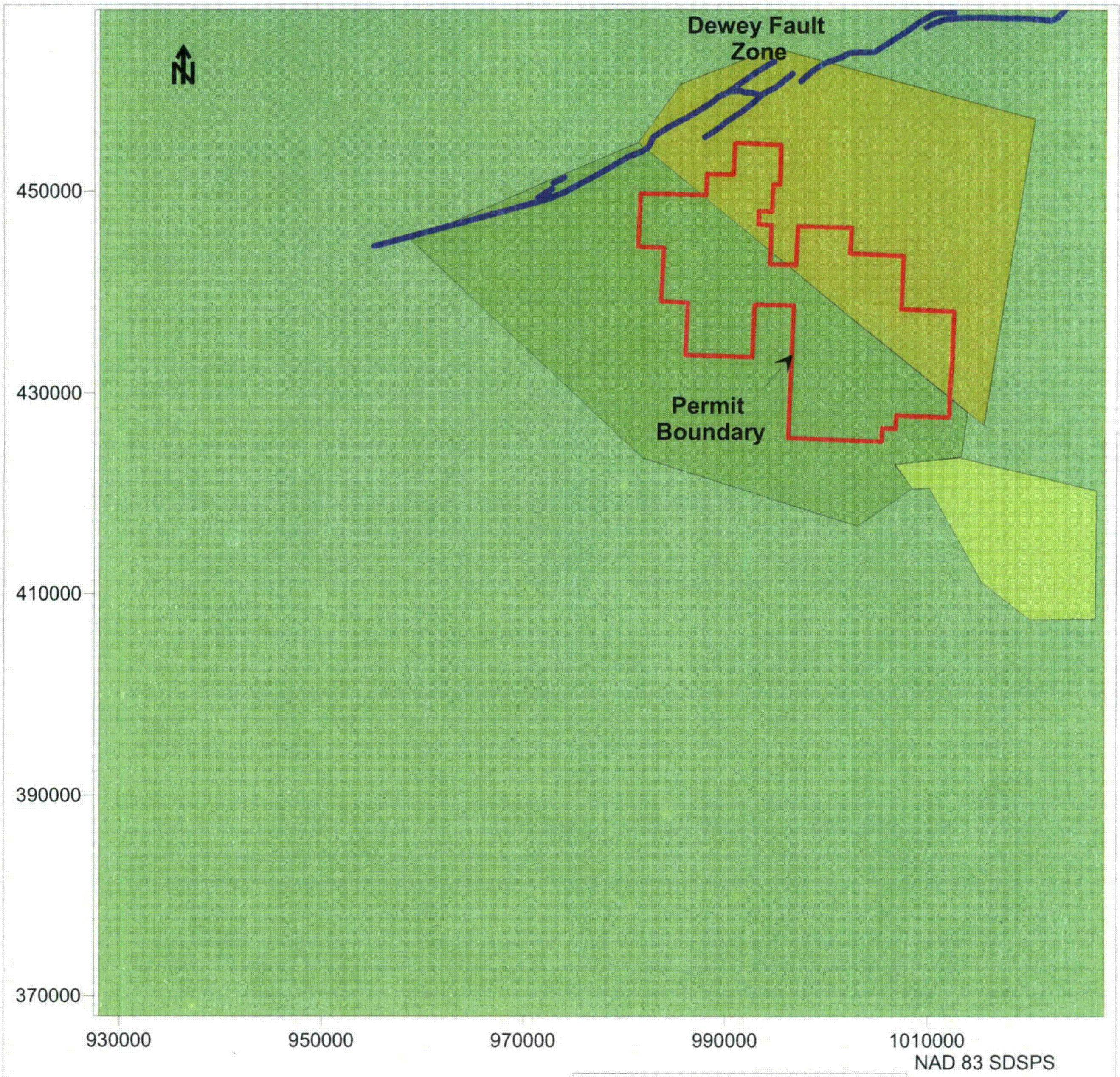
Figure 4-8. Hydraulic Conductivity Zones
Model Layer 2 (Fall River)
Dewey-Burdock Project, South Dakota
By: EL Checked: HD File ID:Fig_DBModel48.srf 2/12/12



No Flow Boundary

Hydraulic Conductivity Zones values in ft/day

Z3 Kh = 0.002, Kz = 0.0005

Z12 Kh = 0.02, Kz = 0.0005

Z13 Kh = 0.02, Kz = 0.00001

Z14 Kh = 0.02, Kz = 0.00002

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Figure 4-9. Hydraulic Conductivity Zones Model Layer 3 (Fuson) Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel49.srf 2/12/12

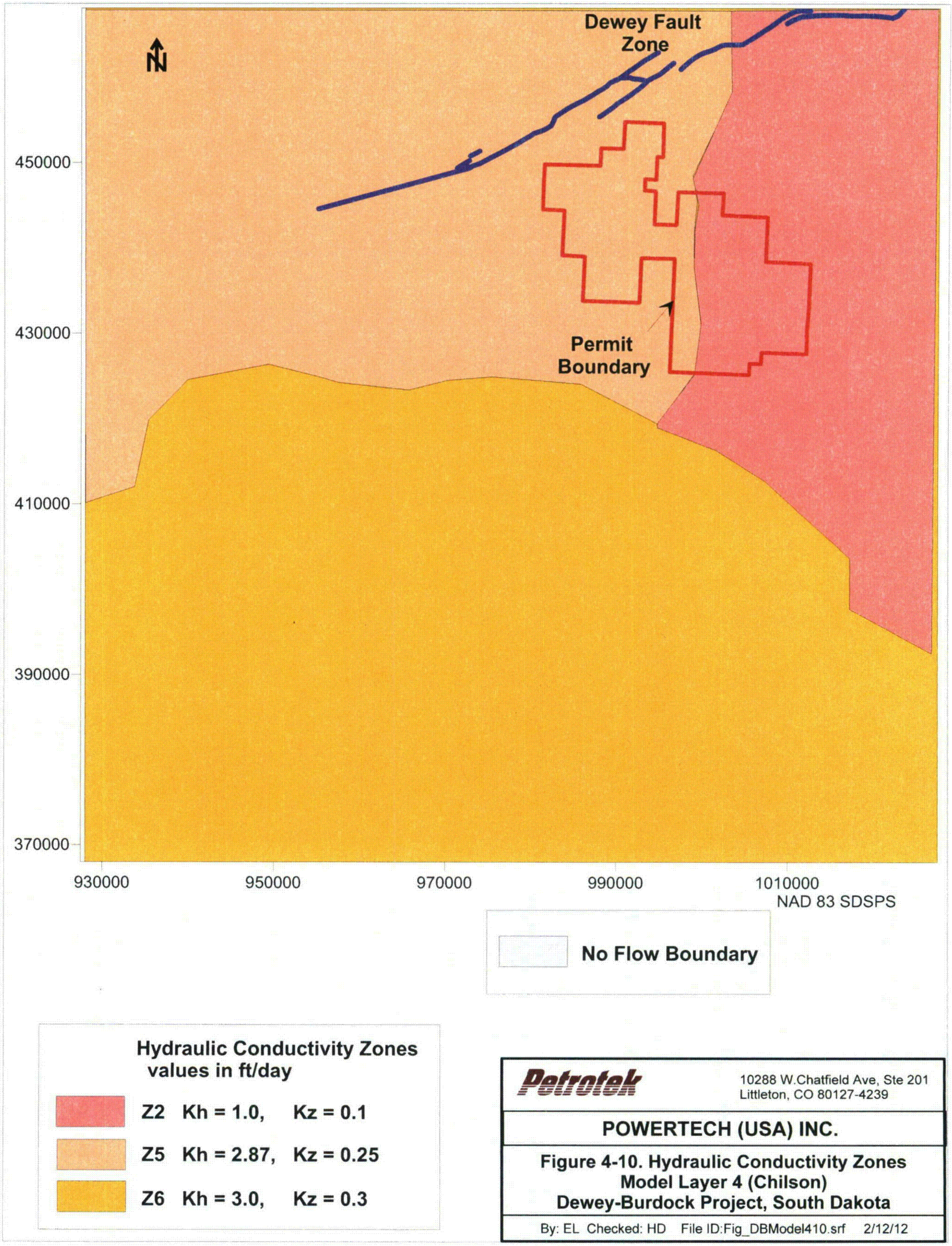

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Figure 4-10. Hydraulic Conductivity Zones Model Layer 4 (Chilson) Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel410.srf 2/12/12

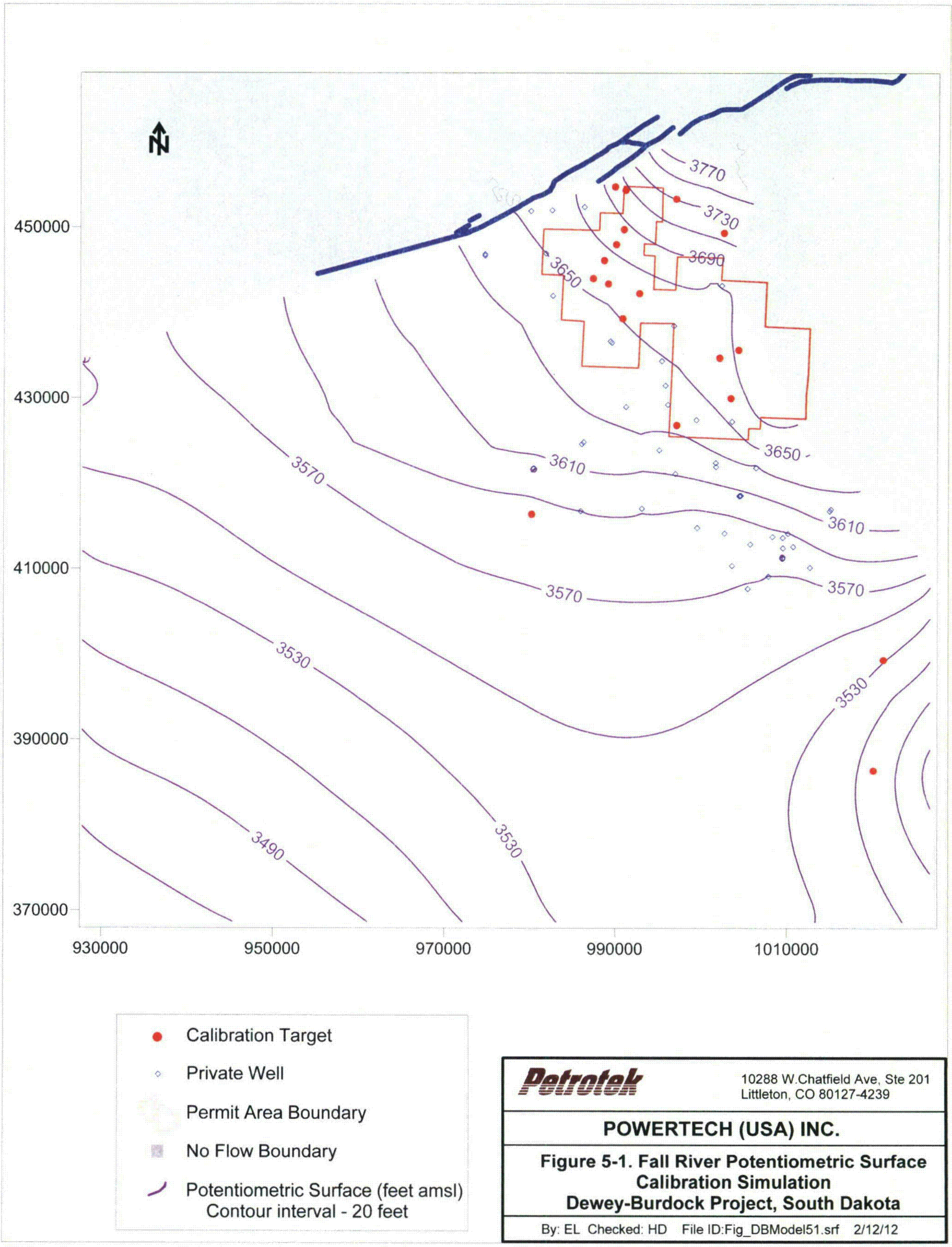

Figure 5-1. Fall River Potentiometric Surface Calibration Simulation Dewey-Burdock Project, South Dakota

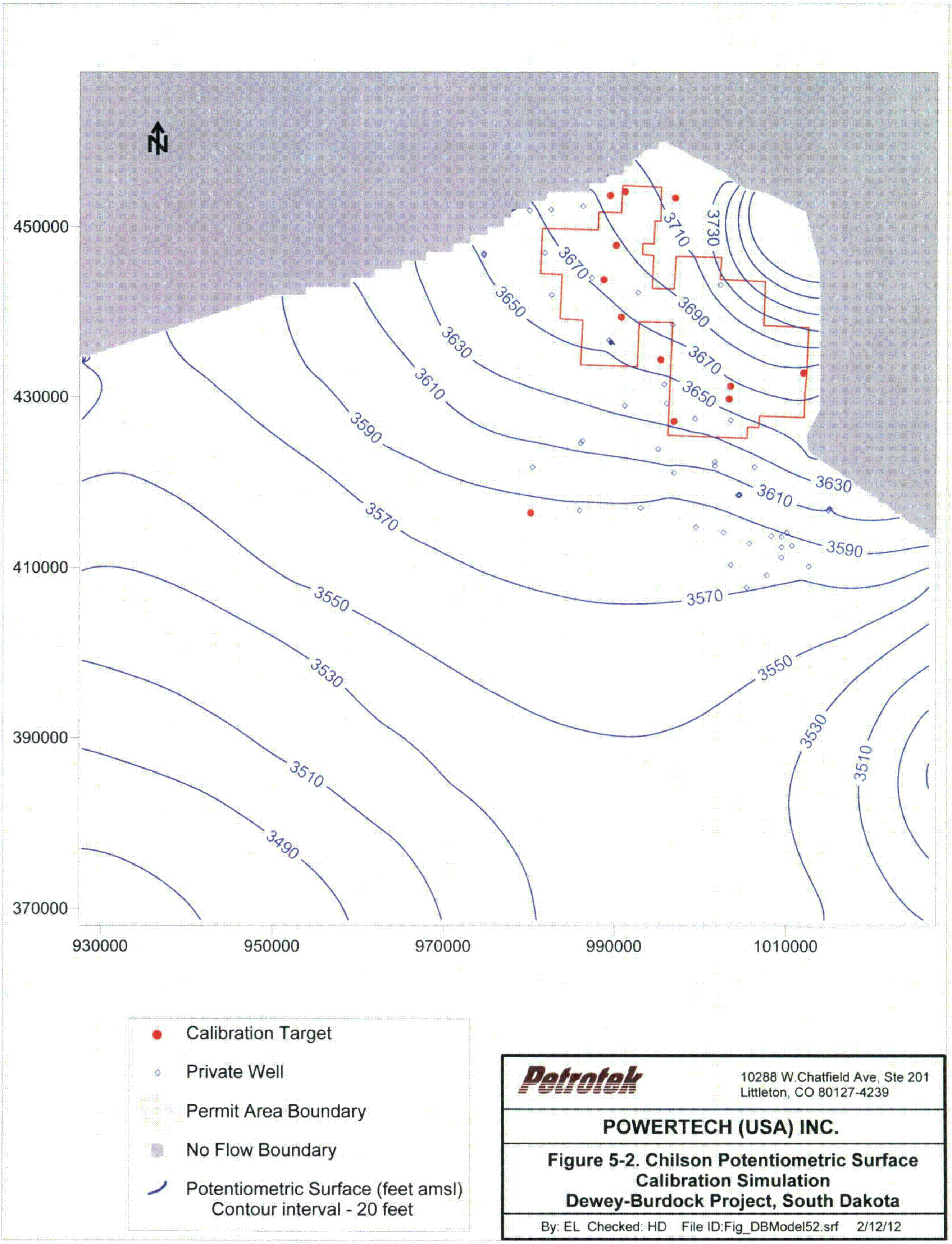

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Figure 5-2. Chilson Potentiometric Surface Calibration Simulation Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel52.srf 2/12/12

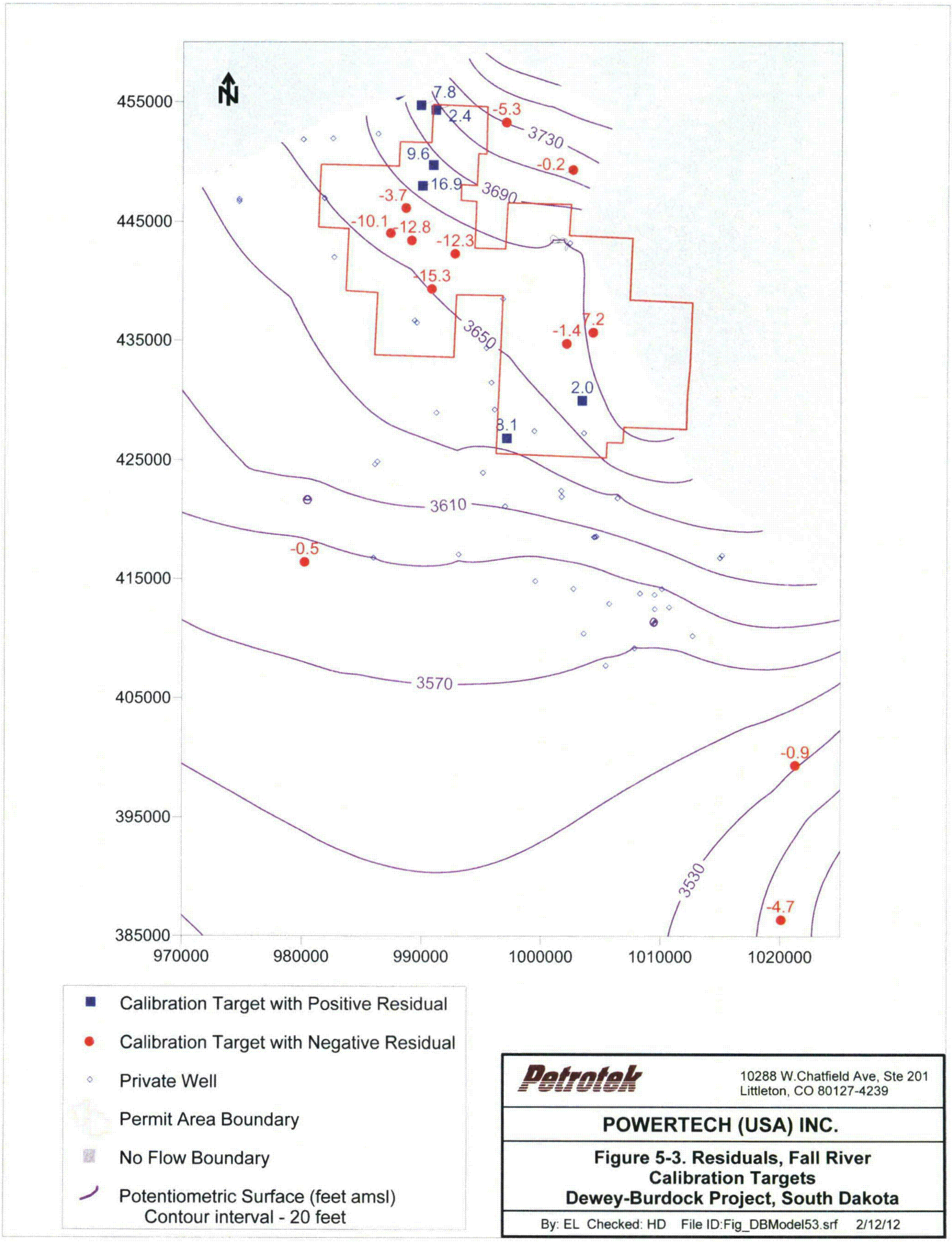

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Figure 5-3. Residuals, Fall River Calibration Targets Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel53.srf 2/12/12

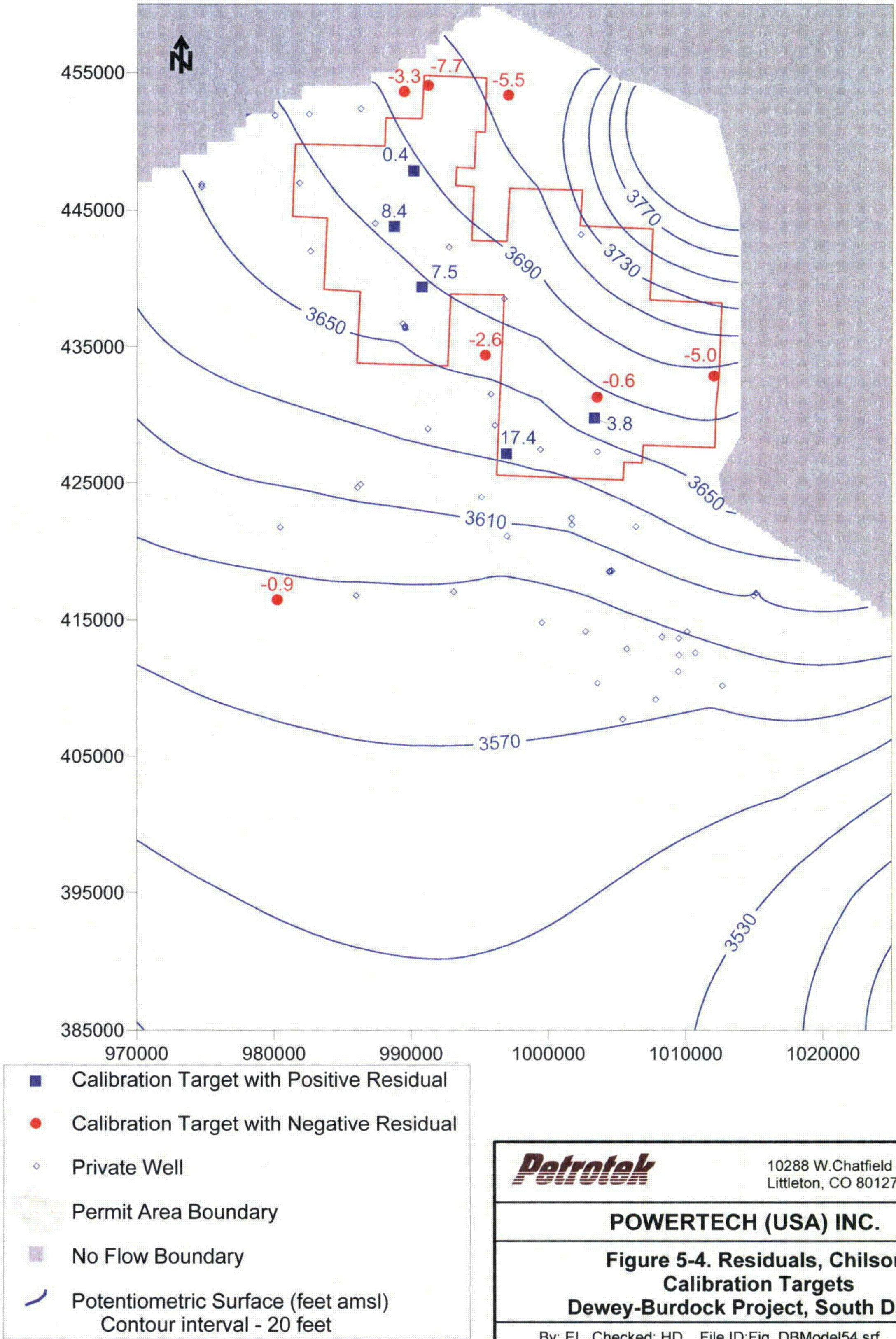

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Figure 5-4. Residuals, Chilson Calibration Targets Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel54.srf 2/12/12

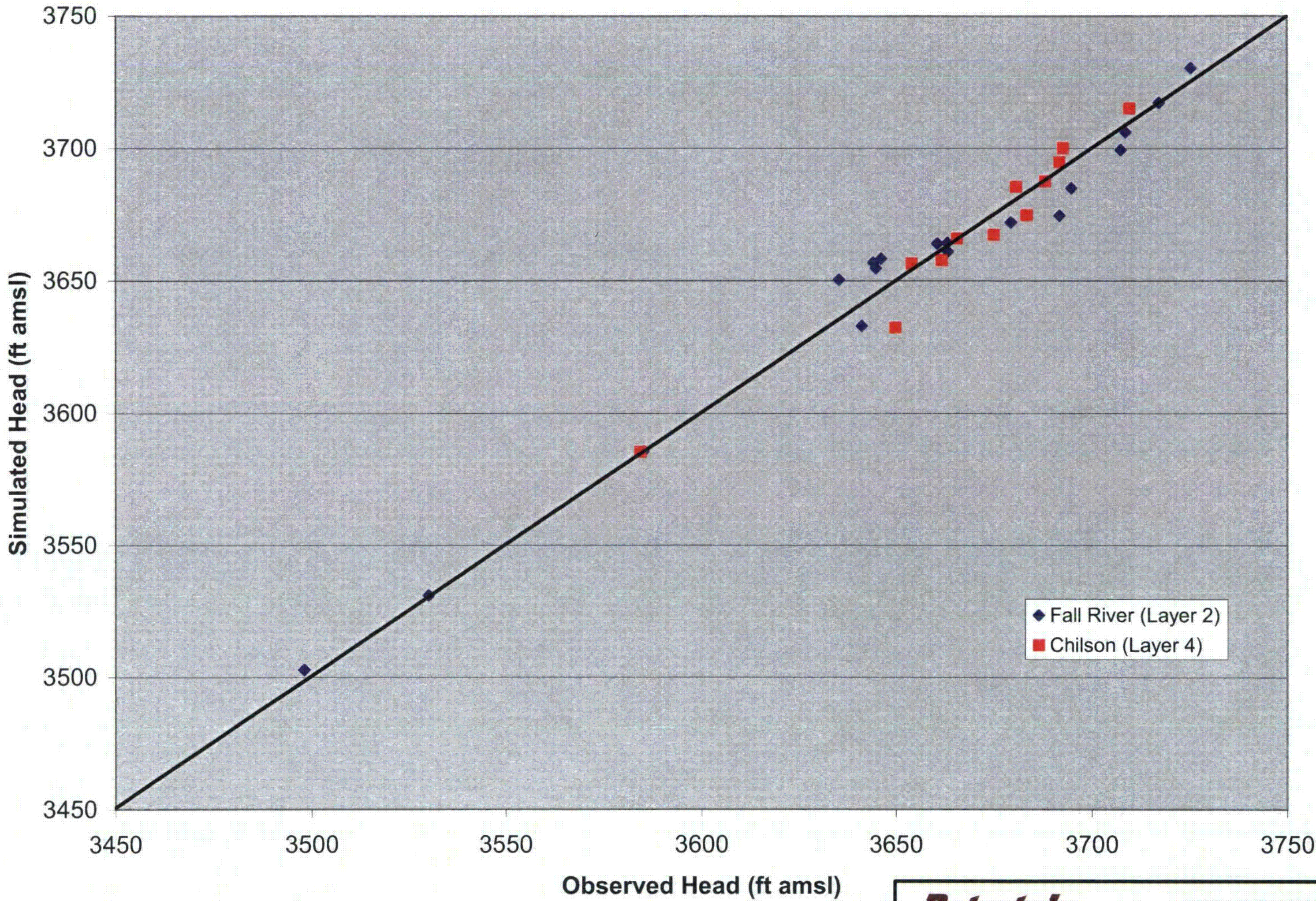

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Figure 5-5. Observed vs Simulated Heads Calibration Simulation Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel55.srf Date: 2/12/12

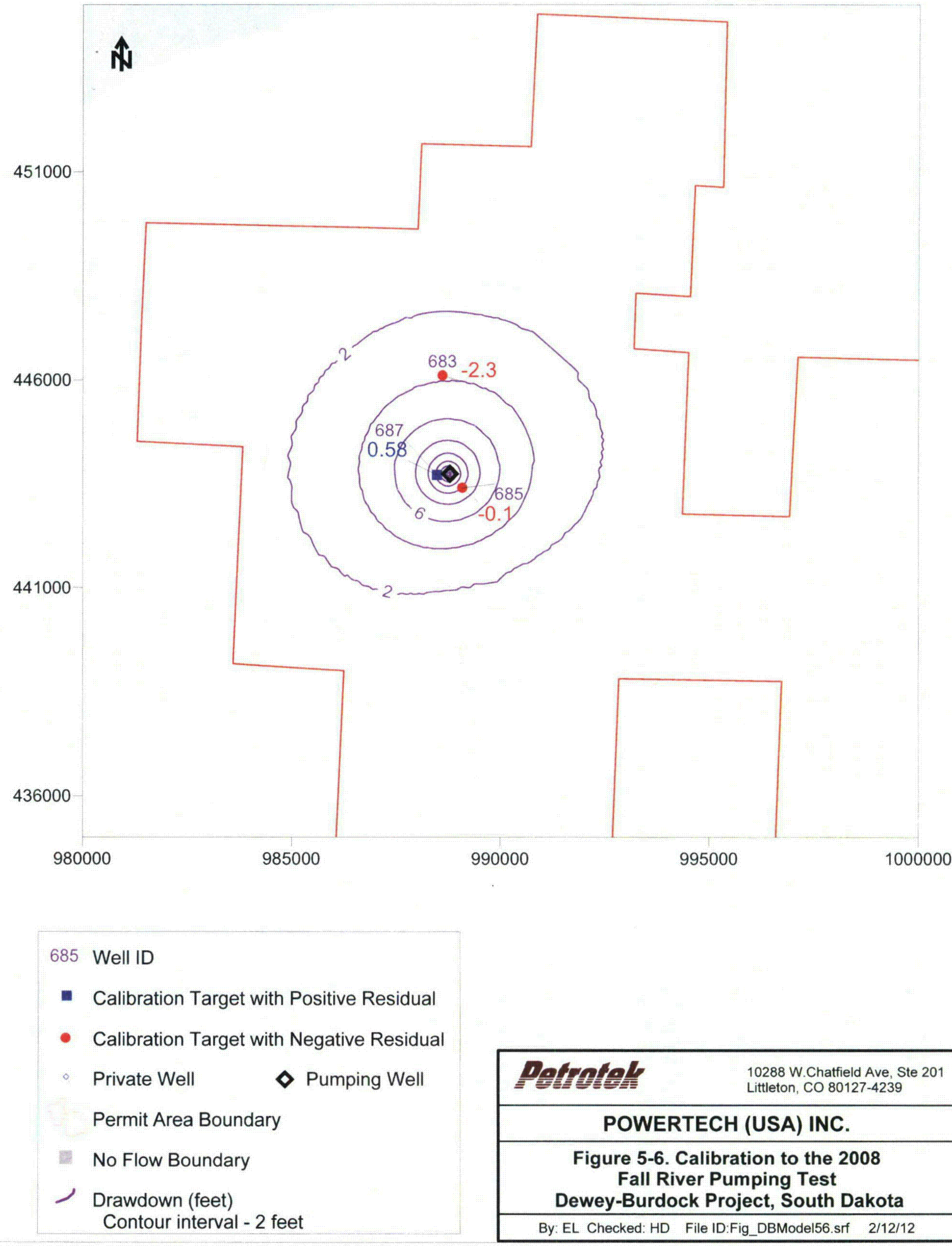

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Figure 5-6. Calibration to the 2008 Fall River Pumping Test Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel56.srf 2/12/12

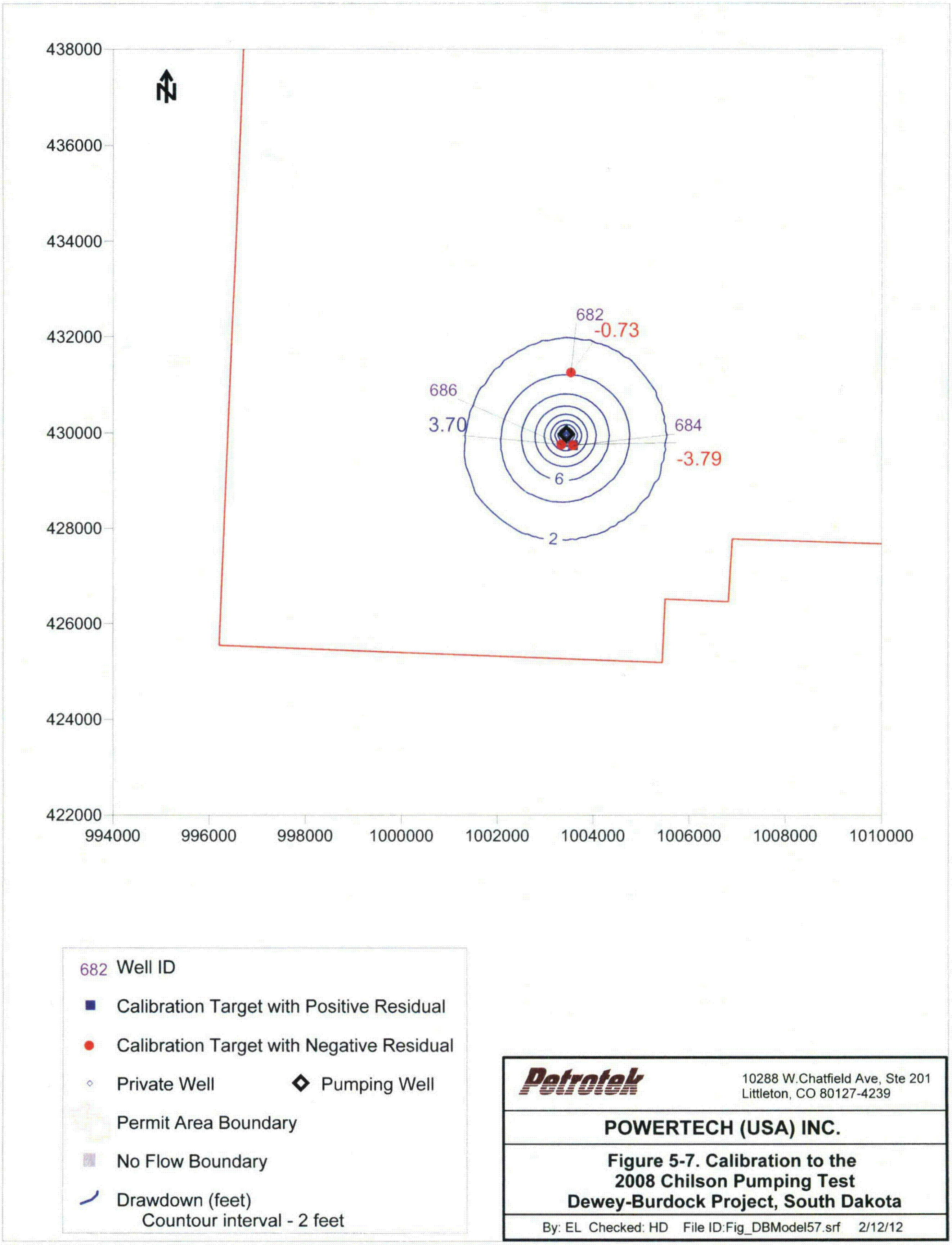

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Figure 5-7. Calibration to the 2008 Chilson Pumping Test Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel57.srf 2/12/12

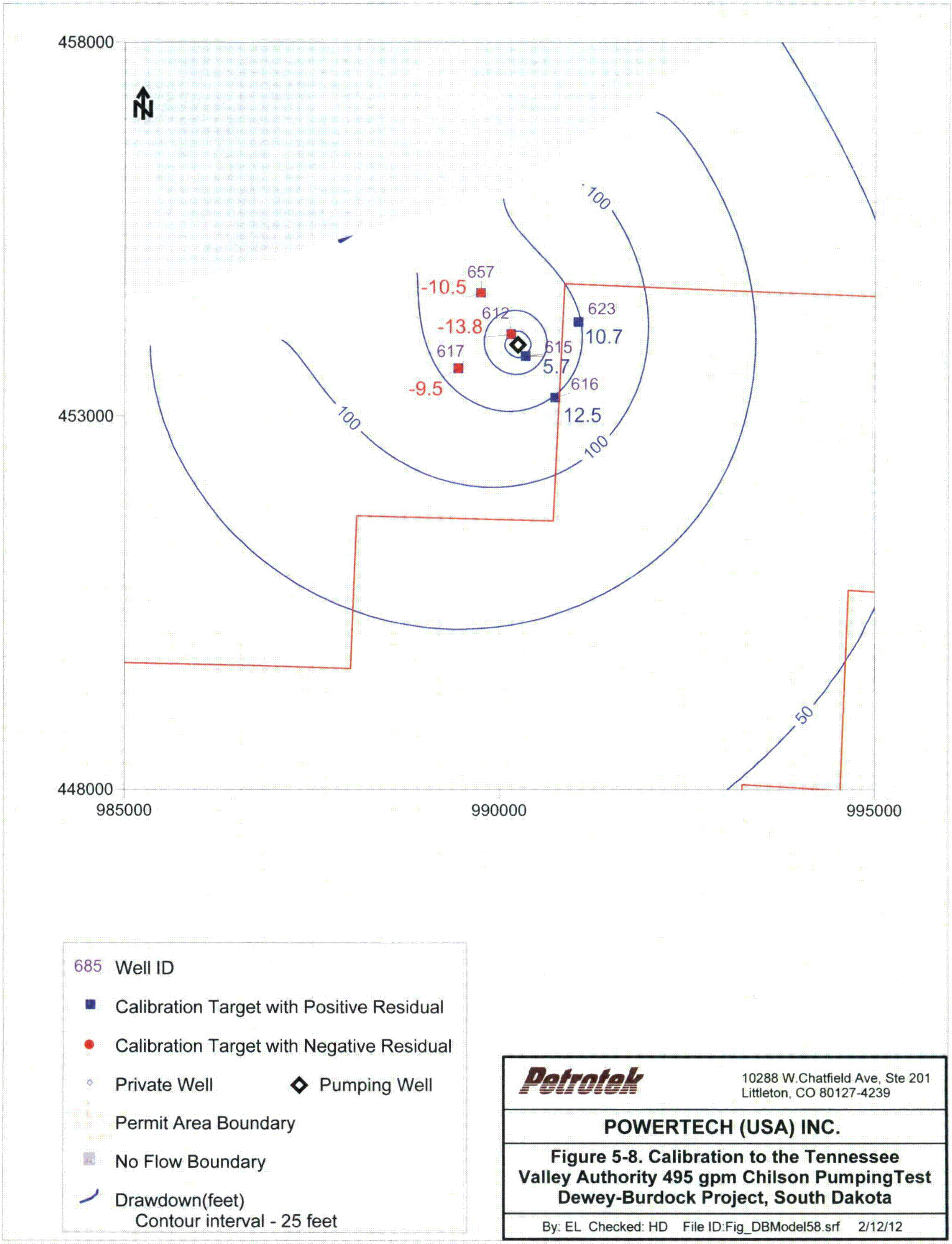

Figure 5-8. Calibration to the Tennessee Valley Authority 495 gpm Chilson PumpingTest Dewey-Burdock Project, South Dakota

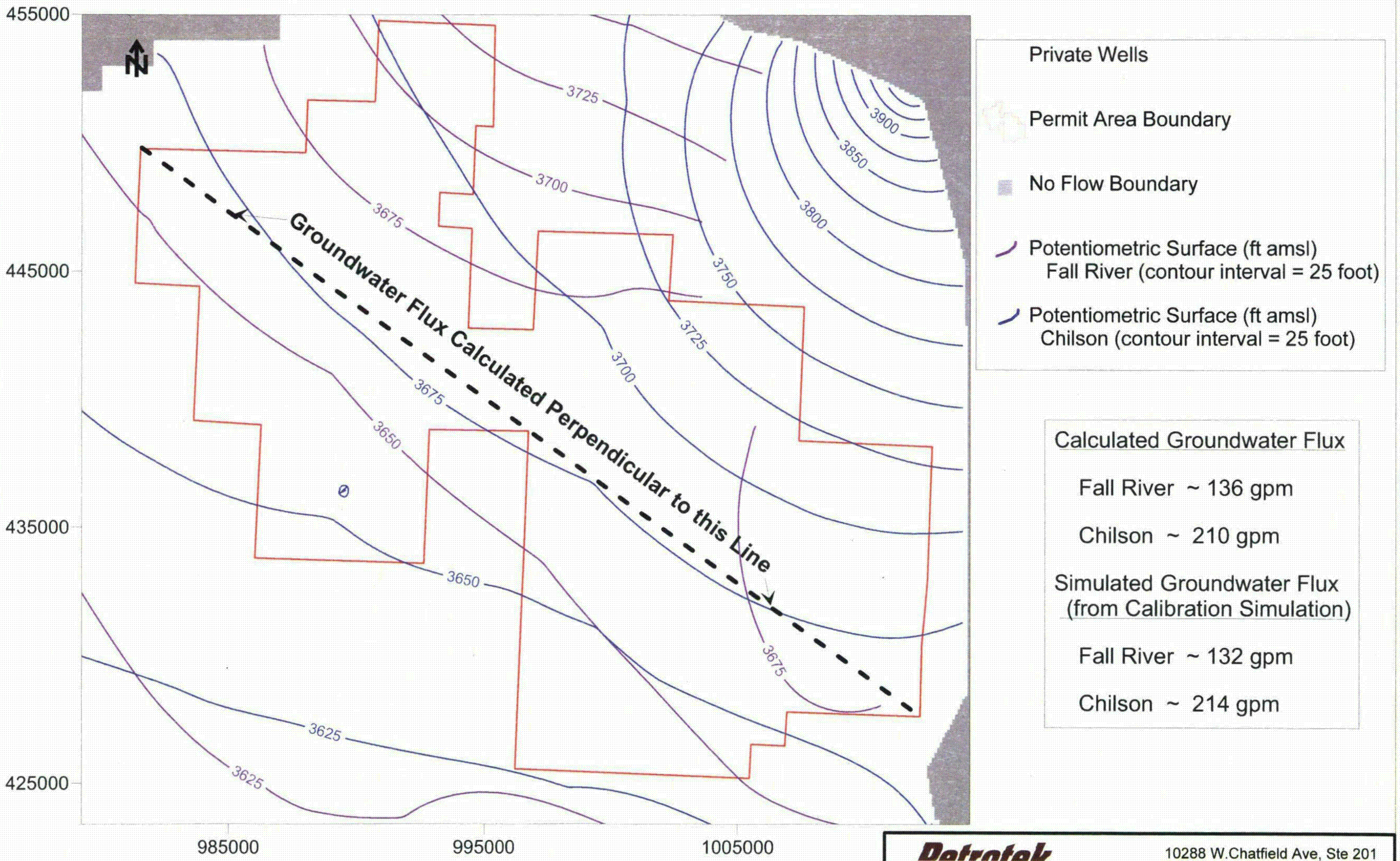

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Figure 5-9. Location of Calculated and Simulated Groundwater Flux through the Project Area Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel59.srf Date: 2/12/12

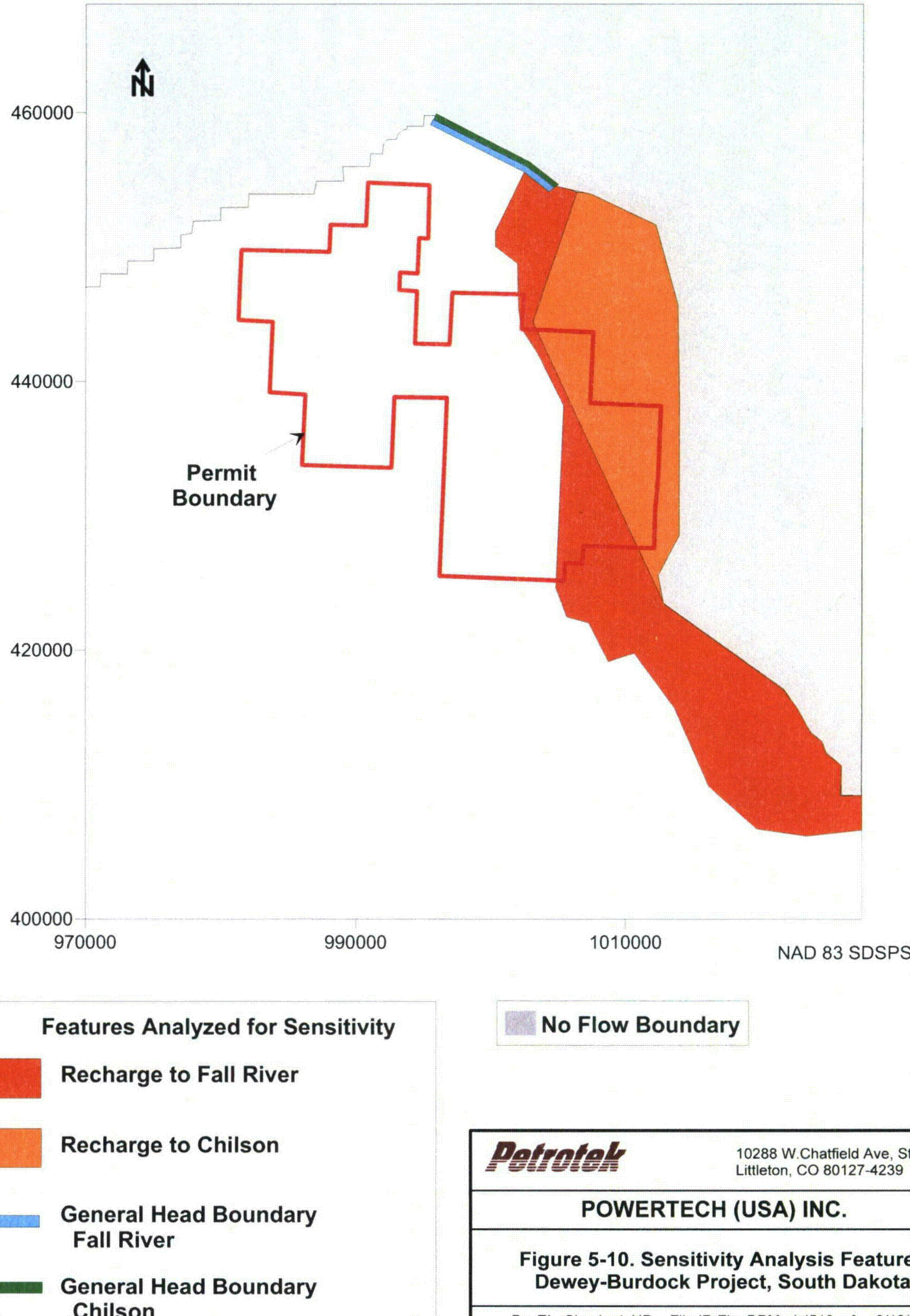

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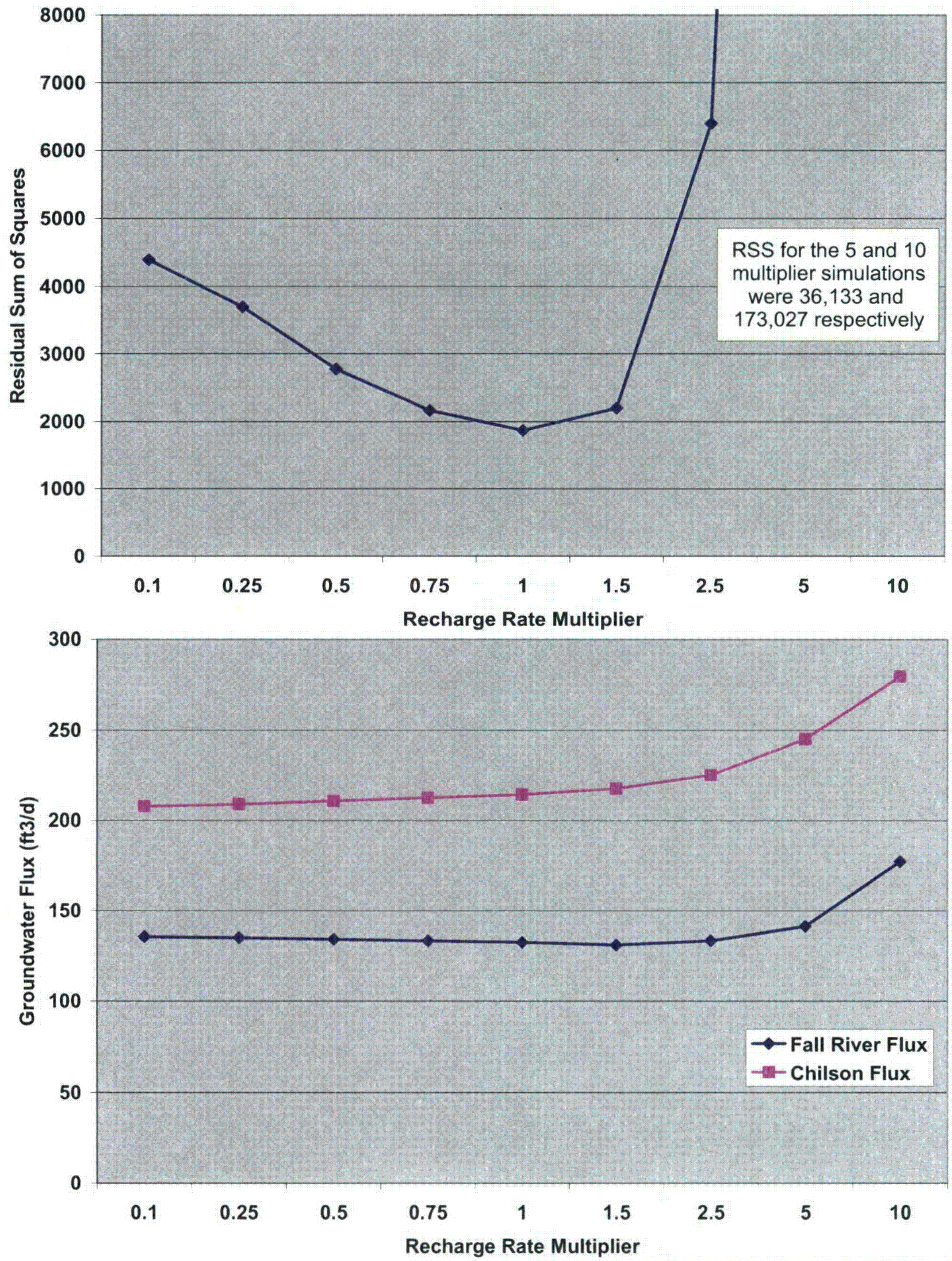
Figure 5-10. Sensitivity Analysis Features Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel510.srf 2/12/12



Groundwater Flux Measured at Location Indicated on Figure 5-9

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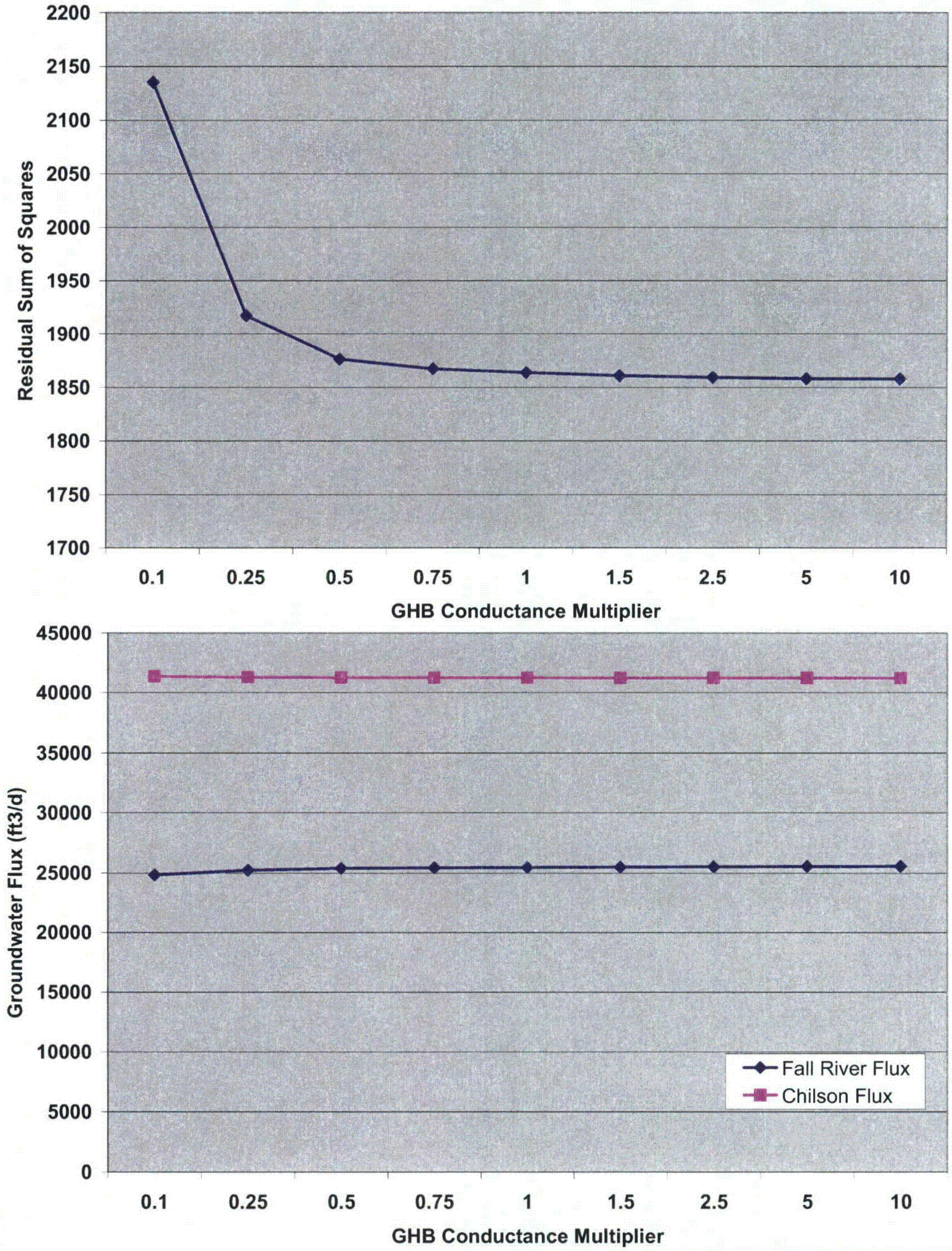
Figure 5-11. Sensitivity Analysis, Recharge Rate
Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel511.srf 2/12/12



Groundwater Flux Measured at Location Indicated on Figure 5-9

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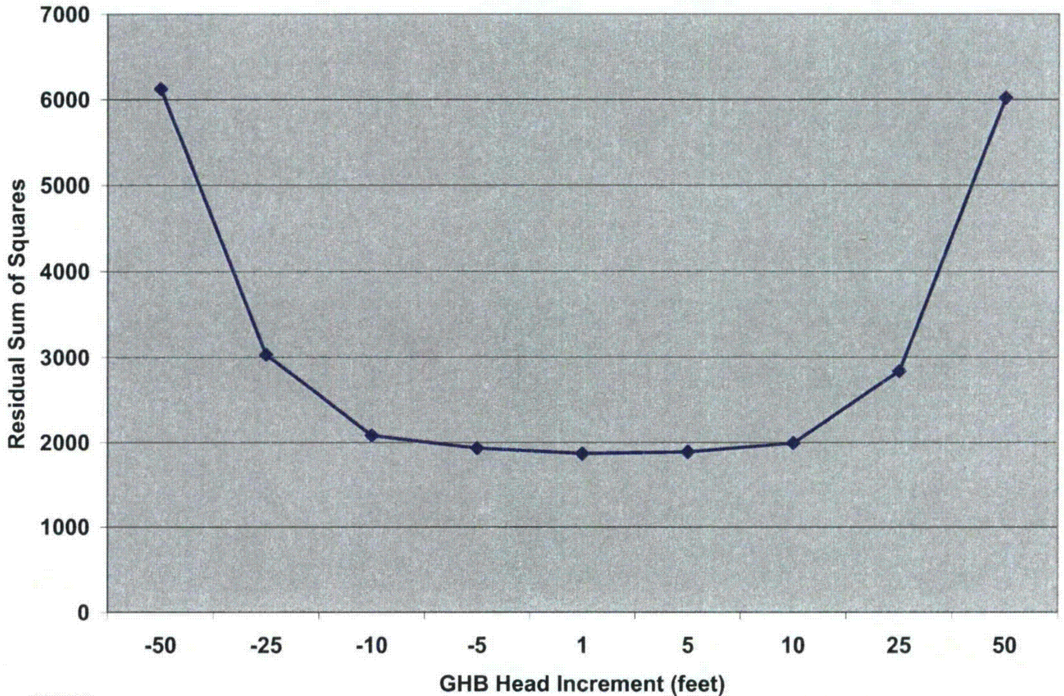
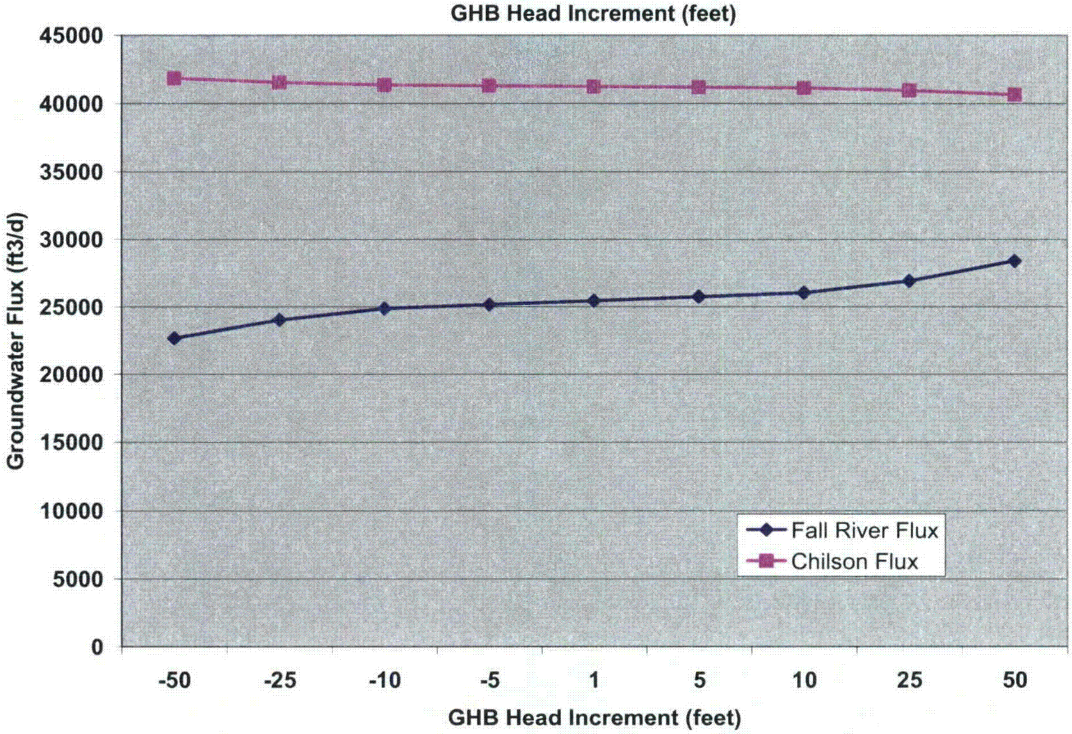
Figure 5-12. Sensitivity Analysis GHB Conductance, Layer 2 (Fall River) Dewey-Burdock Project, South Dakota	
By: EL Checked: HD File ID:Fig_DBModel512.srf 2/12/12	





Groundwater Flux Measured at Location Indicated on Figure 5-9

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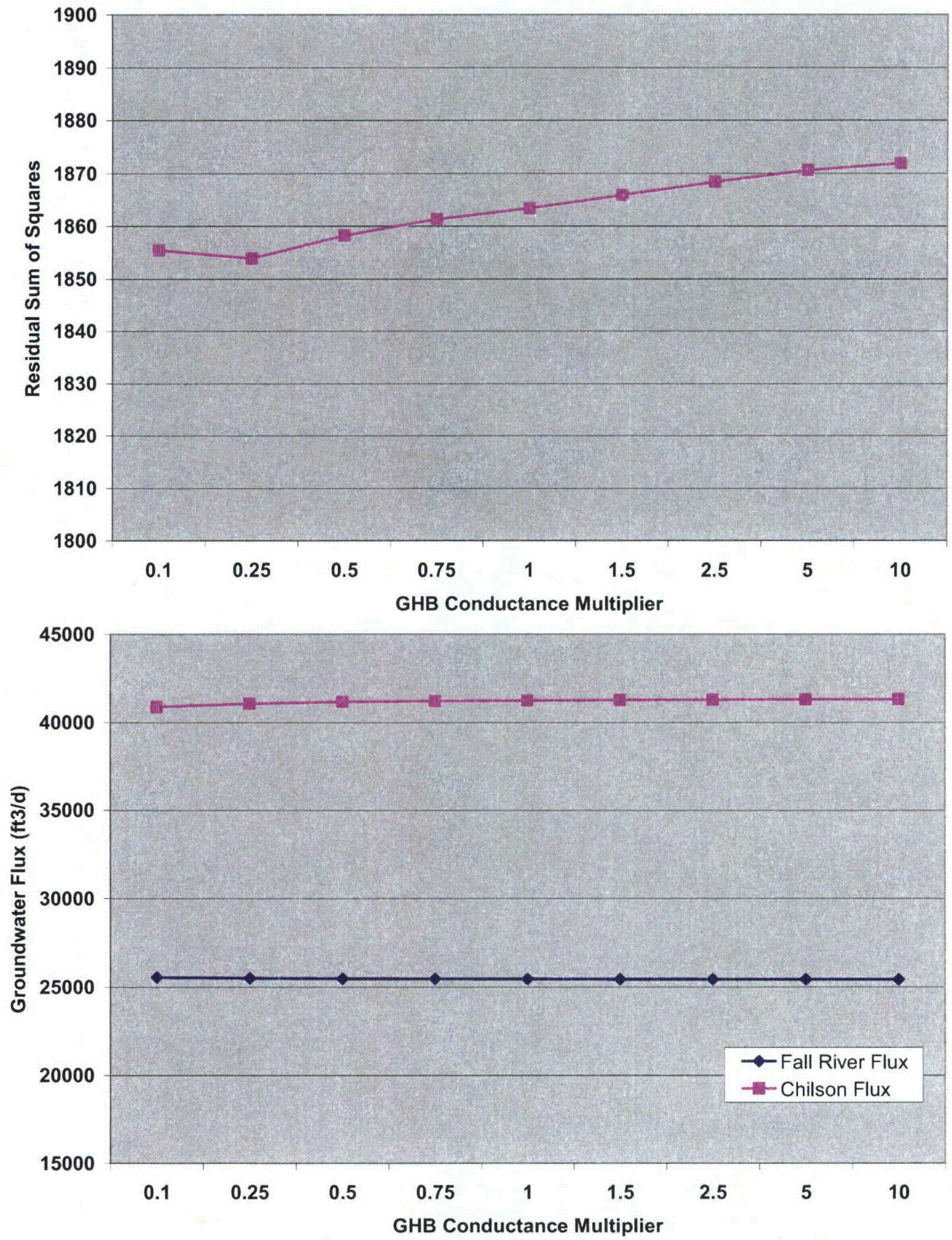
Figure 5-13. Sensitivity Analysis GHB Head, Layer 2 (Fall River) Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel513.srf 1/12/12



Groundwater Flux Measured at Location Indicated on Figure 5-9

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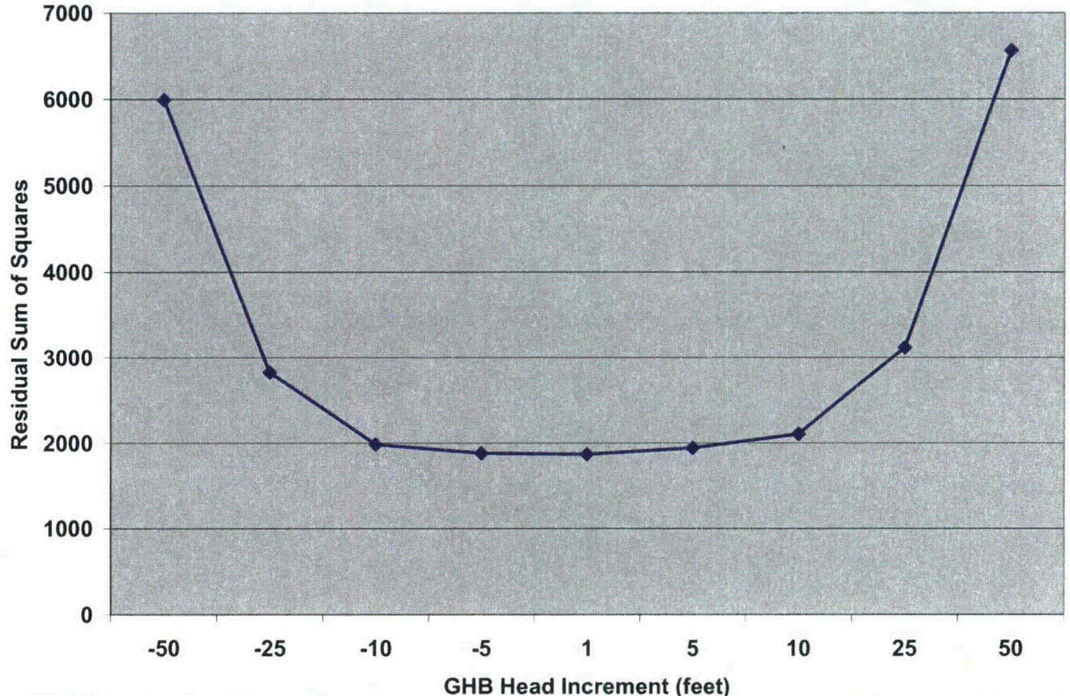
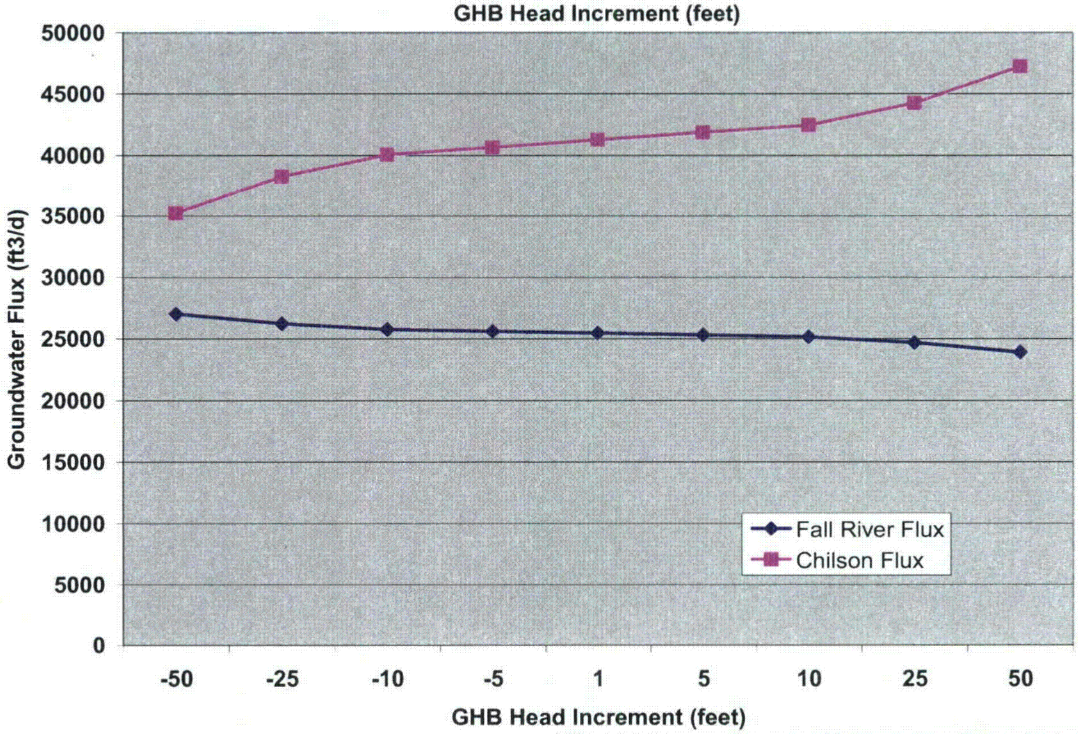
Figure 5-14. Sensitivity Analysis
GHB Conductance, Layer 4 (Chilson)
Dewey-Burdock Project, South Dakota

By: EL Checked: HD File ID:Fig_DBModel514.srf 2/12/12





Groundwater Flux Measured at Location Indicated on Figure 5-9

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Figure 5-15. Sensitivity Analysis GHB Head, Layer 4 (Chilson) Dewey-Burdock Project, South Dakota

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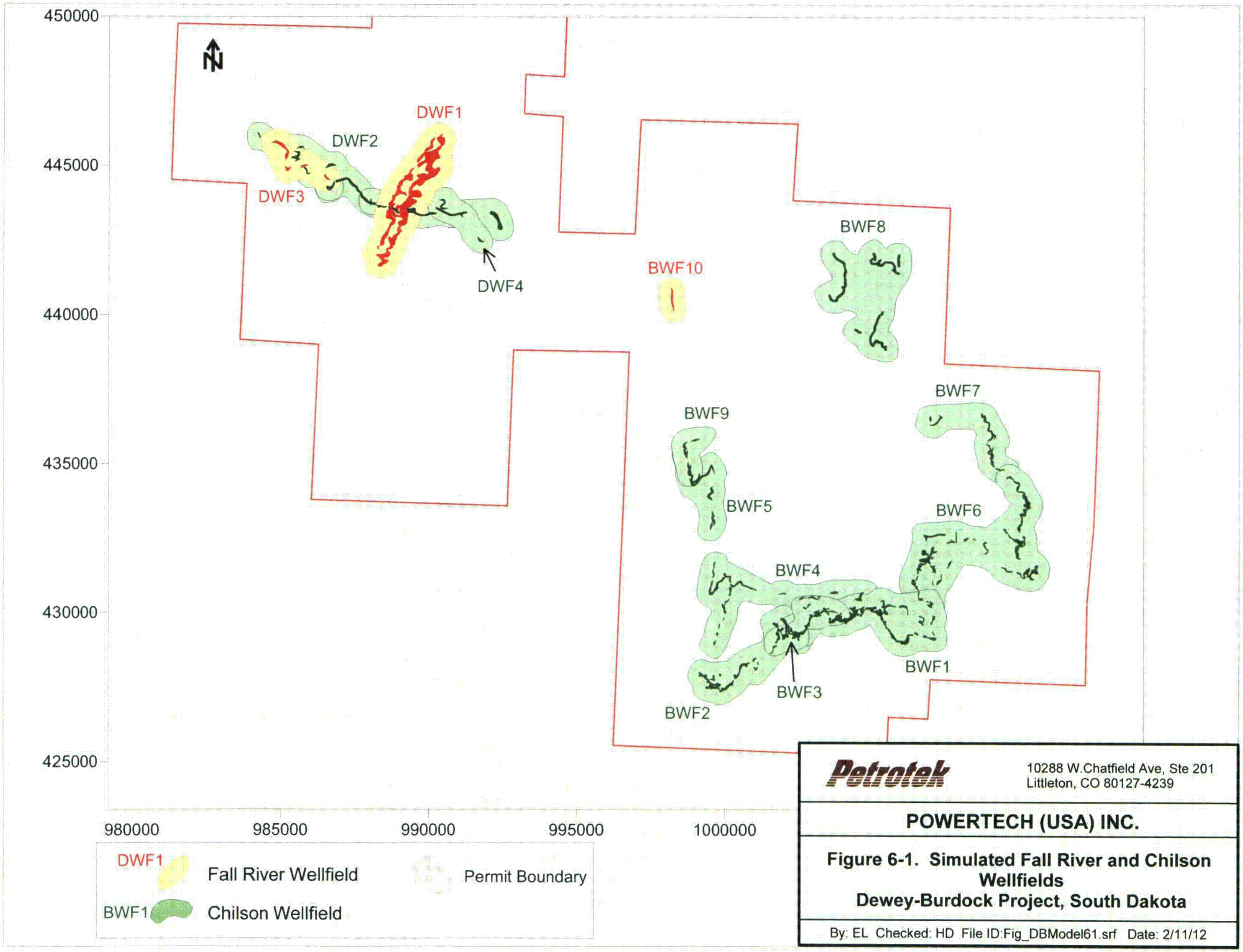

**Figure 6-1. Simulated Fall River and Chilson Wellfields
Dewey-Burdock Project, South Dakota**

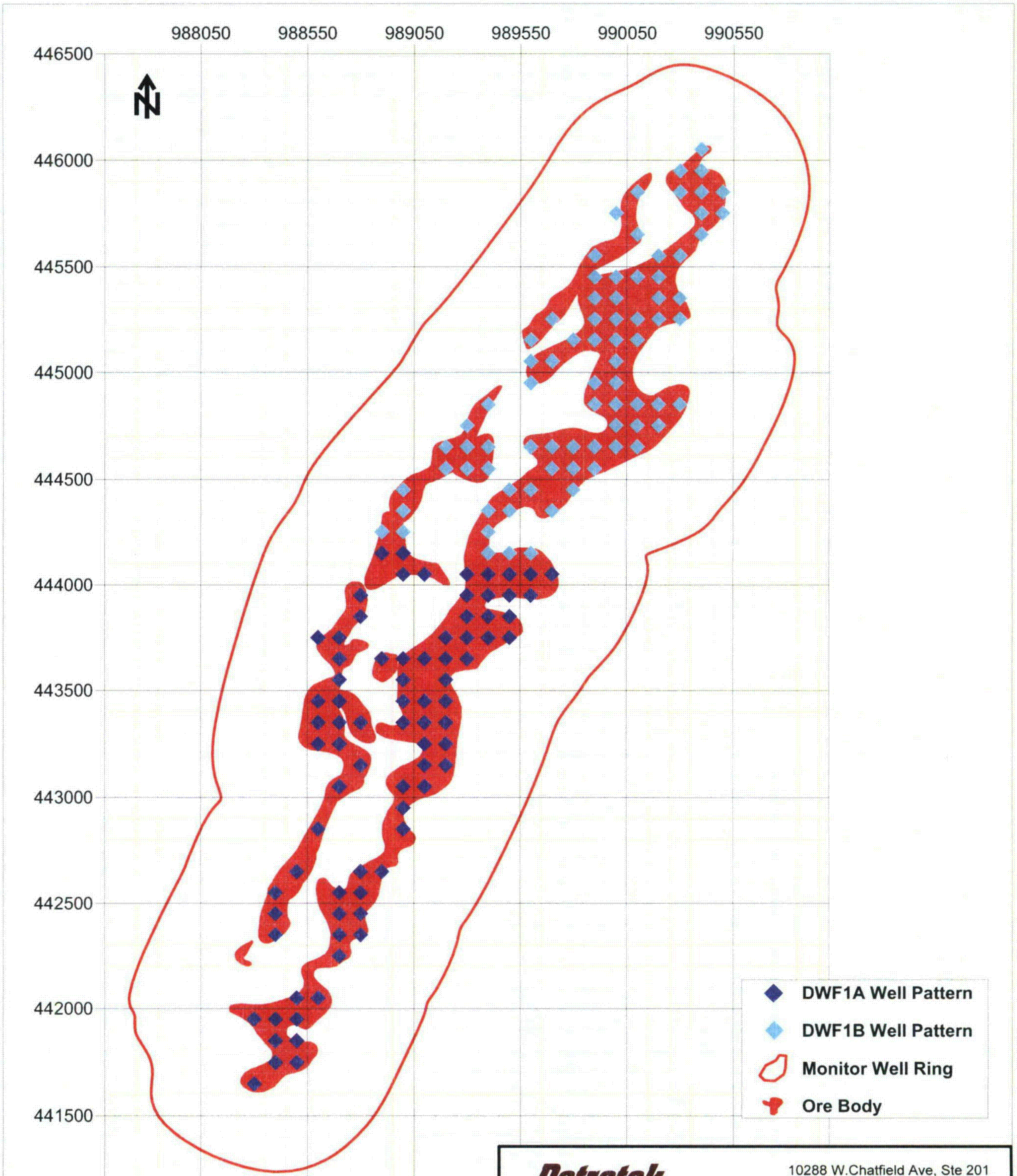

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Figure 6-1A. Simulated Wellfields DWF1A and DWF1B Dewey-Burdock Project, South Dakota

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