Statistical Analysis of Mining Parameters to Create Empirical Models to Predict Mine Pool Formation in Underground Coal Mines

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This thesis titled

Statistical Analysis of Mining Parameters to Create Empirical Models to Predict Mine Pool Formation in Underground Coal Mines

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ABSTRACT

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Statistical analysis of mining parameters to create empirical models to predict mine pool formation in underground coal mines

Director of thesis: Dina L. Lopez

Mining has occurred in Ohio for over two hundred years and has resulted in hundreds of flooded or partially flooded mines releasing acid mine drainage. Present mining regulations in Ohio prevent the approval of a mining permit if it is predicted that the future mine will develop a mine pool that will discharge to the surface. However, there is not a methodology that mining companies and regulators use to determine, with some degree of uncertainty, if a mine will develop a pool or not. This thesis work is part of a larger project that aims to create a tool that can predict if a mine pool will form in a future coal mine, and if it does, where it could discharge. Mines that have been exploited in Ohio during the last 35 years were investigated. Public data sources were used to identify variables that could influence the water elevation within mines during and after mining. Information about boreholes and wells is reported in mine permits and quarterly monitoring reports and in ODNR and EPA web pages. The following variables were investigated: surface elevation of the well, bottom of well elevation, overburden thickness, thickness of the different strata (coal, sandstone, shale, clay and limestone), accumulative coal volume extracted from the mine at different times, water withdraw from the mine and precipitation data was collected and investigated.

Using the statistical program, The Unscrambler X, multivariate statistical analysis was applied to identify the most important variables that determine the potentiometric head and obtain regression equations of potentiometric head as a function of the variables collected. The applied methods include: principal component analysis, principal component regression, and partial least squares regression. These methods were performed on these variables for 359 wells in eleven mines. This analysis resulted in regression equations that allows for the prediction of potentiometric heads at different depths using, hydrological parameters, stratigraphy and topography of the mined area. These equations can be applied to the depth of the bottom of the coal layer and the predicted potentiometric head within the coal layer can be obtained.

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CHAPTER 1: INTRODUCTION

Over two hundred years of coal mining in Ohio has resulted in thousands of underground mines, which are dry, flooded or partially flooded. The flooded and partially flooded mines are a threat to watersheds because they have the potential to discharge and release waters high in acidity, sulfur and metals. The environmental remediation cost for abandoned mines in Ohio is a multi-million-dollar problem. Mines today are created in the up-dip fashion to reduce the risk of discharge from the mine's entrance to the surface. Mine pool formation is still a concern because the lithology of Ohio consists of rocks of variable permeability and mining methods cause tension fractures in the overburden, allowing water to percolate down into the mine cavity (Kendorski, 1993). Present mining regulations in Ohio prevent the approval of a mining permit if it is predicted that the future mine will develop a mine pool that may exceed surface elevation above the mine. However, there is not an established methodology that mining companies and regulators can use to determine, with some degree of uncertainty, if the mine will develop a pool or not.

There is an abundance of underground coal mining data in Ohio. The main source of this data is the Ohio Department of Natural Resources which permits mines, well data and mine extents. The purpose of this thesis was to collect a vast amount of data from public data sources and to create a statistical model for the formation of mine pools in underground coal mines in Ohio.

1.1 Office of Surface Mining and Reclamation Mine Pool Project

Despite the popularity that coal mining has in Ohio, there is not yet a method that can be used as a tool to aid in determining the possible environmental consequences of future mines with respect to the formation of mine pools. A proposal to study mine pools and create a method to determine if a mine will develop a pool and discharge to the surface was proposed to the United States Office of Surface Mining and Reclamation and Enforcement by Ohio University researchers. This thesis work is part of that project. The Office of Surface Mining and Reclamation Mine Pool Project (OSM) is being done in steps starting with the collection of data (Task 1). Mine pool formation is influenced by multiple factors ranging from the stratigraphy and topography of the mine's region to the location of the water table. A vast amount of data was collected from the mines that have mine pools. Special attention was given to mines that have been active during the last 35 years where more information is available and they have followed the most recent regulations.

Once enough data from multiple mines was gathered, statistical multivariate analysis was performed to find correlations between mine pool elevation and different environmental mine parameters (Task 2). The parameters studied were: potentiometric head, well surface elevation, bottom of well elevation, overburden with respect to the mined coal seam, thickness of the mined coal seam, thickness of shale, clay, sandstone, limestone and coal, accumulative coal volume, area of underground mines within four miles of the permitted mine area, average precipitation, water withdraw from the mine and distance from the well to the withdraw point. Once the most significant parameters were statistically identified they were used to develop regression models that can be used to predict water elevation (this thesis work) and to develop artificial neural network models of mine pool formation (Task 3), which is another student's work (Twasumi, 2018). This list will also be used to develop a geographic information system predictive model to statistically determine the formation of mine pools or not, post mining water level and possible discharge locations (Task 4). The work of this thesis involves the first and second tasks of the Mine Pool Research Project. Once an efficient tool has been developed it will be made easily available to use in the future development of coal mines in Ohio and possibly neighboring states with similar geology. Mine operators and regulators could use this tool to predict the formation of mine pools and their consequences in Ohio.

1.2 Objective

The objective of this study was the acquisition of data from mines active in the last 35 years and the creation of a statistical model on mine pool formation using the program The Unscrambler X. This modeling work aims to identify key parameters that affect potentiometric head within an underground coal mining area and result in an equation for the prediction of potentiometric heads in future mining areas. The prediction of potentiometric head in future mining areas is needed to better predict mine pool formation in coal mines in Ohio.

CHAPTER 2: BACKGROUND

2.1 Ohio Geology

The most economic coal beds in Ohio are located on the eastern half of the state, as seen in Figure 1, and they were deposited during the Pennsylvanian and Permian (Shrake et al., 2011). The Pittsburg No.8, Middle Kittanning No.6, Lower Kittanning No.5 and Clarion No.4 coal seams are particularly important economically due to their large thickness. There are multiple other coal beds that were deposited during the Pennsylvanian and Permian but they are typically too thin for economic gain and are not usually mined.

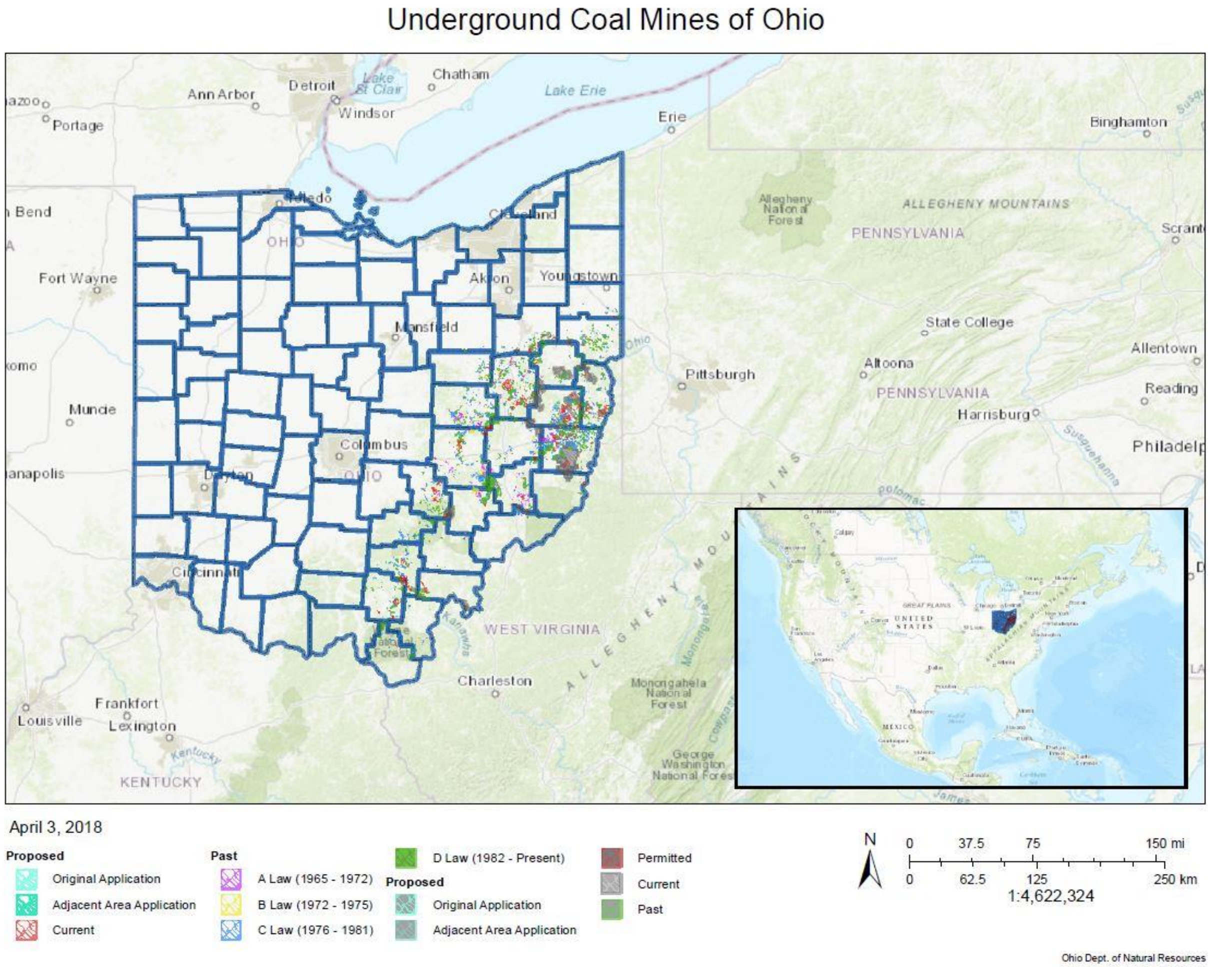

Figure 1: Map of underground coal mines in Ohio. County lines are highlighted in blue. Coal mines are highlighted in varying colors depending on status and time period. (retrieved and modified from https://gis.ohiodnr.gov/MapViewer/?config=OhioMines).

The Pennsylvanian and early Permian consist of five groups (Pottsville, Allegheny, Conemaugh, Monongahela and Dunkard) of interbedded shale, siltstone, sandstone, limestone, mudstone, clay, flint and coals (Shrake et al., 2011). The Kittanning coal seams are part of the Allegheny Group which were deposited early in the Pennsylvanian. The Pittsburg coal, at the base of the Monongahela Group, was deposited in the late Pennsylvanian. The Upper Pennsylvanian which includes sandstones, limestones, siltstones, claystones, shales, siltstones and eight major coal groups can be seen in Figure 2 with the Pittsburg coal separating the Monongahela Group from the Conemaugh Group (Tewalt et al., 2000). The Middle Pennsylvanian which includes the Allegheny Group, consists of many shales, siltstones, claystones, sandstones and relatively thinner coal seams illustrated in Figure 3 (Milici, 2004). The coal found in the Pennsylvanian and Permian is rich in sulfur and ash content (Tewalt et al., 2000). The mining of these coals has exposed sulfide minerals such as pyrite to oxic conditions resulting in the formation of acid mine drainage.

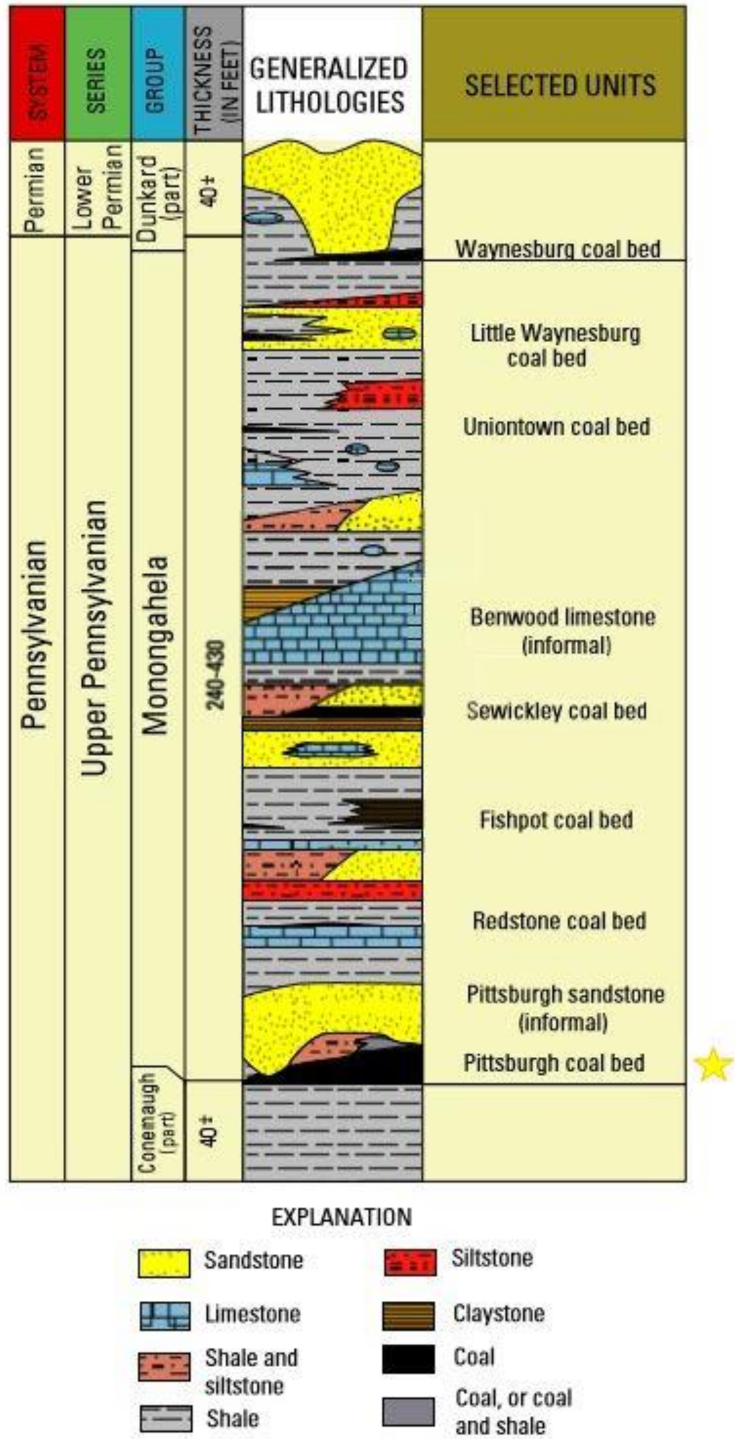

Figure 2: Stratigraphic column of the Upper Pennsylvanian showing the major coal beds. The star represents one of the coal beds for mines that were studied in this thesis (after Tewalt et al., 2000).

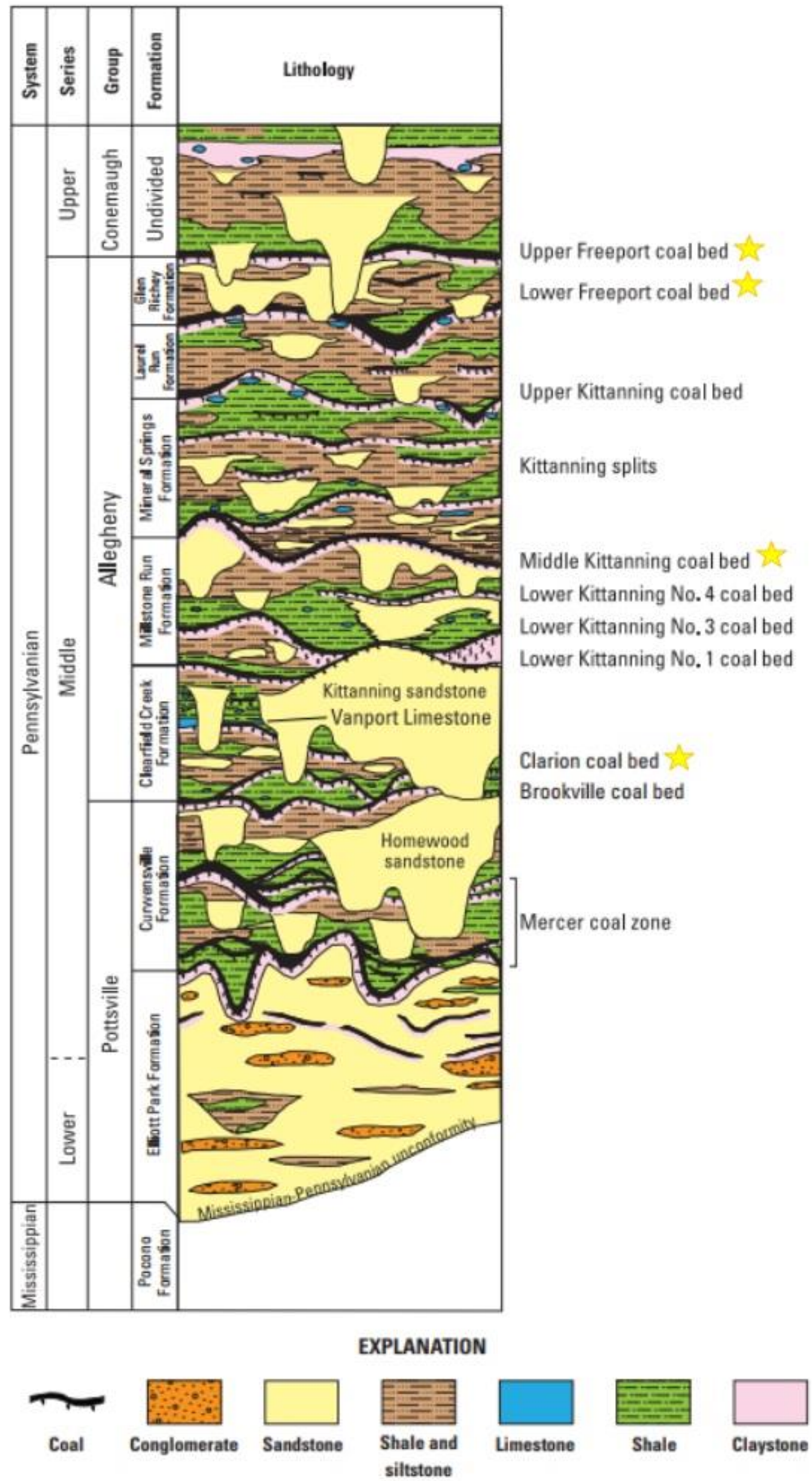

Figure 3: Stratigraphic column of the Middle and Lower Pennsylvanian showing the major coal beds. The stars represent coal bed for mines that were studied in this thesis (after Milici, 2004).

2.2 Climate

Ohio is a midwestern state that has northern and southern climate regions. The southern climate region described as being a humid subtropical climate is on average warmer and more humid than the northern humid continental climate (Funk and Wagnalls New World Encyclopedia, 2017). The state's average summer temperature is 73°F and the average winter temperature is 28°F and annually there is about 38 inches of precipitation (Funk and Wagnalls New World Encyclopedia, 2017).

2.3 Soils

Ohio contains twelve different soil regions which can be seen in Figure 4 (ODNR a, 2018). The Shelocta-Brownsville-Latham-Steinsburg, Coshocton-Westmoreland-Berks and Gilpin-Upshur-Lowell-Guernsey soil regions cover the coal bearing region of Ohio. These soils formed from the weathering of the acidic sedimentary rocks in the region (ODNR a, 2018). This has resulted in Ohio having soils that contain a high amount of clays. Clay minerals are small in size and have a significant impact on water's ability to infiltrate a soil. When clay particles interact with water they begin to swell, creating an impermeable layer which constricts water movement (Smiles, 2000).

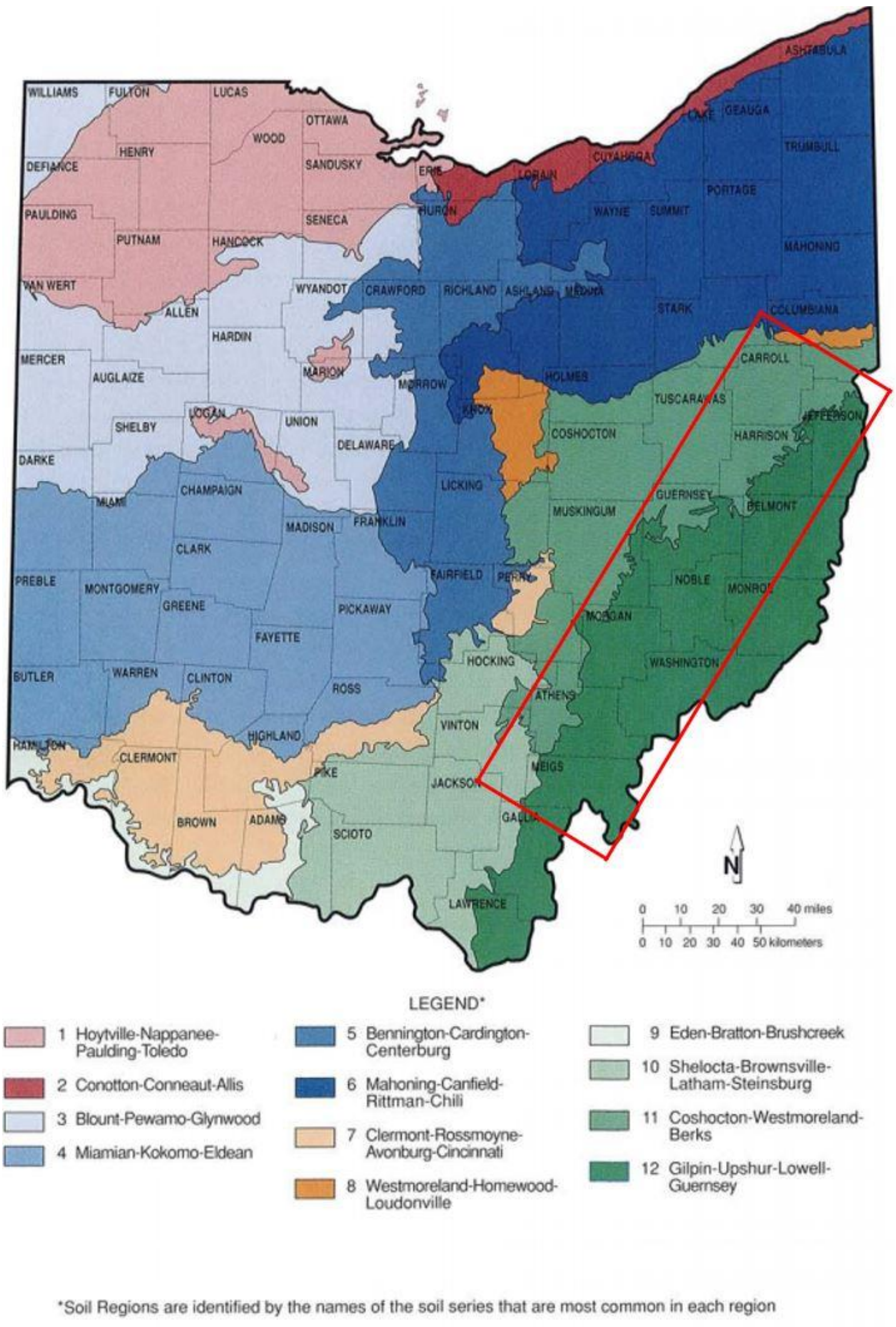

Figure 4: Soil region map of Ohio. Regions 10, 11 and 12 are located in the studied coal mining region represented by the red rectangle (retreived and modified from http://water.ohiodnr.gov/portals/soilwater/pdf/soil/Soil_Regions_of_Ohio_brochure.pdf)

CHAPTER 3: MINING IN OHIO

3.1 Acid Mine Drainage

Ohio's coals contain sulfides, most often in the form of the mineral pyrite (FeS_2). When a coal seam is mined, walls of coal are left exposed which causes previously buried pyrite and other sulfides to react with oxygen and water which causes the pyrite to oxidize (Kruse et al., 2013). The oxidation of pyrite creates acid mine drainage (AMD) which is a low pH, metal and sulfur rich solution. The process of the oxidation of the pyrite occurs in four steps (Singer and Stumm, 1970).

$$2FeS_2\,(s) + 7O_2\,(aq) + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+ \quad (1)$$

$$2Fe^{2+} + 0.5O_2 + 2H^+ \rightarrow 2Fe^{3+} + H_2O \quad (2)$$

$$2Fe^{3+} + 6H_2O \leftrightarrow 2Fe(OH)_3\,(s) + 6H^+ \quad (3)$$

$$14Fe^{3+} + FeS_2\,(s) + 8H_2O \rightarrow 2SO_4^{2-} + 15Fe^{2+} + 16H^+ \quad (4)$$

The initial step of the process is the pyritic sulfur oxidation where the pyrite reacts with oxygen and water to produce ferrous iron, hydrogen ions and sulfate, Equation 1. The second step is the oxidation of ferrous to ferric iron by reacting ferrous iron with oxygen and hydrogen ions to create water and ferric iron, Equation 2. The third step is the iron hydrolysis where ferric iron reacts with water to become iron hydroxide, Equation 3. The final step is further pyrite oxidation of ferric iron by reacting ferric ions with pyrite and water to create sulfate, ferrous iron and hydrogen ions, Equation 4 (Kruse et al., 2013).

The oxidation of pyrite and other sulfide minerals leads to acid mine drainage with high levels of iron, aluminum and manganese trace metal concentrations as well as very low pH values (Kruse et al., 2013). These elevated metal and acid concentrations lead to detrimental environmental impacts and is usually remediated by buffering the drainage with high alkaline materials like calcium carbonate, calcium hydroxide or calcium oxide (Younger et al., 2002).

3.2 Longwall and Room and Pillar Mining

There are two types of underground mining that are practiced in Ohio, longwall and room and pillar. Longwall mining is a process that is entirely mechanized by a large machine with multiple coal shears that strip away at the coal. These mining machines extract large rectangular coal blocks referred to as panels, these panels are on average 1,000 feet wide and over 5,000 feet long (Borch, 2008). As the mining machine advances the overlying roof rock collapses in the empty space left behind. The room and pillar method is similar to that of longwall except pillars of the resource are left to support the overburden, preventing collapse. Since the room and pillar method leaves a significant amount of the resource unmined, longwall mining is the more economically desired method. Since longwall mining is completely mechanized, it is restricted to mining thick coal seams that are relatively flat and continuous.

Since longwall mining involves overburden collapse, fractures form above the mine which can extend from the mine roof to the ground surface (Kendorski, 1993). Kendorski examined the Meigs Mine Complex located in Meigs County Ohio, which was excavated using the longwall technique. The overburden collapse creates tension and compression areas in the overburden shown in Figure 5 (Kendorski, 1993). The collapse creates four zones in the overburden: the caved, fractured, dilated and constrained zones which are capped by surface fractures. Kendorski found that there was an increased amount of aquifer dewatering and water intrusion into the zone of caving due to the enlargement of fractures and creation of new fractures above the overburden subsidence area. The creation of these new fractures in the overburden allows water to flow into the mine resulting in the production of a mine pool.

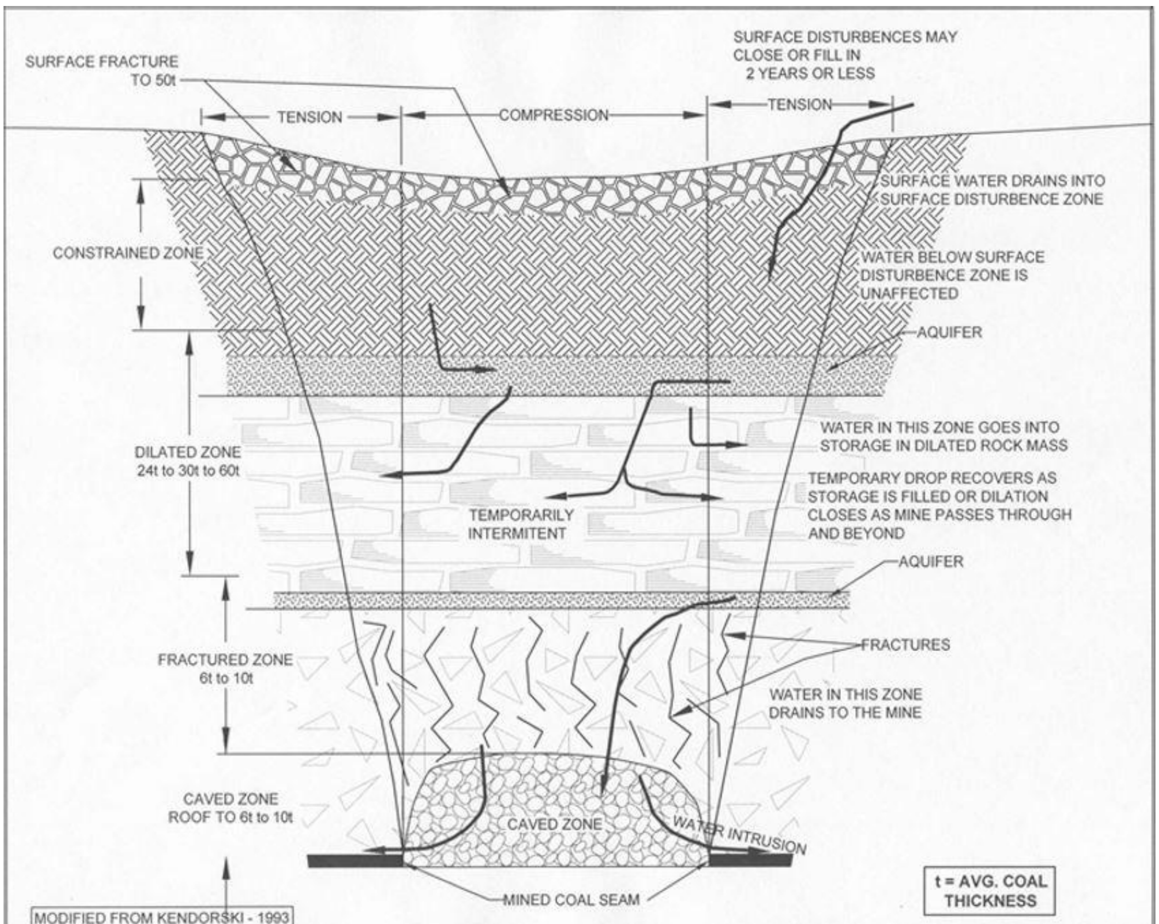

Figure 5: Model of longwall fractures as the result of overburden subsidence (Kendorski, 1993).

3.3 Mine Pools

When an underground mine closes, often mine pools begin to form as a result of uncontrolled water infiltration into the abandoned mine. Water infiltration in abandoned or recently closed mines occurs via percolation through the overburden and water flow through fractures in the overburden that are produced during coal extraction (McCoy et al., 2006). As the water infiltration continues, small pools will merge together and create a main pool saturated region within the mine (McCoy et al., 2006). These mine pools have potential to discharge from mine shafts and connect with adjacent mines or discharge to the surface, polluting streams and aquifers with acid mine drainage (Borch, 2008). Mines today are created in the up-dip fashion to help reduce the amount of acid mine drainage that discharges out of the mine's entrance to the surface. However, mines created in the up-dip fashion can still have mine pool migration problems. Mines that are located below water tables can have water percolate down into the mine shaft from the layers above, travel through fractured overburden or even through coal barriers and infiltrate the open mine shaft. A conceptual model of mine pool formation during mining, after mining and in equilibrium is shown in Figure 6.

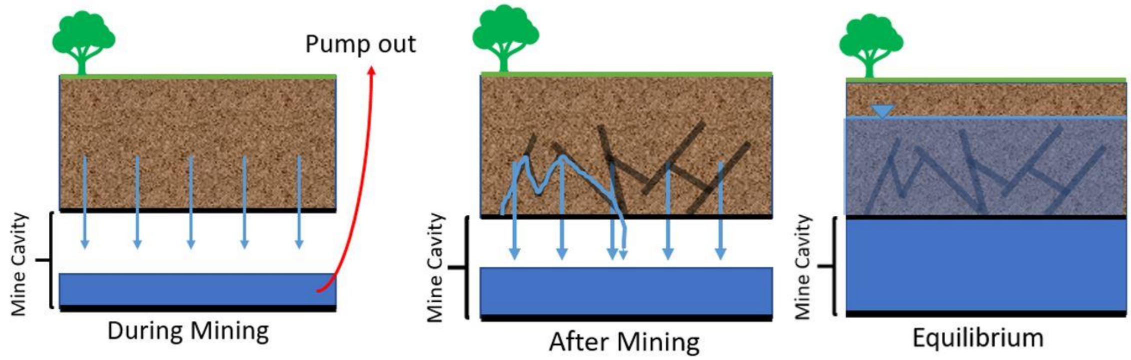

Figure 6: Conceptual model of water migration during mining, after mining and in equilibrium. During mining water infiltrates from the rock above and the water inside the mine cavity is pumped out. After mining, water will migrate through fractures in the overlying rocks caused by mining, increasing water infiltration. The water will then pool and eventually reach a state of equilibrium.

Mine pool formation is impacted by multiple factors: recharge of water into the mine, overburden thickness, development of subsidence fractures, slope of the mine, elevation of the water table of nearby aquifers, stream presence, overburden lithology and mine connectivity with nearby mines. The number of variables that are potentially needed to predict mine pool formation results in a challenging problem.

3.4 Meigs Mine Example

The Meigs mine complex is composed of three mines, Raccoon, Meigs 31 and Meigs 2. These three mines are located in Meigs, Vinton and Gallia counties in southeastern Ohio. The mines used longwall and room and pillar methods to extract the Clarion No.4 coal seam from 1972 until 2002, creating a 23,500-acre footprint (Borch, 2008). During mining, the mine complex was actively having any intruded water pumped to the surface and treated. When the mine complex and dewatering was stopped in 2002, a mine pool began to form. The formation of a mine pool is a concern because one area of the mine complex is low in elevation and if the mine pool rises high enough, it would have potential to discharge into nearby Raccoon Creek. Fractures in the overburden created from longwall mining, act as a channel for the contaminated water to flow through, impacting high elevation aquifers in the area. Therefore, the mine pool levels must be kept at a minimum.

This mine pool is a concern because it has potential to contaminate waters that flow into Leading Creek and Raccoon Creek with high amounts of sulfur and metals. The pool was showing seasonal variations with an average monthly rate of recharge of 1.35 ft/month from January 2006 through 2008 and the inflow rate into the Meigs 2 mine was calculated to be 0.266 gpm/acre (Borch, 2008). In 2008, CONSOL Energy Inc. began pumping water from Meigs 2 into Meigs 31 to combine the contaminated water before pumping into a wastewater treatment plant. A control elevation of 560 feet m.s.l. (83% flooded) was set for the Meigs 2 mine so that in the case of a pump failure or power blackout, the pool would not discharge (Borch, 2008).

3.5 Mining History in Ohio

Coal's presence in Ohio was first noted in 1748 and has been mined for over 200 years which has resulted in 3.7 billion tons of coal being extracted from Ohio (Crowell, 2005). Today there are 4,360 identified abandoned underground mines; 483 of these mines are flooded and 65 are partially flooded (Crowell et al., 2011). The environmental impact of the hundreds of flooded abandoned mines has created an expensive environmental problem. From the year 2005 to 2014, $28,877,746 has been spent on acid mine drainage reclamation in the Racoon Creek, Monday Creek, Sunday Creek, Huff

Run and Leading Creek watersheds alone (Bowman and Johnson, 2015). The best course of action to reduce the cost of acid mine drainage in Ohio is to develop a method to prevent mine discharge in the first place.

CHAPTER 4: STATISTICAL APPROACH

The large number of variables and the number of samples analyzed in this work require special statistical approaches to obtain dependent variable (potentiometric head) and its relationship to the independent variables selected for this study.

4.1 Multivariate Statistical Methods

Statistical analysis for this thesis was performed using the program The Unscrambler X version 10.5 (CAMO Software AS, 2018). This program contains different approaches to analyze multivariate data, they include: multiple linear regression (MLR), principal component regression (PCR), principal least square regression (PLS) and principal component analysis (PCA). These methods were applied to the data sets collected for this research. The algorithms used by The Unscrambler X for principal component analysis, principal component regression and partial least squares regression are described in “Multivariate calibration” by Martens and Næs, 1992.

Principal component analysis (PCA) identifies an axis in multidimensional space that better represents the variance of the data (CAMO Software AS, 2018). This method identifies the axis along which the greatest variance of the data set is present. It also identifies other orthogonal axis that contain the variance of the data in a smaller range. A conceptual model of the axis is displayed in Figure 7. This statistical method is useful in visualizing all data being analyzed because it quantifies the difference of one sample to another and which variables contribute the most to the difference (CAMO Software AS, 2018). Using Equation 5, The Unscrambler X computes the principal component, where

T represents the scores matrix, P represents the loadings matrix and E represents the error matrix (Martens and Næs, 1992).

$$X = TP^T + E \tag{5}$$

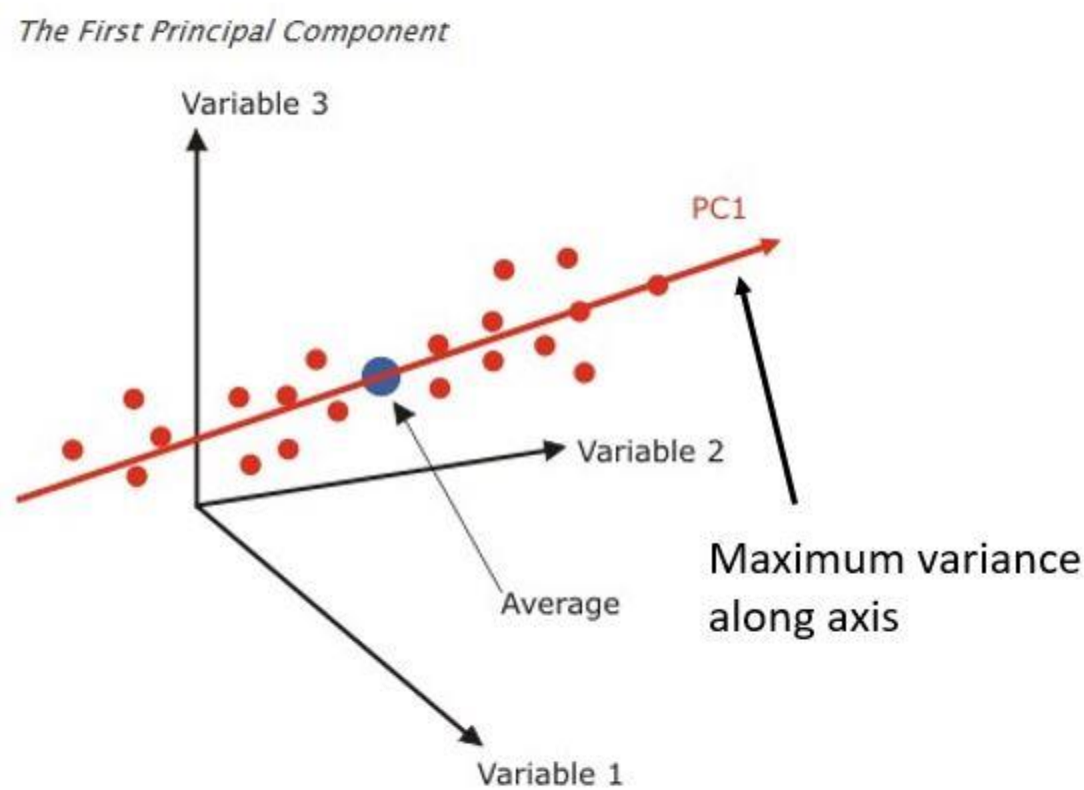

Figure 7. First principal component analysis conceptual model (CAMOSoftware AS, 2018).

Multiple linear regression (MLR) is a multivariate regression performed between X and Y matrices, modeling a relationship of a linear equation between the dependent (Y) and independent variables (Xs). A conceptual model of this relationship is shown in Figure 8. This statistical method works best when the X variables being analyzed are truly independent of each other (CAMO Software AS, 2018). The equation for multiple linear regression, Equation 6, is an extension of a univariate straight-line equation that relates a Y-variable to several X-variables (Martens and Næs, 1992). This equation in matrix notation is shown in Equation 7. The program aims to find a regression equation that minimizes the f error term.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + f \tag{6}$$

In matrix notation:

$$y = T \cdot b + f \tag{7}$$

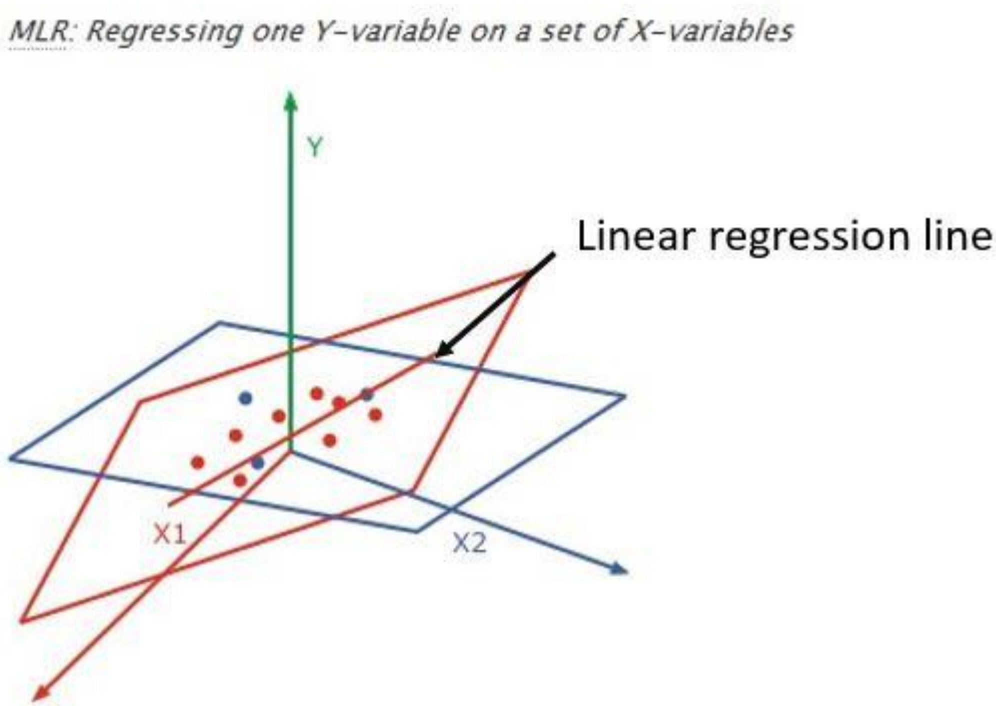

Figure 8. Multiple linear regression conceptual model (after CAMO Software AS, 2018).

Principal component regression (PCR) relates variance in Y (response) to the variance in X (predictor) using the principle components found in PCA as the regressors (CAMO Software AS, 2018). In other words, it is a regression of the data in a new space formed by the principal components. A conceptual model of the principle component regression is shown in Figure 9. Principal component analysis uses the same equation as PCA (Equation 5) and multiple linear regression equations (Equation 6 and 7) (Martens and Næs, 1992).

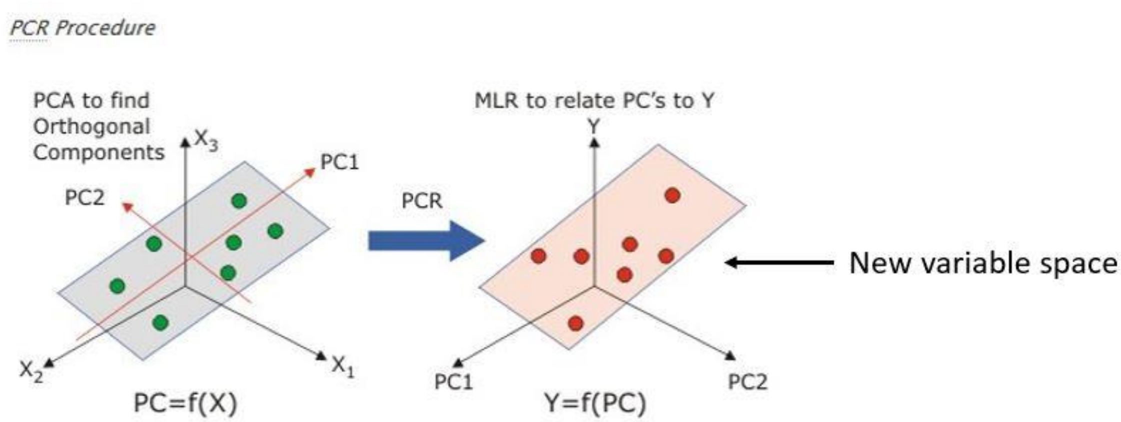

Figure 9. Principal component regression conceptual model (after CAMO Software AS, 2018).

Partial Least Squares Regression (PLS) finds the multidimensional direction in the X space that explains the maximum multidimensional variance direction in the Y space, represented by a linear regression model (CAMO Software AS, 2018). A conceptual model of the principle least squares regression process is shown in Figure 10. This statistical method combines features found in principle component analysis and multiple regression. PLS is one of the more common regressions for explaining complex relationships for application and prediction problems. Partial least squares regression uses the same general form model equations as PCA (Equation 5) and MLR (Equation 7) (Martens and Næs, 1992).

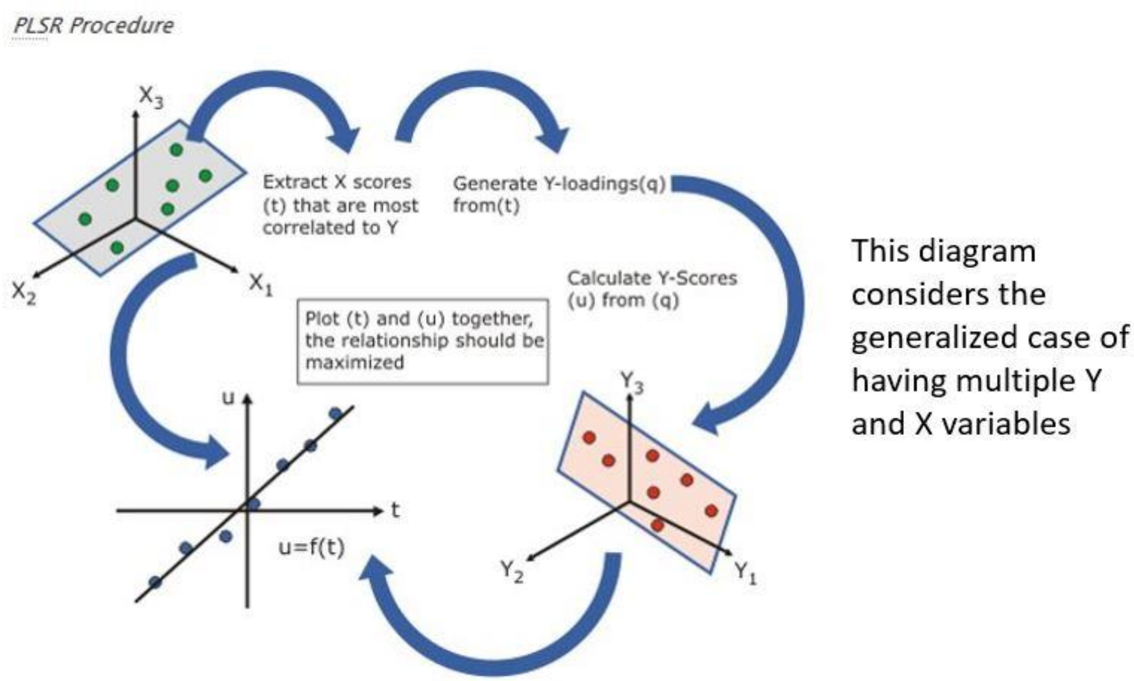

Figure 10. Partial least squares regression conceptual model (after CAMO Software AS, 2018).

4.2 Statistical Goodness-of-fit Indexes

To determine the statistical difference between the modeled and observed data, six goodness-of-fit indexes were calculated. For each of the following equations, the variable O_i and S_i are represented by the observed potentiometric head and simulated potentiometric head respectively, and $\bar{o}$ signifies the average observed potentiometric head.

The most common index measure for hydrologic models is the Nash-Sutcliffe efficiency (NSE), shown in Equation 8. Values for the NSE can range from negative infinity to the ideal value of 1, which indicates perfect fit (Nash and Sutcliffe, 1970).

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n} (O_i - S_i)^2}{\sum_{i=1}^{n} (O_i - \bar{o})^2} \right] \tag{8}$$

Percent bias (PBIAS) quantifies the average deviation between the observed and simulated potentiometric head values with respect to the observed data, as displayed in Equation 9 (Gupta et al., 1999). This value ranges from negative infinity to infinity but has an ideal value of zero which indicates no average deviation, or bias, between the two data sets.

$$\mathrm{PBIAS} = \left[\frac{\sum_{i=1}^{n} (S_i - O_i) \cdot 100}{\sum_{i=1}^{n} (O_i)} \right] \tag{9}$$

Relative index of agreement (rd) determines how well the observed and simulated potentiometric heads agree with each other, and is calculated using Equation 10 (Willmott, 1981). The values of rd range from negative infinity to 1 where 1 is the ideal value indicating perfect agreement between the observed and simulated potentiometric heads (Gebremariam et al., 2014).

$$\mathrm{rd} = 1 - \frac{\sum_{i=1}^{n}\left(\frac{O_i - S_i}{O_i}\right)^2}{\sum_{i=1}^{n}\left(\frac{|S_i - \bar{O}| + |O_i - \bar{O}|}{\bar{O}}\right)} \tag{10}$$

Mean absolute error (MAE) calculates the absolute deviation between the observed and simulated potentiometric head values with respect to the number of wells as shown in Equation 11 (Gebremariam et al., 2014). Values for MAE range from zero to infinity where zero indicates a perfect fit between the two data sets.

$$\mathrm{MAE} = n^{-1}\left[\sum_{i=1}^{n}|S_i - O_i|\right] \tag{11}$$

Volumetric efficiency (VE), shown in Equation 12, is similar to MAE but is normalized by the total sum of the observed potentiometric heads and ranges from 0 to 1 where a value of 1 indicates perfect agreement (Criss and Winston, 2008).

$$\mathrm{VE} = 1 - \frac{\sum_{i=1}^{n}|S_i - O_i|}{\sum_{i=1}^{n}O_i} \tag{12}$$

The root mean square error (RSME) calculates the fit between the observed and simulated potentiometric heads using Equation 13, where a value of zero indicates a perfect fit (Davis, 2002).

$$\text{RSME} = \sqrt{\frac{\sum_{i=1}^{n}(O_i - S_i)^2}{n}} \tag{13}$$

CHAPTER 5: METHODOLOGY

5.1 Data Acquisition

There is a vast amount of coal mining data available in Ohio. In order to develop a tool that applicants and regulators could use in the future, data for this project was collected from public sources. The main source of information for this project was data from the Ohio Department of Natural Resources such as: Online Mines of Ohio Viewer, Online Well Viewer, Division of Mineral Resources Management, Geologic Survey and Division of Water Resources.

The problem investigated in the OSM project is basically a hydrogeological problem. The response of groundwater to the perturbation of exploiting an underground mine is the object of this investigation. For that reason, variables that determine the occurrence and movement of groundwater should be collected for this work. The most important variables are probably the water levels reported for the wells found in the mine permits and quarterly monitoring reports during and after mining, and variables such as the lithology of the wells, water extracted from the mines, and precipitation. It is understood that the potentiometric heads in the monitoring wells are not the same as the potentiometric heads in the coal layer once the mine closes. However, if we assume that all the groundwater systems are connected, the regression found considering the monitoring wells can be extrapolated to the coal layer. This assumption is consistent with the conclusions of Means and Montrella, 2018.

5.1.1 Mine Permits

In 1977 the Surface Mining Control and Reclamation Act (SMCRA) was passed. SMCRA is a federal law which is responsible for the environmental regulations of coal mining within the United States (Power and Adkins II, 2010). Under this law companies must propose a permit which states the mining method, engineering techniques, potential hydrological and environmental impacts and remediation plans for any surface or underground mine impacts (Power and Adkins II, 2010). This results in a lengthy permit that contains information regarding lithology and hydrology of the potential mining area which was desired for this thesis.

Mining permits for this project were received from the Ohio Division of Natural Resources (ODNR) and provided information regarding the archeology, lithology, hydrology, and mine engineering regarding an area to be mined in Ohio. Depending on the law that was emplaced when the mine was proposed (A law: 1965 – 1972, B law: 1972 – 1975, C law: 1976 – 1981, D law: 1982 – present) availability and the amount of useful information obtained from the permits may vary. For this thesis, only D law permits were analyzed because they were put in place post-SMCRA (Surface Mining Control and Reclamation Act) and typically contain more hydrological and geological data.

Twenty-Eight D law coal mine permits were received from ODNR. Eleven of these have a mining status of “sealed” and coal is no longer being excavated from them, four have a mining status of “idle” and are not currently being excavated but may be in the future, six have a mining status of “active” and are currently being excavated and seven mines have not been mined yet or have no listed status. The mine name, permit number and mine status of these twenty-eight mines are shown in Table 1. Mines with a status of sealed or idled with lithological and hydrological data were the focus of this thesis, the studied mines are highlighted in red in Table 1. The location of these mines can be seen in Figure 11, the stared mines indicate the ones analyzed in this thesis. The sealed mines that were not considered for this study did not have enough well, borehole or quarterly monitoring report data to complete the analysis.

For each mine, every new extension of the mined area is required to have its own mine permit containing unique information about the extended area. For example, thirty permits were received from ODNR for Powhatan Mine No.6, permit number D-0360 with extension permits ranging from D-0360-00 to D-0360-30. The permit for each extension was thoroughly reviewed and borehole and well data was collected based on permit number, and extension.

Table 1: Mine permits and status received from ODNR. Mines in red were analyzed in this thesis.

Mine Name	Permit Number	Mine Status
Meigs 2	**D-0355**	**Sealed**
Sterling South	**D-1019**	**Sealed**
Powhatan No.6	**D-0360**	**Sealed**
Sterling North	D-0949	Sealed
Meigs 31	**D-0354**	**Sealed**

Mine Name	Permit Number	Mine Status
Quarto/Marcoll	D-0433	Sealed
Raccoon No. 3	D-0463	Sealed
Buckingham No. 2	D-1163	Sealed
Carrol Hollow	**D-2091**	**Sealed**
Buskingham No.7	**D-2223**	**Sealed**
Rosebud Deep Mine No.16	D-2397	Sealed
Nelms/Cadiz	D-0426	Idle
Shean Hill	**D-2187**	**Idle**
Yellowbush	**D-2317**	**Idle**
Mountain Spring/Deep Mine No.10	**D-1180**	**Idle**
Tusky	D-2177	Active
Buckingham No. 6	D-2269	Active
Vail	D-2355	Active

Mine Name	Permit Number	Mine Status
Century	D-0425	Active
Hopedale	D-0424	Active
Carrollton	D-2438	Active
KLM No. 7	D-2401	Not Started
Dohrman	D-2453	Not Started
Ginger Bend	D-2448	Not Started
Leesville	D-2385	Not Started
Sunny Hill No. 7	D-0325	N/A
Sagnaw	D-0328	N/A
Deep Mine No.9 / Guernsey	D-2241	N/A

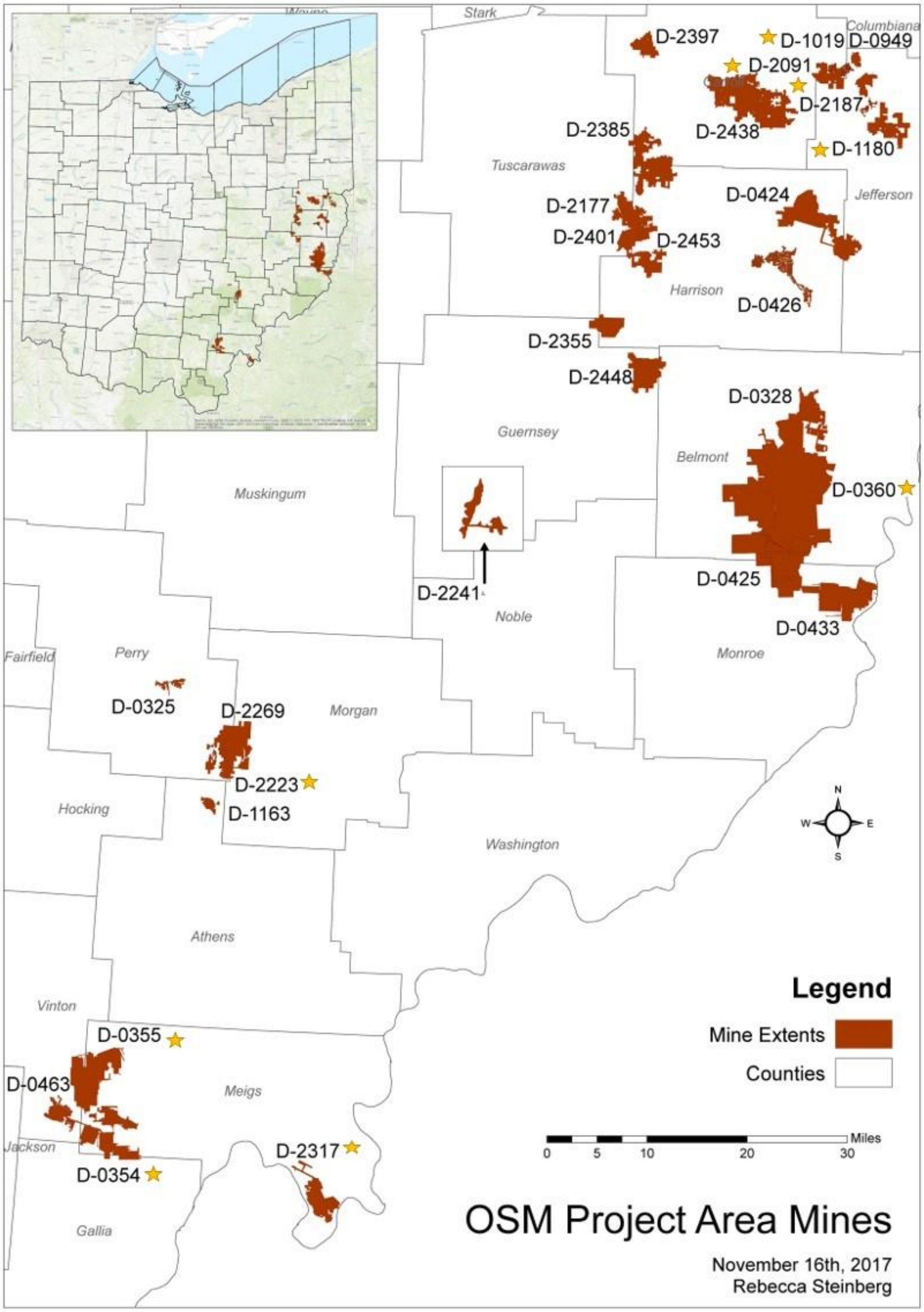

Figure 11. Location of mines received from ODNR. Mines labeled with a star indicated mines used in this study. (Elaborated by Rebecca Steinberg for this project).

Borehole Data

To obtain detailed descriptions of the lithology within the mine areas, borehole logs reported in the mine permits were collected. The data recorded from mine permit borehole logs is shown in Table 2. The recorded mine permit number corresponds to the permit and the adjacent area the borehole was found in. The X and Y coordinates were recorded as displayed on the borehole log and later changed by the project Geographic Information Systems team (GIS team) to State Plane 83 Ohio South for mapping purposes. Surface elevation of the borehole was recorded as displayed on the borehole log in feet above mean sea level (msl). The borehole's depth from surface was calculated by taking the sum of all strata in the borehole log. The bottom of borehole elevation was calculated by subtracting the depth from surface from the surface elevation. Overburden thickness above the mined coal seam is calculated by subtracting the sum of strata thickness below the top of the mined coal seam from the total extent of the borehole. Overburden thickness in this project is considered as all rock above the mined coal seam. Thickness of the mined coal seam in feet was recorded as identified in the borehole log. The strata above and below the mined coal seam were recorded as identified in the borehole log. Lastly, the total thickness of each rock type was calculated by taking the sum of each type of strata for the entire borehole.

Table 2: Collected borehole data. Source of data: mine permits provided by ODNR.

Borehole Data
Mine permit number
Drill hole name

Borehole Data
Coordinate X
Coordinate Y
Date
Surface elevation (msl)
Borehole depth from surface (ft)
Bottom of borehole elevation (msl)
Overburden thickness (ft)
Thickness of mined coal seam (ft)
Strata above
Strata below
Thickness shale (ft)
Thickness sandstone (ft)
Thickness limestone (ft)
Thickness clay (ft)
Thickness coal (ft)

Well Data

To obtain detailed descriptions of the hydrology within the mine areas, groundwater descriptions reported in the mine permits were collected. The type of data recorded from each well is shown in Table 3. The recorded mine permit number corresponds to the permit and/or expansion the well was found in. The X and Y coordinates were recorded as displayed on the borehole log and later changed by the project GIS team to State Plane 83 Ohio South for mapping purposes. The date that the water was sampled was recorded. Surface elevation of the sampling station was recorded in feet above mean sea level. Depth of well below the land surface was recorded in feet.

Static water level was recorded in feet. Some wells that had recorded static water levels for multiple dates throughout a year and average potentiometric heads could be calculated. The bottom of well elevation was calculated by subtracting the reported well depth from the surface elevation of sampling station. Potentiometric head values were calculated by subtracting the reported static water level from the surface elevation for the sampling station.

Table 3: Collected well data. Source of data: mine permits and quarterly monitoring reports provided by ODNR.

Well Data
Mine permit number
Well name
Coordinate X
Coordinate Y
Date
Surface elevation for sampling station (msl)
Depth of well below land surface (ft)
Static water level (ft)
Bottom of well elevation (msl)
Potentiometric head (msl)

In the groundwater descriptions, aquifer identification letters are given to each well, where aquifers are identified by using a “coal seam up” cyclothem method. This method groups aquifers into cyclothems which are identified as being above a coal seam. For mine D-0360 there were three identified cyclothems, Washington No.12, Waynesburg No.11 and Sewickley No.9 shown in Figure 12. Wells were identified by the mining companies into cyclothem groups depending on their depth. For example, a well that is not deeper than the Washington No.12 coal seam would therefore be placed into the Washington No.12 cyclothem group whereas a well that terminates below both the Washington No.12 and Waynesburg No.11 coal seams would be placed into the Sewickley No.9 cyclothem.

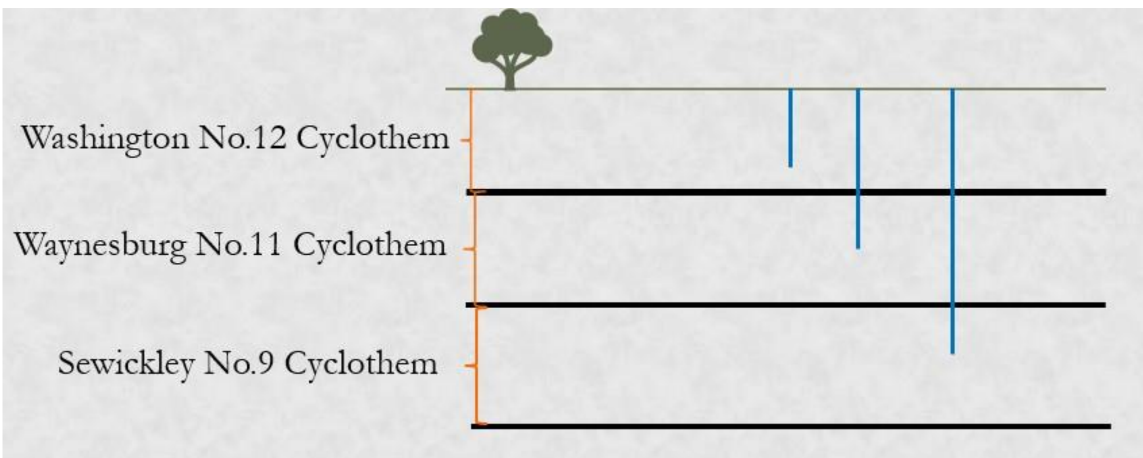

Figure 12: D-0360 cyclothem aquifers. The blue lines represent different well depths that fall into the three cyclothems.

Potentiometric head maps were created using the kriging method in Surfer, but these maps showed great complexity that is probably not real, as seen in Figure 13. Ohio’s geology is complex and what mine researchers had reported as an aquifer related to the cyclothem is likely composed of a series of small aquifers. For that reason, instead of using an identification of the aquifer or the depth of the aquifer in general, it was decided only to use the bottom of well elevation as one of the regression variables in the statistical analysis.

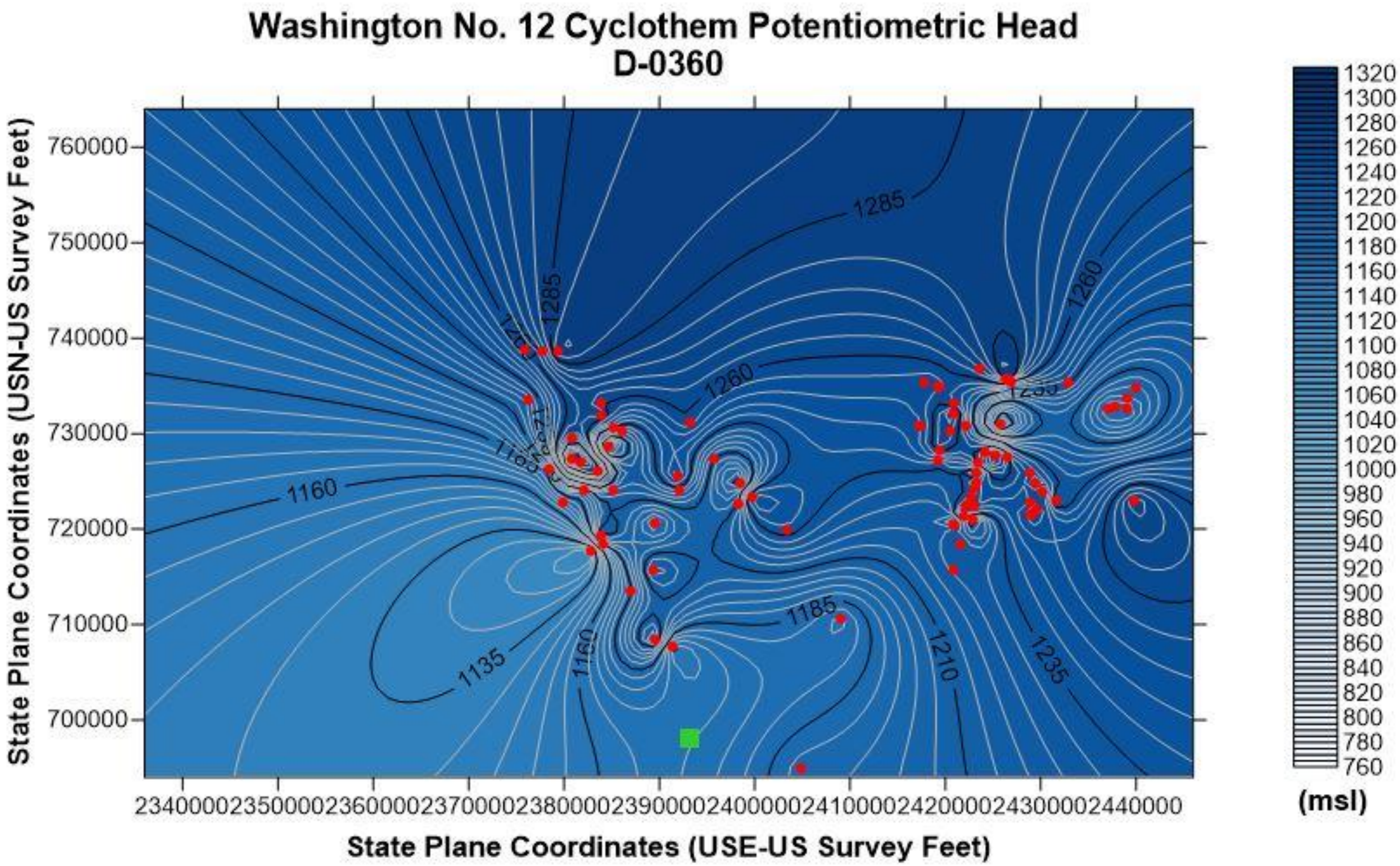

Figure 13: D-0360 Washington No.12 cyclothem potentiometric head map. The red dots represent wells and the green square represents a water extraction point. Note the great complexity of the model that suggests multiple aquifers rather than one.

5.1.2 Data Acquisition from Additional Sources

The two mines within the Meigs Mine Complex that were studied in this project (D-0354 and D-0355) did not have adequate well data provided in the mine permits. Therefore, shaft data provided by Mary Ann Brorch was substituted for well data for these two mines. The shaft data provided water level data within shafts in the mine workings from January 2008 to December 2016.

Quarterly monitoring reports (QMRs) were obtained from ODNR to obtain more well data. Under SMCRA, mining companies are required to submit quarterly water monitoring reports to assess if there has been a hydrological impact (Power and Adkins, 2010). These reports contain hydrological data for wells that were listed in mining permits for multiple years after a mine section has closed, even if other parts of the mine are still being exploited. The same parameters that were recorded for wells found in the mine permits were recorded for the QMRs.

A significant parameter that was required for this study was the volume of water that was extracted from mines while mining was occurring. This information however, is not recorded by mining companies and had to be approximated from water withdraw data collected from ODNR Division of Water Resources (ODNR-DWR) and the United States Environmental Protection Agency's National Pollutant Discharge Elimination System (NPDES) permit program.

The ODNR-DWR extraction data was obtained for each county that contained a studied mine. This extraction data supplied monthly extraction volumes in millions of gallons per month for hydro fracturing, mineral extraction, public uses, power and industry. Each of these points was mapped by the OSM GIS team to illustrate their location relative to the mine areas. Powhattan No. 6 (D-0360) was the only mine that had a labeled mineral extraction water withdraw within the mine boundaries shown in Figure 14. The other mines did not have any mineral extraction withdraw points near their boundaries that had data, and therefore no ODNR-DWR extraction data could be collected for the remaining mines. It should be noted that the water withdraw data needed for this study was data reported for the period of time that the wells have reported head measurements.

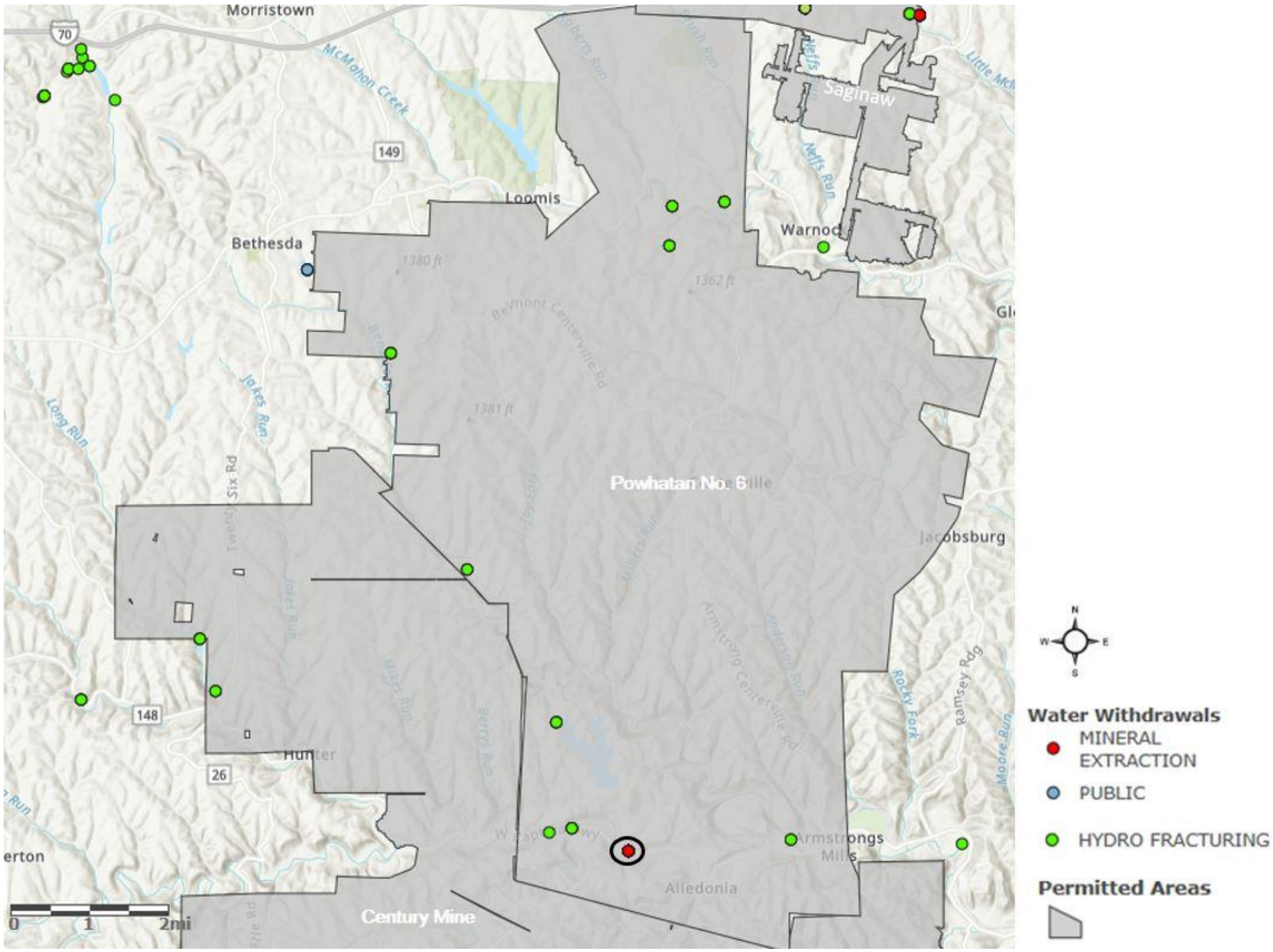

Figure 14. ODNR-DWR water withdraw locations for mine D-0360. The circled mineral extraction was identified as belonging to Powhatan No.6.

National Pollutant Discharge Elimination data is water data reported to the USEPA under the Clean Water Act (US EPA, 2018). This data is reported by county and contains watershed, water chemistry, pollutant load and average daily flow in millions of gallons per day and reported in a publicly available online format from only January 2007 to December 2016. NPDES data was collected for seven of the mines under investigation (D-0354, D-0355, D-0360, D-1019, D-2091, D-2223 and D-2317) and data was not found for the remaining mines (D-2187 and 1180). The NPDES reports several locations of water withdraw, therefore the centroid of these points was assumed to be the withdraw location. The NPDES locations for D-0360 can be seen in Figure 15.

One parameter that was added to the data set for the statistical analysis is the distance of wells to the water withdraw points. It is reasonable to assume that the shorter the distance to the water extraction point to the well, the impact of the water extraction on the well head should be greater. With the information collected from the ODNR-DWR and NPDES, the OSM GIS team was able to provide the distances from the well to the withdraw points. The water withdraw should have a higher impact if the volume extracted is greater. The parameter W/D was then included in the regression set, where W is the average volume of water extracted during the period of time that water heads were recorded for the well, and D is the distance from the well to the withdraw point. The level of water in the wells after the mine closes and when there is no more water extraction of the mine should correspond to a value of zero for the parameter W/D.

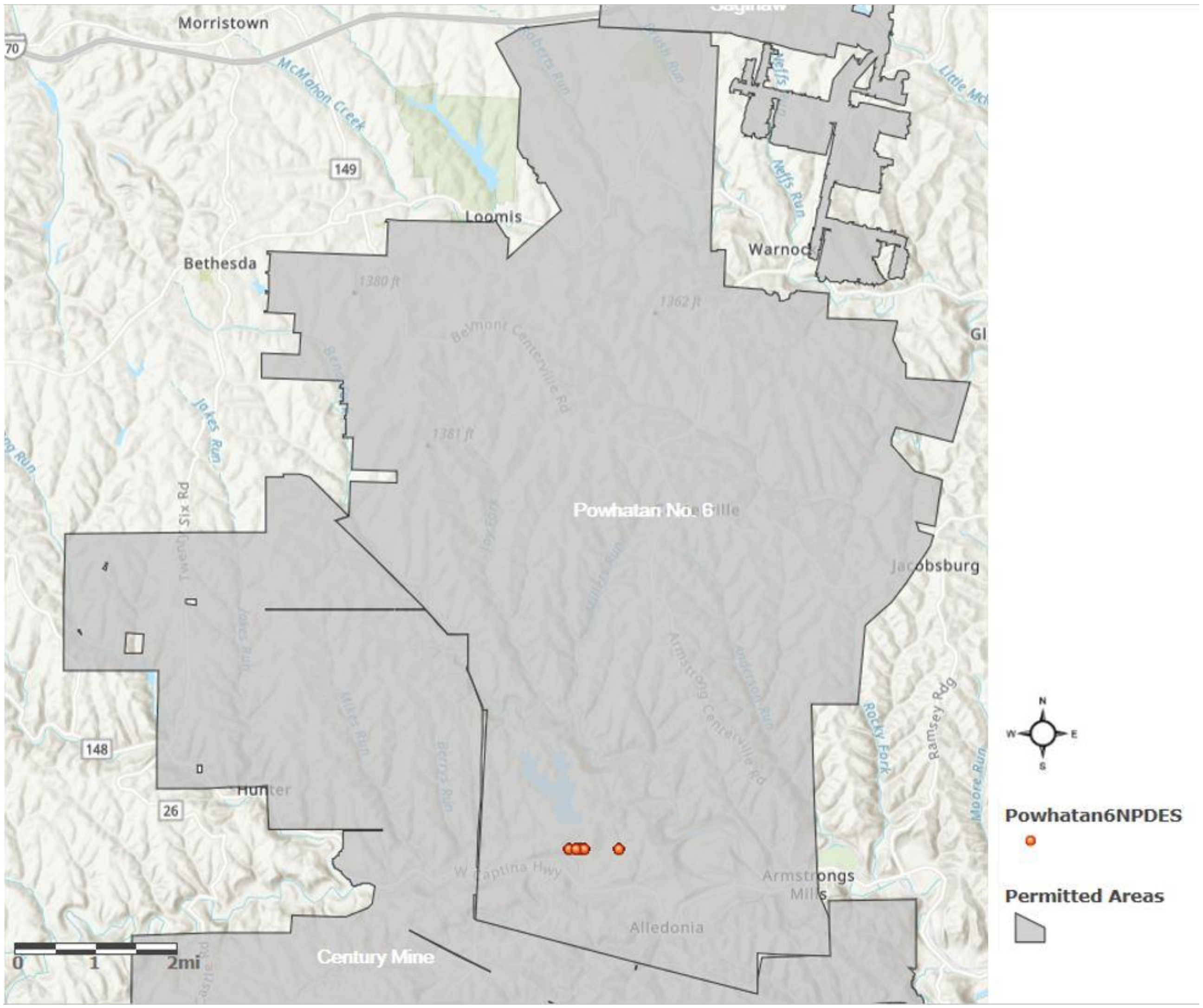

Figure 15. NPDES water withdraw locations for mine D-0360.

It is very common in Ohio to have recent coal mines surrounded by large areas of old and abandoned underground coal mines. These areas with large underground cavities should impact the hydrogeological system of the area. For that reason, it was necessary to include the in the statistical analysis the presence of these mines. As the thickness of the coal layers is not very variable, it was decided to consider only the area around the mine that contained abandoned or more recent mines that had been mined or are mined at the present time. Mine shape files were obtained from the ODNR Online Mines of Ohio Viewer and transferred into ArcOnline (ODNR b, 2018). Using these shape files, the OSM GIS team calculated spatial parameters such as the final mined out area (total area of the mine of interest that has been mined), acreage of underground mines within 1, 2 and 4-mile buffers. An example of the 4-mile buffer with respect to D-0360 can be seen in Figure 16.

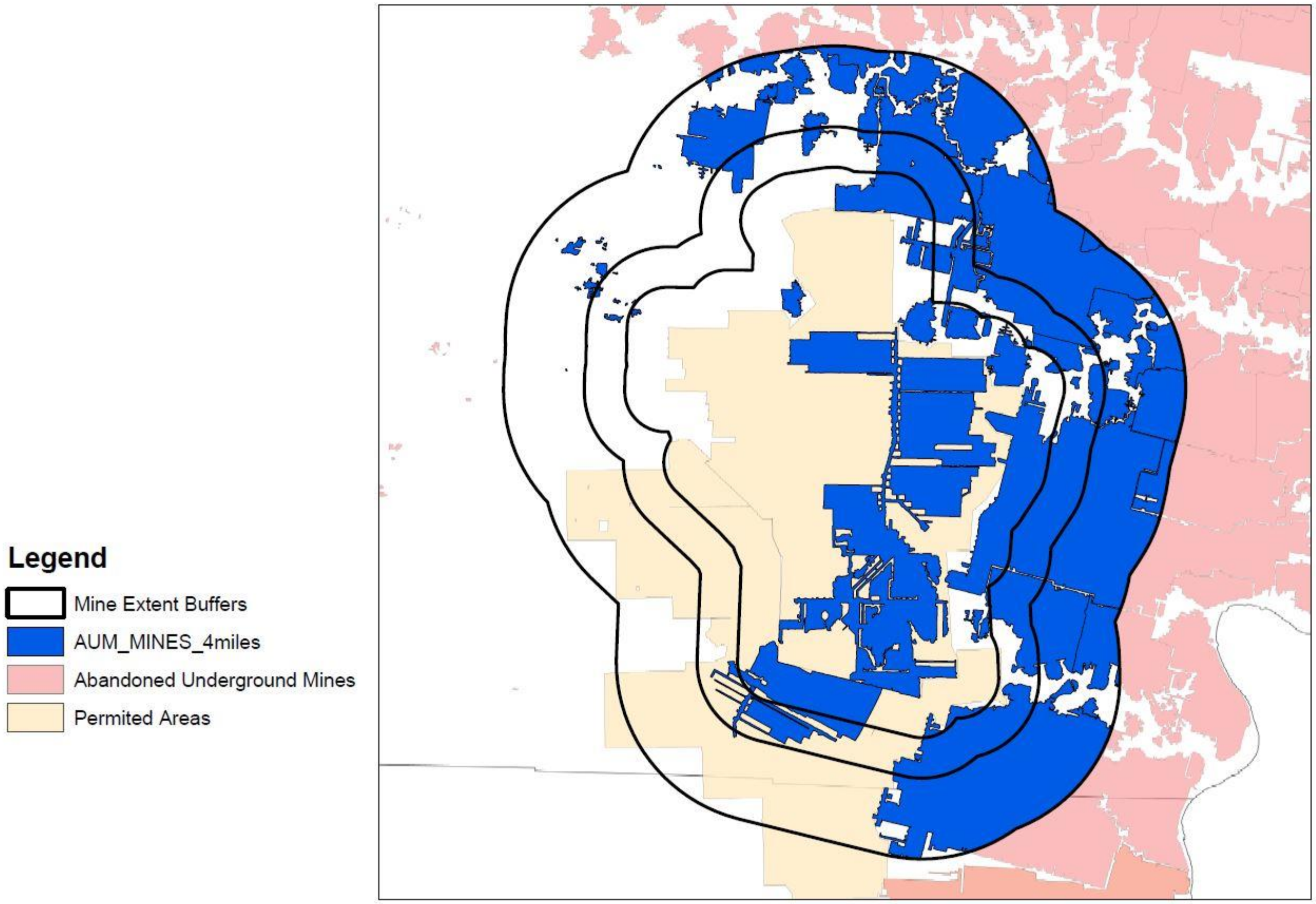

Figure 16. Mine D-0360 4,2, and 1-mile buffer area. The outer black line represents the 4-mile area, the middle black line represents the 2-mile area and the internal black line represents the 4 mile area of abandoned mines. Permitted areas for mines D-0360 and D-0425 are shown in tan and abandoned underground mine areas within 4 miles are shown in blue. (Elaborated by Rebecca Steinberg for this project).

Important parameters that should be collected are the geology of the wells under consideration. However, in most of the wells found in the mine permits and QMRs, the stratigraphy of the wells is not listed. Another source of information that we could use are the lithologies reported for the hundreds of boreholes drilled for each mine and presented in the mine permits. It was decided to use the nearest borehole to each well under consideration and input the thickness of each lithology. The nearest borehole to each well was identified by the OSM GIS team. The lithology considered was the thickness of shales, clays, sandstones, limestones and coals within the borehole.

Another parameter that should influence the water levels in the monitoring wells is the extent of mine exploitation at the time the heads were measured in each well. Quarterly weight of coal removed from each mine was obtained from the Mine Safety and Health Administration (MSHA) mine data retrieval system (MSHA, 2018). This data was converted into volume of coal removed using the bulk density of coal of 833kg/m^3.

Average precipitation values were recorded using an average annual precipitation map obtained from ODNR Division of Water Resources Hydrologic Atlas. The mines map was overlaid on the precipitation map by the OSM GIS team as shown in Figure 17. This map was created using data collected from the National Oceanic and Atmospheric Administration from the years 1931 – 1980 (ODNR c, 2018). More precise monthly precipitation data was collected from the National Oceanic and Atmospheric Administration's archived climatological data for Columbus, Ohio between the years 1996 and 2017 (NOAA, 2018).

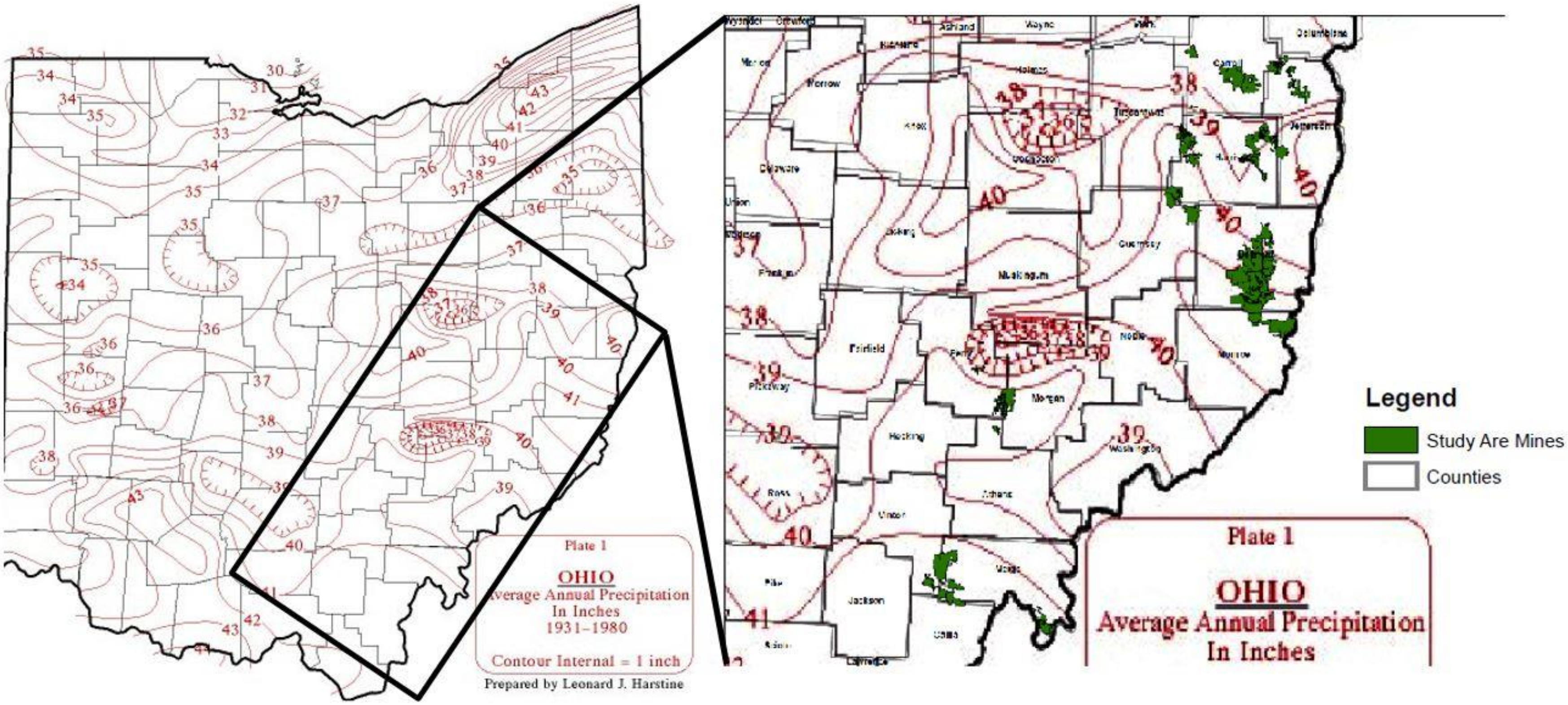

Figure 17. Average annual precipitation map of Ohio showing studied mines in green. (retrieved and modified from http://water.ohiodnr.gov/maps/hydrologic-atlas#PRE)

5.2 D-0360 Well Analysis

To understand hydrological responses for a single mine, D-0360 was chosen for analysis because this mine had the largest number of wells and data available. The primary focus of the data analysis were the wells.

Three time periods were established for this mine, pre-mining: pre-1984, active mining: 1984-2014 and post-mining: 2014-present. These time periods are based on the D law permit start date of permit D-0360-00 and expiration date of D-0360-30, not the time period of when mining actually occurred. Mining began prior to 1984 for D-0360 and ended in 2016 but there was no data received prior to 1984 and no permit data received past 2014.

Wells that had static water levels recorded in both the active mining and post-mining periods were selected for the hydrological response analysis. There were no wells listed in the permits that had static water levels recorded during the pre-mining period, therefore no analysis could be done on this time period. Note that wells can have data for different periods of time, there is not a consistent continuous way of collecting data in all of the mine permits. For that reason, the average, maximum and minimum head for each well correspond to a period of time that is characteristic of each well. This occurs with all of the wells for all of the studied mines. For this reason, variables such as accumulated coal volume extracted and water withdraw have been calculated for each well during the period of time considered for the evaluation of the heads.

At first, the idea was to consider pre-and post-mining conditions for each mine. However, the analysis of D-0360 and other mines made us realize that mine activity is a very complex matter in Ohio. Clear periods of time such as pre- and post-mining are difficult to elucidate and in addition, a mine can close but another active mine can be installed very near the closed mine. This is the case with Powhatan No.6 (D-0360) and Century mine (D-0425). For that reason, the approach considering pre-and post-mining was abandoned. It was decided to instead consider the variables that determine the heads during the monitoring period of each well to obtain a regression equation. For the application to the coal layer and the possible water head after mine closure, the consideration of maximum extracted coal and zero water withdraw should give the extrapolated water head conditions at the coal elevation. Note that extracted coal should also determine the amount of dewatering that the mined-out area should be experiencing.

To compare the active and post-mining potentiometric head levels, potentiometric head values were plotted against the date they were reported. To determine if there was a relationship between potentiometric head levels and precipitation, post-mining potentiometric heads were plotted against the date they were reported and graphed with monthly precipitation data collected in Columbus, Ohio. To establish the lag time between the potentiometric head levels and precipitation, the program PAST (Hammer et al., 2001) was used to construct a cross-correlogram of monthly precipitation and potentiometric head at the wells. This program gradually shifts the two data sets until they have the best fit together. The points with high correlation values and lower p values correspond to the lag times between the two variables, or how long one variable is delayed with respect to the other.

5.3 Single Mine Models: D-0360

To create a statistical model of a single mine, multivariate statistical analysis was performed on D-0360 because this mine had the largest amount of data. Four different models were made for this single mine analysis because D-0360 was the only mine that had water extraction data from the ODNR-DWR and NPDES resources. For analysis, ten percent of the wells for each model were randomly selected and used as the validation set for the model, the remaining wells were used as the prediction set.

The first model (D-0360 ODNR-DWR) was ran using ODNR-DWR water withdraw data and wells that had data sometime during the time period of January 1991 to December 2016. Average potentiometric heads and average water withdraw in millions of gallons per month for each well were calculated using data recorded during 1991 to 2016. The distance from each well to the ODNR-DWR water withdraw point was calculated by the OSM GIS team. For the statistical analysis, the average monthly water withdraw for the whole mine was divided by the distance from the well to the withdraw point. The concept is that the closer the well to the withdraw point and the greater the water withdraw, the greater the impact on the potentiometric head at the well.

The X variables used in the multi-variate statistical analysis for the 0360 ODNR-DWR model are shown in Table 4. The Y variable for the analysis was the average potentiometric head of the wells at a time point between during 1991 to 2016. Each well has a particular period of time when the potentiometric heads were measured. For example, well W-291 from D-0360 has recorded heads from November 1993 to April 1994. See Table B1 in Appendix B for the time periods of each well. The second 0360 model was run using the same X and Y variables but removed the withdraw divided by distance parameter.

Table 4. D-0360 ODNR-DWR statistical model X variables.

X variables
Well surface elevation for sampling station (msl)

Bottom of well elevation (msl)
ODNR-DWR withdraw (MGal/Month) / Distance to withdraw point (ft)
Overburden thickness with respect to the mined coal seam (ft)
Mined coal seam thickness (ft)
Clay + Shale thickness (ft)
Sandstone thickness (ft)
Limestone thickness (ft)
Total coal thickness (ft)

The third 0360 model (D-0360 NPDES) was run using the NPDES water withdraw data and wells that had data sometime during the time period from January 2007 to December 2016. Average potentiometric heads and average water withdraw in millions of gallons per day for each well were calculated using data recorded from 2007 to 2016. The distance from each well to the NPDES water withdraw point was calculated by the OSM GIS team. For the statistical analysis, the average monthly water withdraw for each well was divided by the distance to the withdraw point.

The X variables used in the multi-variate statistical analysis for the 0360 NPDES model are the same variables in Table 4 with the exception of the variable ODNR-DWR withdraw (MGal/Month) / Distance to withdraw point (ft), which instead is NPDES withdraw (MGal/Day) / Distance to withdraw point (ft). The Y variable for the analysis was the average potentiometric head of the wells sometime during 2007 to 2016.

The fourth 0360 model (D-0360 All wells) was run without considering any withdraw data and all the wells that have data for some period of time within the long-time period of 1984 to 2017. Therefore, the X variables used in the multi-variate statistical analysis were the same as the second model. The Y variable for the analysis was the average potentiometric head of the wells sometime during 1984 to 2017.

5.4 Multi-Mine Model without Water Withdraw

A statistical model was created using data from eleven mines shown in Table 5. In two of these mines (D-1180 and D-2187), two different coal seams were mined and are therefore identified separately by coal seam (D-1180-6, D-1180-7, D-2187-6 and D-2187-7). Where D-2187-7 indicates the removal of the #7A Mahoning coal, D-1180-7 indicates the removal of the #7 Upper Freeport D-2187-6 and D-1180-6 indicate the removal of the #6A Lower Freeport.

Table 5: Mines studied in multi-mine without water withdraw model.

Permit
D-0354
D-0355
D-0360
D-1019
D-1180-7
D-1180-6
D-2091
D-2187-7
D-2187-6
D-2223
D-2317

The X variables analyzed for the multi-mine without water withdraw are the same as the D-0360 fourth model with the addition of accumulative coal volume (Mm^3), underground mine area within 4 miles (acres) and average annual precipitation (in). The accumulative coal volume is the sum of coal volume extracted up to the most recent day the static water level was recorded for each well. This is done because the water withdraw should be related to the accumulated coal extracted, and that variable is already under consideration. The greater the accumulated coal extracted, the larger the volume of water that should be extracted to dewater the mine to maintain the workings. The underground mine area within 4 miles is the sum of void space from abandoned and recent mines within a 4-mile radius of the mine extent. The Y variable for the analysis was the average potentiometric head of the wells. The maximum and minimum potentiometric heads were analyzed using the same methods.

5.5 Multi-Mine Model with NPDES Water Withdraw

The multi-mine with water withdraw model was created using the mines shown in Table 6 with the exception of D-1180 andD-2187 because no NPDES data was found for these mines. The data set for the multi-mine model that considers the NPDES water withdraw is therefore smaller.

The X variables analyzed for the multi-mine with water withdraw the same as the multi-mine model without water withdraw with the addition of withdraw (MGal/D)/distance to the withdraw point (ft). The accumulative coal volume is the sum of coal volume extracted up to the most recent day the static water level was recorded for each well. The underground mine area within 4 miles is the sum of void space from abandoned and recent mines within a 4-mile radius of the mine extent. The Y variable for the analysis was the average potentiometric head of the wells that had data sometime between 2007 to 2016. The maximum and minimum potentiometric heads were analyzed using the same methods.

CHAPTER 6: RESULTS AND DISCUSSION

6.1 D-0360 Well Analysis

Hydrological data for 200 wells was collected from D-0360 mine permits. Although the number of wells for this mine is large, only eighteen of these wells, shown in Table 6 had active and post-mining data. The data for these wells is shown in Appendix A. The location of these eighteen wells in relation to D-0360's mine extent is shown in Figure 18. Well W336.375.00 will be used as the example for this thesis.

Table 6. D-0360 wells analyzed.

Well Name
DW-406
DW-719
W231.356.04
W336.375.00
W-410
W-413
W-414
W-415
W-428
W501.077.00
W501.077.01
W501.343000
W-709
WL231.362.00
WL336.373.00
WL-674
WL-721

Well Name
WL-736

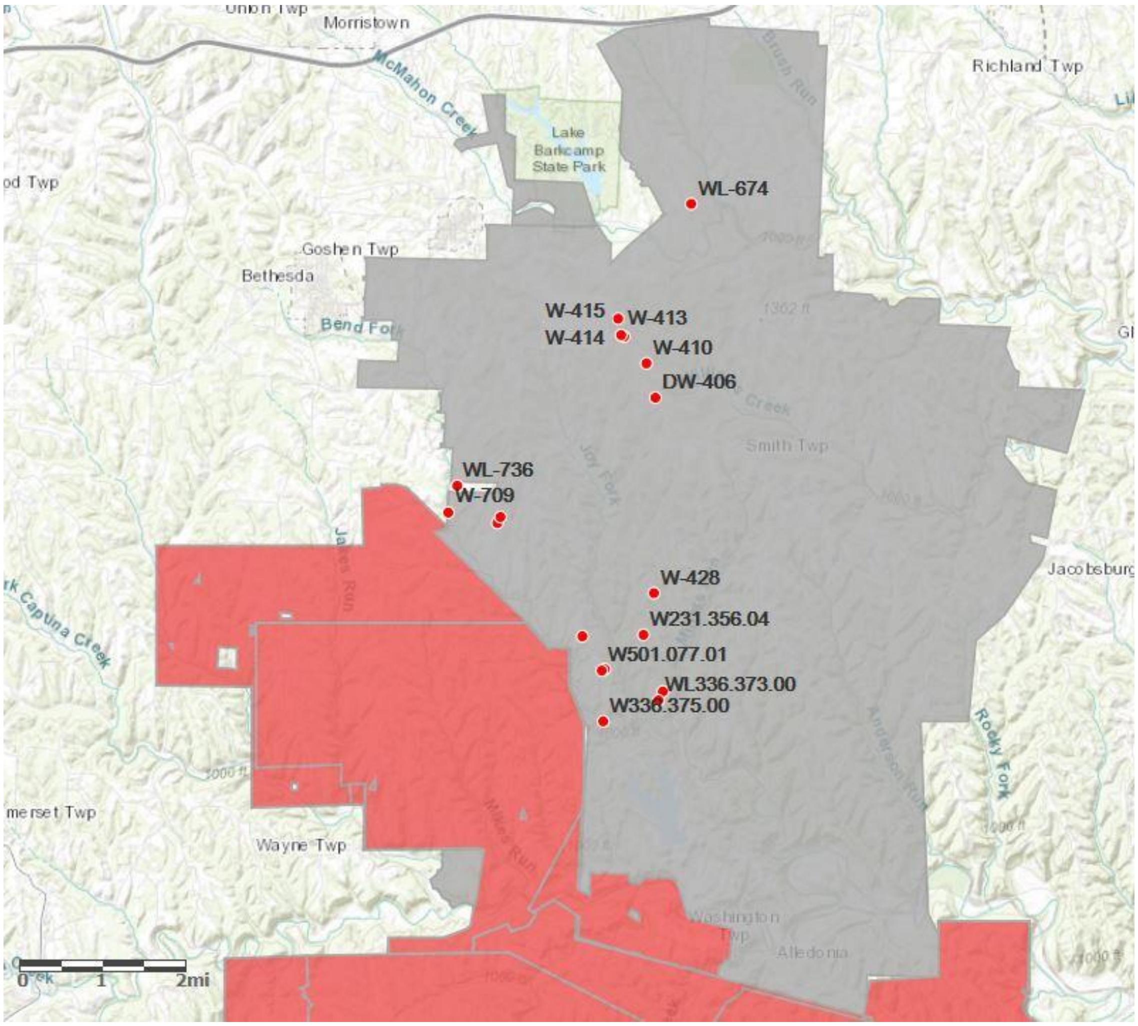

Figure 18. D-0360 wells with active and post-mining data (red dots) in relation to D-0360's area (grey) and D-0425's area (red).

To visualize changes in active and post-mining potentiometric heads, potentiometric head versus date graphs were made for each of the eighteen wells, this graph for well W336.375.00 is shown in Figure 19.

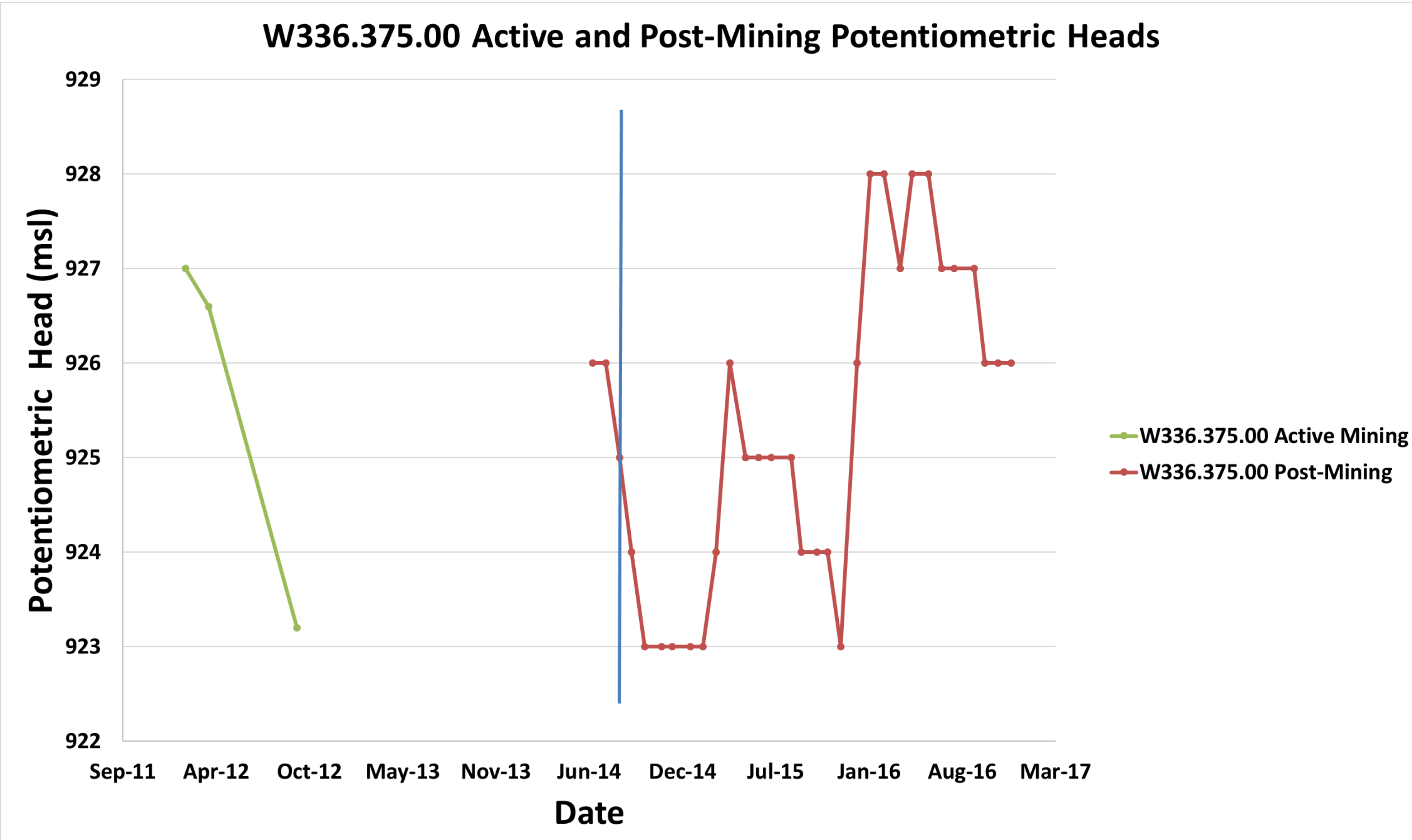

Figure 19. W336.375.00 Active (green) and post-mining (red) potentiometric heads versus time where the blue line represents the expiration date of the last mine permit received for D-0360.

The variability of the heads with time observed in Figure 19 could be produced by variations in the infiltrating water caused by precipitation. To determine if there was a relationship between potentiometric head levels and precipitation, post-mining potentiometric heads were plotted against the date they were reported and graphed with monthly precipitation data collected in Columbus, Ohio, this graph for W.336.375.00 can be seen in Figure 20. From this graph, it was concluded that fluctuations in potentiometric head have a relationship to precipitation. To quantify the lag time between precipitation and potentiometric head, the program PAST was used to evaluate the cross-correlogram between the two variables. The correlation and p-value versus lag time graph for W.336.375.00 is shown in Figure 21. By performing this test on fifteen of the eighteen wells that had consistent potentiometric head data, a lag time of one to three months was found between precipitation and potentiometric head levels for this mine. The average depth of these wells is 81.7 ft, which means the velocity for the infiltrating water is between 0.90 ft/day to 2.68 ft/day, which is a relatively high groundwater velocity.

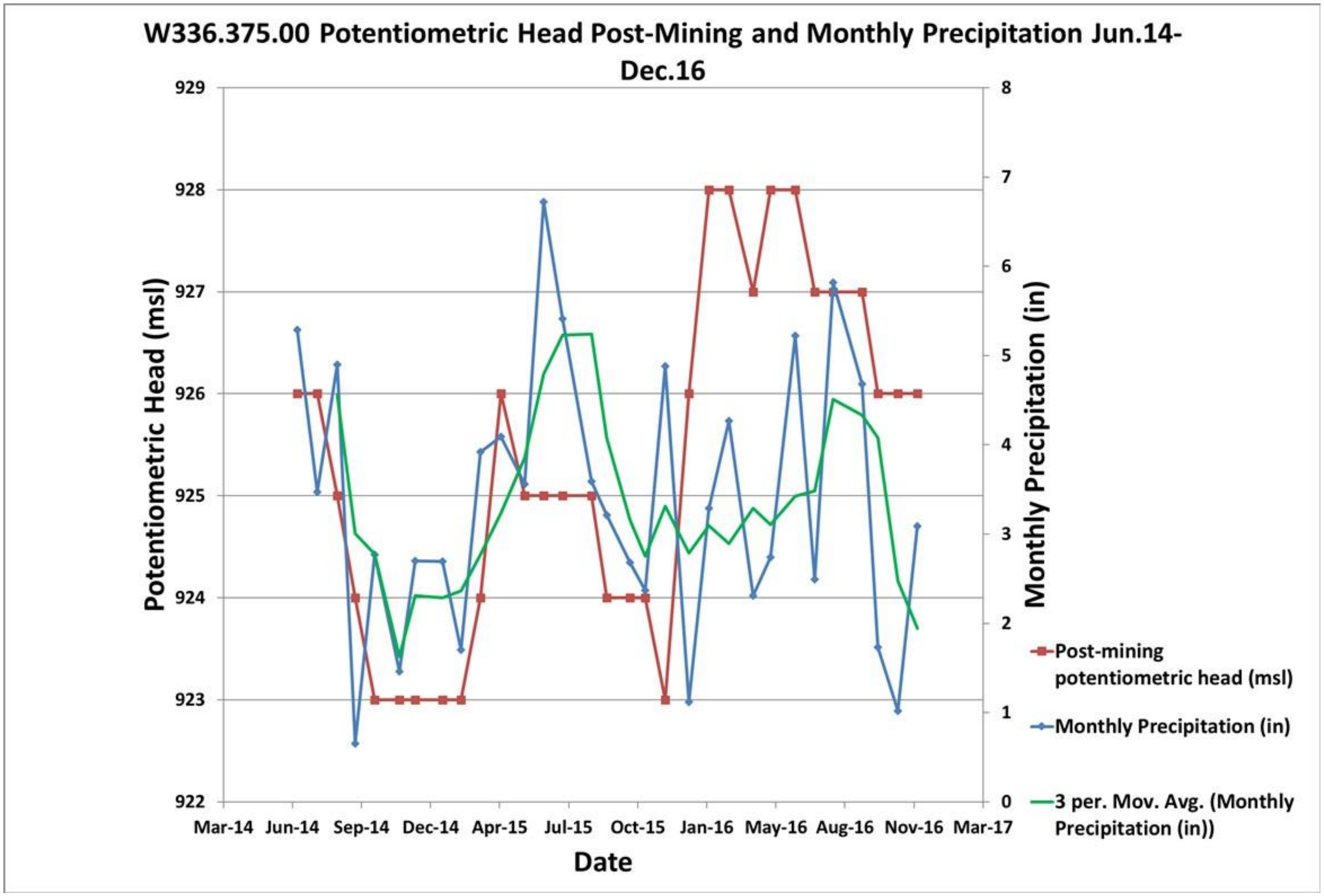

Figure 20. W336.375.00 post-mining potentiometric head (red) and monthly precipitation (blue) from June 2014 - December 2016. The green line represents the 3-month average of precipitation.

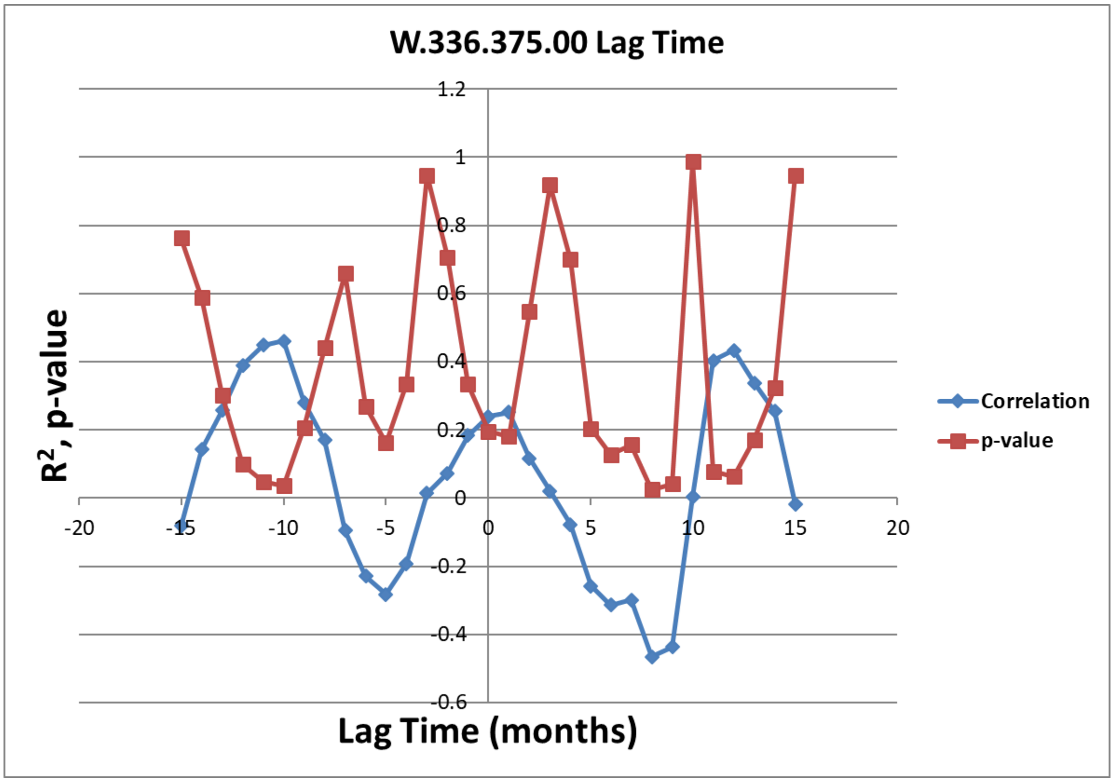

Figure 21. W.336.375.00 lag time graph. Correlation (blue) and p-value (red) versus lag time (months). Lag times are identified as points with high correlation and low p-values. A lag time of 1 month is observed in this graph.

6.2 Multivariate Statistical Analysis of Single Mine Models: D-0360

The first model ran for 0360 used ODNR-DWR water withdraw data and well data for 189 wells during the time period of January 1991 to December 2016. The data used in this analysis is shown in Appendix B.

6.2.1 Principal Component Analysis

For mine D-0360, the principal component analysis was run using 168 prediction wells and 19 validation wells. Unlike the PCR and PLS which analyze the relationship between the X variables and the Y variables, PCA investigates the relationship between samples and variables as a group.

The principal component analysis was able to explain 100% of the variance considering four principle components, shown in Figure 22. Unscrambler X computes explained variance using Equation 10, where the residual variance is the sum of squares of the Y-variable (average potentiometric head) divided by the number of degrees of freedom.

$$Explained\ variance = 100 \cdot \frac{(initial\ variance - residual\ variance)}{(initial\ variance)} \quad (10)$$

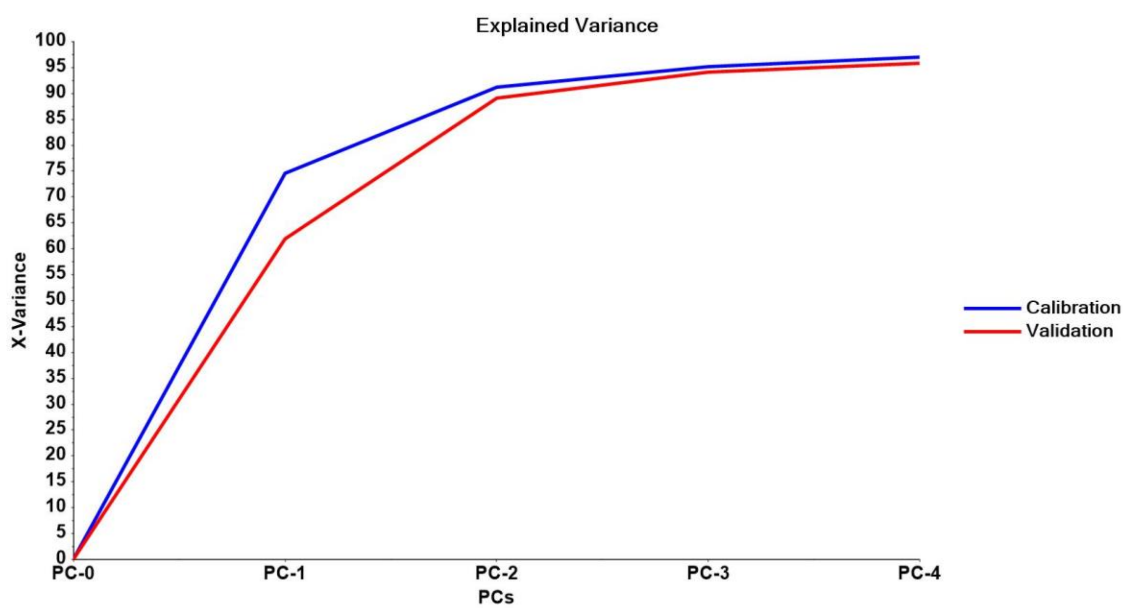

Figure 22. Principal component analysis explained variance graph for D-0360 ODNR-DWR average potentiometric head model. The blue line represents the calibration and the red represents the validation. It can be seen that there is 100% explained variance at PC-4.

To visualize the structure in the data a correlation loadings plot is examined (Figure 23), where the X and Y axes are the principal components that explain the most variance of the regression. The X and Y axes are the principal components that explain the most variance in the X-variables. This plot has two ellipses where the outer ellipse signifies 100% explained variance and the inner ellipse signifies 50% explained variance and the center of the plot is 0% explained variance. Therefore, the closer a variable is to the outer ellipse, the more variance it explains. Variables that are close to each other on this plot have a positive correlation and are dependent on each other, such as surface elevation and bottom elevation. Variables that are on opposite sides of the quadrant are negatively correlated and are independent of each other. As it will be shown later, the correlation loadings plot, shown in Figure 23, had the same relationships as those in PCR and PLS. Surface elevation, bottom of well elevation and average potentiometric head are all highly correlated variables and are inversely related to overburden thickness and thickness of limestone. Accumulative coal volume was the variable that explained the least amount of variance.

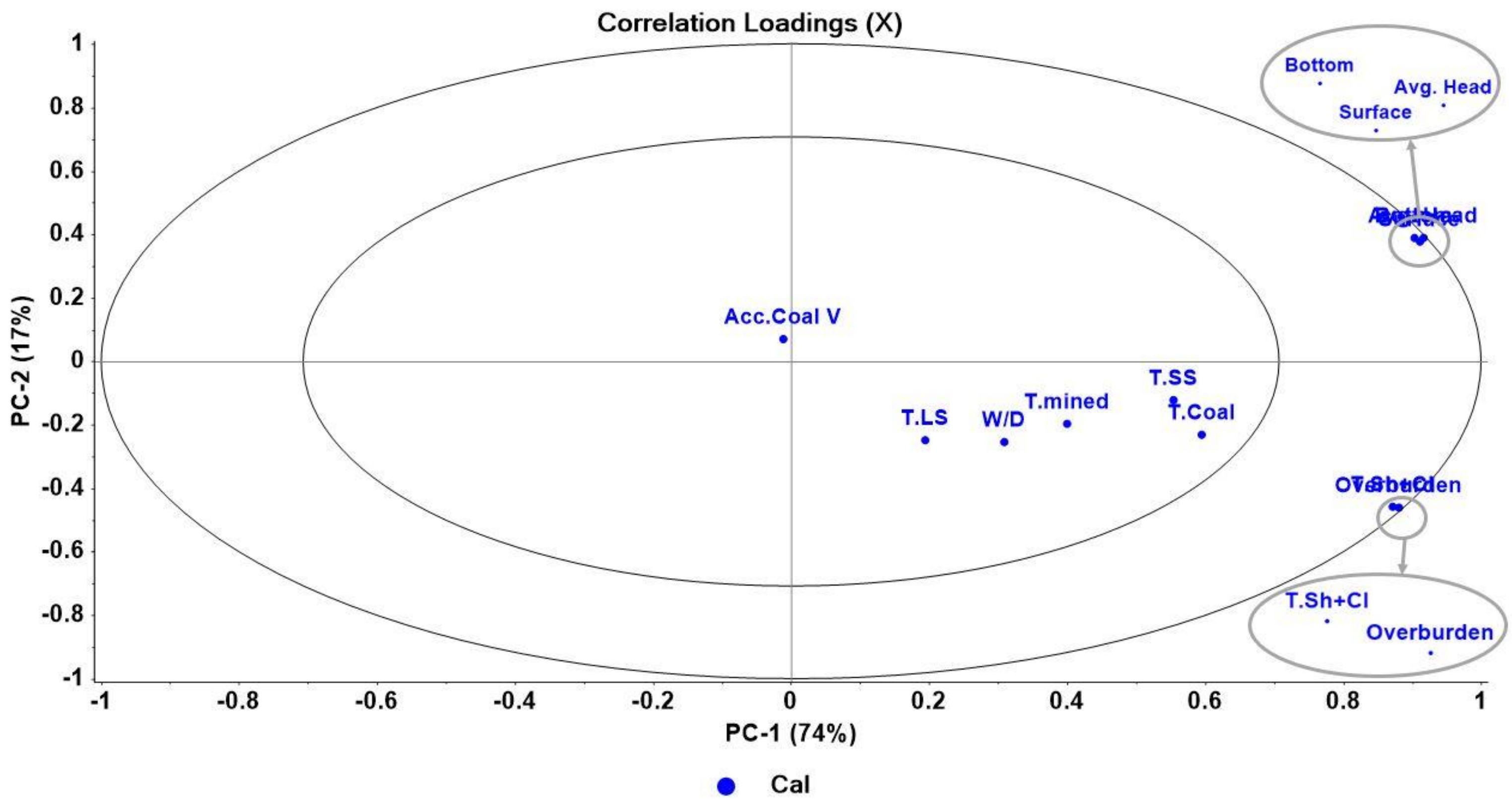

Figure 23. Principal component analysis correlation loadings plot D-0360 ODNR average potentiometric head model. The two axes are the principal components that explain the most variance. The inner ellipse represents 50% of the explained variance and the outer ellipse represents 100% of the explained variance. Therefore, parameters that fall within the first ellipse describe less than 50% of the explained variance and those that fall outside explain more than 50% of the variance. Parameters that are close together are highly correlated. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

To identify any patterns in the samples, a scores scatter plot is analyzed (Figure 24), where the X and Y axis are the principal components that explain the most variance of the regression. Samples which are close together on this plot are similar with respect to the principal components concerned and samples which plot far away from each other are different. This plot can also be used to detect grouping of samples, but in this case, all of the samples are fairly similar and there is no grouping. In this case, there was no unusual grouping of the samples found.

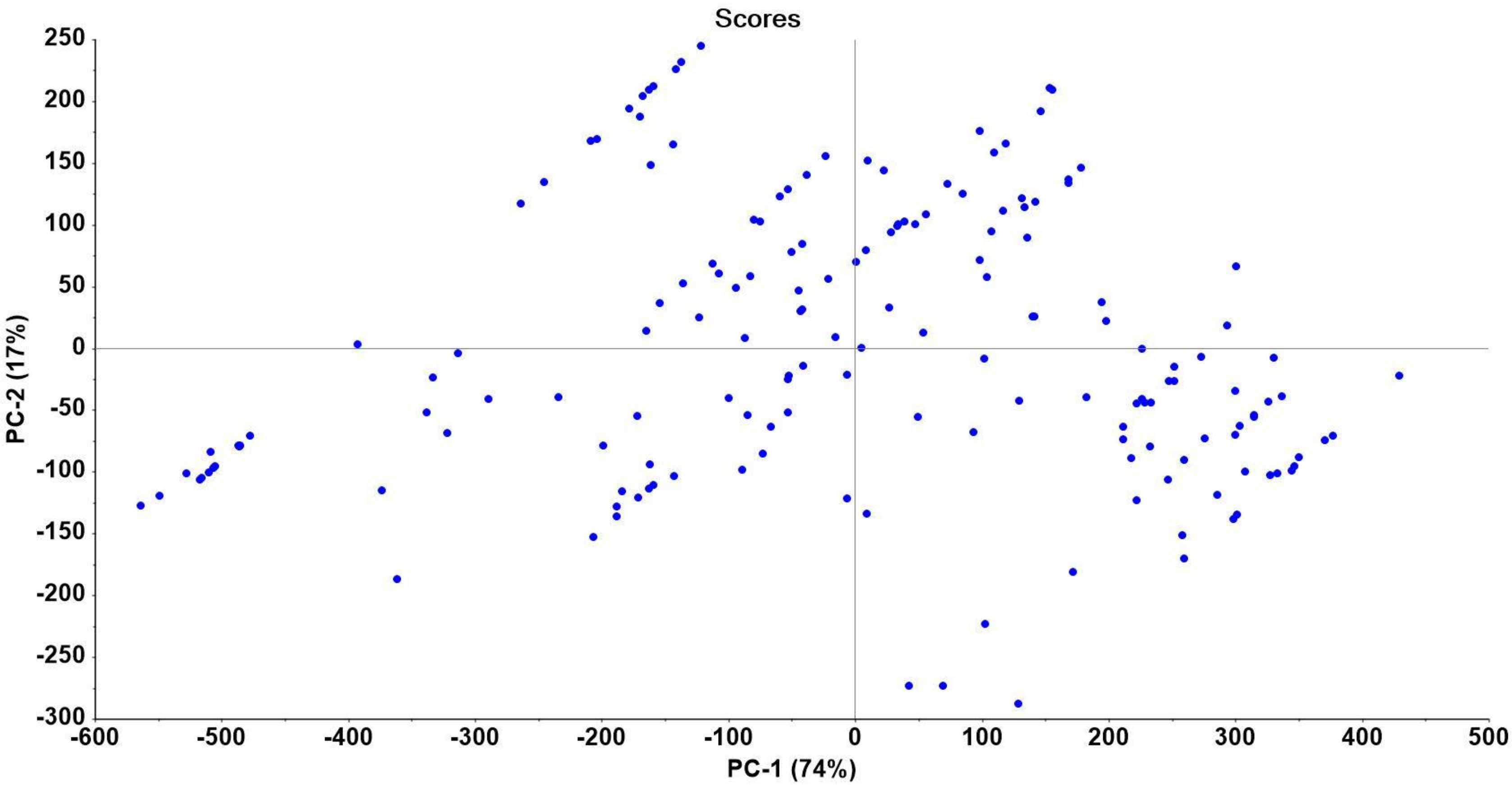

Figure 24. Principal component analysis scores plot for the D-0360 ODNR-DWR average potentiometric head model. There are no noticeable groupings of the samples indicating that all of the samples are similar.

6.2.2 Multiple Linear Regression

Multiple linear regression is a statistical method that performs well when all X variables under consideration are very independent of each other. For this reason, the MLR regression was not consistently effective on this data set because the surface and bottom elevations of the wells are highly correlated. The other statistical methods (PCR and PLS) were found to be more reliable and give better regression coefficients MLR was no longer considered for single mine analysis.

6.2.3 Principal Component Regression

The first run of the principal component regression was run with 170 prediction wells, and 19 validation wells. Leverage is a parameter that determines how far away the independent variable values of a sampling point are from those of the other sampling points. It allows for the identification of outliers in the data. Outliers were found using an influence plot of the X and Y residual variances versus leverage (Figure 25) and a residual sample calibration variance graph which plots the x variance for each sample (well) (Figure 26). Samples with high values on either of these graphs are outliers. Two wells were found to be outliers for this data set, W21-165.04 and W-426. The area of underground mines within a 1-mile, 2-mile and 4-mile buffers were run through PCR and it was determined that the 4-mile buffer was the most significant because it gave the highest correlation coefficient and lower errors. Therefore, only the area of underground mines within a 4-mile buffer was considered for the statistical analysis.

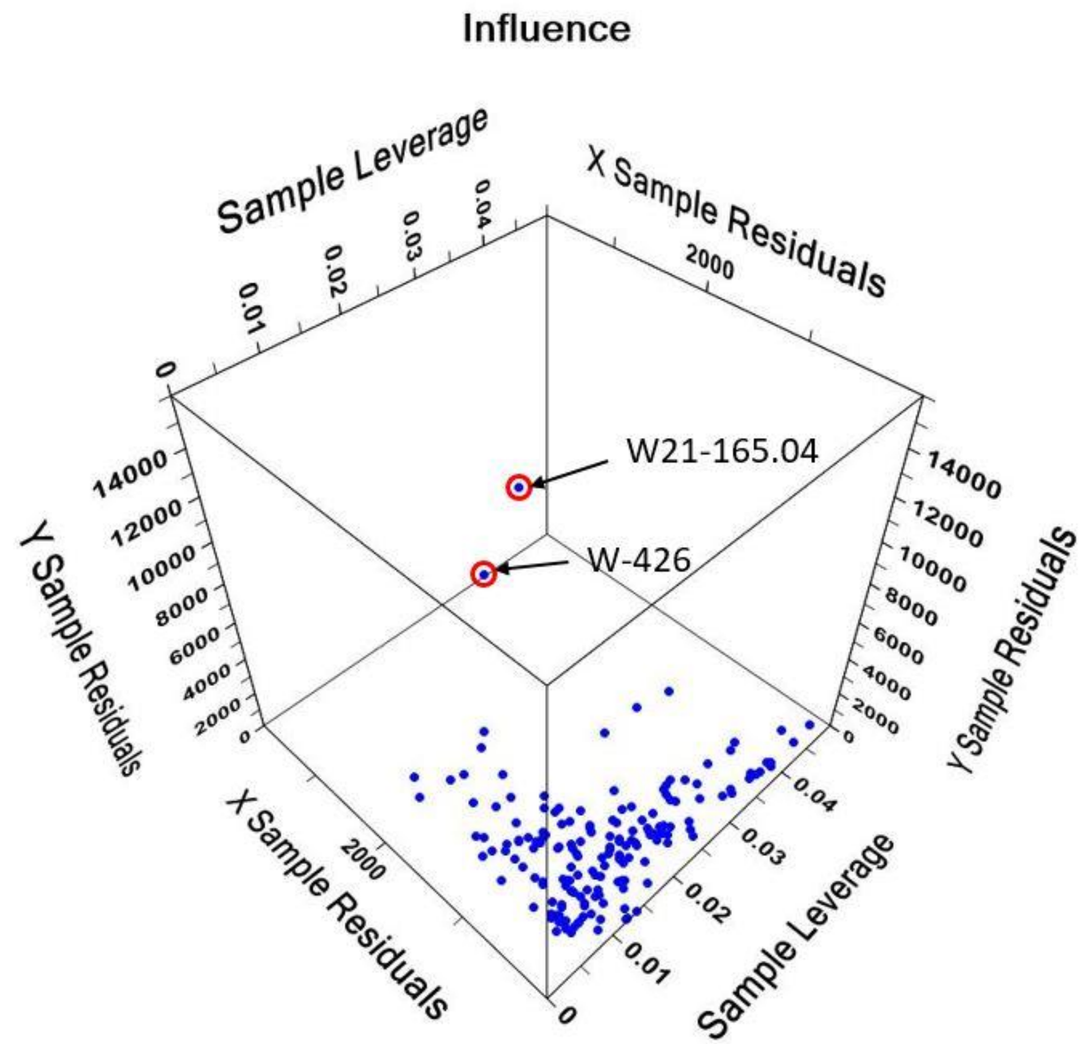

Figure 25. Influence plot for the D-0360 ODNR-DWR average potentiometric head model, principal component regression. Outliers (circled in red) vary dramatically in leverage and residual in both X and Y from the other samples.

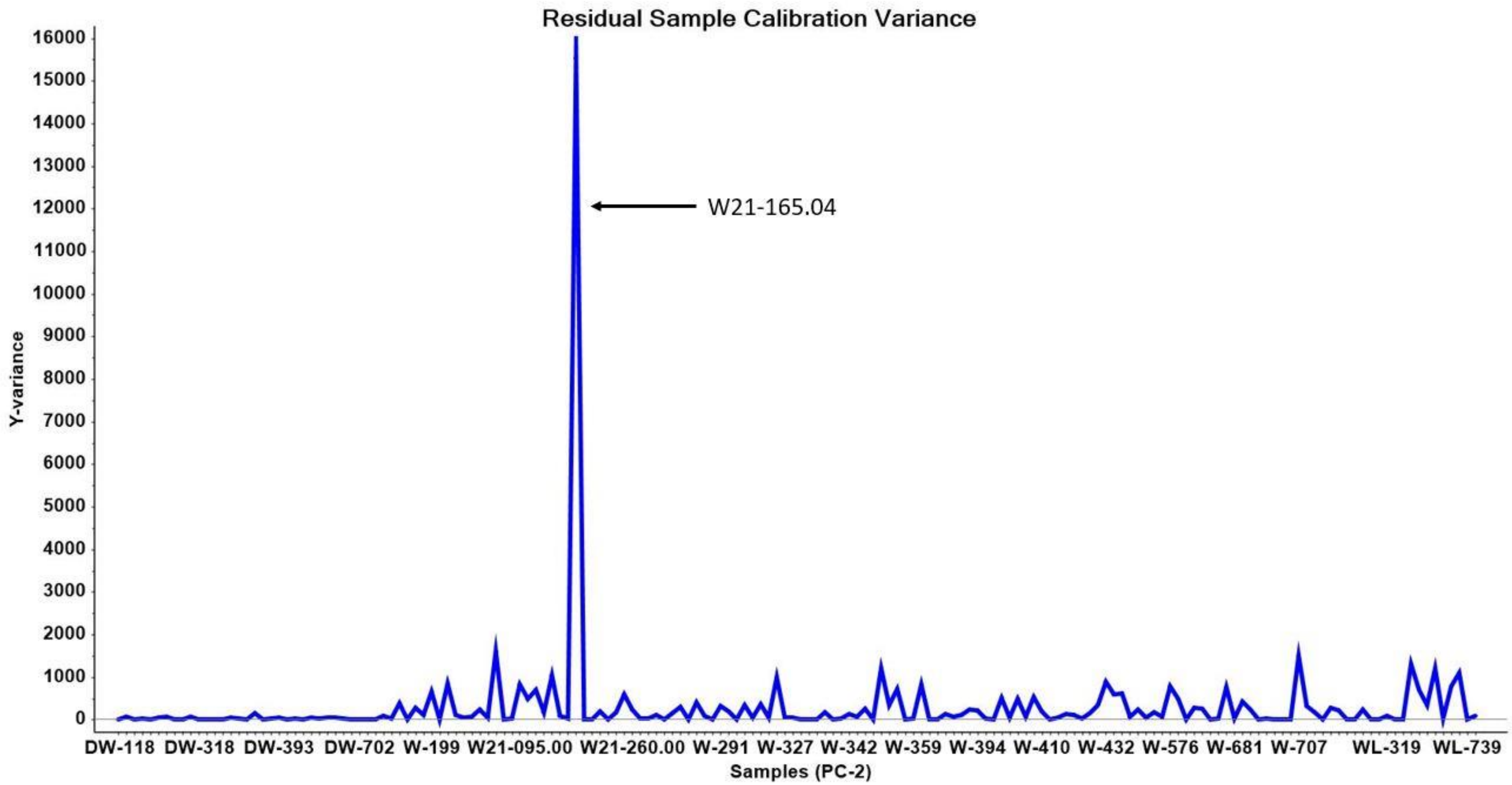

Figure 26. Principal component regression residual sample calibration variance plot for the D-0360 ODNR-DWR average potentiometric head model. Wells are on the X axis and y-variance is on the Y-axis. The outlier, W21-165.04 is identified from its high y-variance.

After the outliers were removed, the PCR was run again using 168 prediction wells and 19 validation wells. The second run of principal component analysis found that within the first two principle components, there is 100% explained variance, shown in Figure 27. PCR was able to explain 100% of the variance within the first two principal components instead of within four principal components in PCA.

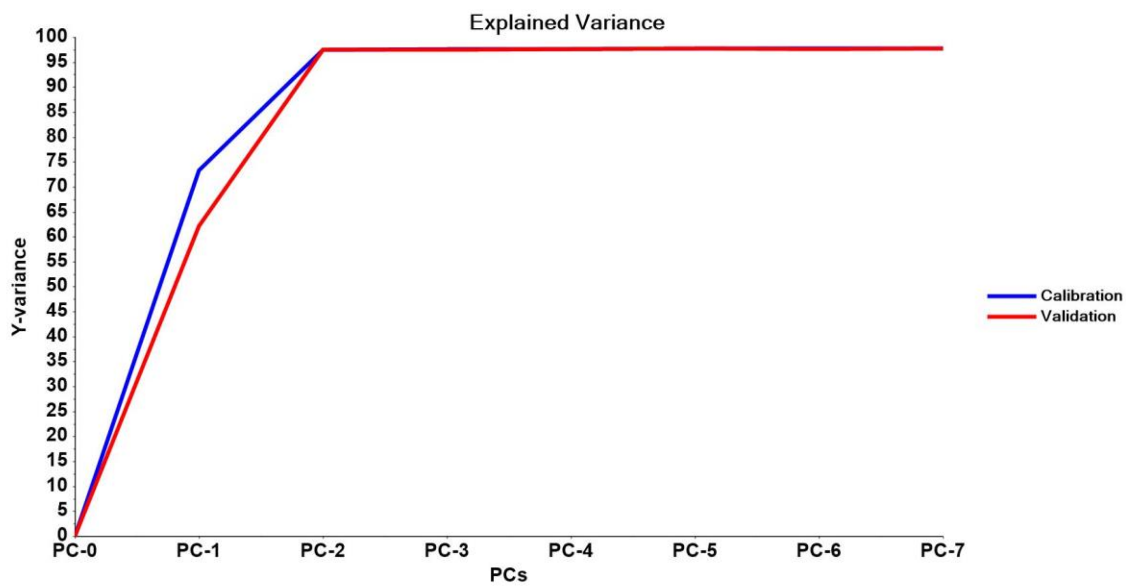

Figure 27. Principal component regression explained variance plot for D-0360 ODNR-DWR average potentiometric head model. The blue line represents the calibration and the red line represents the validation. There is 100% explained variance within two principal components.

To check the quality of the regression model, a predicted versus reference plot is analyzed, shown in Figure 28. This plot graphs the predicted Y-value against the measured Y-value. If the samples plot in a line with a slope value of 1, model is good at predicting the Y-values. In this case, the slope of the line for the calibration is 0.983 for calibration and 0.992 for validation, indicating a precise model.

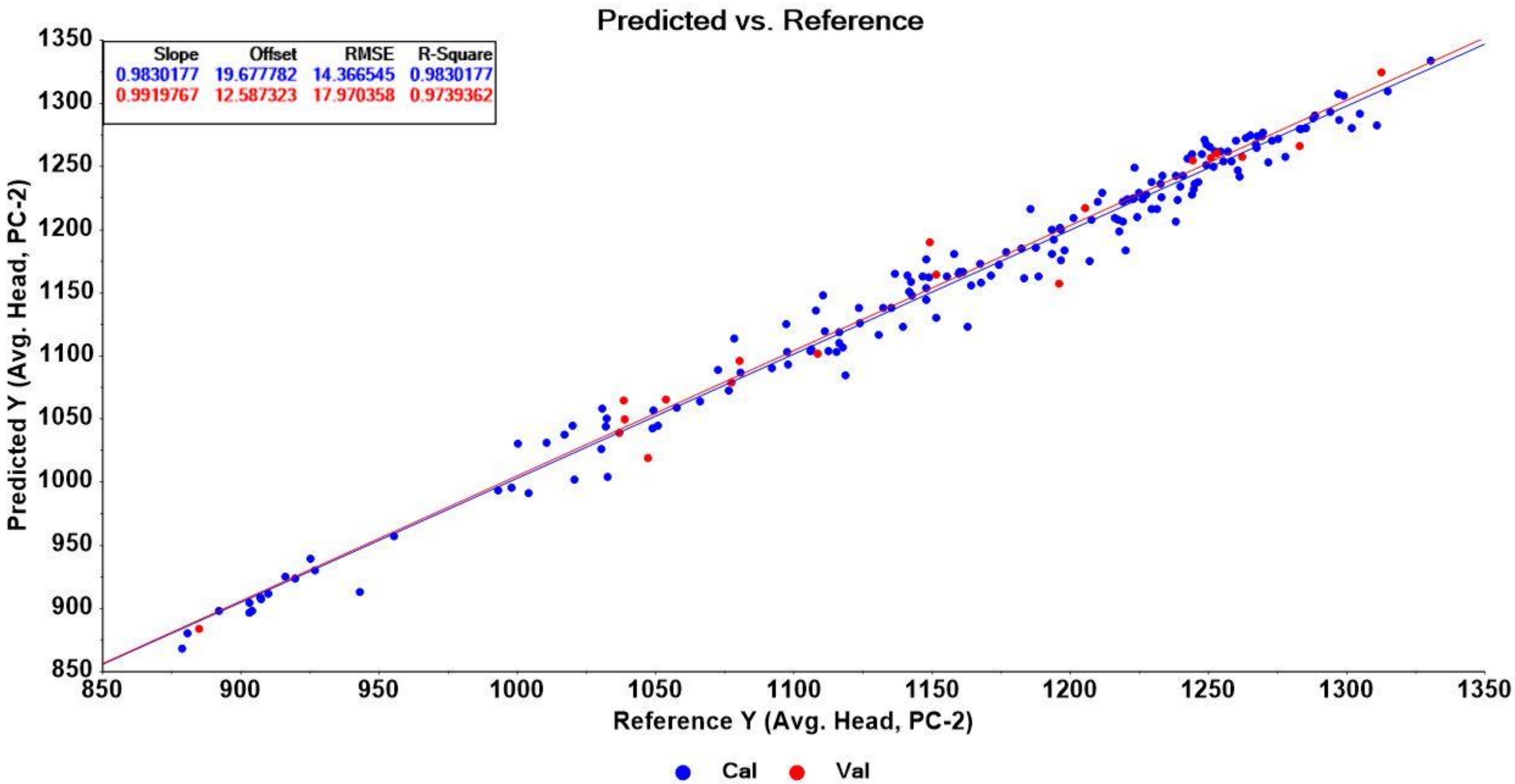

Figure 28. Principal component regression predicted versus reference plot for the D-0360 ODNR-DWR average potentiometric head model, principle component 2. Where the blue represents the calibration and the red represents the validation points. The slope is 0.9830177 for the calibration line indicating a precise model.

The correlation's loading plot for PCR, Figure 29, is similar to the one in PCA. The X and Y-axes are represented by the principal components that explain the most variance in the X and Y-variables. The percentages within the parentheses are the percent of explained variance for X-variables and Y-variable, respectively. Surface elevation, bottom of well elevation, overburden thickness and thickness of shale and clay are the variables that explain the most variance and the accumulated coal volume explains the least. Surface elevation and bottom of well elevation are the variables that are the most correlated with the Y-variable or average potentiometric head. The scores plot for PCR was equivalent the PCA's score plot and showed no grouping of the samples.

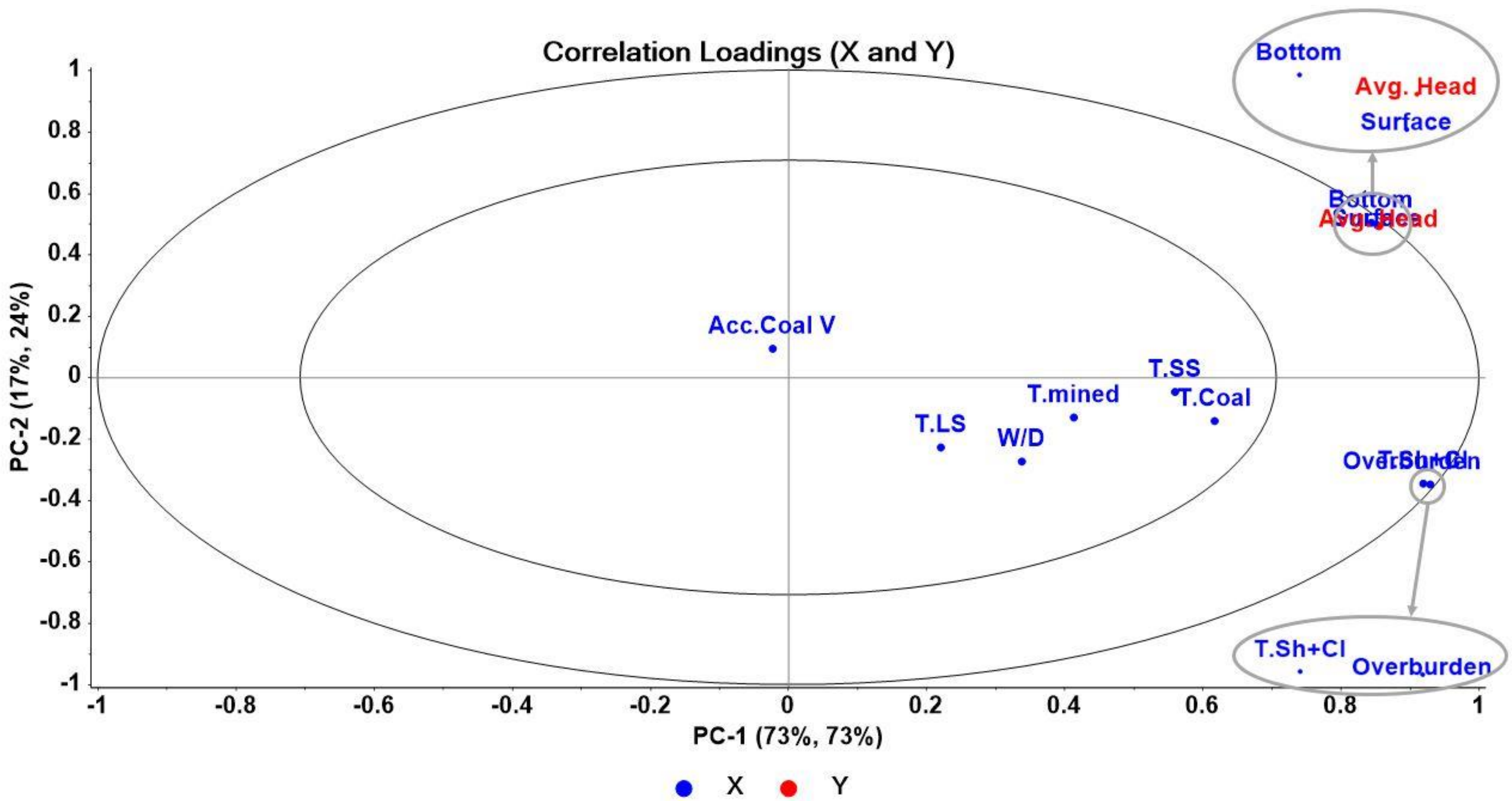

Figure 29. Principal component regression correlation loadings plot for the D-0360 ODNR-DWR average potentiometric head model. The two axes are the principal components that explain the most variance, in the parentheses are percentages of explained variance in X and Y, respectively. The inner ellipse represents 50% of the explained variance and the outer ellipse represents 100% of the explained variance. Therefore, parameters that fall within the first ellipse describe less than 50% of the explained variance and those that fall outside explain more than 50% of the variance. Parameters that are close together are highly correlated. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

To visualize the relationship between the X variables and the Y variable a weighted regression coefficient plot, as shown in Figure 30, is examined. The weight applied to all variables for this regression was 1. This plot summarizes the regression coefficients (β) of the of the X variables with respect to Y for the principal component that explains the most variance. Variables that have large regression coefficients are important variables in the regression model. Positive values are directly correlated to the Y variable whereas negative values are negatively correlated. The constant value (β0) is shown at the bottom of the graph in Figure 30 as BOW.

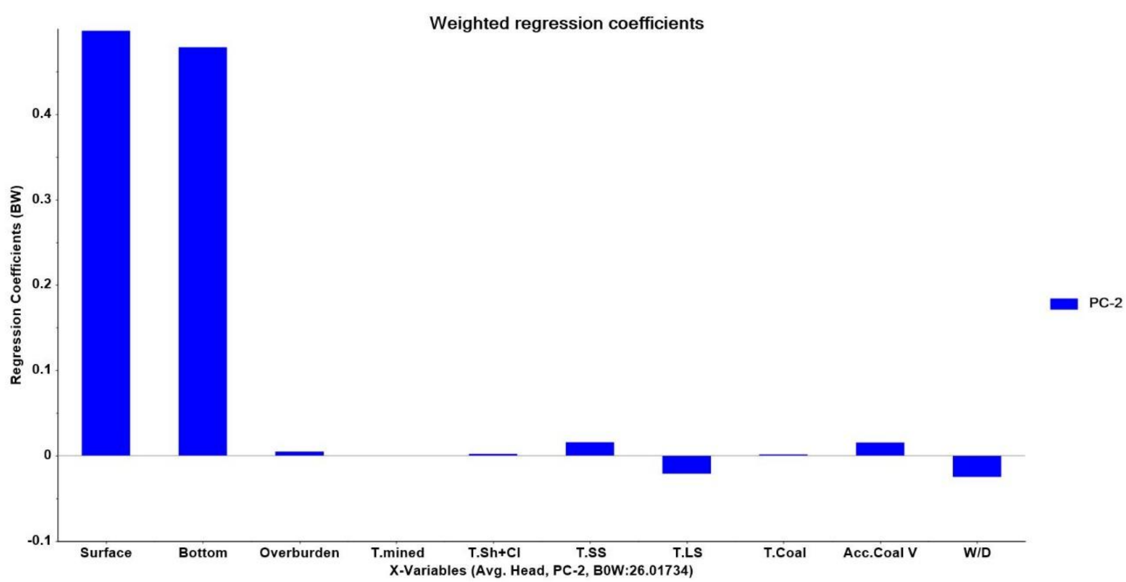

Figure 30. Principal component regression regression coefficients plot for the D-0360 ODNR-DWR average potentiometric head model, principal component 2. Surface and bottom elevation are parameters highly correlated with the average potentiometric head. Thickness of limestone and withdraw/distance are negatively related to the average potentiometric head. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

In the weighted regression coefficients chart, it can be seen that surface elevation and bottom of well elevation are the most important parameters with a positive correlation to the average potentiometric head. The variable that has the lowest significance is the thickness of the mined coal seam, followed by the total thickness of coal layers in all of the borehole. At some boreholes there were several layers in addition to the mined coal. Thickness of limestone and withdraw/distance are variables that are negatively related to the average potentiometric head. The regression coefficients of each variable are displayed in Table 7. Using these regression coefficients, an equation to solve for average potentiometric head can be made and is shown in Equation 14.

Table 7. Principal component analysis regression coefficients for the D-0360 ODNR-DWR model, principal component 2.

Variable	β
β0	26.082
Surface elevation (msl)	0.497
Bottom elevation (msl)	0.480
Overburden thickness (ft)	0.00393
Thickness of the mined coal seam (ft)	9.47E-05
Thickness of shale + clay (ft)	0.00224
Thickness of sandstone (ft)	0.0178
Thickness of limestone (ft)	-0.0262
Total thickness of coal (ft)	0.00181
Accumulative coal volume (Mm^3)	0.00809
Withdraw/Distance (MGal/Month)/(ft)	-0.01791

$$\begin{aligned}
&\mathit{Average\ potentiometric\ head} \\
&\qquad = 26.0173 + 0.498 \cdot (\mathit{Surface\ elevation}) + 0.479 \\
&\qquad \cdot (\mathit{Bottom\ of\ well\ elevation}) + 0.00502 \\
&\qquad \cdot (\mathit{Overburden\ thickness}) + 1.64 \cdot 10^{-4} \\
&\qquad \cdot (\mathit{Thickness\ of\ mined\ coal\ seam}) + 0.00232 \\
&\qquad \cdot (\mathit{Thickness\ of\ shale} + \mathit{clay}) + 0.0160 \\
&\qquad \cdot (\mathit{Thickness\ of\ sandstone}) - 0.0207 \\
&\qquad \cdot (\mathit{Thickness\ of\ limestone}) + 0.00176 \\
&\qquad \cdot (\mathit{Total\ thickness\ of\ coal}) + 0.0156 \\
&\qquad \cdot (\mathit{Accumulataive\ coal\ volume}) - 0.0245 \cdot \left(\frac{\mathit{Withdrawal}}{\mathit{Distance}}\right)
\end{aligned} \tag{14}$$

6.2.4 Partial Least Squares Regression

The first run of the partial least squares regression was done with 170 prediction wells, and 19 validation wells. Outliers were found using the same method described for principle component regression and found to be again W21-165.04 and W-426.

After the outliers were removed, the PLS was run again using 168 prediction wells and 19 validation wells. The second run of the partial least squares regression found that within two factors, there is 100% explained variance, as shown in Figure 31.

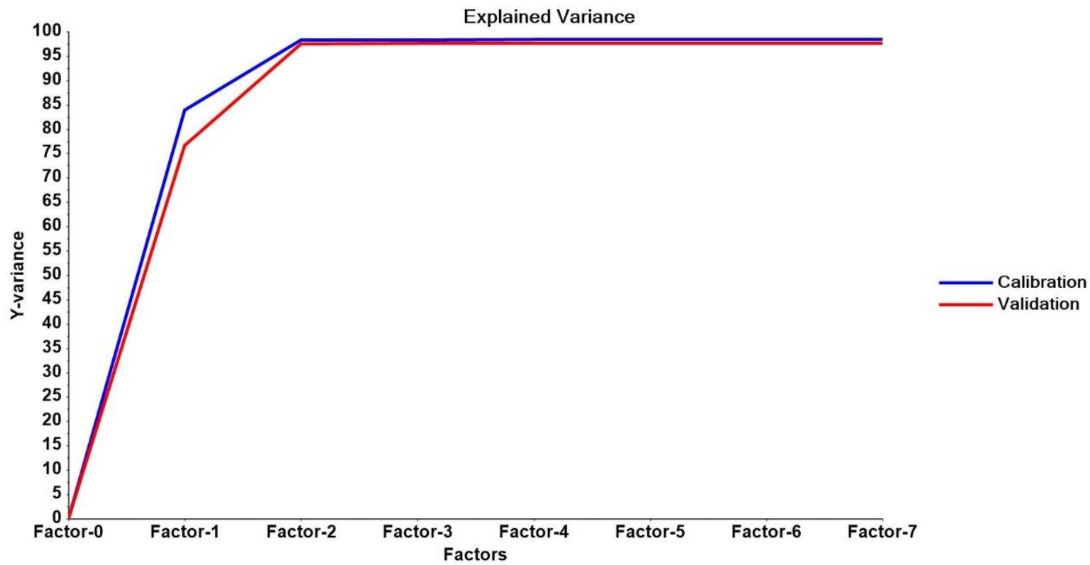

Figure 31. Partial least squares regression explained variance plot for D-0360 ODNR-DWR average potentiometric head model. The blue line represents the calibration and the red line represents the validation. There is 100% explained variance within two factors.

The predicted versus reference graph for the partial least squares regression indicates a very good model as shown in Figure 32. The slope of the line for the calibration is 0.983 and 0.992 for validation, indicating a precise model that is slightly better than the PCR model.

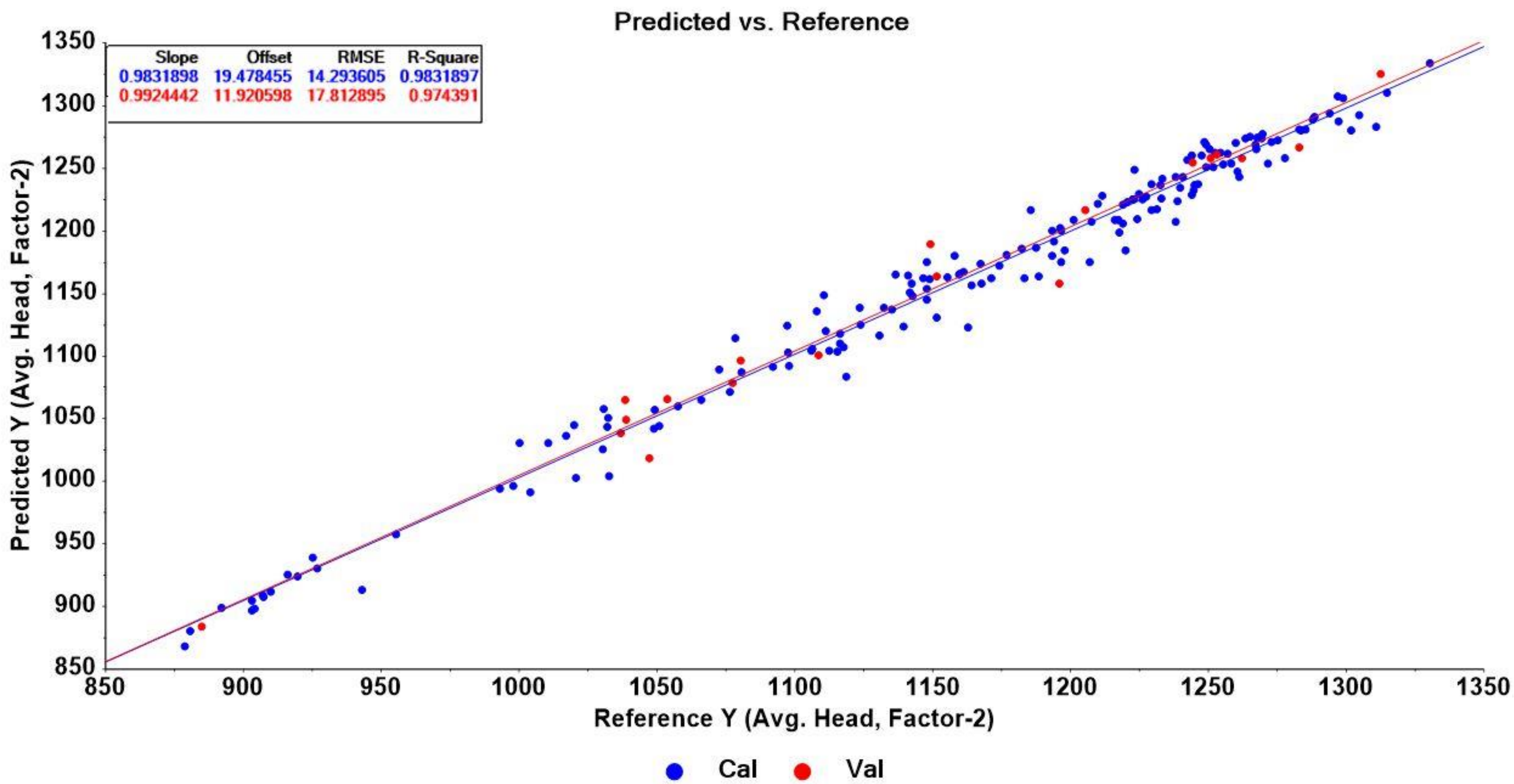

Figure 32. Partial least squares regression predicted versus reference plot for D-0360 ODNR-DWR average potentiometric head model. The blue represents the calibration and the red represents the validation where the slope for the calibration is 0.983, indicating a precise model.

The partial least squares correlation loadings plot shown gave similar results to the principal component regression correlation loadings where the surface elevation, bottom of well elevation, overburden thickness and thickness of limestone explain the most variance in the data. Surface elevation and bottom of well elevation are the variables that are highest in relation to the average potentiometric head. Surface elevation and bottom of well elevation are inversely related to the overburden thickness and thickness of limestone.

Similar to the principal component analysis scores plot, the partial least squares regression scores plot showed no grouping. This indicates that all the wells behave in a similar way with respect to the first and second factors.

The weighted regression coefficient plot was also similar to that for the principal component regression. Surface elevation and bottom of well elevation were the variables found to have the highest correlation with average potentiometric head. Thickness of the mined coal seam and thickness of total coal layers are the least important variables and have a low correlation with average potentiometric head. Thickness of limestone and withdraw/distance were negatively related to the average potentiometric head. The regression coefficients for these variables, shown in Table 8, varied slightly from the ones found in the principal component regression. With these coefficients, an equation similar to Equation 10 can be constructed to explain the potentiometric head.

Table 8. Partial least squares regression regression coefficients for the D-0360 ODNR-DWR model, factor 2.

Variable	β
β0	26.0816
Surface elevation (msl)	0.497
Bottom elevation (msl)	0.480
Overburden thickness (ft)	0.00393
Thickness of the mined coal seam (ft)	9.47E-05
Thickness of shale + clay (ft)	0.00224
Thickness of sandstone (ft)	0.0178
Thickness of limestone (ft)	-0.0262
Total thickness of coal (ft)	0.00181
Accumulative coal volume (Mm^3)	0.00809
Withdraw/Distance (MGal/Month)/(ft)	-0.0179

6.2.5 Additional D-0360 Models

The procedure used for the D-0360 ODNR-DWR regressions was the same used for the D-0360 ODNR-DWR without withdraw, D-0360 NPDES and D-0360 All Wells models.

For the ODNR-DWR model without water withdraw, analysis was run on 169 prediction wells and 19 validation wells after outlier removal. The NPDES model had the least amount of data because only wells that were monitored sometime between 2007 and 2016 could be used. For this model there were 60 prediction wells and 7 validation wells after outlier removal. The All wells model had the highest number of samples because there was no time period established, so all wells could be used. This resulted in a data set of 179 prediction wells and 20 validation wells after outlier removal. The list of outliers removed can be seen in Appendix B.

The results from these regressions were all very similar to those found in the D-0360 ODNR-DWR model regressions. The goodness-of-fit index values for each model are shown below in Table 9. The NPDES model was the only one that had more favorable goodness-of-fit index values for the principal component regression. Note that all of the models are good models according to the different indexes and their ideal values.

Table 9. D-0360 model's goodness-of-fit index values for the Nash-Sutcliffe efficiency, percent bias, mean absolute error, volumetric efficiency, root mean square error and relative index of agreement.

	NSE	**PBIAS**	**MAE**	**VE**	**RMSE**	**rd**
Ideal Value	**1**	**0**	**0**	**1**	**0**	**1**
ODNR-DWR - PCR	0.98	-6.86E-09	0.029	1	15.148	0.995
ODNR-DWR - PLS	0.98	-2.96E-08	0.024	1	14.866	0.995
ODNR-DWR w/o WD - PCR	0.98	-2.84E-06	0.005	1	14.236	0.996
ODNR-DWR w/o WD - PLS	0.98	-2.82E-06	0.007	1	14.209	0.996
NPDES - PCR	0.98	-6.14E-06	0.101	1	13.106	0.994
NPDES - PLS	0.96	-6.15E-06	0.233	1	18.488	0.989
All Wells - PCR	0.98	1.53E-06	0.002	1	14.733	0.996
All Wells - PLS	0.98	1.42E-06	0.001	1	14.672	0.996

The predicted versus reference graphs for the four models is shown in Figure 33. Although their slope values differ slightly, their values are all close to 1 indicating a precise predictive model. The ODNR-DWR, ODNR-DWR without withdraw and all wells models predicted versus reference graph shown is representative for the PLS regression because that regression had the best fit index values. The NPDES predicted versus reference graph is shown using the PCR regression because that model had more favorable goodness-of-fit indexes.

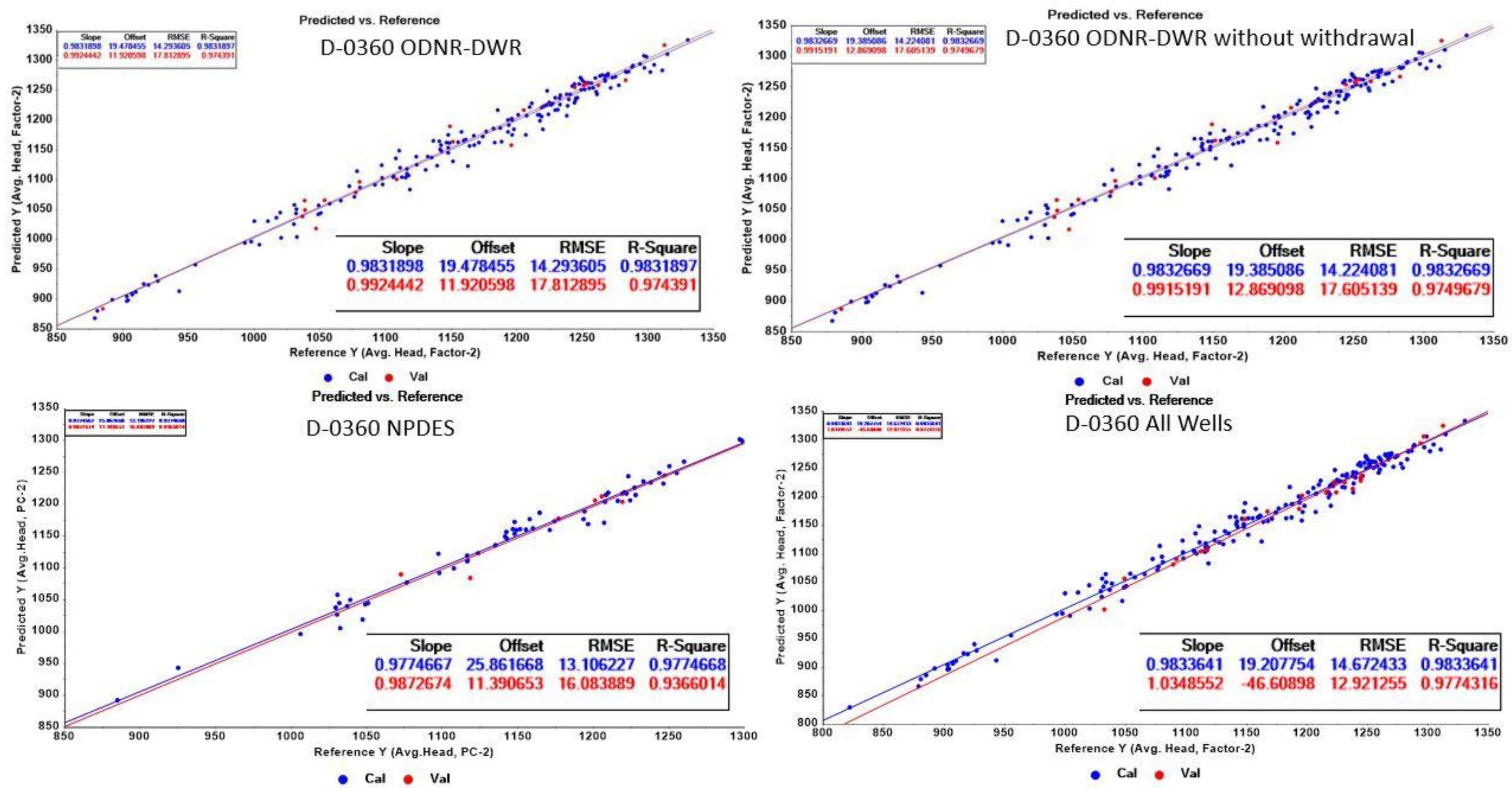

Figure 33. Predicted versus reference graphs for D-0360 average potentiometric head models. The four models all have a slope close to 1, indicating precise models. The D-0360 All Wells model has the highest slope value.

The regression coefficients for each model's best fit regression are displayed in Table 10. The withdraw divided by distance (W/D) variable is more significant in the ODNR-DWR model than the W/D variable in the NPDES model, this suggests that the ODNR-DWR withdraw data is more significantly connected to water levels in the mine. This shows the importance of being able to retrieve accurate and comprehensive withdraw data for the mines. The surface elevation and bottom of well elevation are the most important variables for each model. In all the models, the thickness of the mined coal and the total thickness of the coal layers present in the boreholes are the least significant variables, and could be removed from the model without great impact.

Table 10. Regression coefficients for D-0360 models.

Regression Variable	ODNR-DWR PLS	ODNR-DWR w/o W/D PLS	NPDES PCR	All Wells PLS
β0	26.0816	25.0390	56.6601	19.7219
Surface elevation (msl)	0.497	0.496	0.4679	0.500
Bottom elevation (msl)	0.4800	0.481	0.4804	0.480
Overburden thickness (ft)	0.0039	0.0017	-0.0024	-0.0008
Thickness of the mined coal seam (ft)	9.47E-05	-1E-05	-0.0017	-0.0007
Thickness of shale + clay (ft)	0.0022	0.0023	0.0092	0.0031
Thickness of sandstone (ft)	0.0178	0.0184	0.0091	0.0211
Thickness of limestone (ft)	-0.0262	-0.0292	-0.0183	-0.0261
Total thickness of coal (ft)	0.0018	0.0019	0.0058	0.0005
Accumulative coal volume (Mm^3)	0.0081	0.0071	0.0198	0.0156
Withdraw/Distance (Mgal/Month)/(ft) and (Mgal/Day)/(ft)	-0.01791	-	-1E-07	-

6.3 Multivariate Statistical Analysis of Multi-Mine Model without Water Withdraw

For the multi-mine regression without water withdraw for average potentiometric head, data for 381 wells was compiled from eleven mines. After outliers were removed, 322 wells were used as predictors and 37 were used as validators.

6.3.1 Principal Component Analysis

Principal component analysis explained 100% of the variance in 1 principal component for the multi-mine without withdraw model. The correlation loading plot, Figure 34, showed that all of the variables explain more than 50% of the variance with the exception of overburden thickness and thickness of the mined coal seam.

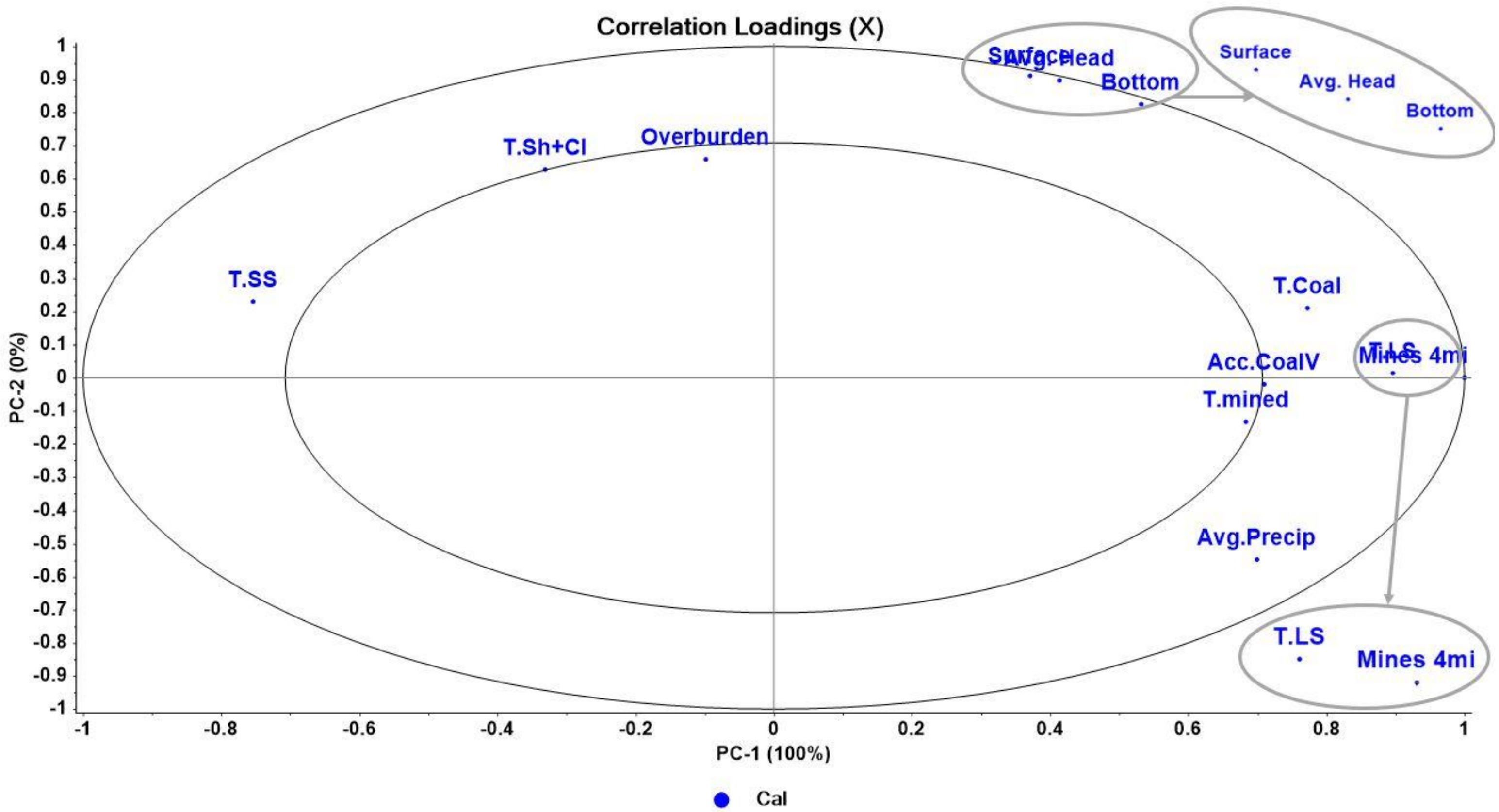

Figure 34. Principal component analysis correlation loadings plot for the multi-mine without withdraw average potentiometric head model. The two axes are the principal components that explain the most variance. The inner ellipse represents 50% of the explained variance and the outer ellipse represents 100% of the explained variance. Therefore, parameters that fall within the first ellipse describe less than 50% of the explained variance and those that fall outside explain more than 50% of the variance. Parameters that are close together are highly correlated. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

The scores plot (Figure 35) shows intense grouping of the samples. The group to the far right represents data from D-0360 and the groups to the far left are the other mines. The gap in this data is most likely caused by the significant difference in mine size. D-0360 is the largest mine in this study and will therefore have higher accumulative coal volumes. D-0360 also has the largest area of abandoned underground mines within a 4-mile buffer.

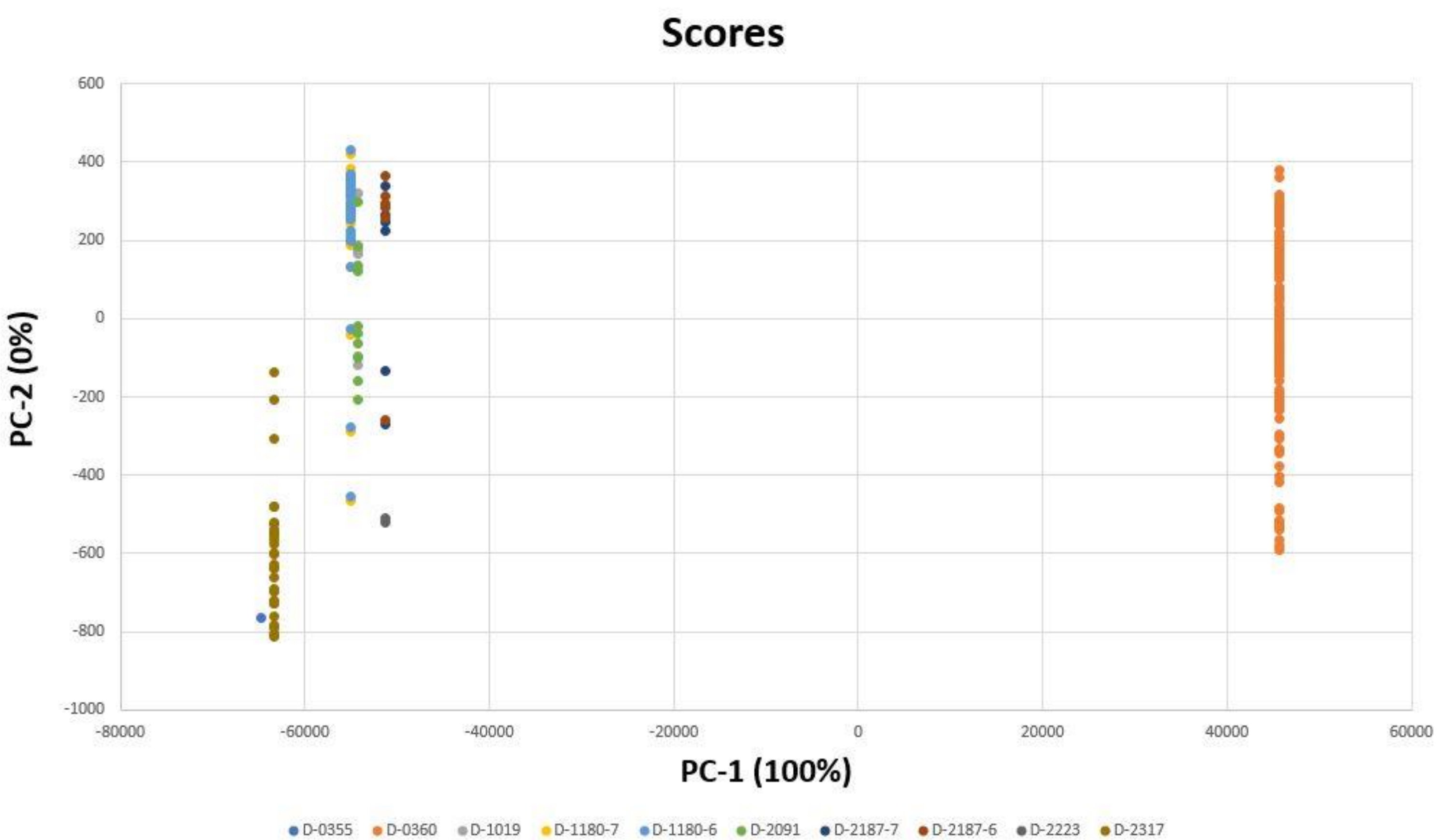

Figure 35. Principal component analysis scores plot for the multi-mine without withdraw model. Samples that are similar group together, whereas samples that are different are spaced apart. D-0360 is located to the right of all the other mines most likely because it is much larger than the other mines being studied.

6.3.2 Principal Component Regression

Principle component regression for the multi-mine without withdraw model explained 100% of the variance within the first 3 principal components. The predicted versus reference plot for this regression gave a slope equal to 0.9873363 for calibration and 0.9616842 for validation, indicating a precise model.

The correlation loadings plot for this regression is displayed in Figure 36. All of the variables with the exception of thickness of the mined coal seam explain at least 50% of the variance. Surface elevation and bottom of well elevation are the two variables that are highly correlated with the y-variable, average potentiometric head. These results are similar to those found in the principal component analysis. The scores plot for PCR was similar to the scores plot for PCA and showed sample grouping where D-0360 samples were located to the right of the other mines' samples.

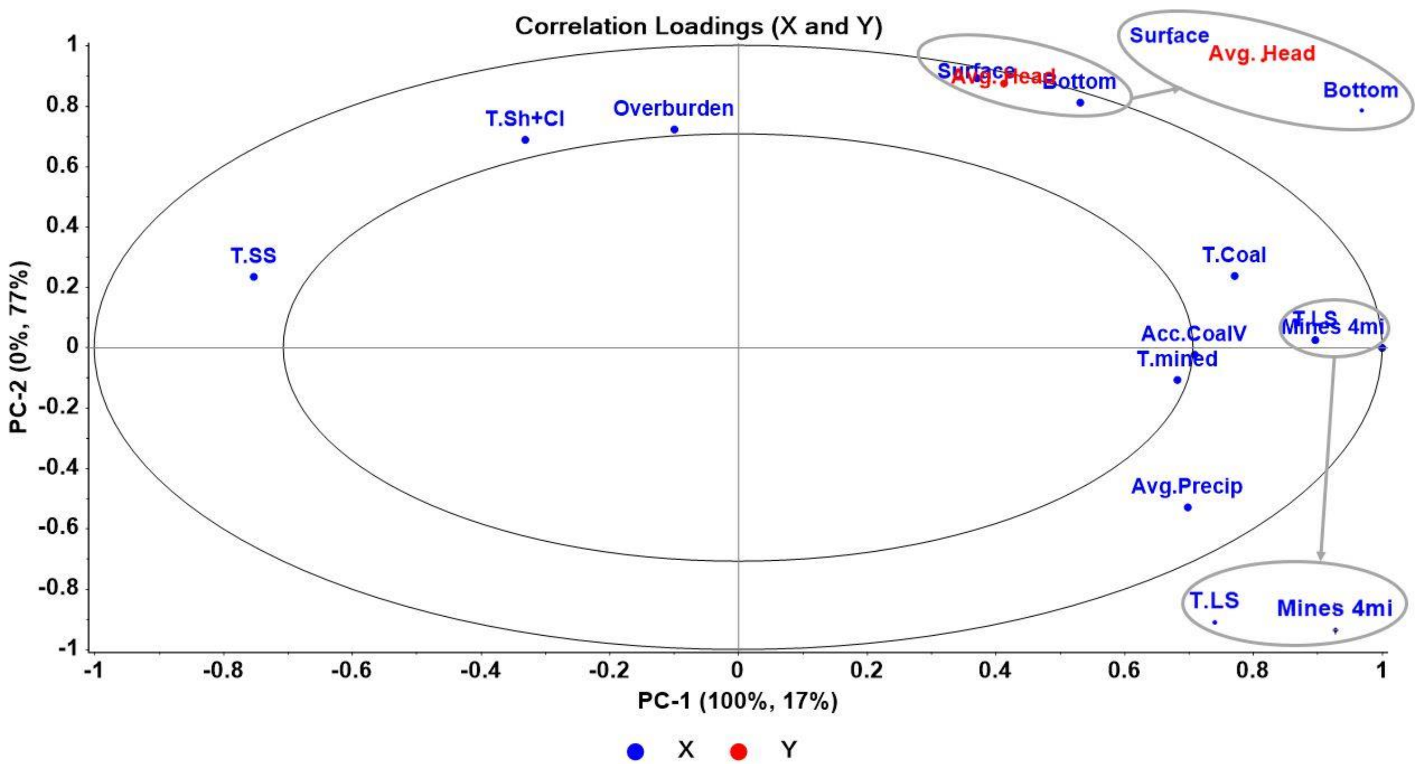

Figure 36. Principal component regression correlation loadings plot for the multi-mine without withdraw model. The two axes are the principal components that explain the most variance, in the parentheses are percentages of explained variance in X and Y, respectively. The inner ellipse represents 50% of the explained variance and the outer ellipse represents 100% of the explained variance. Therefore, parameters that fall within the first ellipse describe less than 50% of the explained variance and those that fall outside explain more than 50% of the variance. Parameters that are close together are highly correlated. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

The weighed regression coefficient chart (Figure 37) shows that the important variables for this regression are the surface elevation, bottom of well elevation and thickness of sandstone. Other variables such as area of underground mines within a 4-mile buffer and thickness of coal have very small regression coefficients and do not contribute much to the model. Surface elevation, bottom of well elevation, thickness of sandstone and accumulative coal volume are variables that are positively correlated to the average potentiometric head.

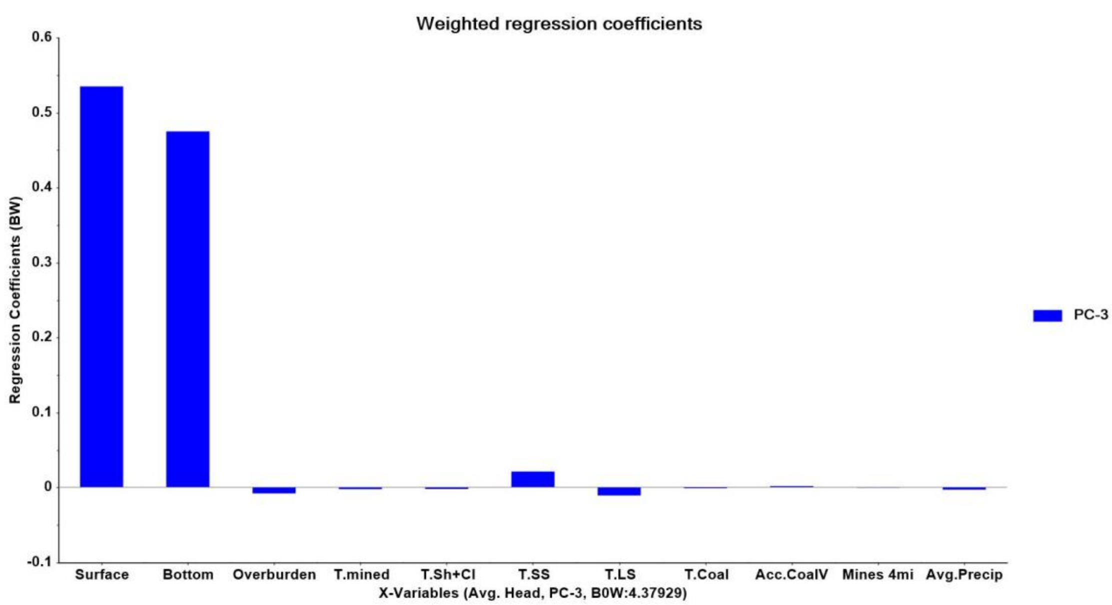

Figure 37. Principal component regression weighted regression coefficient chart for the multi-mine without withdraw model. Surface and bottom elevation are highly correlated to the average potentiometric head. Parameters such as the area of underground mines within a 4-mile buffer, total thickness of coal, thickness of the mined coal seam, thickness of shale + clay and accumulative coal volume are not very significant parameters. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

6.3.3 Partial Least Squares Regression

Partial least squares regression for the multi-mine without withdraw model explained 100% of the variance within the first 3 factors. The predicted versus reference plot for this regression gave a slope equal to 0.988 for calibration and 0.990 for validation shown in Figure 38, indicating a precise model.

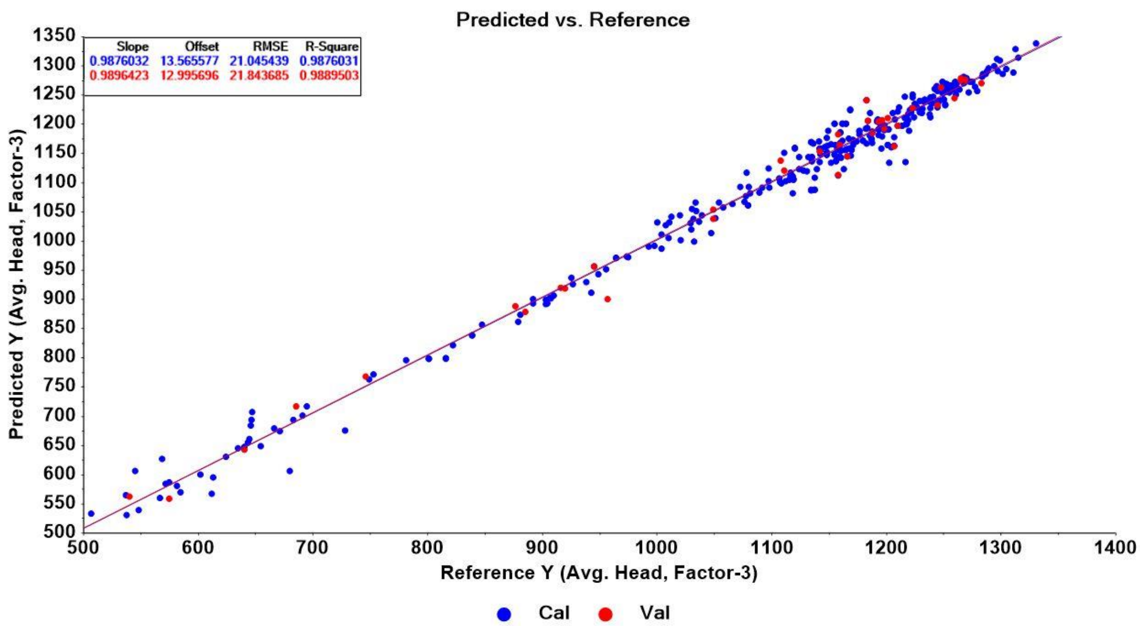

Figure 38. Partial least squares regression predicted vs. reference graph for the multi-mine without withdraw average potentiometric head model. Blue represents the calibration and red represents the validation points. The slope of the calibration is 0.988 indicating a precise model.

The correlation loadings plot had similar results to those found in principal component regression except both overburden and thickness of the mined coal seam explained under

50% of the variance, all other variables explained over 50% variance, as shown in Figure 39.

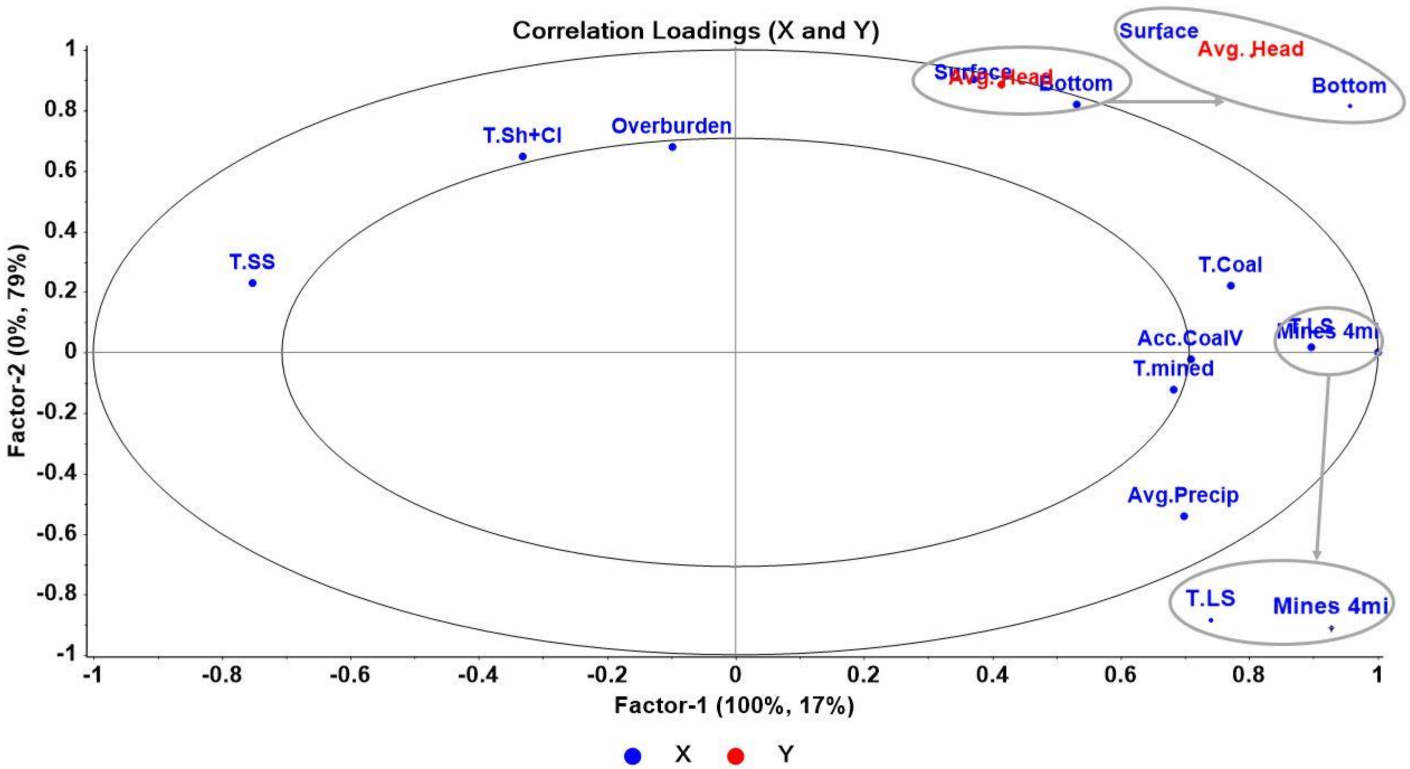

Figure 39. Partial least squares regression correlation loadings plot for the multi-mine without withdraw average potentiometric head model. The two axes are the principal components that explain the most variance, in the parentheses are percentages of explained variance in X and Y, respectively. The inner ellipse represents 50% of the explained variance and the outer ellipse represents 100% of the explained variance. Therefore, parameters that fall within the first ellipse describe less than 50% of the explained variance and those that fall outside explain more than 50% of the variance. Parameters that are close together are highly correlated. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

The scores plot had the same grouping as the scores plot for the PCR where D-0360 wells were far to the right and the other mines' wells were far to the left. The regression coefficient chart showed that surface elevation and bottom of well elevation were the most important variables (Figure 40). The variables thickness of the mined coal seam, thickness of shale and clay, thickness of coal, accumulative coal volume and area of underground mines within a 4-mile buffer did not have high regression coefficient values.

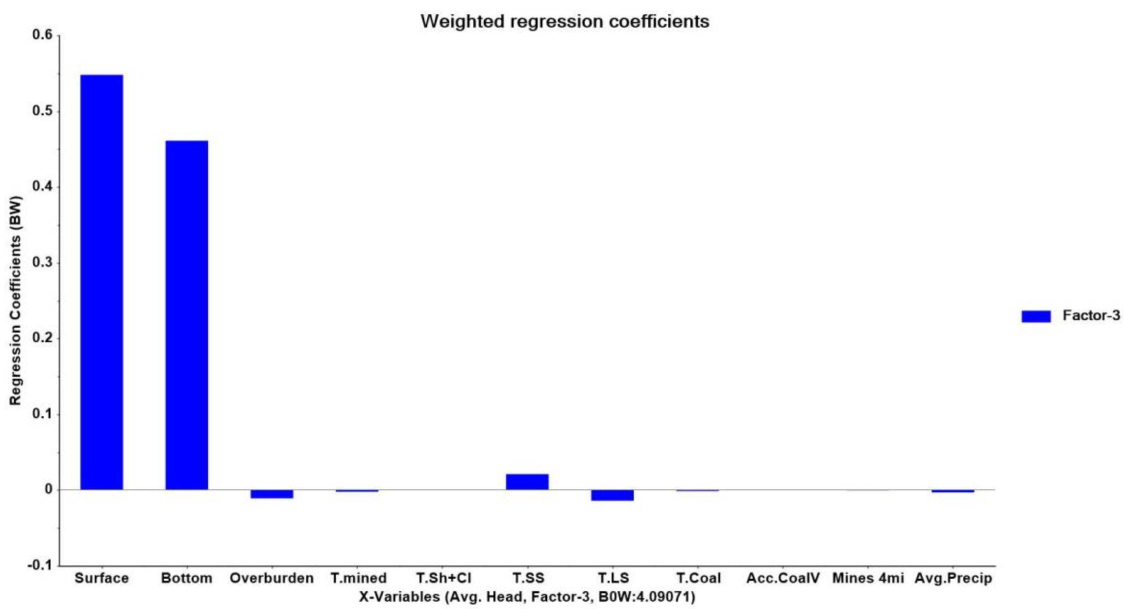

Figure 40. Partial least squares regression weighted regression coefficients chart for the multi-mine without withdraw model. Surface and bottom elevation are highly correlated with average potentiometric head. Thickness of shale + clay, total thickness of coal, accumulative coal volume and area of underground mines within a 4-mile buffer are not significant parameters. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

6.3.4 Model Summary

The goodness-of-fit index values shown in Table 11, indicate that PLS is the best fit regression for this model.

Table 11. Multi-mine without withdraw average potentiometric head model goodness-of-fit indexes for Nash-Sutcliffe efficiency, percent bias, mean absolute error, volumetric efficiency, root mean square error and relative index of agreement.

	NSE	**PBIAS**	**MAE**	**VE**	**RMSE**	**rd**
Ideal value	**1**	**0**	**0**	**1**	**0**	**1**
PCR	0.9873	4.49804E-07	0.029	1	21.042	0.9958
PLS	0.9876	1.47997E-06	0.024	1	20.797	0.9959

The regression coefficients for each regression are shown in Table 12. Surface elevation and bottom of well elevation have the highest values and therefore the highest correlation with average potentiometric head.

Table 12. Multi-mine without withdraw average potentiometric head model regression coefficients.

Variable	**PCR**	**PLS**
β0	4.379	4.0907
Surface elevation (msl)	0.535	0.548
Bottom elevation (msl)	0.475	0.461
Overburden thickness (ft)	-0.0077	-0.0107
Thickness of the mined coal seam (ft)	-0.0019	-0.0021
Thickness of shale + clay (ft)	-0.0018	0.00069

Variable	PCR	PLS
Thickness of sandstone (ft)	0.0215	0.0212
Thickness of limestone (ft)	-0.0104	-0.0138
Total thickness of coal (ft)	-0.0009	-0.0012
Accumulative coal volume (Mm^3)	0.00204	0.00041
Area of underground mines in a 4mile buffer (acres)	-0.0001	-0.0001
Average precipitation (in)	-0.0027	-0.003

6.3.5 Maximum and Minimum Potentiometric Heads

The same procedure was performed for both maximum and minimum potentiometric heads, giving similar results to those found in the average potentiometric head regression model. Partial least squares regression was the model that had the best goodness-of-fit index values for both maximum and minimum models. The root mean square errors were slightly higher than those of the average potentiometric head model. The RSME for maximum potentiometric head PLS was 22.36 ft and 28.39 ft for minimum, whereas the RSME for the average potentiometric head from PLS was 20.79 ft. Maximum and minimum potentiometric heads are influenced by precipitation, with a more accurate average precipitation dataset, these error values may decrease. The regression coefficients for the maximum and minimum partial least squares regression are shown in Table 13.

Table 13. Maximum and minimum potentiometric head regression coefficients for the multi-mine without water withdraw model, partial least squares regression.

	Maximum Head	**Minimum Head**
β0	7.206	18.466
Surface elevation (msl)	0.762	0.542
Bottom elevation (msl)	0.225	0.453
Overburden thickness (ft)	-0.0403	-0.0148
Thickness of the mined coal seam (ft)	-2.83E-03	-2.19E-03
Thickness of shale + clay (ft)	0.0282	0.0034
Thickness of sandstone (ft)	-9.64E-03	1.77E-02
Thickness of limestone (ft)	-0.0294	-0.0152
Total thickness of coal (ft)	-3.44E-03	-1.04E-03
Accumulative coal volume (Mm^3)	6.32E-03	-7.66E-03
Area of underground mines in a 4mile buffer (acres)	2.73E-05	-1.35E-04
Average precipitation (in)	-4.52E-03	-3.08E-03

6.4 Multivariate Statistical Analysis of Multi-Mine Model with Water Withdraw

For the multi-mine regression with water withdraw for average potentiometric head, data for 111 wells was compiled from seven mines. After initial PCA and PCR analysis, 13 outliers were removed, 88 wells were used as predictors and 10 were used as validators.

6.4.1 Principal Component Analysis

Principal component analysis explained 100% of the variance in the first principal component. The correlation loading plot, Figure 41, shows that the only variables to explain more than 50% of the variance were thickness of sandstone, bottom of well elevation, average potentiometric head, surface elevation, thickness of coal, thickness of limestone, underground mine area within a 4-mile buffer. The scores plot for PCA for the multi-mine with withdraw model was similar to the scores plots for the multi-mine without withdraw model (Figure 35) where D-0360 wells were located far to the right of the other mines' wells.

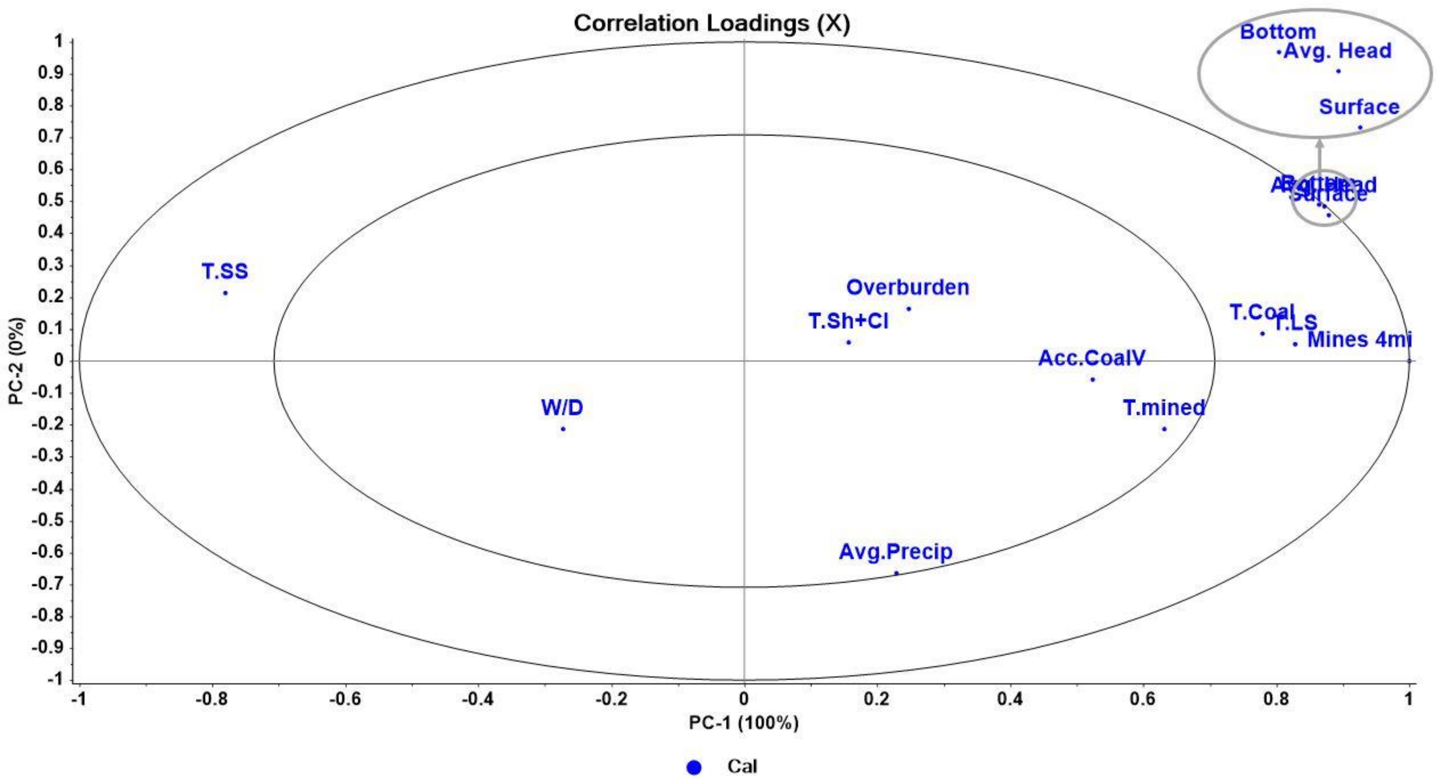

Figure 41. Principal component analysis correlation loadings plot for the multi-mine with withdraw average potentiometric head model. The two axes are the principal components that explain the most variance. The inner ellipse represents 50% of the explained variance and the outer ellipse represents 100% of the explained variance. Therefore, parameters that fall within the first ellipse describe less than 50% of the explained variance and those that fall outside explain more than 50% of the variance. Parameters that are close together are highly correlated. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

6.4.2 Principal Component Regression

Principal component regression was able to explain 100% of the variance within the first two principal components with a predicted versus reference slope of 0.987 for calibration and 0.999 for validation. The correlation loadings plot (Figure 42) was different than the one for the multi-mine without withdraw model. The only variables that explain over 50% of the variance are thickness of sandstone, bottom of well elevation, surface elevation, thickness of coal, thickness of limestone and area of underground mines within a 4-mile buffer. Overburden thickness, thickness of shale and clay, accumulative coal volume, thickness of the mined coal seam, average precipitation and withdraw/distance all explained under 50% of the variance.

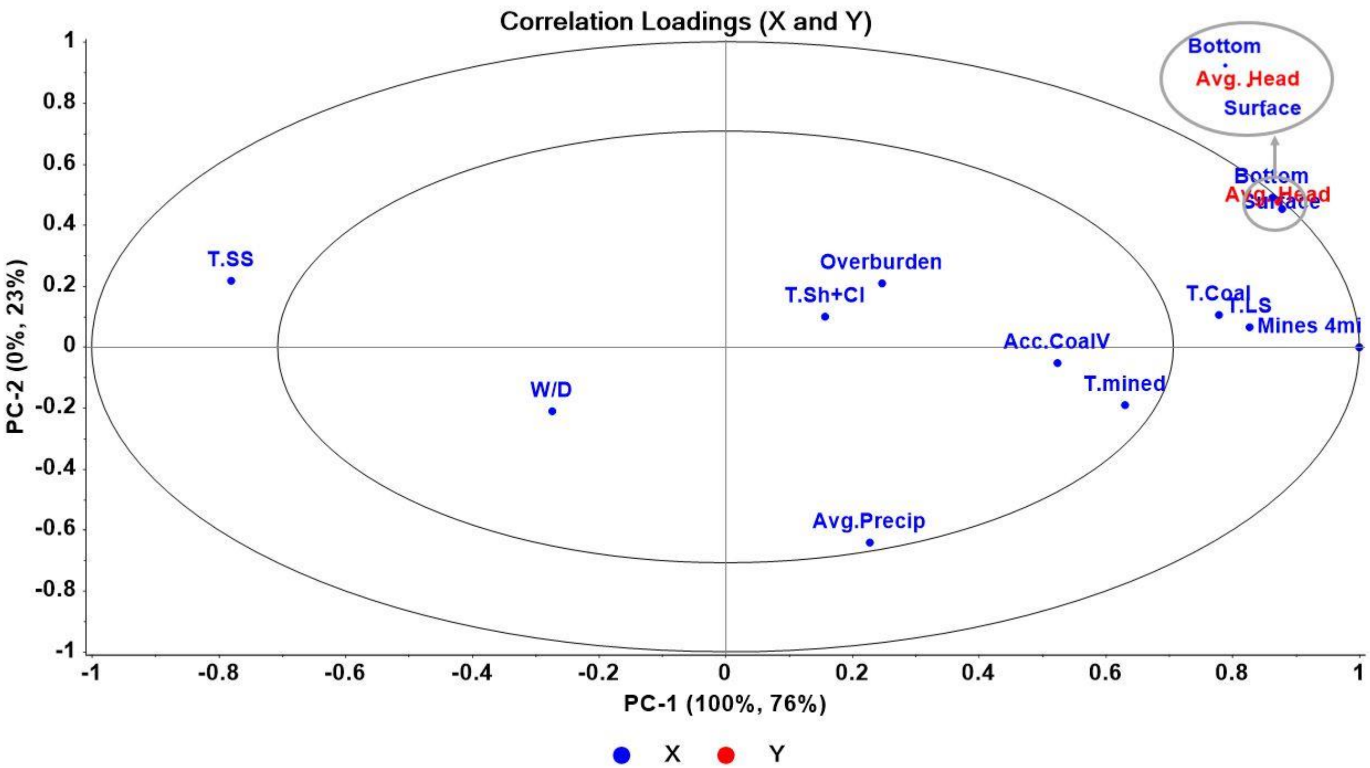

Figure 42. Principal component regression correlation loadings for the multi-mine with withdraw average potentiometric head model. The two axes are the principal components that explain the most variance, in the parentheses are percentages of explained variance in X and Y, respectively. The inner ellipse represents 50% of the explained variance and the outer ellipse represents 100% of the explained variance. Therefore, parameters that fall within the first ellipse describe less than 50% of the explained variance and those that fall outside explain more than 50% of the variance. Parameters that are close together are highly correlated. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

The scores plot had similar grouping patterns to those in the without withdraw model where D-0360 wells were to the right of the other mines' wells. The important variables for the with withdraw model differed than those found in the without withdraw model. In the weighted regression coefficients chart shown in Figure 43, bottom of well elevation, surface elevation and overburden thickness are the most important variables. The only variables with a negative relationship to the average potentiometric head were the thickness of mined coal seam, thickness of coal, accumulative coal volume and average precipitation. Regression coefficient values of the thickness of mined coal seam, thickness of coal, area of underground mines within a 4-mile buffer, average precipitation and withdraw/distance were all very low.

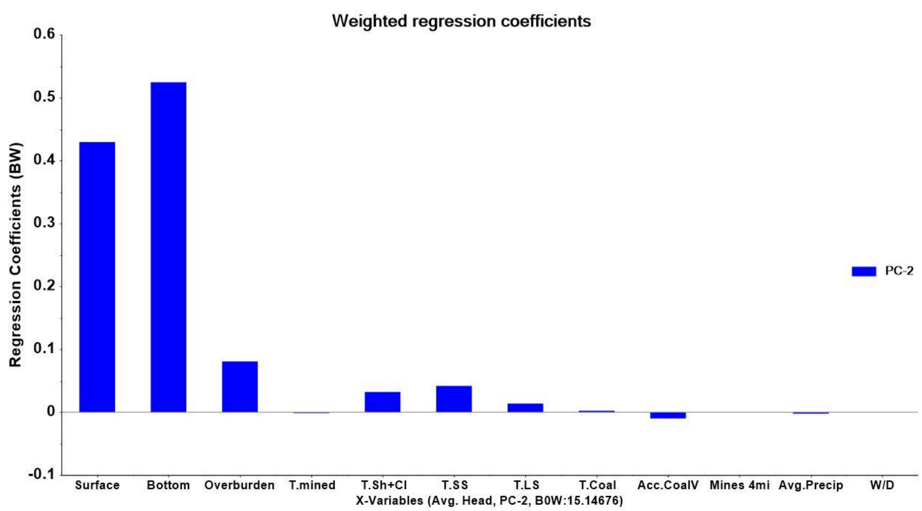

Figure 43. Principal component regression weighed regression coefficients for the multi-mine with withdraw model, principal component 2. Surface elevation, bottom elevation, overburden thickness, thickness of shale + clay, thickness of sandstone and thickness of limestone are all positively correlated with average potentiometric head. Withdraw/distance, area of underground mines within a 4-mile buffer, annual average precipitation, total thickness of coal and thickness of the mined coal seam are not significant variables. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

6.4.3 Partial Least Squares Regression

Partial least squares regression for the multi-mine with withdraw model explained 100% of the variance in 2 factors with a predicted versus reference slope of 0.988 for calibration and 0.988 for validation. The correlation loadings plot for PLS was similar to that for PCR of the multi-mine with withdraw model where bottom of well elevation, surface elevation, thickness of coal, thickness of limestone, area of underground within a 4-mile buffer and thickness of sandstone all explain over 50% of the variance. The scores plot had the same grouping pattern with D-0360 wells to the right of the wells from the other mines. The weighed regression coefficient chart is similar to that found in the PCR for the with water withdraw model. Bottom of well elevation, surface elevation, overburden thickness and thickness of sandstone are the variables with the largest regression coefficients. The impact from the variables thickness of mined coal seam, thickness of coal, area of underground mines within a 4-mile buffer, average precipitation and withdraw/distance is low because they have small regression coefficient values.

6.4.4 Model Summary

The goodness-of-fit index values shown in Table 15 indicate that PLS is the best fit regression for this model.

Table 14. Multi-mine with withdraw average potentiometric head model goodness-of-fit indexes for Nash-Sutcliffe efficiency, percent bias, mean absolute error, volumetric efficiency, root mean square error, relative index of agreement.

	NSE	**PBIAS**	**MAE**	**VE**	**RMSE**	**rd**
Ideal value	**1**	**0**	**0**	**1**	**0**	**1**
PCR	0.9870	-2.85E-06	0.6104	0.9994	25.1099	0.9949
PLS	0.9885	-3.40E-06	0.6349	0.9994	23.6163	0.9951

The regression coefficients for each regression are shown in Table 16. Surface elevation and bottom of well elevation have the highest values and therefore the highest correlation with average potentiometric head.

Table 15. Multi-mine with withdraw average potentiometric head model regression coefficients.

Variable	PCR	PLS
β0	15.147	20.457
Surface elevation (msl)	0.430	0.440
Bottom elevation (msl)	0.525	0.525
Overburden thickness (ft)	0.0808	0.0461
Thickness of the mined coal seam (ft)	-1.55E-03	-2.02E-03
Thickness of shale + clay (ft)	0.0322	0.0055
Thickness of sandstone (ft)	0.0420	0.0409
Thickness of limestone (ft)	0.0138	0.0084
Total thickness of coal (ft)	2.40E-03	1.54E-03
Accumulative coal volume (Mm3)	-1.00E-02	-1.22E-02
Area of underground mines in a 4mile buffer (acres)	6.42E-05	4.80E-05
Average precipitation (in)	-2.23E-03	-2.49E-03
Withdraw/Distance (Mgal/Day)/(ft)	-5.42E-07	-5.51E-07

6.4.5 Maximum and Minimum Potentiometric Head

The same procedure was performed for both maximum and minimum potentiometric heads, giving similar results to those found in the average potentiometric head regression model. Partial least squares regression was the model that had the best goodness-of-fit index values for both maximum and minimum models. The root mean square errors were slightly higher than those of the average potentiometric head model. The RSME for maximum potentiometric head PLS was 35.60ft and 26.92ft for minimum, whereas the RSME for the average potentiometric head from PLS was 23.62ft. This phenomenon is consistent with the maximum and minimum potentiometric head models for the multi-mine model without withdraw. The regression coefficients for the maximum and minimum partial least squares regression are shown in Table 17.

Table 16. Maximum and minimum potentiometric head partial least squares regression coefficients for the multi-mine with water withdraw model.

Variable	Maximum Head	Minimum Head
β0	-21.271	-11.0032
Surface elevation (msl)	0.520	0.500
Bottom elevation (msl)	0.547	0.535
Overburden thickness (ft)	-0.0181	-0.0119
Thickness of the mined coal seam (ft)	-1.67E-03	-1.90E-03
Thickness of shale + clay (ft)	0.0179	0.0051
Thickness of sandstone (ft)	-0.0192	-0.0048
Thickness of limestone (ft)	3.88E-03	4.54E-03
Total thickness of coal (ft)	-8.03E-04	-2.63E-04
Accumulative coal volume (Mm3)	-0.0184	-0.0152
Area of underground mines in a 4mile buffer (acres)	-4.07E-04	-3.00E-04
Average precipitation (in)	-2.80E-03	-2.72E-03

Variable	Maximum Head	Minimum Head
Withdraw/Distance (Mgal/Day)/(ft)	-7.29E-07	-6.99E-07

6.5 Applying the Model

By using the regression coefficients (β) for each model, an equation to solve for average potentiometric head can be made. With this equation, the average potentiometric head with respect to the bottom of the coal layer after the mine closes can be calculated. To do this, the elevation of the bottom of the mined coal layer is input into the bottom of well variable, the value for the accumulative coal volume is the max accumulative coal volume planned for the mine and withdraw/distance is set to zero because it is assumed there will be zero withdraw at the time of the highest post-mining water level.

The multi-mine with and without withdraw PLS model equations were applied to the 381 wells that were collected for the eleven studied mines. The calculated average potentiometric heads for each multi-mine model were plotted with the bottom of coal elevation in Figure 44 to see if the calculated heads would fall above the coal, indicating pool formation, or below the coal, indicating no pool formation. The multi-mine without withdraw model calculates slightly higher average potentiometric heads than the multi-mine with withdraw but both models predict that pools will form in the studied mines.

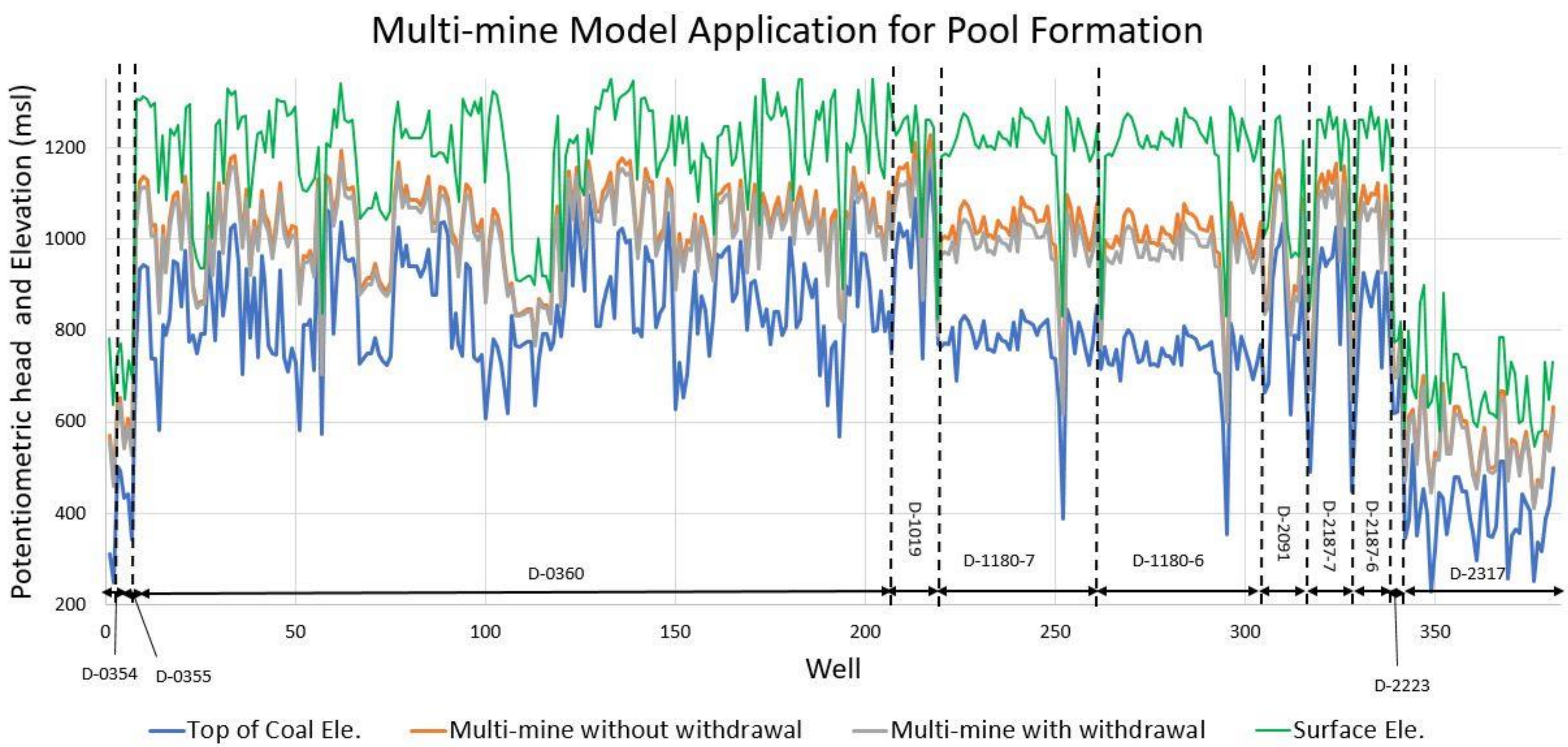

Figure 44. Multi-mine average potentiometric head model application for pool formation. The orange and grey lines are the potentiometric head predicted at the coal bottom for the two models for all of the mines without water withdraw and with water withdraw, respectively. The blue line represents the elevation of the top of the coal layer at the same horizontal coordinates of the well locations and the green line represents the surface elevation. The two models predict that all of these mines will be forming pools.

These equations can also be used to predict the behavior in the wells after mining and water withdraw stop. To do this, the parameters are inputted into the equation as normal except the value for the accumulative coal volume is the max accumulative coal volume and withdraw/distance is set to zero. The calculated average potentiometric heads for each well using the multi-mine models were plotted with their observed average potentiometric head in Figure 45 to see the change in head after mine closure. The multi-mine without withdraw model found 47.8% of the wells saw an increase between 0 and 179 ft after mining ceased and 52.2% saw a decrease in potentiometric head between 0 and 472 ft. The multi-mine with withdraw model found that 47.5% of the wells saw an increase between 0 and 181 ft and 52.5% saw a decrease in potentiometric between 0 and 560 ft.

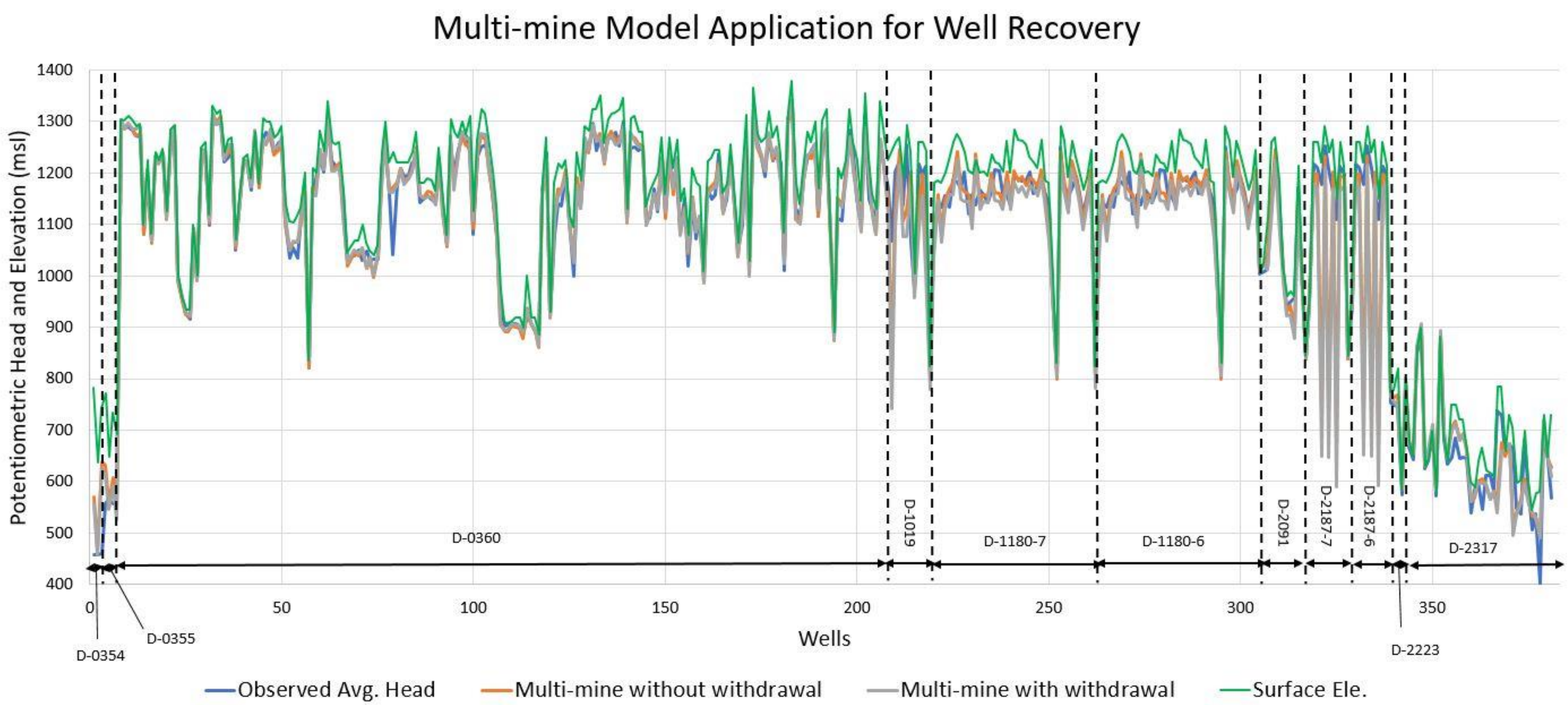

Figure 45. Multi-mine average potentiometric head model application for well recovery. The orange and grey lines are the potentiometric head predicted at the well bottom for the two models for all of the mines without water withdraw and with water withdraw, respectively. The blue line represents the average observed potentiometric head for each well and the green line is the surface elevation. Around 47% of these wells saw a decrease in potentiometric head after mining and 52% saw an increase.

CHAPTER 7: CONCLUSIONS

This study investigated eleven mines and 359 wells and their hydrological and lithological data. By using multivariate methods, it was determined that surface elevation, bottom of well elevation, overburden thickness, thickness of sandstone, thickness of limestone and accumulative coal volume are the parameters with the highest correlation to potentiometric head. Thickness of the mined coal seam and total thickness of coal were found to be insignificant in predicting potentiometric head.

This study has also identified the parameters that should be collected before mining, during mining and after mining, to better understand the behavior of the mine hydrology. An adequate collection of water withdraw rate from the mine during mining is an important parameter that is currently not carefully recorded or regulated during mining. Fortunately, a surrogate variable to water withdraw is the volume of coal extracted as the mine progresses, and that parameter is reported to the government agencies. More complete and accurate collection of water levels in wells before, during, and after mining could have improved this model or future models to predict pool formation. Regulators should ask for the collection of this parameter, which is also important for the possible impact on domestic or water supply wells in the area.

It is understood that this work and the other student thesis (Twumasi, 2018) that has been worked in parallel to this thesis, is an initial effort to construct a model to predict the formation of mine pools and that the model should be improved with future research. For example, only the area of underground mines within 1, 2, and 4 miles was found and the best of these areas to include in the model was the 4-mile area. However, a sensitivity analysis should be done by incrementally increasing the buffer area of underground mines around the studied mine. This analysis could allow for the identification of the optimum area that should be considered to assess the impact of the mines around the mine of interest on the potentiometric heads.

Multivariate analysis (PCA, PCR, and PLS) has proven to be effective in the identification of important parameters and the equations that better predict the potentiometric heads and possible pool formation. PLS was the preferred method because it can analyze multiple Y-variables and typically gave lower error values.

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APPENDIX A: D-0360 WELL ANALYSIS DATA

Table A 1. D-0360 well analysis well data. Values in black represent active mining data and values in red represent post-mining data.

Well	Date	Potentiometric Head (msl)
DW-406	2/13/97	1300
	3/19/97	1302
	4/23/97	1300
	5/27/97	1301
	6/28/97	1300
	7/20/97	1299
	1/23/14	**1298**
	2/13/14	**1298**
	3/12/14	**1299**
	4/17/14	**1297**
	5/8/14	**1298**
	3/24/15	**1299**
	4/21/15	**1298**
	6/18/15	**1298**
	7/2/15	**1301**
	12/17/15	**1297**
	1/12/16	**1301**
	2/16/16	**1299**
	3/21/16	**1300**
	5/25/16	**1295**
	12/26/16	**1298**
	1/23/17	**1301**
DW-719	7/26/03	1174
	10/3/03	1174
	2/24/04	1174
	10/20/06	1177
	1/24/07	1177
	4/30/10	1176.1
	1/21/16	**1175**
	2/9/16	**1175**
	3/14/16	**1175**
	4/12/16	**1175**

Well	Date	Potentiometric Head (msl)
	5/17/16	1175.4
	6/13/16	1174
	7/14/16	1174
	8/16/16	1174
	9/29/16	1172
	10/13/16	1172
	11/22/16	1173
	12/22/16	1173
	2/21/17	1174
	2/21/17	1174
	3/13/17	1175
W231.356.04	10/27/08	1225.4
	1/22/09	1225.3
	3/10/09	1225.4
	1/21/14	1226
	2/6/14	1227
	3/12/14	1226
	4/22/14	1226
	5/15/14	1227
	6/4/14	1228
	7/17/14	1226
	8/14/14	1224
	9/3/14	1224
	10/2/14	1223
	11/11/14	1265
	12/3/14	1239
	2/11/15	1267
	3/25/15	1267
	4/1/15	1265
	5/4/15	1267
	6/3/15	1267
	7/6/15	1264.5
	8/25/15	1266.6
	9/7/15	1263
	10/1/15	1267
	11/2/15	1267
	12/3/15	1267

Well	Date	Potentiometric Head (msl)
	2/21/16	**1266**
	3/3/16	**1267**
W-410	2/13/97	1254
	3/19/97	1258
	4/23/97	1254
	5/27/97	1257
	6/28/97	1244
	7/20/97	1238
	1/23/14	**1261**
	2/13/14	**1258**
	3/13/14	**1256**
	4/17/14	**1259**
	5/8/14	**1260**
	7/15/14	**1237**
	8/14/14	**1238**
	9/4/14	**1242**
	1/22/15	**1250**
	2/20/15	**1250**
	3/24/15	**1251**
	9/16/15	**1243**
	1/27/16	**1248**
	2/24/16	**1263**
	3/21/16	**1258**
	4/25/16	**1248**
	5/31/16	**1250**
	6/16/16	**1247**
	7/25/16	**1239**
	12/26/16	**1251**
	1/30/17	**1259**
	2/22/17	**1249**
	3/20/17	**1254**
W-413	2/13/97	1253
	3/19/97	1253
	4/23/97	1248
	5/27/97	1249
	6/28/97	1247
	7/20/97	1244

Well	Date	Potentiometric Head (msl)
	2/13/14	**1245**
	3/13/14	**1248**
	4/17/14	**1249**
	5/8/14	**1250**
	6/13/14	**1243**
	7/15/14	**1242**
	8/14/14	**1241**
	9/4/14	**1240**
	10/16/14	**1241**
	11/19/14	**1241**
	12/12/14	**1241**
	1/28/15	**1243**
	2/20/15	**1243**
	3/24/15	**1245**
	4/22/15	**1246**
	5/21/15	**1243**
	6/18/15	**1242**
	7/13/15	**1246**
	8/24/15	**1241**
	9/10/15	**1240**
	1/13/16	**1247**
	2/9/16	**1247**
	3/21/16	**1249**
	4/25/16	**1246**
	5/25/16	**1247**
	6/16/16	**1242**
	7/25/16	**1241**
	8/29/16	**1241**
	9/26/16	**1240**
	10/31/16	**1243**
	11/21/16	**1241**
	12/26/16	**1246**
	1/23/17	**1249**
	2/27/17	**1245**
	3/20/17	**1247**
W-414	2/13/97	1266
	3/19/97	1267

Well	Date	Potentiometric Head (msl)
	4/23/97	1264
	5/27/97	1265
	6/28/97	1245
	7/20/97	1253
	1/23/14	**1234**
	2/13/14	**1255**
	3/13/14	**1252**
	4/17/14	**1266**
	5/8/14	**1266**
	6/13/14	**1231**
	7/15/14	**1229**
	8/14/14	**1228**
	9/4/14	**1230**
	10/16/14	**1231**
	11/19/14	**1231**
	12/12/14	**1240**
	1/28/15	**1261**
	2/20/15	**1235**
	3/24/15	**1266**
	4/22/15	**1267**
	5/21/15	**1232**
	6/18/15	**1265**
	7/13/15	**1265**
	8/24/15	**1230**
	9/10/15	**1231**
	1/13/16	**1266**
	2/9/16	**1265**
	3/21/16	**1267**
	4/25/16	**1246**
	5/25/16	**1267**
	6/16/16	**1248**
	8/29/16	**1232**
	9/26/16	**1231**
	10/31/16	**1231**
	12/26/16	**1265**
	1/23/17	**1267**
	2/27/17	**1264**

Well	Date	Potentiometric Head (msl)
	3/20/17	**1265**
W-415	2/13/97	1115
	3/14/97	1115
	4/23/97	1113
	5/22/97	1113
	6/27/97	1114
	7/20/97	1110
	1/23/14	**1112**
	2/13/14	**1112**
	3/13/14	**1112**
	4/17/14	**1114**
	5/8/14	**1115**
	6/13/14	**1109**
	7/15/14	**1107**
	8/14/14	**1109**
	9/4/14	**1107**
	10/16/14	**1103**
	11/19/14	**1101**
	12/12/14	**1107**
	1/28/15	**1109**
	2/20/15	**1109**
	3/24/15	**1113**
	4/22/15	**1113**
	5/21/15	**1105**
	6/18/15	**1106**
	7/13/15	**1105**
	8/24/15	**1103**
	9/10/15	**1102**
	1/16/16	**1112**
	2/9/16	**1111**
	3/21/16	**1113**
	4/25/16	**1109**
	5/25/16	**1112**
	6/16/16	**1105**
	7/25/16	**1104**
	8/29/16	**1103**
	9/26/16	**1102**

Well	Date	Potentiometric Head (msl)
	10/31/16	**1102**
	11/21/16	**1102**
	12/26/16	**1110**
	1/23/17	**1114**
	2/17/17	**1113**
	3/20/17	**1112**
W-428	2/28/98	1233
	3/5/98	1234
	4/13/98	1228
	5/20/98	1231
	2/20/14	**1222**
	3/13/14	**1220**
	4/29/14	**1201**
	5/15/14	**1200**
	6/4/14	**1199**
	7/17/14	**1196**
	8/14/14	**1194**
	9/3/14	**1210**
	10/2/14	**1205**
	11/11/14	**1210**
	12/3/14	**1212**
	1/13/15	**1218**
	2/11/15	**1225**
	3/10/15	**1227**
	4/1/15	**1221**
	5/4/15	**1196**
	6/17/15	**1200**
	7/6/15	**1207**
	8/11/15	**1200**
	9/4/15	**1197**
	1/5/16	**1208**
	2/3/16	**1207**
	3/3/16	**1212**
	4/14/16	**1213**
W501.077.00	**6/18/14**	**1167**
	7/16/14	**1166**
	8/14/14	**1165**

Well	Date	Potentiometric Head (msl)
	9/9/14	1162
	10/7/14	1161
	11/11/14	1160
	12/5/14	1161
	1/14/15	1164
	2/9/15	1166
	3/4/15	1166
	4/8/15	1168
	5/12/15	1167
	6/5/15	1164
	7/8/15	1169
	8/17/15	1165
	9/8/15	1163
	1/5/16	1169
	2/3/16	1098
	3/1/16	1118
	4/5/16	1106
	5/9/16	1104
	6/7/16	1106
	7/5/16	1102
	8/1/16	1100
	9/12/16	1098
	10/5/16	1098
	11/3/16	1099
	12/2/16	1097
	1/3/17	1105
	1/3/17	1073
	2/1/17	1108
	2/1/17	1074
W501.077.01	11/3/13	1071
	6/18/14	1071
	7/16/14	1076
	8/14/14	1074
	9/9/14	1068
	12/9/14	1070
	1/14/15	1070
	2/9/15	1070

Well	Date	Potentiometric Head (msl)
	3/4/15	**1070**
	4/8/15	**1070**
	5/12/15	**1070**
	6/5/15	**1070**
	7/8/15	**1070**
	8/17/15	**1070**
	9/8/15	**1070**
	1/5/16	**1070**
	2/3/16	**1034**
	3/1/16	**1073**
	4/5/16	**1075**
	5/9/16	**1071**
	6/7/16	**1071**
	7/5/16	**1071**
	8/1/16	**1072**
	9/12/16	**1071**
	10/5/16	**1071**
	12/1/16	**1071**
W-709	7/7/03	1010
	9/24/03	1012
	2/18/04	1010.3
	1/19/17	**1011**
	2/16/17	**1012**
	3/13/17	**1012**
WL231.362.00	8/25/10	1120
	1/17/11	1127.3
	2/23/11	1128.6
	3/25/14	**1133**
	4/22/14	**1136**
	5/13/14	**1136**
	6/4/14	**1130**
	7/16/14	**1125**
	8/4/14	**1125**
	9/3/14	**1115**
	10/2/14	**1116**
	11/11/14	**1116**
	12/3/14	**1116**

Well	Date	Potentiometric Head (msl)
	1/13/15	**1122**
	2/3/15	**1128**
	3/2/15	**1121**
	4/1/15	**1124**
	5/4/15	**1128**
	6/3/15	**1116**
	7/6/15	**1111**
	8/11/15	**1106**
	9/1/15	**1103**
	10/1/15	**1100**
	11/2/15	**1104**
	12/2/15	**1106**
	1/5/16	**1113**
	2/1/16	**1114**
	3/3/16	**1115**
	4/4/16	**1114**
	5/2/16	**1114**
	6/1/16	**1114**
	7/5/16	**1108**
	8/1/16	**1106**
	9/1/16	**1106**
	10/3/16	**1106**
	11/1/16	**1107**
	12/1/16	**1106**
	1/2/17	**1110**
	2/1/17	**1116**
	3/1/17	**1119**
WL336.373.00	8/25/10	1070.3
	1/17/11	1066.3
	2/23/11	1070.7
	3/25/14	**1075**
	4/22/14	**1082**
	5/13/14	**1081**
	6/4/14	**1085**
	7/9/14	**1083**
	8/4/14	**1081**
	9/3/14	**1069**

Well	Date	Potentiometric Head (msl)
	10/2/14	1072
	11/11/14	1071
	12/3/14	1079
	1/13/15	1080
	2/3/15	1080
	3/2/15	1081
	4/1/15	1065
	5/4/15	1083
	6/3/15	1081
	7/6/15	1079
	8/11/15	1078
	9/1/15	1077
	10/1/15	1075
	11/2/15	1074
	12/3/15	1075
	1/5/16	1076
	2/1/16	1077
	3/3/16	1078
	4/4/16	1079
	5/2/16	1078
WL-674	3/30/01	1092
	5/29/01	1097
	8/31/01	1099
	1/15/14	1100
	2/18/14	1101
	3/12/14	1102
	4/15/14	1101
	5/7/14	1102
	6/3/14	1101
	7/10/14	1099
	8/19/14	1099
	9/3/14	1099
	10/15/14	1098
	11/10/14	1093
	12/3/14	1093
	1/12/15	1092
	2/5/15	1091

Well	Date	Potentiometric Head (msl)
	3/2/15	**1100**
	4/7/15	**1099**
	5/11/15	**1101**
	6/1/15	**1101**
	7/1/15	**1100**
	8/24/15	**1089**
	9/16/15	**1099**
	1/4/16	**1102**
	2/1/16	**1100**
	3/1/16	**1103**
	4/4/16	**1103**
	5/2/16	**1102**
	6/1/16	**1102**
	7/5/16	**1101**
	8/1/16	**1100**
	9/1/16	**1098**
	10/3/16	**1094**
	11/1/16	**1097**
	12/1/16	**1078**
	1/19/17	**1131**
	2/16/17	**1132**
	3/13/17	**1133**
WL-721	4/30/10	1167.5
	7/27/10	1168
	9/21/12	1157.6
	1/19/16	**1167**
	2/11/16	**1162**
	3/14/16	**1202**
	4/19/16	**1163**
	5/17/16	**1161**
	6/13/16	**1163**
	7/14/16	**1159**
	8/16/16	**1157**
	9/29/16	**1157**
	10/13/16	**1165**
	11/22/16	**1157**
	12/22/16	**1157**

Well	Date	Potentiometric Head (msl)
	1/2/17	**1160**
	2/21/17	**1161**
	3/13/17	**1165**
WL-736	7/21/03	1119
	9/30/03	1119
	10/3/03	1120
	2/18/04	1119
	1/13/16	**1121**
	2/8/16	**1120**
	3/14/16	**1118**
	4/26/16	**1118**
	5/11/16	**1116**
	6/13/16	**1130.87**
	7/29/16	**1118**
	8/16/16	**1117**
	9/15/16	**1116**
	10/13/16	**1116**
	11/14/16	**1115**
	12/22/16	**1117**
	1/19/17	**1120**
	2/16/17	**1120**
	3/13/17	**1119**

Table A 2. D-0360 well analysis potentiometric head and precipitation data.

Well	Date	Potentiometric Head (msl)	Monthly Precipitation (in)
DW-719	1/21/2016	1175	1.12
	2/9/2016	1175	3.29
	3/14/2016	1175	4.27
	4/12/2016	1175	2.31
	5/17/2016	1175.4	2.74
	6/13/2016	1174	5.22
	7/14/2016	1174	2.49
	8/16/2016	1174	5.82
	9/29/2016	1172	4.68
	10/13/2016	1172	1.73
	11/22/2016	1173	1.02
	12/22/2016	1173	3.09
	2/21/2017	1174	2.83
	2/21/2017	1174	2.45
	3/13/2017	1175	5.39
W231.356.04	1/21/2014	1226	2.4
	2/6/2014	1227	2.39
	3/12/2014	1226	2.59
	4/22/2014	1226	5.47
	5/15/2014	1227	4
	6/4/2014	1228	5.29
	7/17/2014	1226	3.47
	8/14/2014	1224	4.9
	9/3/2014	1224	0.65
	10/2/2014	1223	2.77
	11/11/2014	1265	1.46
	12/3/2014	1239	2.7
W231.356.04	2/11/2015	1267	1.7
	3/25/2015	1267	3.92
	4/1/2015	1265	4.09
	5/4/2015	1267	3.56
	6/3/2015	1267	6.72
	7/6/2015	1264.5	5.41
	8/25/2015	1266.6	3.59
	9/7/2015	1263	3.21
	10/1/2015	1267	2.68

Well	Date	Potentiometric Head (msl)	Monthly Precipitation (in)
	11/2/2015	1267	2.37
	12/3/2015	1267	4.88
W-410	1/23/2014	1261	2.4
	2/13/2014	1258	2.39
	3/13/2014	1256	2.59
	4/17/2014	1259	5.47
	5/8/2014	1260	4
	7/15/2014	1237	5.29
	8/14/2014	1238	3.47
	9/4/2014	1242	4.9
W-410	1/27/2016	1248	1.12
	2/24/2016	1263	3.29
	3/21/2016	1258	4.27
	4/25/2016	1248	2.31
	5/31/2016	1250	2.74
	6/16/2016	1247	5.22
	7/25/2016	1239	2.49
W-413	2/13/2014	1245	2.39
	3/13/2014	1248	2.59
	4/17/2014	1249	5.47
	5/8/2014	1250	4
	6/13/2014	1243	5.29
	7/15/2014	1242	3.47
	8/14/2014	1241	4.9
	9/4/2014	1240	0.65
	10/16/2014	1241	2.77
	11/19/2014	1241	1.46
	12/12/2014	1241	2.7
	1/28/2015	1243	2.69
	2/20/2015	1243	1.7
	3/24/2015	1245	3.92
	4/22/2015	1246	4.09
	5/21/2015	1243	3.56
	6/18/2015	1242	6.72
	7/13/2015	1246	5.41
	8/24/2015	1241	3.59
	9/10/2015	1240	3.21

Well	Date	Potentiometric Head (msl)	Monthly Precipitation (in)
W-413	1/13/2016	1247	1.12
	2/9/2016	1247	3.29
	3/21/2016	1249	4.27
	4/25/2016	1246	2.31
	5/25/2016	1247	2.74
	6/16/2016	1242	5.22
	7/25/2016	1241	2.49
	8/29/2016	1241	5.82
	9/26/2016	1240	4.68
	10/31/2016	1243	1.73
	11/21/2016	1241	1.02
	12/26/2016	1246	3.09
W-414	1/23/2014	1234	2.4
	2/13/2014	1255	2.39
	3/13/2014	1252	2.59
	4/17/2014	1266	5.47
	5/8/2014	1266	4
	6/13/2014	1231	5.29
	7/15/2014	1229	3.47
	8/14/2014	1228	4.9
	9/4/2014	1230	0.65
	10/16/2014	1231	2.77
	11/19/2014	1231	1.46
	12/12/2014	1240	2.7
	1/28/2015	1261	2.69
	2/20/2015	1235	1.7
	3/24/2015	1266	3.92
	4/22/2015	1267	4.09
	5/21/2015	1232	3.56
	6/18/2015	1265	6.72
	7/13/2015	1265	5.41
	8/24/2015	1230	3.59
	9/10/2015	1231	3.21
W-415	1/23/2014	1112	2.4
	2/13/2014	1112	2.39
	3/13/2014	1112	2.59
	4/17/2014	1114	5.47

Well	Date	Potentiometric Head (msl)	Monthly Precipitation (in)
	5/8/2014	1115	4
	6/13/2014	1109	5.29
	7/15/2014	1107	3.47
	8/14/2014	1109	4.9
	9/4/2014	1107	0.65
	10/16/2014	1103	2.77
	11/19/2014	1101	1.46
	12/12/2014	1107	2.7
	1/28/2015	1109	2.69
	2/20/2015	1109	1.7
	3/24/2015	1113	3.92
	4/22/2015	1113	4.09
	5/21/2015	1105	3.56
	6/18/2015	1106	6.72
	7/13/2015	1105	5.41
	8/24/2015	1103	3.59
	9/10/2015	1102	3.21
W-415	1/16/2016	1112	1.12
	2/9/2016	1111	3.29
	3/21/2016	1113	4.27
	4/25/2016	1109	2.31
	5/25/2016	1112	2.74
	6/16/2016	1105	5.22
	7/25/2016	1104	2.49
	8/29/2016	1103	5.82
	9/26/2016	1102	4.68
	10/31/2016	1102	1.73
	11/21/2016	1102	1.02
	12/26/2016	1110	3.09
W-428	2/20/2014	1222	2.39
	3/13/2014	1220	2.59
	4/29/2014	1201	5.47
	5/15/2014	1200	4
	6/4/2014	1199	5.29
	7/17/2014	1196	3.47
	8/14/2014	1194	4.9
	9/3/2014	1210	0.65

Well	Date	Potentiometric Head (msl)	Monthly Precipitation (in)
	10/2/2014	1205	2.77
	11/11/2014	1210	1.46
	12/3/2014	1212	2.7
	1/13/2015	1218	2.69
	2/11/2015	1225	1.7
	3/10/2015	1227	3.92
	4/1/2015	1221	4.09
	5/4/2015	1196	3.56
	6/17/2015	1200	6.72
	7/6/2015	1207	5.41
	8/11/2015	1200	3.59
	9/4/2015	1197	3.21
W501.077.00	6/18/2014	1167	5.29
	7/16/2014	1166	3.47
	8/14/2014	1165	4.9
	9/9/2014	1162	0.65
	10/7/2014	1161	2.77
	11/11/2014	1160	1.46
	12/5/2014	1161	2.7
	1/14/2015	1164	2.69
	2/9/2015	1166	1.7
	3/4/2015	1166	3.92
	4/8/2015	1168	4.09
	5/12/2015	1167	3.56
	6/5/2015	1164	6.72
	7/8/2015	1169	5.41
	8/17/2015	1165	3.59
	9/8/2015	1163	3.21
WL231.362.00	3/25/2014	1133	2.59
	4/22/2014	1136	5.47
	5/13/2014	1136	4
	6/4/2014	1130	5.29
	7/16/2014	1125	3.47
	8/4/2014	1125	4.9
	9/3/2014	1115	0.65
	10/2/2014	1116	2.77
	11/11/2014	1116	1.46

Well	Date	Potentiometric Head (msl)	Monthly Precipitation (in)
	12/3/2014	1116	2.7
	1/13/2015	1122	2.69
	2/3/2015	1128	1.7
	3/2/2015	1121	3.92
	4/1/2015	1124	4.09
	5/4/2015	1128	3.56
	6/3/2015	1116	6.72
	7/6/2015	1111	5.41
	8/11/2015	1106	3.59
	9/1/2015	1103	3.21
	10/1/2015	1100	2.68
	11/2/2015	1104	2.37
	12/2/2015	1106	4.88
	1/5/2016	1113	1.12
	2/1/2016	1114	3.29
	3/3/2016	1115	4.27
	4/4/2016	1114	2.31
	5/2/2016	1114	2.74
	6/1/2016	1114	5.22
	7/5/2016	1108	2.49
	8/1/2016	1106	5.82
	9/1/2016	1106	4.68
	10/3/2016	1106	1.73
	11/1/2016	1107	1.02
	12/1/2016	1106	3.09
	1/2/2017	1110	2.83
	2/1/2017	1116	2.45
	3/1/2017	1119	5.39
WL336.373.00	3/25/2014	1075	2.59
	4/22/2014	1082	5.47
	5/13/2014	1081	4
	6/4/2014	1085	5.29
	7/9/2014	1083	3.47
	8/4/2014	1081	4.9
	9/3/2014	1069	0.65
	10/2/2014	1072	2.77
	11/11/2014	1071	1.46

Well	Date	Potentiometric Head (msl)	Monthly Precipitation (in)
	12/3/2014	1079	2.7
	1/13/2015	1080	2.69
	2/3/2015	1080	1.7
	3/2/2015	1081	3.92
	4/1/2015	1065	4.09
	5/4/2015	1083	3.56
	6/3/2015	1081	6.72
	7/6/2015	1079	5.41
	8/11/2015	1078	3.59
	9/1/2015	1077	3.21
	10/1/2015	1075	2.68
	11/2/2015	1074	2.37
	12/3/2015	1075	4.88
	1/5/2016	1076	1.12
	2/1/2016	1077	3.29
	3/3/2016	1078	4.27
	4/4/2016	1079	2.31
	5/2/2016	1078	2.74
WL-674	1/15/2014	1100	2.4
	2/18/2014	1101	2.39
	3/12/2014	1102	2.59
	4/15/2014	1101	5.47
	5/7/2014	1102	4
	6/3/2014	1101	5.29
	7/10/2014	1099	3.47
	8/19/2014	1099	4.9
	9/3/2014	1099	0.65
	10/15/2014	1098	2.77
	11/10/2014	1093	1.46
	12/3/2014	1093	2.7
	1/12/2015	1092	2.69
	2/5/2015	1091	1.7
	3/2/2015	1100	3.92
	4/7/2015	1099	4.09
	5/11/2015	1101	3.56
	6/1/2015	1101	6.72
	7/1/2015	1100	5.41

Well	Date	Potentiometric Head (msl)	Monthly Precipitation (in)
	8/24/2015	1089	3.59
	9/16/2015	1099	3.21
WL-674	1/4/2016	1102	1.12
	2/1/2016	1100	3.29
	3/1/2016	1103	4.27
	4/4/2016	1103	2.31
	5/2/2016	1102	2.74
	6/1/2016	1102	5.22
	7/5/2016	1101	2.49
	8/1/2016	1100	5.82
	9/1/2016	1098	4.68
	10/3/2016	1094	1.73
	11/1/2016	1097	1.02
	12/1/2016	1078	3.09
	1/19/2017	1131	2.83
	2/16/2017	1132	2.45
	3/13/2017	1133	5.39
WL-721	1/19/2016	1167	1.12
	2/11/2016	1162	3.29
	3/14/2016	1202	4.27
	4/19/2016	1163	2.31
	5/17/2016	1161	2.74
	6/13/2016	1163	5.22
	7/14/2016	1159	2.49
	8/16/2016	1157	5.82
	9/29/2016	1157	4.68
	10/13/2016	1165	1.73
	11/22/2016	1157	1.02
	12/22/2016	1157	3.09
	1/2/2017	1160	2.83
	2/21/2017	1161	2.45
	3/13/2017	1165	5.39
WL-736	1/13/2016	1121	1.12
	2/8/2016	1120	3.29
	3/14/2016	1118	4.27
	4/26/2016	1118	2.31
	5/11/2016	1116	2.74

Well	Date	Potentiometric Head (msl)	Monthly Precipitation (in)
	6/13/2016	1130.87	5.22
	7/29/2016	1118	2.49
	8/16/2016	1117	5.82
	9/15/2016	1116	4.68
	10/13/2016	1116	1.73
	11/14/2016	1115	1.02
	12/22/2016	1117	3.09
	1/19/2017	1120	2.83
	2/16/2017	1120	2.45
	3/13/2017	1119	5.39

APPENDIX B: MULTIVARIATE ANALYSIS SINGLE MINE MODELS DATA

Table B 1. D-0360 ODNR-DWR with water withdraw model data. The 0360-ODNR-DWR without water withdraw model uses the same data except the withdraw/distance variable. ($1m^3 = 35.315\ ft^3$) ($1acre = 43560ft^2$)

Well	First Date	Last Date	Num. Measurements	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Withdrawal/Distance (MGal/Month)/(ft)
DW-118	1/29/1991	3/20/1991	3	1288.00	1305.00	1283.00	559.04	6.47	398.42	36.41	91.79	19.89	13.68	175.08
DW-122	1/29/1991	3/20/1991	3	1285.33	1302.00	1273.00	367.85	6.20	166.26	55.30	131.78	11.66	13.68	153.22
DW-126	1/29/1991	3/20/1991	3	1288.67	1311.00	1284.00	367.85	6.20	166.26	55.30	131.78	11.66	13.68	151.82
DW-129	1/29/1991	3/20/1991	3	1283.00	1305.00	1270.00	367.85	6.20	166.26	55.30	131.78	11.66	13.68	172.65
DW-161	1/7/1991	4/24/1991	4	1273.00	1290.00	1264.00	550.70	7.10	325.95	44.97	162.21	15.14	14.48	149.67
DW-162	1/22/1991	4/24/1991	4	1269.75	1296.00	1267.00	559.04	6.47	398.42	36.41	91.79	19.89	14.48	149.99
DW-169	1/7/1991	4/8/1991	4	1081.00	1100.00	1075.00	518.47	7.08	373.81	9.26	93.89	21.49	14.48	136.68
DW-178	1/4/1991	4/9/1991	4	1196.75	1225.00	1181.00	414.16	6.47	221.29	50.89	100.31	19.91	14.48	121.59
DW-180	1/14/1991	4/16/1991	4	1066.25	1083.00	1051.00	293.90	7.12	127.60	10.23	132.06	16.83	14.48	140.34
DW-196	1/16/1991	4/17/1991	4	1233.00	1240.00	1219.00	414.16	6.47	221.29	50.89	100.31	19.91	14.48	123.82
DW-318	11/30/1993	3/31/1994	5	1283.70	1294.00	1276.00	518.47	7.08	373.81	9.26	93.89	21.49	26.02	136.05
DW-324	11/14/1995	2/3/1996	6	998.00	1000.00	991.00	209.68	4.28	93.70	32.00	105.70	7.82	35.38	117.50
DW-330	11/17/1995	4/15/1996	6	955.67	960.00	952.00	209.68	4.28	93.70	32.00	105.70	7.82	35.38	116.92
DW-331	11/20/1995	4/15/1996	6	927.00	935.00	924.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	116.41
DW-354	11/25/1995	4/23/1996	6	916.33	935.00	913.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	115.85
DW-356	11/28/1995	4/23/1996	6	1092.17	1100.00	1088.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	131.76
DW-362	11/30/1995	4/23/1996	6	993.17	1000.00	989.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	127.75
DW-376	1/27/1997	6/21/1997	6	1244.83	1250.00	1220.00	471.79	5.29	321.05	61.70	78.55	18.20	40.52	133.15
DW-387	4/25/1997	6/28/1997	3	1241.00	1260.00	1236.00	287.45	6.85	195.67	43.79	129.97	13.52	40.52	118.86

Well	First Date	Last Date	Num. Measurements	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Withdrawal/Distance (MGal/Month)/(ft)
DW-391	1/28/1997	6/21/1997	6	1097.67	1120.00	1090.00	287.45	6.85	195.67	43.79	129.97	13.52	40.52	121.46
DW-393	1/28/1997	6/28/1997	6	1315.00	1330.00	1300.00	433.09	5.12	321.97	32.71	69.59	16.17	40.52	131.36
DW-399	1/30/1997	6/27/1997	6	1294.17	1315.00	1285.00	291.50	6.25	177.75	23.01	71.99	15.15	40.52	156.98
DW-406	2/13/1997	1/23/2017	22	1298.95	1322.00	1298.00	291.50	6.25	177.75	23.01	71.99	15.15	146.18	98.16
DW-420	3/22/1997	8/23/1997	6	1222.80	1241.00	1218.00	291.50	6.25	177.75	23.01	71.99	15.15	41.98	167.64
DW-427	2/27/1998	5/20/1998	4	1229.50	1265.00	1224.00	562.20	5.50	277.65	65.48	204.97	11.83	46.09	214.46
DW-430	4/13/1998	5/20/1998	2	1252.00	1270.00	1246.00	335.45	7.45	211.84	21.69	92.72	12.98	46.09	254.20
DW-457	9/7/1999	11/22/1999	2	1049.50	1070.00	1045.00	287.45	6.85	195.67	43.79	129.97	13.52	52.95	116.06
DW-481	7/18/2001	7/18/2001	1	1148.00	1155.00	1143.00	241.40	2.31	140.36	34.51	73.45	10.11	59.37	217.48
DW502-338.08	10/29/2008	3/9/2009	3	1219.23	1230.00	1214.00	489.71	11.76	347.06	30.83	115.94	26.19	101.40	17.86
DW-679	1/21/2014	4/15/2014	4	1220.75	1235.00	1216.00	271.01	6.19	157.00	0.91	85.09	13.65	136.09	34.52
DW-702	8/7/2003	2/25/2004	3	1167.50	1190.00	1163.00	281.47	7.00	172.33	25.96	70.19	7.31	73.96	164.29
DW-717	7/22/2003	2/19/2004	3	1275.17	1280.00	1273.00	512.33	7.27	337.40	56.38	101.13	13.43	73.96	154.18
DW-719	7/26/2003	12/22/2016	18	1174.42	1178.00	1171.00	428.45	7.05	259.73	45.00	112.83	14.77	146.18	170.02
W-140	1/29/1991	3/21/1991	2	1263.50	1300.00	1256.00	559.04	6.47	398.42	36.41	91.79	19.89	13.68	174.14
W-153	1/29/1991	3/21/1991	3	1240.00	1269.00	1207.00	559.04	6.47	398.42	36.41	91.79	19.89	13.68	164.27
W-157	1/29/1991	3/21/1991	3	1261.33	1275.00	1219.00	514.70	7.57	350.60	23.74	78.65	19.66	13.68	186.39
W-159	1/4/1991	4/10/1991	5	1251.00	1290.00	1233.00	559.04	6.47	398.42	36.41	91.79	19.89	14.48	157.50
W-165	1/7/1991	4/19/1991	4	1106.25	1140.00	1069.00	559.04	6.47	398.42	36.41	91.79	19.89	14.48	159.59
W-166	1/4/1991	4/8/1991	4	1032.50	1106.00	998.00	293.90	7.12	127.60	10.23	132.06	16.83	14.48	137.92
W-170	1/18/1991	4/8/1991	4	1054.00	1105.00	1030.00	293.90	7.12	127.60	10.23	132.06	16.83	14.48	135.40
W-174	1/18/1991	4/8/1991	4	1038.75	1117.00	1016.00	293.90	7.12	127.60	10.23	132.06	16.83	14.48	131.12
W-175	1/14/1991	4/9/1991	4	1117.75	1132.00	1086.00	420.17	7.53	223.66	72.28	173.45	25.63	14.48	127.06
W-199	1/16/1991	4/17/1991	4	1183.50	1200.00	1133.00	143.32	3.00	15.48	0.00	96.63	9.60	14.48	120.82

Well	First Date	Last Date	Num. Measurements	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Withdrawal/Distance (MGal/Month)/(ft)
W-202	1/16/1991	4/17/1991	4	1161.50	1210.00	1132.00	143.32	3.00	15.48	0.00	96.63	9.60	14.48	119.72
W-204	1/16/1991	4/17/1991	4	1188.50	1200.00	1136.00	143.32	3.00	15.48	0.00	96.63	9.60	14.48	119.39
W21-029.00	5/1/2008	8/4/2008	3	1233.33	1283.00	1204.00	490.16	5.17	323.67	11.34	108.77	13.68	98.01	49.92
W21-043.00	5/1/2008	8/14/2008	3	1201.20	1242.00	1179.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	56.45
W21-045.01	5/1/2008	8/6/2008	3	1296.97	1340.00	1282.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	47.95
W21-057.00	5/3/2008	8/12/2008	3	1224.43	1260.00	1161.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	56.22
W21-059.00	5/3/2008	8/9/2008	3	1216.17	1255.00	1164.50	303.36	7.40	175.10	23.60	87.50	17.29	98.01	47.12
W21-064.00	5/2/2008	8/13/2008	3	1205.67	1260.00	1177.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	55.99
W21-066.00	5/1/2008	8/21/2008	3	1162.83	1165.00	1081.50	259.18	7.05	122.95	13.10	106.91	11.26	98.01	56.46
W21-080.00	5/3/2008	8/18/2008	3	1030.40	1045.00	1001.00	317.45	7.29	204.12	2.04	78.09	10.82	98.01	55.31
W21-083.00	5/2/2008	8/8/2008	3	1037.10	1055.00	1017.50	317.45	7.29	204.12	2.04	78.09	10.82	98.01	55.06
W21-087.00	5/5/2008	8/11/2008	3	1039.10	1068.00	1026.30	317.45	7.29	204.12	2.04	78.09	10.82	98.01	54.78
W21-087.01	5/5/2008	8/11/2008	3	1050.97	1068.00	1015.80	317.45	7.29	204.12	2.04	78.09	10.82	98.01	54.50
W21-095.00	5/2/2008	8/9/2008	3	1030.83	1100.00	1011.00	317.45	7.29	204.12	2.04	78.09	10.82	98.01	54.21
W21-106.00	5/3/2008	8/11/2008	3	1047.33	1065.00	965.00	317.45	7.29	204.12	2.04	78.09	10.82	98.01	54.94
W21-110.01	8/8/2008	8/8/2008	1	1017.20	1050.00	1017.20	317.45	7.29	204.12	2.04	78.09	10.82	98.01	9.17
W21-111.00	5/2/2008	8/8/2008	3	1032.63	1040.00	961.00	317.45	7.29	204.12	2.04	78.09	10.82	98.01	54.88
W21-112.00	5/8/2008	8/11/2008	3	1032.07	1060.00	1023.40	317.45	7.29	204.12	2.04	78.09	10.82	98.01	54.60
W21-138.00	5/3/2008	8/4/2008	3	1207.30	1240.00	1109.70	303.36	7.40	175.10	23.60	87.50	17.29	98.01	46.93
W21-155.08	6/24/2008	4/30/2008	3	1259.97	1300.00	1245.00	274.25	5.45	194.05	15.51	61.90	11.27	96.35	34.95
W21-160.00	4/30/2008	8/6/2008	3	1160.17	1220.00	1115.00	279.00	6.90	77.16	24.69	145.59	12.54	98.01	35.73
W21-165.04	5/3/2008	8/23/2008	3	1042.07	1240.00	1100.00	253.20	9.20	50.40	31.39	165.59	12.60	98.01	56.58
W21-171.00	4/30/2008	8/6/2008	3	1176.93	1220.00	1147.00	279.00	6.90	77.16	24.69	145.59	12.54	98.01	35.10
W21-173.01	4/29/2008	8/7/2008	3	1207.83	1220.00	1201.50	279.00	6.90	77.16	24.69	145.59	12.54	98.01	34.66
W21-180.01	4/29/2008	8/6/2008	3	1193.63	1220.00	1144.50	279.00	6.90	77.16	24.69	145.59	12.54	98.01	34.45

Well	First Date	Last Date	Num. Measurements	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Withdrawal/Distance (MGal/Month)/(ft)
W21-183.01	4/29/2008	8/6/2008	3	1194.20	1220.00	1164.00	302.03	5.68	178.44	31.29	74.71	12.42	98.01	34.07
W21-187.00	5/1/2008	8/7/2008	3	1219.23	1240.00	1173.50	302.03	5.68	178.44	31.29	74.71	12.42	98.01	43.51
W21-195.00	5/1/2008	8/23/2008	3	1223.37	1280.00	1221.00	302.03	5.68	178.44	31.29	74.71	12.42	98.01	53.80
W21-260.00	5/6/2008	8/19/2008	3	1142.47	1180.00	1137.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	54.84
W21-265.00	5/5/2008	8/19/2008	3	1148.03	1180.00	1127.50	303.36	7.40	175.10	23.60	87.50	17.29	98.01	54.64
W21-452.00	5/8/2008	8/19/2008	3	1155.50	1190.00	1137.00	156.50	7.10	92.72	0.00	41.26	9.32	98.01	52.59
W21-481.00	5/5/2008	9/2/2008	3	1149.13	1185.00	1143.00	148.57	6.55	43.93	0.00	95.92	9.60	98.01	52.29
W21-502.00	7/16/2008	8/26/2008	2	1142.85	1165.00	1132.00	156.50	7.10	92.72	0.00	41.26	9.32	98.01	60.29
W-22.007.00	10/29/2008	12/21/2016	12	1209.92	1250.00	1198.00	489.71	11.76	347.06	30.83	115.94	26.19	146.18	139.71
W-225	1/21/1991	4/11/1991	4	1139.50	1148.00	1102.00	311.66	5.89	203.68	6.59	88.74	15.19	14.48	114.20
W-226	1/21/1991	4/11/1991	4	1057.75	1080.00	1040.00	311.66	5.89	203.68	6.59	88.74	15.19	14.48	112.52
W-229A	1/26/1991	6/14/1991	6	1262.33	1305.00	1225.00	562.60	4.58	351.36	15.02	176.44	12.24	14.48	181.84
W231.356.00	1/22/2009	3/10/2009	2	1196.65	1280.00	1068.00	335.45	7.45	211.84	21.69	92.72	12.98	94.66	22.66
W231.356.04	10/27/2008	3/3/2016	28	1246.36	1270.00	1209.70	335.45	7.45	211.84	21.69	92.72	12.98	144.60	94.16
W-289	11/15/1993	4/29/1994	6	1267.33	1300.00	1246.00	557.74	2.40	398.53	47.72	103.50	11.13	26.02	184.67
W-291	11/16/1993	4/29/1994	6	1271.83	1275.00	1240.00	542.40	5.04	412.92	16.15	92.07	13.88	26.02	149.87
W-292	11/16/1993	3/31/1994	5	1242.40	1310.00	1216.00	562.60	4.58	351.36	15.02	176.44	12.24	26.02	177.23
W-294	11/17/1993	4/28/1994	6	1080.50	1125.00	1068.00	518.47	7.08	373.81	9.26	93.89	21.49	26.02	133.75
W-295	11/17/1993	3/31/1994	5	1232.80	1264.00	1222.00	562.60	4.58	351.36	15.02	176.44	12.24	26.02	171.22
W-299	11/18/1993	3/31/1994	5	1249.40	1324.00	1221.00	542.40	5.04	412.92	16.15	92.07	13.88	26.02	165.24
W-312A	12/5/1994	6/23/1995	6	1254.67	1315.00	1220.00	550.70	7.10	325.95	44.97	162.21	15.14	30.70	154.71
W-314A	7/21/2001	10/2/2001	2	1218.00	1270.00	1132.00	542.40	5.04	412.92	16.15	92.07	13.88	63.00	192.81
W-316	11/29/1993	4/28/1994	5	1159.67	1203.00	1131.00	518.47	7.08	373.81	9.26	93.89	21.49	26.02	131.88
W-323	6/25/1994	7/26/1994	2	1077.50	1138.00	1018.00	518.47	7.08	373.81	9.26	93.89	21.49	27.47	134.87
W-325	11/14/1995	4/23/1996	6	943.17	975.00	846.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	116.99

Well	First Date	Last Date	Num. Measurements	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Withdrawal/Distance (MGal/Month)/(ft)
W-327	11/17/1995	4/24/1996	6	903.17	910.00	880.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	118.56
W-333	11/20/1995	4/24/1996	6	904.33	908.00	885.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	117.70
W-334	11/20/1995	4/24/1996	6	907.17	913.00	901.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	116.62
W-335	11/20/1995	4/24/1996	6	907.50	918.00	893.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	116.82
W-336	11/20/1995	4/24/1996	6	903.17	918.00	888.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	117.32
W336.367.00	8/25/2010	2/23/2011	3	885.20	900.00	865.00	263.05	7.55	115.24	35.79	109.05	13.01	115.82	254.85
W336.375.00	1/27/2012	12/1/2016	34	925.35	1000.00	873.00	263.05	7.55	115.24	35.79	109.05	13.01	146.18	186.71
W-340	11/21/1995	4/22/1996	6	910.17	920.00	900.00	128.30	5.87	17.73	0.00	82.11	9.03	35.38	113.98
W-341	11/21/1995	4/22/1996	6	892.17	920.00	872.00	128.30	5.87	17.73	0.00	82.11	9.03	35.38	113.97
W-342	11/21/1995	11/21/1995	1	879.00	885.00	843.00	128.30	5.87	17.73	0.00	82.11	9.03	35.38	81.84
W-344	11/22/1995	4/25/1996	6	1164.33	1185.00	1131.00	414.16	6.47	221.29	50.89	100.31	19.91	35.38	124.40
W-345	11/22/1995	4/18/1996	6	1238.83	1270.00	1184.00	414.16	6.47	221.29	50.89	100.31	19.91	35.38	129.34
W-346	11/24/1995	4/15/1996	6	919.83	930.00	915.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	121.31
W-347	11/24/1995	4/19/1996	6	1078.50	1180.00	1050.00	311.66	5.89	203.68	6.59	88.74	15.19	35.38	123.07
W-350	11/24/1995	4/19/1996	6	1141.33	1218.00	1118.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	123.70
W-353	11/24/1995	4/24/1996	6	1136.67	1210.00	1125.00	311.66	5.89	203.68	6.59	88.74	15.19	35.38	119.29
W-358	11/28/1995	4/18/1996	6	1196.50	1225.00	1190.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	128.51
W-359	11/29/1995	4/19/1996	6	1106.50	1118.00	1100.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	127.47
W-363	11/30/1995	4/18/1996	6	1000.17	1095.00	965.00	209.68	4.28	93.70	32.00	105.70	7.82	35.38	120.31
W-365	11/30/1995	4/26/1996	6	1182.50	1240.00	1140.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	132.49
W-368	4/26/1996	9/13/1996	6	1132.33	1185.00	1100.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	141.05
W-374	1/15/1997	6/27/1997	6	1247.67	1290.00	1239.00	480.07	7.29	317.33	35.19	104.86	16.00	40.52	148.77
W-377	1/27/1997	6/21/1997	6	1245.17	1282.00	1196.00	471.79	5.29	321.05	61.70	78.55	18.20	40.52	133.43
W-378	1/27/1997	6/21/1997	6	1297.33	1325.00	1257.00	471.79	5.29	321.05	61.70	78.55	18.20	40.52	132.22
W-379	1/27/1997	6/21/1997	6	1244.00	1323.00	1203.00	433.09	5.12	321.97	32.71	69.59	16.17	40.52	131.67

Well	First Date	Last Date	Num. Measurements	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Withdrawal/Distance (MGal/Month)/(ft)
W-394	1/28/1997	6/21/1997	6	1231.33	1259.00	1179.00	433.09	5.12	321.97	32.71	69.59	16.17	40.52	128.93
W-396	1/30/1997	6/27/1997	6	1267.67	1305.00	1235.00	291.50	6.25	177.75	23.01	71.99	15.15	40.52	153.43
W-400	1/30/1997	6/27/1997	6	1267.83	1315.00	1245.00	291.50	6.25	177.75	23.01	71.99	15.15	40.52	162.39
W-401	1/30/1997	6/28/1997	6	1277.83	1318.00	1205.00	327.53	4.87	218.18	24.31	55.90	14.42	40.52	145.18
W-402	1/30/1997	6/27/1997	6	1252.67	1325.00	1206.00	327.53	4.87	218.18	24.31	55.90	14.42	40.52	131.52
W-403	1/31/1997	6/28/1997	6	1301.83	1345.00	1227.00	550.70	7.10	325.95	44.97	162.21	15.14	40.52	167.45
W-404	1/31/1997	6/21/1997	6	1112.50	1130.00	1078.00	327.53	4.87	218.18	24.31	55.90	14.42	60.64	128.01
W-407	2/13/1997	7/20/1997	6	1248.83	1306.00	1243.00	518.47	7.08	373.81	9.26	93.89	21.49	146.18	149.70
W-410	2/13/1997	12/26/2016	26	1250.54	1310.00	1225.00	327.53	4.87	218.18	24.31	55.90	14.42	146.18	96.49
W-413	2/13/1997	12/26/2016	38	1244.58	1280.00	1233.00	327.53	4.87	218.18	24.31	55.90	14.42	146.18	81.64
W-414	2/13/1997	12/26/2016	37	1249.27	1280.00	1225.00	327.53	4.87	218.18	24.31	55.90	14.42	146.18	78.95
W-415	2/13/1997	12/26/2016	39	1108.67	1135.00	1063.00	327.53	4.87	218.18	24.31	55.90	14.42	146.18	78.69
W-417	2/24/1997	7/19/1997	6	1111.33	1165.00	1075.00	327.53	4.87	218.18	24.31	55.90	14.42	41.98	126.31
W-418	5/22/1997	7/19/1997	6	1167.83	1180.00	1139.00	327.53	4.87	218.18	24.31	55.90	14.42	41.98	126.20
W-423	1/23/1998	6/10/1998	6	1123.83	1200.00	1083.00	143.32	3.00	15.48	0.00	96.63	9.60	46.09	120.45
W-425	2/27/1998	5/20/1998	4	1226.25	1270.00	1193.00	335.45	7.45	211.84	21.69	92.72	12.98	46.09	269.79
W-426	2/27/1998	5/22/1998	4	1118.50	1160.00	1070.00	534.00	7.98	316.06	23.80	187.04	13.10	46.09	342.65
W-428	2/28/1998	4/14/2016	28	1211.64	1270.00	1195.00	540.40	5.50	336.95	11.82	178.25	12.88	145.62	121.61
W-429	2/28/1998	5/22/1998	4	1196.00	1210.00	1109.00	557.74	2.40	398.53	47.72	103.50	11.13	46.09	211.87
W-432	5/20/1998	10/3/2007	3	1185.83	1265.00	1179.00	562.20	5.50	277.65	65.48	204.97	11.83	93.06	216.32
W-452	7/18/2001	10/16/2007	2	1151.75	1170.00	1097.00	241.40	2.31	140.36	34.51	73.45	10.11	93.06	217.17
W-455	3/27/1999	4/30/1999	2	1020.00	1080.00	1010.00	287.45	6.85	195.67	43.79	129.97	13.52	50.61	122.96
W501.077.00	7/23/2007	12/2/2016	29	1141.78	1210.00	1095.00	335.45	7.45	211.84	21.69	92.72	12.98	146.18	173.66
W501.077.01	4/30/2007	12/1/2016	27	1072.70	1180.00	997.50	335.45	7.45	211.84	21.69	92.72	12.98	146.18	187.81
W501.343000	11/14/2012	3/1/2016	4	1116.63	1175.00	1045.00	431.50	6.60	236.12	77.80	118.08	12.12	146.18	195.35

Well	First Date	Last Date	Num. Measurements	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Withdrawal/Distance (MGal/Month)/(ft)
W-53.01	11/4/2005	3/16/2012	3	1004.23	1010.00	969.00	181.70	7.40	100.39	2.00	91.20	12.29	122.05	95.21
W-568	1/21/2014	3/12/2014	3	1171.33	1222.00	1104.00	257.46	4.90	113.13	22.11	116.39	9.10	134.15	35.96
W-576	1/21/2014	4/15/2014	4	1148.00	1230.00	1121.00	271.01	6.19	157.00	0.91	85.09	13.65	136.09	34.26
W-583	1/21/2014	3/12/2014	3	1158.00	1245.00	1115.00	271.01	6.19	157.00	0.91	85.09	13.65	134.15	36.71
W-609	1/21/2014	6/1/2015	15	1123.87	1162.00	1084.00	298.86	5.45	166.14	34.91	78.29	9.15	142.33	33.43
W-620	1/21/2014	11/24/2014	11	1146.64	1178.00	1146.00	298.86	5.45	166.14	34.91	78.29	9.15	142.33	34.12
W6-6	2/20/1998	8/24/2012	5	1229.54	1256.00	1184.00	263.05	7.55	115.24	35.79	109.05	13.01	125.58	143.07
W-660	1/14/2014	4/7/2015	16	1135.25	1170.00	1104.50	276.95	5.10	94.67	17.81	110.04	11.95	140.86	29.54
W-666	1/13/2014	12/5/2014	12	1049.08	1065.00	1012.00	263.35	7.00	108.55	53.31	84.24	5.91	138.08	35.00
W-671	1/15/2014	9/3/2014	6	1097.50	1183.00	1063.00	278.52	7.88	130.58	24.35	89.21	10.00	137.37	40.96
W-681	7/29/2003	2/26/2004	3	1258.50	1312.00	1203.00	404.43	7.01	276.76	17.32	84.19	12.07	73.96	143.48
W-683	7/29/2003	2/23/2004	3	1020.67	1030.00	977.00	171.63	5.20	65.90	1.30	100.36	11.56	73.96	175.14
W-690	7/31/2003	2/24/2004	3	1312.67	1366.00	1296.00	556.98	7.61	404.08	9.37	114.93	14.37	73.96	167.37
W-691	8/31/2003	2/24/2004	3	1260.67	1275.00	1229.00	428.45	7.05	259.73	45.00	112.83	14.77	73.96	174.07
W-694	4/23/2007	12/22/2016	13	1227.62	1260.00	1200.50	489.71	11.76	347.06	30.83	115.94	26.19	146.18	159.97
W-696	8/4/2003	2/27/2004	3	1193.50	1270.00	1136.00	428.45	7.05	259.73	45.00	112.83	14.77	73.96	184.37
W-701	8/5/2003	2/26/2004	3	1269.33	1320.00	1236.00	480.07	7.29	317.33	35.19	104.86	16.00	73.96	148.34
W-705	8/6/2003	2/27/2004	3	1222.93	1270.00	1187.00	480.07	7.29	317.33	35.19	104.86	16.00	73.96	157.86
W-706	8/8/2003	2/26/2004	3	1238.30	1290.00	1203.00	480.07	7.29	317.33	35.19	104.86	16.00	73.96	155.90
W-707	7/7/2003	2/17/2004	3	1220.00	1235.00	1140.00	233.13	7.55	117.80	5.49	98.95	10.71	73.96	131.25
W-709	7/7/2003	2/18/2004	3	1010.77	1085.00	977.00	171.63	5.20	65.90	1.30	100.36	11.56	146.18	170.53
W-716	7/23/2003	2/19/2004	3	1305.00	1320.00	1273.00	512.33	7.27	337.40	56.38	101.13	13.43	73.96	158.63
W-722	7/26/2003	2/23/2004	3	1330.67	1380.00	1300.00	556.98	7.61	404.08	9.37	114.93	14.37	73.96	164.07
W-723	7/11/2003	2/7/2004	3	1131.00	1180.00	1056.00	233.13	7.55	117.80	5.49	98.95	10.71	73.96	132.25
W-728	7/15/2003	2/19/2004	3	1115.67	1140.00	1070.00	233.13	7.55	117.80	5.49	98.95	10.71	73.96	135.13

Well	First Date	Last Date	Num. Measurements	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Withdrawal/Distance (MGal/Month)/(ft)
W-734	7/18/2003	2/19/2004	3	1187.67	1205.00	1173.00	333.34	4.90	243.57	13.34	48.14	14.88	73.96	162.10
WL-113	11/18/1998	11/18/1998	1	1225.00	1280.00	1188.00	367.85	6.20	166.26	55.30	131.78	11.66	48.18	171.13
WL-116	2/25/1991	3/21/1991	2	1244.00	1260.00	1204.00	559.04	6.47	398.42	36.41	91.79	19.89	13.68	173.11
WL21-041.01	5/1/2008	8/8/2008	3	1255.37	1300.00	1210.00	490.16	5.17	323.67	11.34	108.77	13.68	98.01	50.19
WL231.362.00	8/25/2010	12/1/2016	37	1116.65	1170.00	1071.00	534.00	7.98	316.06	23.80	187.04	13.10	146.18	181.46
WL-301	11/18/1993	3/21/1994	5	1253.40	1303.00	1227.00	542.40	5.04	412.92	16.15	92.07	13.88	26.02	162.59
WL-319	1/26/1994	12/15/1994	6	1265.17	1325.00	1236.00	550.70	7.10	325.95	44.97	162.21	15.14	28.51	141.63
WL336.373.00	8/25/2010	5/2/2016	30	1076.71	1100.00	1046.00	534.00	7.98	316.06	23.80	187.04	13.10	145.62	163.47
WL-338	11/20/1995	4/22/1996	6	881.00	890.00	865.00	128.30	5.87	17.73	0.00	82.11	9.03	35.38	111.96
WL-348	11/29/1995	4/19/1996	6	1110.83	1210.00	1090.00	311.66	5.89	203.68	6.59	88.74	15.19	35.38	122.89
WL-349	11/24/1995	4/18/1996	6	1108.00	1190.00	1085.00	311.66	5.89	203.68	6.59	88.74	15.19	35.38	124.27
WL-351	11/24/1995	4/18/1996	6	1198.17	1225.00	1152.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	124.40
WL-381	1/27/1997	6/21/1997	6	1283.17	1325.00	1213.00	471.79	5.29	321.05	61.70	78.55	18.20	40.52	139.82
WL-419	3/22/1997	8/23/1997	6	1238.33	1261.00	1160.00	291.50	6.25	177.75	23.01	71.99	15.15	41.98	168.42
WL-567	1/21/2014	3/12/2014	3	1151.67	1224.00	1104.00	257.46	4.90	113.13	22.11	116.39	9.10	134.15	35.61
WL-674	3/30/2001	12/1/2016	36	1098.00	1145.00	1036.00	238.05	6.60	146.59	0.00	68.14	11.96	146.18	63.90
WL-692	8/1/2003	2/25/2004	3	1311.00	1355.00	1220.00	556.98	7.61	404.08	9.37	114.93	14.37	73.96	175.63
WL-721	4/30/2010	12/22/2016	15	1149.20	1230.00	1150.00	428.45	7.05	259.73	45.00	112.83	14.77	146.18	89.07
WL-736	7/21/2003	12/22/2016	16	1118.74	1131.00	1031.00	333.34	4.90	243.57	13.34	48.14	14.88	146.18	82.84
WL-739	7/23/2003	2/23/2004	3	1257.00	1340.00	1190.00	500.76	7.61	275.70	57.23	136.09	33.23	73.96	141.95
WL-747	8/11/2003	2/25/2004	3	1217.67	1270.00	1150.00	520.40	6.58	417.07	32.62	64.63	15.68	73.96	191.88

Table B 2. D-0360 ODNR-DWR model outliers.

Wells
W21-165.04
W-426

Table B 3. D-0360 ODNR-DWR without water withdraw model outliers.

Wells
W21-165.04

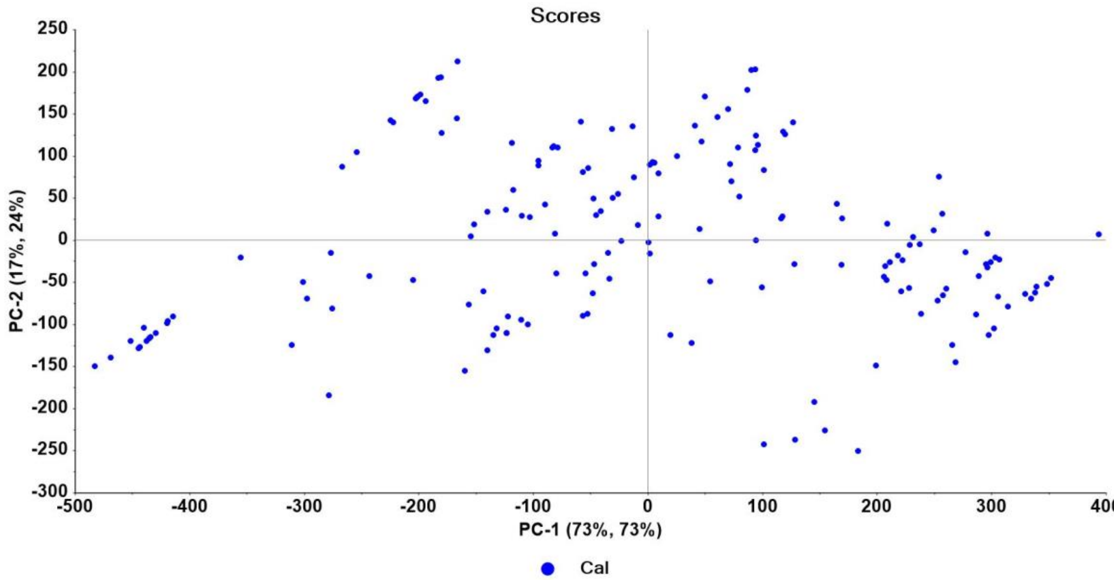

Figure B 1. Principal component regression scores plot for the D-0360 ODNR-DWR average potentiometric head model.

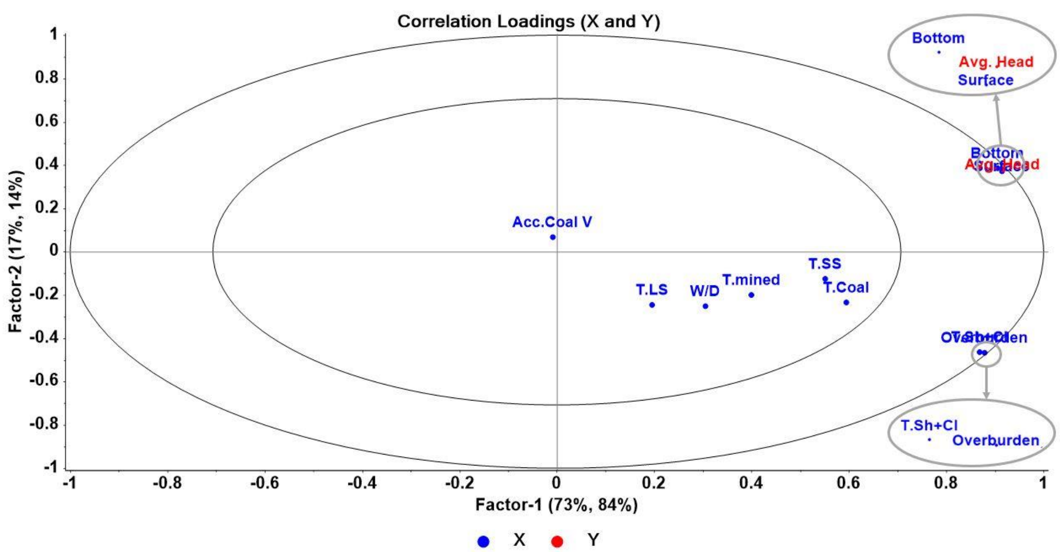

Figure B 2. Partial least squares regression correlation loadings plot for the D-0360 ODNR-DWR average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

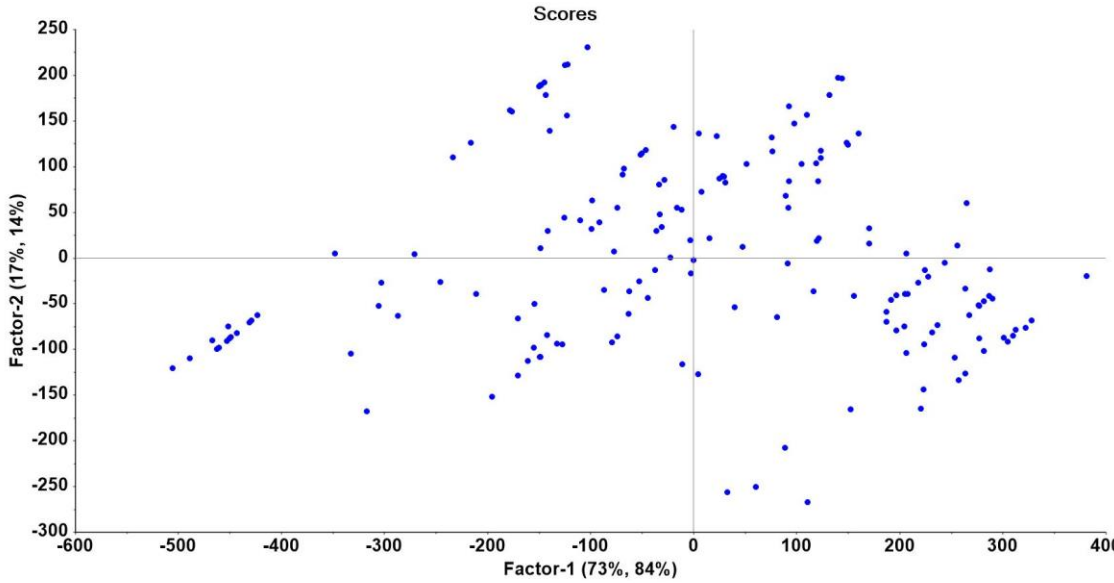

Figure B 3. Partial least squares regression scores plot for the D-0360 ODNR-DWR average potentiometric head model.

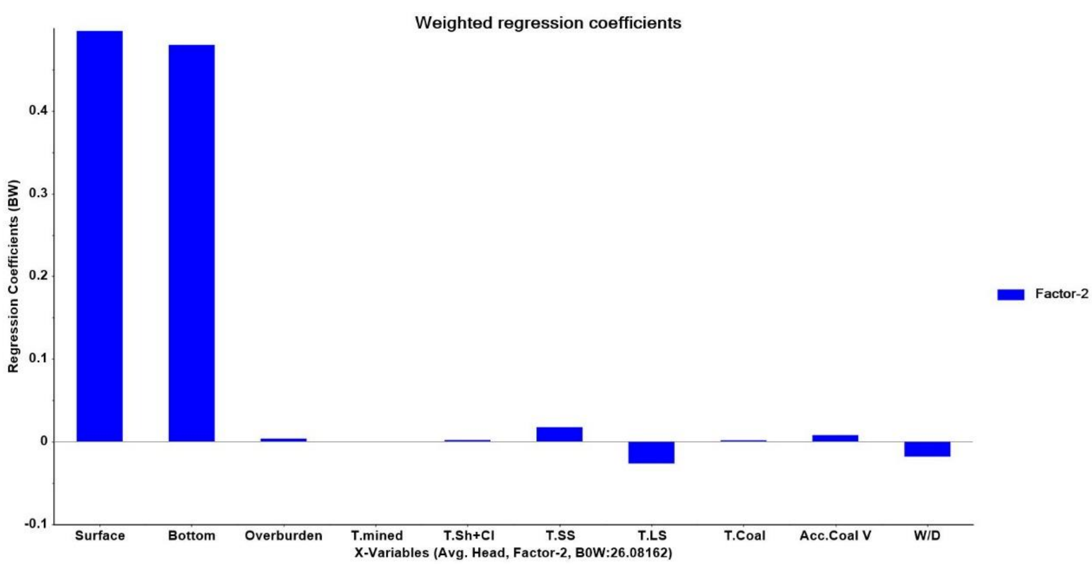

Figure B 4. Partial least squares regression weighted regression coefficients chart for the D-0360 ODNR-DWR average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

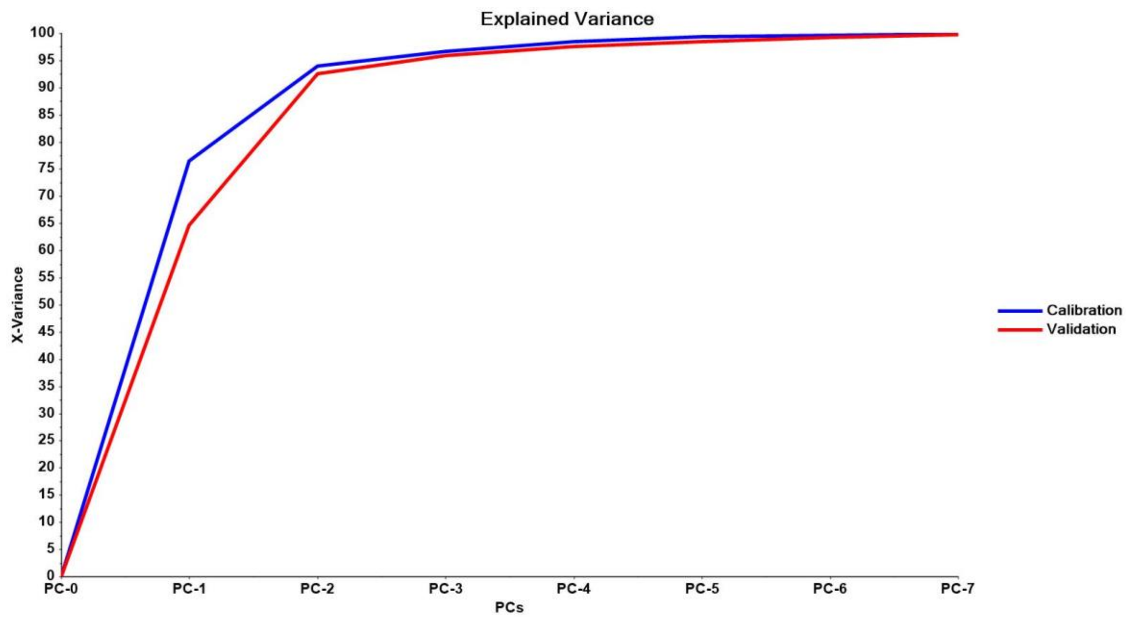

Figure B 5. Principal component analysis explained variance graph for the D-0360 ODNR-DWR without water withdraw average potentiometric head model.

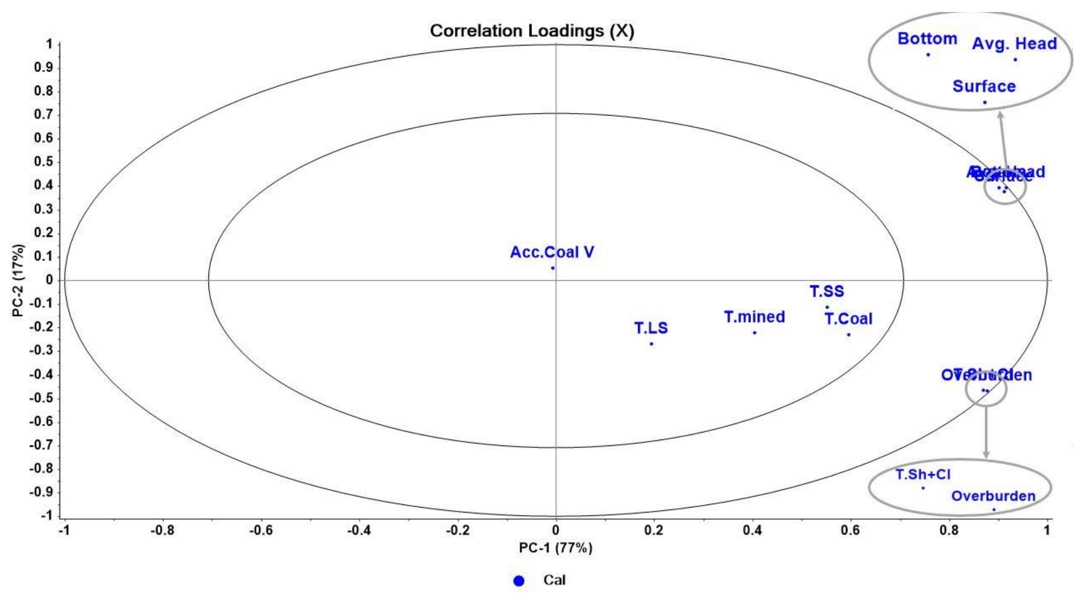

Figure B 6. Principal component analysis correlation loadings plot for the D-0360 ODNR-DWR without water withdraw average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

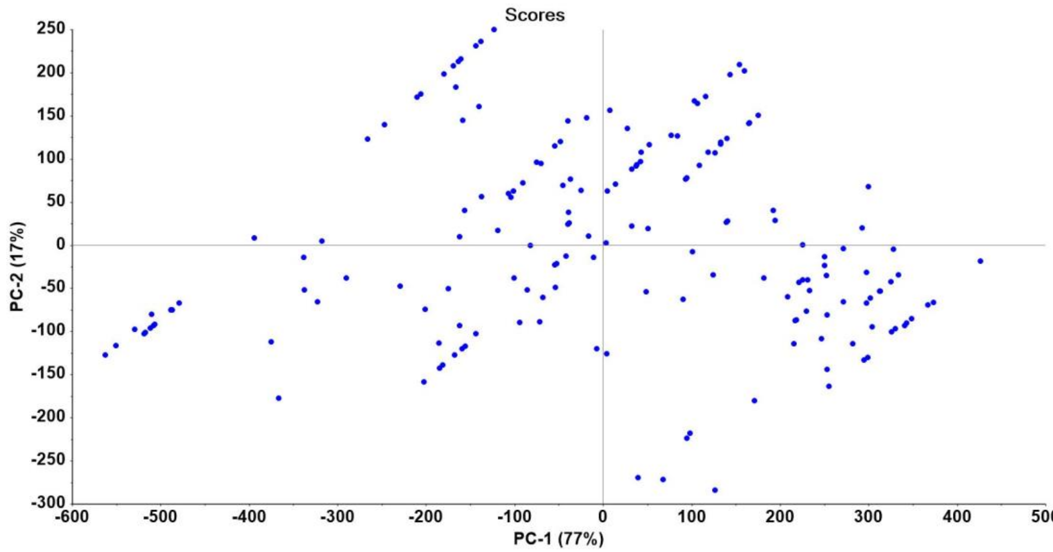

Figure B 7. Principal component analysis scores plot for the D-0360 ODNR-DWR without water withdraw average potentiometric head model.

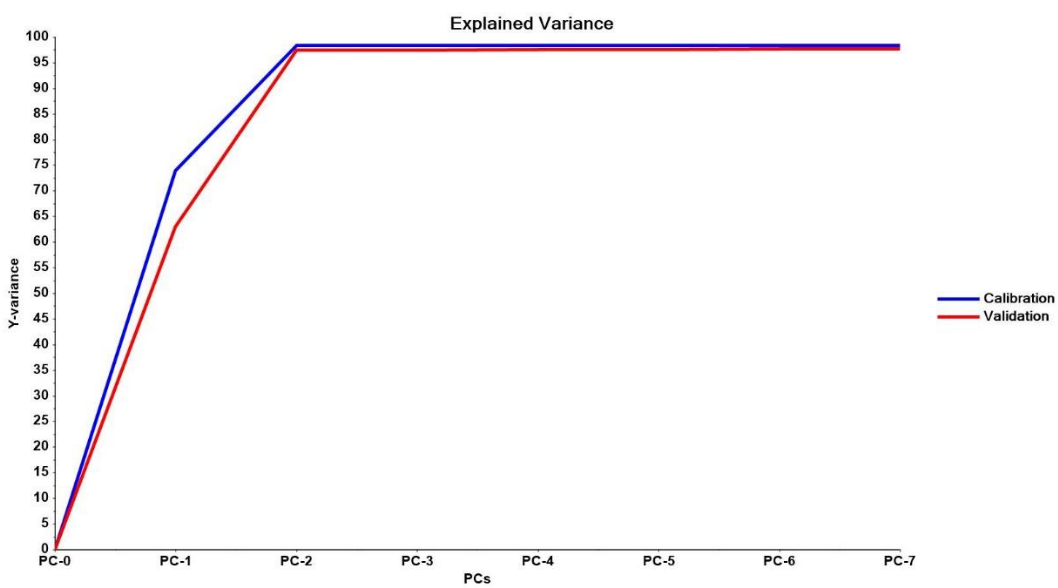

Figure B 8. Principal component regression explained variance graph for the D-0360 ODNR-DWR without water withdraw average potentiometric head model.

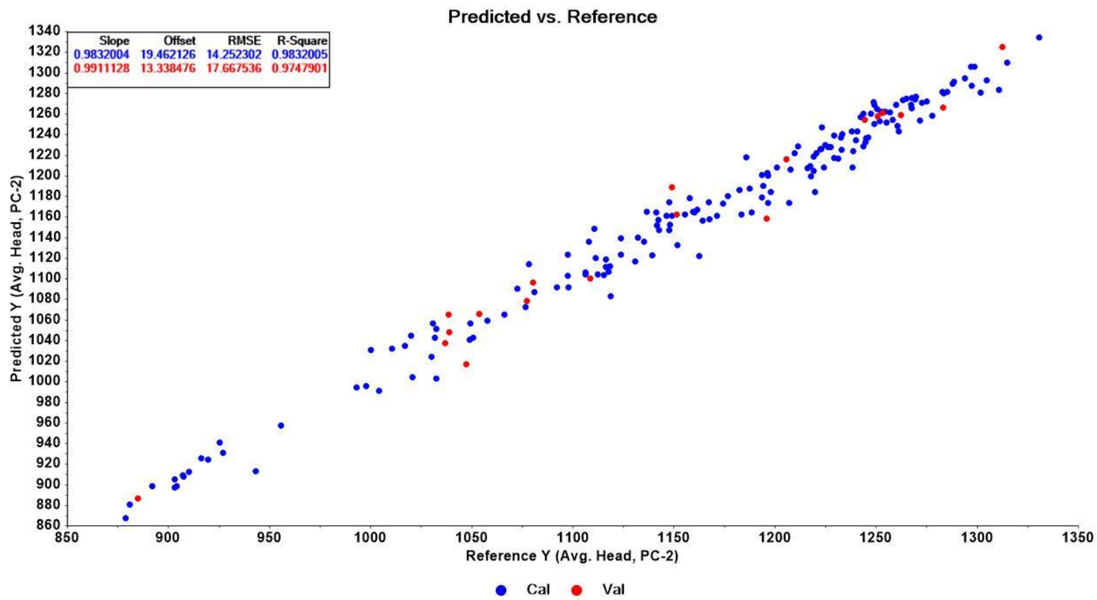

Figure B 9. Principal component regression predicted vs. reference graph for the D-0360 ODNR-DWR without water withdraw average potentiometric head model.

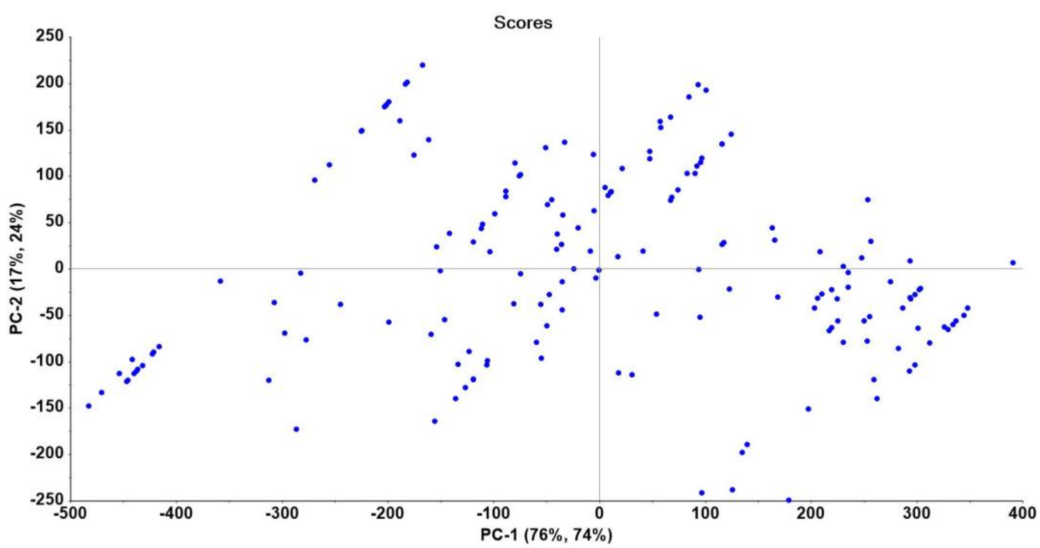

Figure B 10. Principal component regression scores plot for the D-0360 ODNR-DWR without water withdraw average potentiometric head model.

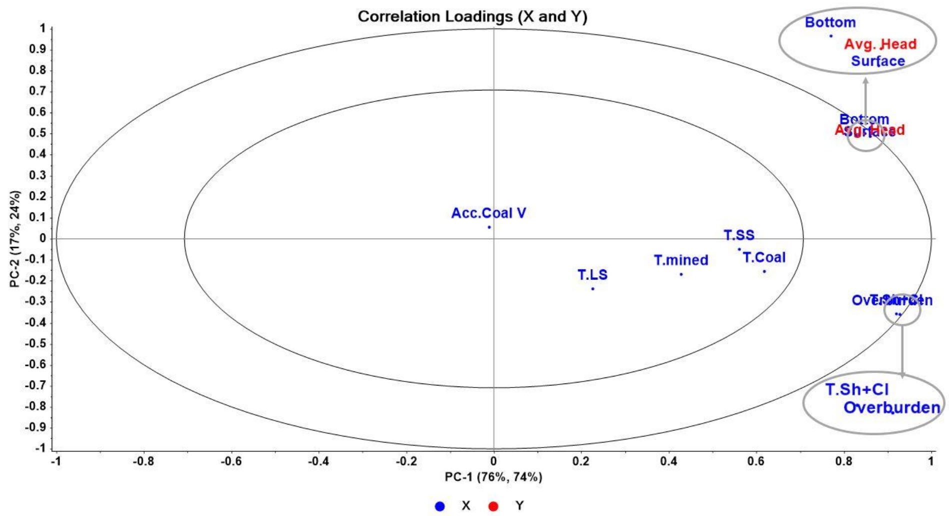

Figure B 11. Principal component regression correlation loadings plot for the D-0360 ODNR-DWR average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

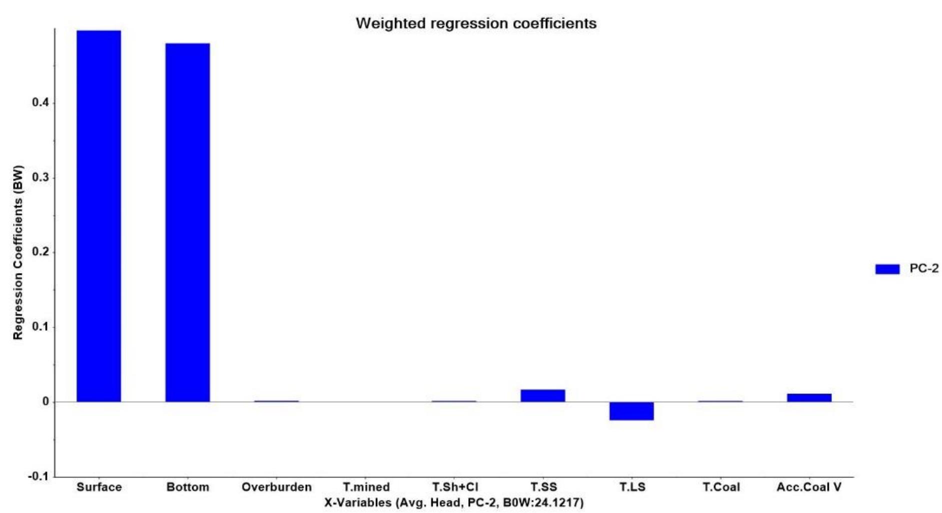

Figure B 12. Principal component regression weighted regression coefficients chart for the D-0360 ODNR-DWR without water withdraw average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

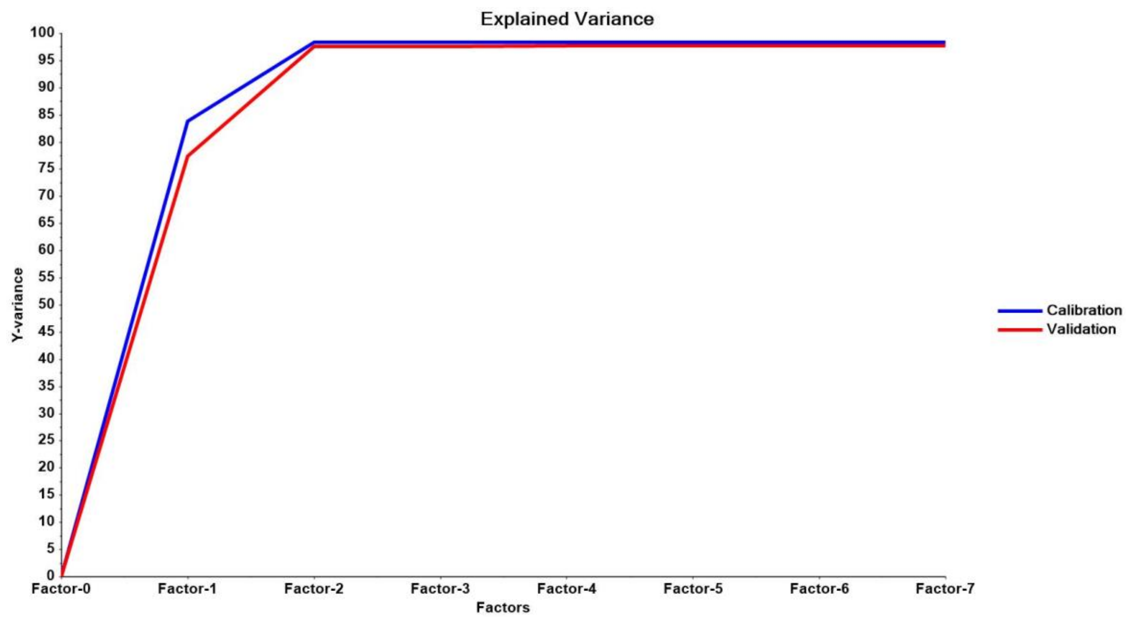

Figure B 13. Partial least squares regression explained variance graph for the D-0360 ODNR-DWR without water withdraw average potentiometric head model.

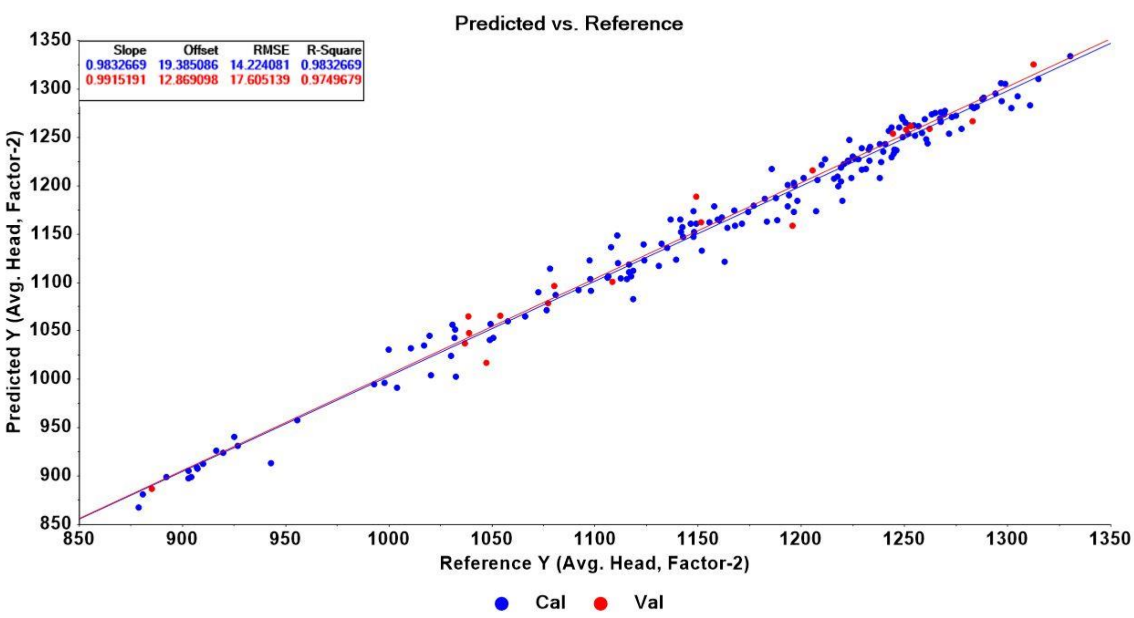

Figure B 14. Partial least squares regression predicted vs. reference plot for the D-0360 ODNR-DWR without water withdraw average potentiometric head model.

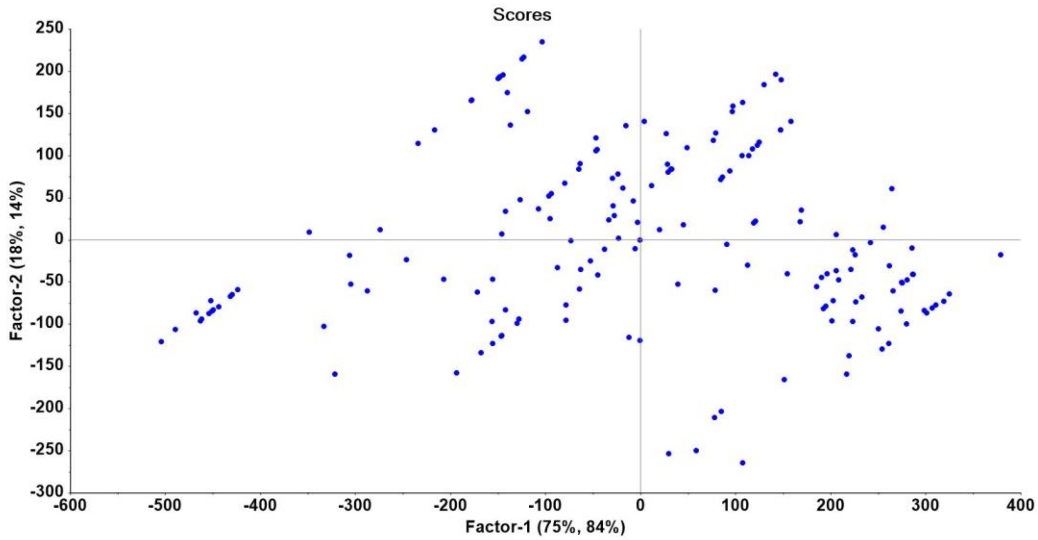

Figure B 15. Partial least squares regression scores plot for the D-0360 ODNR-DWR without water withdraw average potentiometric head model.

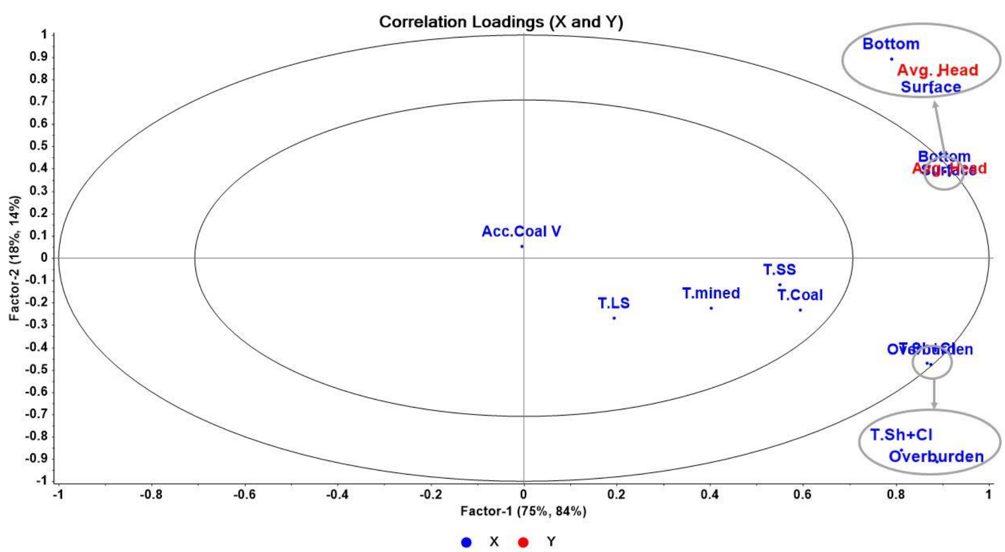

Figure B 16. Partial least squares regression correlation loadings plot for the D-0360 ODNR-DWR without water withdraw average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

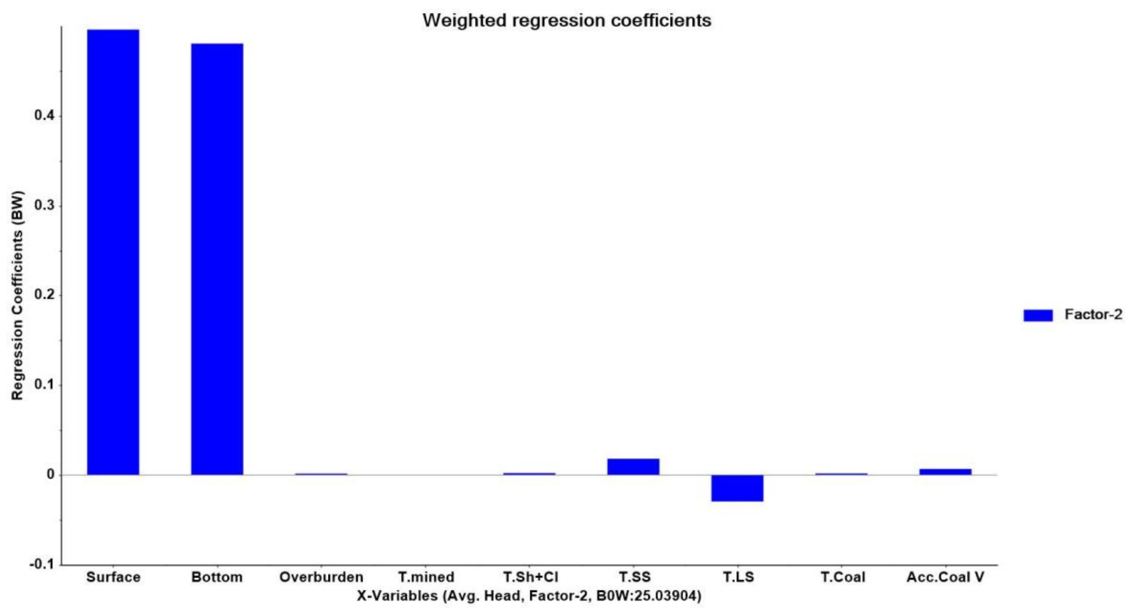

Figure B 17. Figure B 18. Partial least squares regression weighted regression coefficients chart for the D-0360 ODNR-DWR without water withdraw average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

Table B 4. D-0360 NPDES model data. ($1m^3 = 35.315ft^3$) ($1acre=43560ft^2$)

Well	First Date	Last Date	Num. Measurements	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Withdrawal/Distance (MGal/Day)/(ft)
DW21-156.00	4/27/2008	8/6/2008	3	1222.00	1225.00	1219.00	274.25	5.45	194.05	15.51	61.90	11.27	13.68	5.11E-05
DW21-190.00	4/27/2008	8/22/2008	3	1237.98	1248.00	1233.00	302.03	5.68	178.44	31.29	74.71	12.42	13.68	5.089E-05
DW-22.004.00	10/23/2008	3/9/2009	3	1117.00	1125.00	1101.00	272.09	7.81	114.19	33.51	114.10	11.82	13.68	4.49735E-05
DW-406	1/23/2014	12/26/2016	29	1298.43	1322.00	1298.00	291.50	6.25	177.75	23.01	71.99	15.15	14.48	8.49741E-05
DW502-338.08	10/29/2008	3/9/2009	3	1219.23	1230.00	1214.00	489.71	11.76	347.06	30.83	115.94	26.19	14.48	3.81787E-05
DW-679	1/21/2014	4/15/2014	5	1220.75	1235.00	1216.00	271.01	6.19	157.00	0.91	85.09	13.65	14.48	6.62171E-05
DW-719	1/24/2007	12/22/2016	14	1174.32	1180.00	1173.00	428.45	7.05	259.73	45.00	112.83	14.77	14.48	7.3738E-05
W21-029.00	5/1/2008	8/4/2008	3	1233.33	1283.00	1204.00	490.16	5.17	323.67	11.34	108.77	13.68	14.48	6.77857E-05
W21-043.00	5/1/2008	8/6/2008	3	1201.20	1242.00	1179.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	6.94192E-05
W21-045.01	5/1/2008	8/6/2008	3	1296.97	1340.00	1282.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	9.4136E-05
W21-057.00	5/3/2008	8/12/2008	3	1224.43	1260.00	1161.00	303.36	7.40	175.10	23.60	87.50	17.29	101.40	6.83579E-05
W21-059.00	5/3/2008	8/9/2008	3	1216.17	1255.00	1164.50	303.36	7.40	175.10	23.60	87.50	17.29	101.40	6.48096E-05
W21-064.00	5/2/2008	8/13/2008	3	1205.67	1260.00	1177.00	303.36	7.40	175.10	23.60	87.50	17.29	26.02	6.51875E-05
W21-066.00	5/1/2008	8/21/2008	3	1162.83	1165.00	1081.50	259.18	7.05	122.95	13.10	106.91	11.26	35.38	6.08992E-05
W21-080.00	5/3/2008	8/18/2008	3	1030.40	1045.00	1001.00	317.45	7.29	204.12	2.04	78.09	10.82	35.38	6.20899E-05
W21-083.00	5/2/2008	8/8/2008	3	1037.10	1055.00	1017.50	317.45	7.29	204.12	2.04	78.09	10.82	35.38	6.06111E-05
W21-087.00	5/5/2008	8/11/2008	3	1039.10	1068.00	1026.30	317.45	7.29	204.12	2.04	78.09	10.82	35.38	6.09692E-05
W21-087.01	5/5/2008	8/11/2008	3	1050.97	1068.00	1015.80	317.45	7.29	204.12	2.04	78.09	10.82	35.38	6.0393E-05
W21-095.00	5/2/2008	8/9/2008	3	1030.83	1100.00	1011.00	317.45	7.29	204.12	2.04	78.09	10.82	35.38	6.09508E-05
W21-106.00	5/3/2008	8/11/2008	3	1047.33	1065.00	965.00	317.45	7.29	204.12	2.04	78.09	10.82	40.52	5.96735E-05
W21-110.01	5/9/2008	8/8/2008	3	1029.60	1050.00	1017.20	317.45	7.29	204.12	2.04	78.09	10.82	40.52	5.93852E-05
W21-111.00	5/2/2008	8/8/2008	3	1032.63	1040.00	961.00	317.45	7.29	204.12	2.04	78.09	10.82	40.52	5.90598E-05
W21-112.00	5/8/2008	8/11/2008	3	1032.07	1060.00	1023.40	317.45	7.29	204.12	2.04	78.09	10.82	40.52	5.8741E-05

W21-138.00	5/3/2008	8/4/2008	3	1207.30	1240.00	1109.70	303.36	7.40	175.10	23.60	87.50	17.29	40.52	5.84117E-05
W21-155.08	6/24/2008	4/30/2008	3	1259.97	1300.00	1245.00	274.25	5.45	194.05	15.51	61.90	11.27	146.18	5.12871E-05
W21-160.00	4/30/2008	8/6/2008	3	1160.17	1220.00	1115.00	279.00	6.90	77.16	24.69	145.59	12.54	41.98	5.08884E-05
W21-165.04	5/3/2008	8/23/2008	3	1042.07	1240.00	1100.00	253.20	9.20	50.40	31.39	165.59	12.60	46.09	5.917E-05
W21-171.00	4/30/2008	8/6/2008	3	1176.93	1220.00	1147.00	279.00	6.90	77.16	24.69	145.59	12.54	46.09	5.09285E-05
W21-173.01	4/29/2008	8/7/2008	3	1207.83	1220.00	1201.50	279.00	6.90	77.16	24.69	145.59	12.54	52.95	5.25578E-05
W21-180.01	4/29/2008	8/6/2008	3	1193.63	1220.00	1144.50	279.00	6.90	77.16	24.69	145.59	12.54	59.37	5.18619E-05
W21-183.01	4/29/2008	8/6/2008	3	1194.20	1220.00	1164.00	302.03	5.68	178.44	31.29	74.71	12.42	101.40	5.30289E-05
W21-187.00	5/1/2008	8/7/2008	3	1219.23	1240.00	1173.50	302.03	5.68	178.44	31.29	74.71	12.42	136.09	6.07092E-05
W21-195.00	5/1/2008	8/23/2008	3	1223.37	1280.00	1221.00	302.03	5.68	178.44	31.29	74.71	12.42	73.96	6.00592E-05
W21-260.00	5/6/2008	8/19/2008	3	1142.47	1180.00	1137.00	303.36	7.40	175.10	23.60	87.50	17.29	73.96	5.92435E-05
W21-265.00	5/5/2008	8/19/2008	3	1148.03	1180.00	1127.50	303.36	7.40	175.10	23.60	87.50	17.29	146.18	5.88852E-05
W21-452.00	5/8/2008	8/19/2008	3	1155.50	1190.00	1137.00	156.50	7.10	92.72	0.00	41.26	9.32	13.68	5.81594E-05
W21-481.00	5/5/2008	9/2/2008	3	1149.13	1185.00	1143.00	148.57	6.55	43.93	0.00	95.92	9.60	12.78	5.5813E-05
W21-502.00	5/6/2008	8/26/2008	3	1142.85	1165.00	1132.00	156.50	7.10	92.72	0.00	41.26	9.32	13.68	5.77523E-05
W-22.007.00	10/29/2008	12/21/2016	13	1209.92	1250.00	1198.00	489.71	11.76	347.06	30.83	115.94	26.19	13.68	0.000295627
W231.356.00	10/27/2008	3/10/2009	3	1196.65	1280.00	1068.00	335.45	7.45	211.84	21.69	92.72	12.98	13.68	9.88031E-05
W231.356.04	10/27/2008	3/3/2016	28	1246.36	1270.00	1209.70	335.45	7.45	211.84	21.69	92.72	12.98	14.48	0.000108815
W336.367.00	8/25/2010	2/23/2011	3	885.20	900.00	865.00	263.05	7.55	115.24	35.79	109.05	13.01	14.48	0.000299866
W336.375.00	1/27/2012	12/1/2016	34	925.35	1000.00	873.00	263.05	7.55	115.24	35.79	109.05	13.01	14.48	0.000185335
W-410	1/23/2014	12/26/2016	29	1250.45	1310.00	1225.00	327.53	4.87	218.18	24.31	55.90	14.42	14.48	8.0651E-05
W-413	2/13/2014	7/2008	32	1243.75	1280.00	1233.00	327.53	4.87	218.18	24.31	55.90	14.42	14.48	8.47593E-05
W-414	1/23/2014	12/26/2016	33	1247.19	1280.00	1225.00	327.53	4.87	218.18	24.31	55.90	14.42	14.48	9.02589E-05
W-415	1/23/2014	7/2008	33	1107.82	1135.00	1063.00	327.53	4.87	218.18	24.31	55.90	14.42	14.48	8.4489E-05
W-428	2/20/2014	4/14/2016	24	1208.33	1260.00	1185.00	540.40	5.50	336.95	11.82	178.25	12.88	1.52	0.000144556
W-452	10/16/2007	10/16/2007	1	1173.33	1160.00	1092.50	241.40	2.31	140.36	34.51	73.45	10.11	14.48	5.19621E-06
W501.077.00	7/23/2007	12/2/2016	29	1141.78	1210.00	1095.00	335.45	7.45	211.84	21.69	92.72	12.98	14.48	0.000152202
W501.077.01	4/30/2007	12/1/2016	27	1072.70	1180.00	997.50	335.45	7.45	211.84	21.69	92.72	12.98	98.01	0.000152202

W501.343000	11/14/2012	6/7/2016	7	1116.63	1175.00	1045.00	431.50	6.60	236.12	77.80	118.08	12.12	98.01	0.000141647
W-53.01	12/29/2011	3/16/2012	2	1006.35	1010.00	969.00	181.70	7.40	100.39	2.00	91.20	12.29	98.01	0.00013622
W-568	1/21/2014	3/12/2014	3	1171.33	1222.00	1104.00	257.46	4.90	113.13	22.11	116.39	9.10	98.01	7.68306E-05
W-576	1/21/2014	4/15/2014	4	1148.00	1230.00	1121.00	271.01	6.19	157.00	0.91	85.09	13.65	98.01	6.501E-05
W-583	1/21/2014	3/12/2014	3	1158.00	1245.00	1115.00	271.01	6.19	157.00	0.91	85.09	13.65	98.01	0.000107498
W-609	1/21/2014	9/21/2015	20	1123.87	1162.00	1084.00	298.86	5.45	166.14	34.91	78.29	9.15	98.01	6.0082E-05
W-620	1/21/2014	9/21/2015	21	1146.64	1178.00	1146.00	298.86	5.45	166.14	34.91	78.29	9.15	98.01	5.9173E-05
W6-6	10/7/2009	8/24/2012	4	1228.18	1256.00	1184.00	263.05	7.55	115.24	35.79	109.05	13.01	98.01	4.15991E-05
W-660	1/14/2014	4/7/2015	16	1135.25	1170.00	1104.50	276.95	5.10	94.67	17.81	110.04	11.95	98.01	5.36165E-05
W-666	1/13/2014	12/5/2014	12	1049.08	1065.00	1012.00	263.35	7.00	108.55	53.31	84.24	5.91	98.01	4.60808E-05
W-671	1/15/2014	9/3/2014	9	1097.50	1183.00	1063.00	278.52	7.88	130.58	24.35	89.21	10.00	98.01	6.14147E-05
W-694	4/23/2007	12/22/2016	13	1227.62	1260.00	1200.50	489.71	11.76	347.06	30.83	115.94	26.19	98.01	0.000224619
WL21-041.01	5/1/2008	8/8/2008	3	1255.37	1300.00	1210.00	490.16	5.17	323.67	11.34	108.77	13.68	98.01	6.65882E-05
WL231.362.00	8/25/2010	12/1/2016	37	1116.65	1170.00	1070.50	534.00	7.98	316.06	23.80	187.04	13.10	98.01	0.000331188
WL336.373.00	8/25/2010	5/2/2016	30	1076.71	1100.00	1050.50	534.00	7.98	316.06	23.80	187.04	13.10	98.01	0.00024483
WL-567	1/21/2014	3/12/2014	3	1151.67	1224.00	1104.00	257.46	4.90	113.13	22.11	116.39	9.10	98.01	7.70801E-05
WL-674	1/15/2014	12/1/2016	33	1098.18	1145.00	1036.00	238.05	6.60	146.59	0.00	68.14	11.96	96.35	6.41439E-05
WL-721	4/30/2010	12/22/2016	15	1164.72	1230.00	1150.00	428.45	7.05	259.73	45.00	112.83	14.77	98.01	0.000142128
WL-736	1/13/2016	12/22/2016	12	1118.57	1131.00	1031.00	333.34	4.90	243.57	13.34	48.14	14.88	98.01	8.78024E-05

Table B 5. D-0360 NPDES average potentiometric head model outliers.

Wells
W21-165.04
W-452
W21-066.00

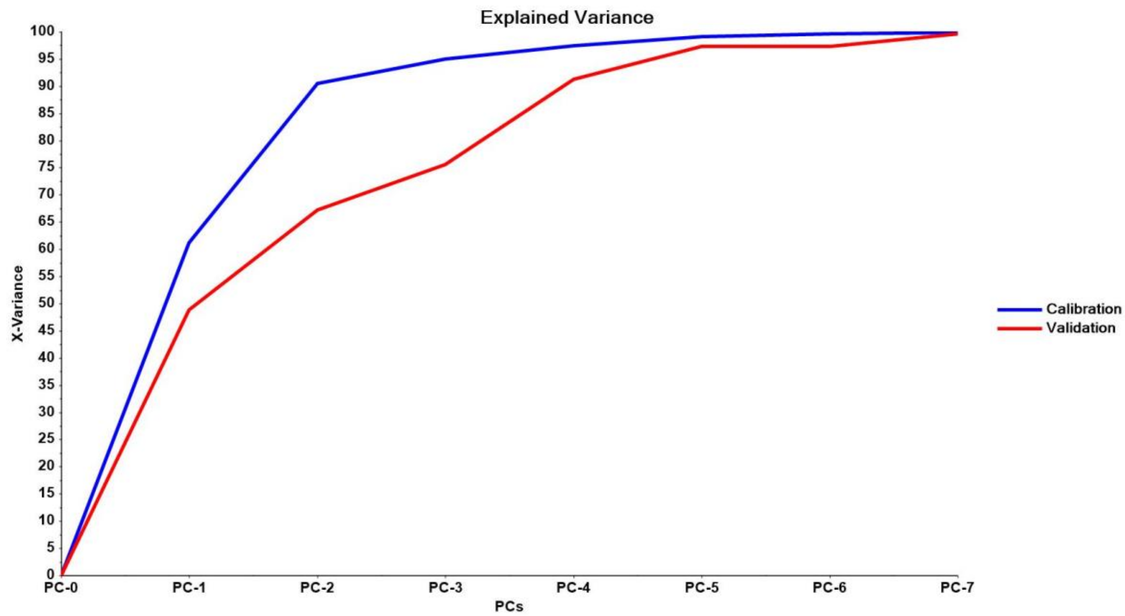

Figure B 18. Principal component analysis explained variance graph for the D-0360 NPDES average potentiometric head model.

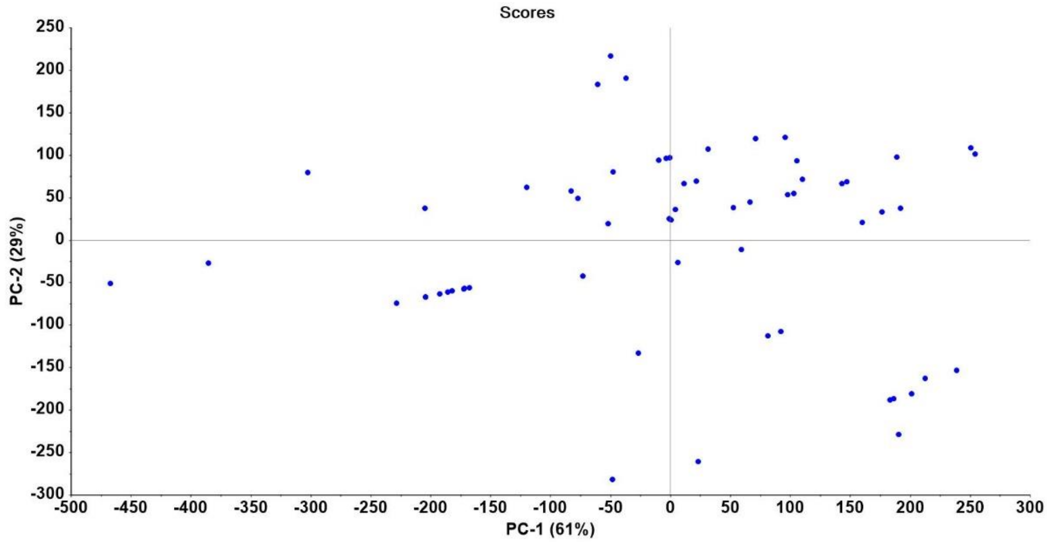

Figure B 19. Principal component analysis scores plot for the D-0360 NPDES average potentiometric head model.

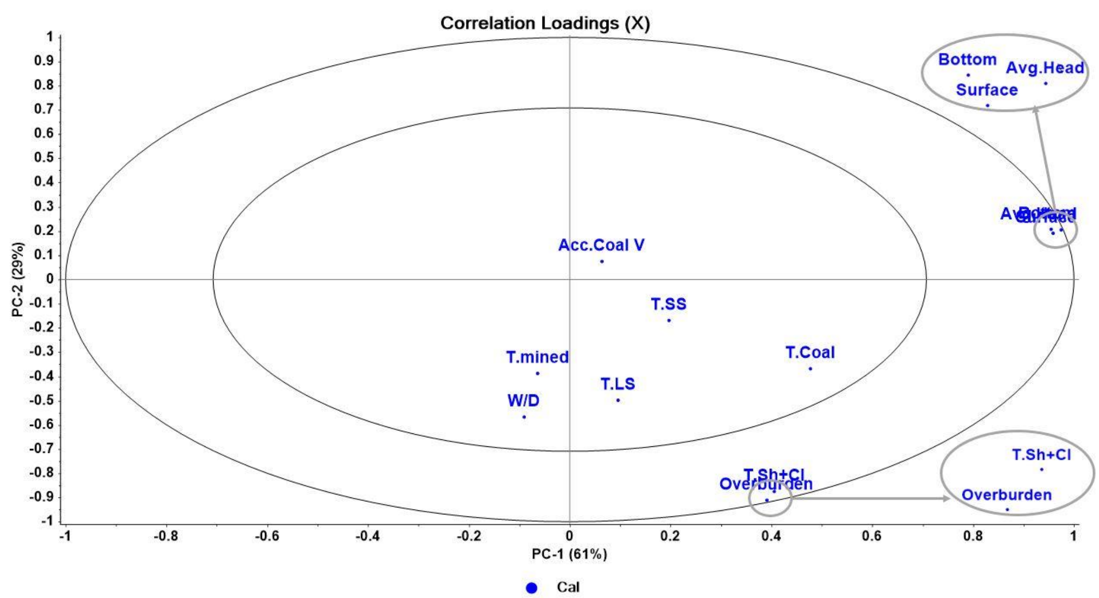

Figure B 20. Principal component regression correlation loadings plot for the D-0360 NPDES model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

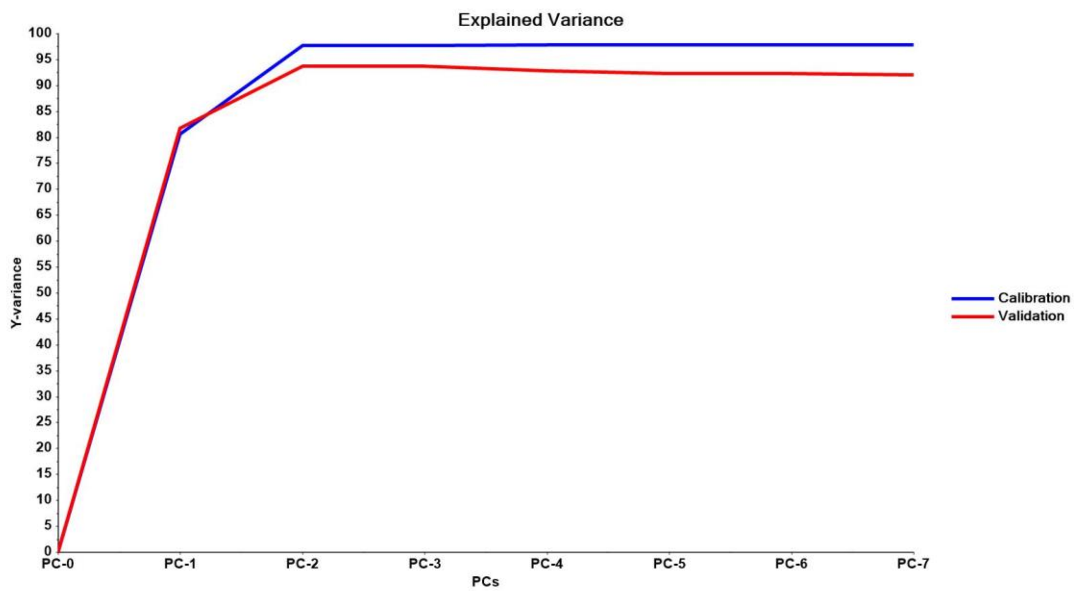

Figure B 21. Principal component regression explained variance graph for the D-0360 NPDES average potentiometric head model.

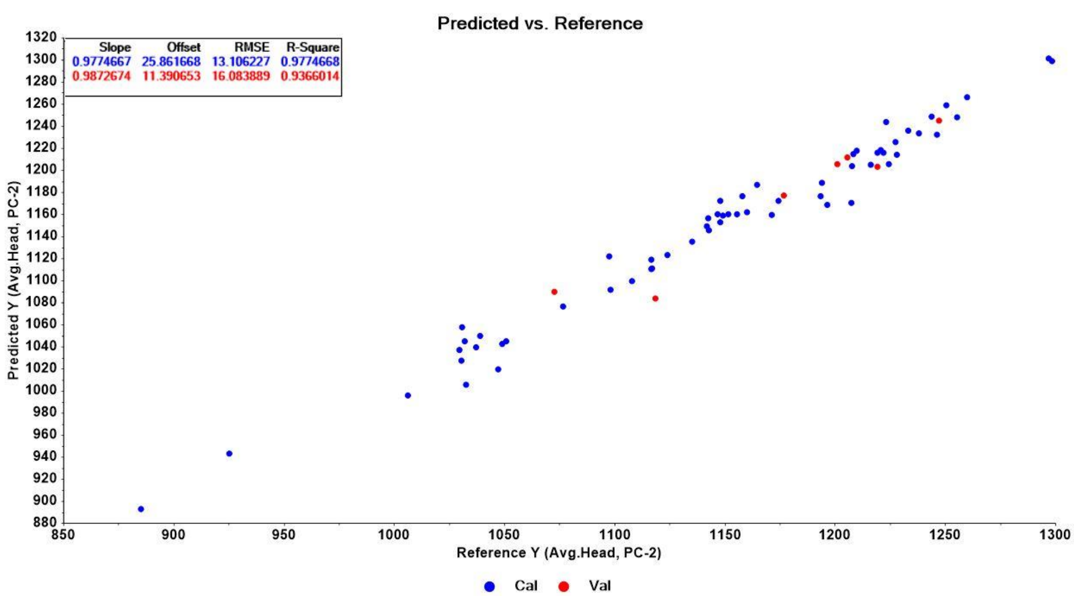

Figure B 22. Principal component regression predicted vs. reference plot for the D-0360 NPDES average potentiometric head model.

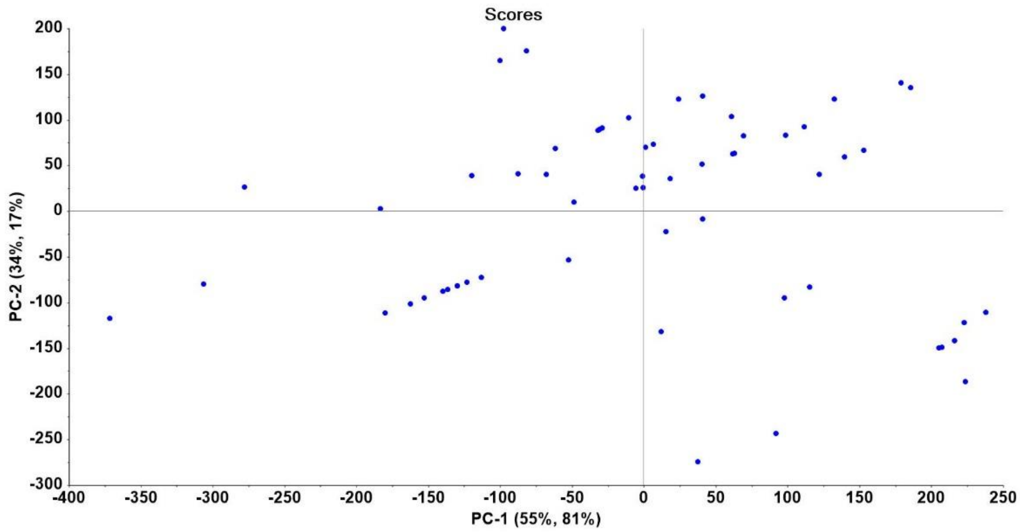

Figure B 23. Principal component regression scores plot for the D-0360 NPDES average potentiometric head model.

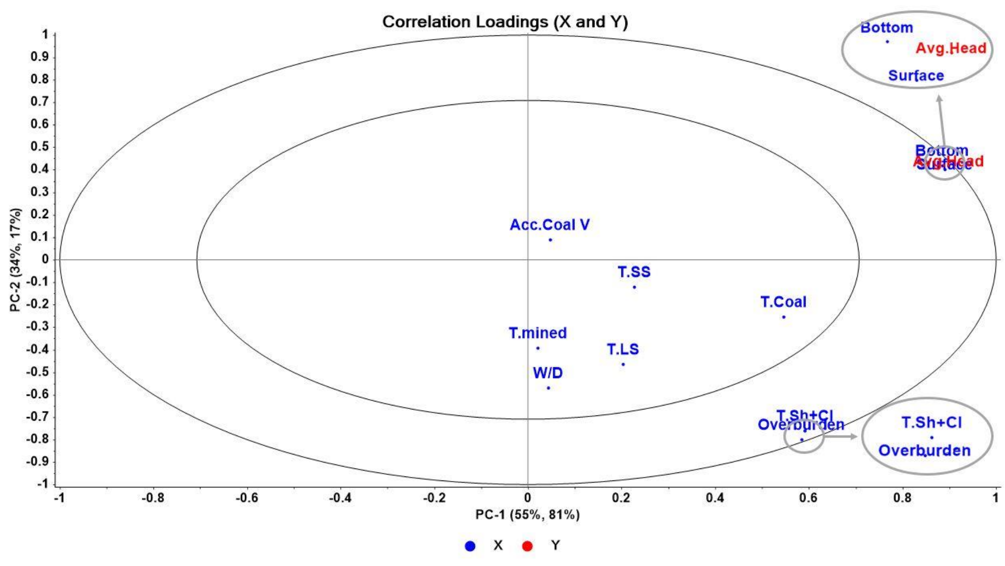

Figure B 24. Principal component regression correlation loadings plot for the D-0360 NPDES average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

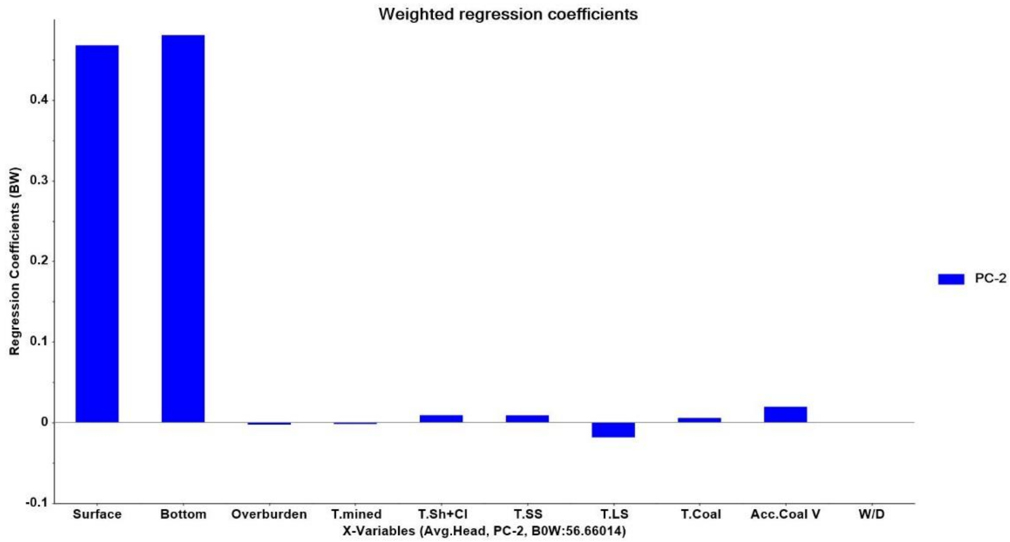

Figure B 25. Principal component regression weighted regression coefficients chart for the D-0360 NPDES average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

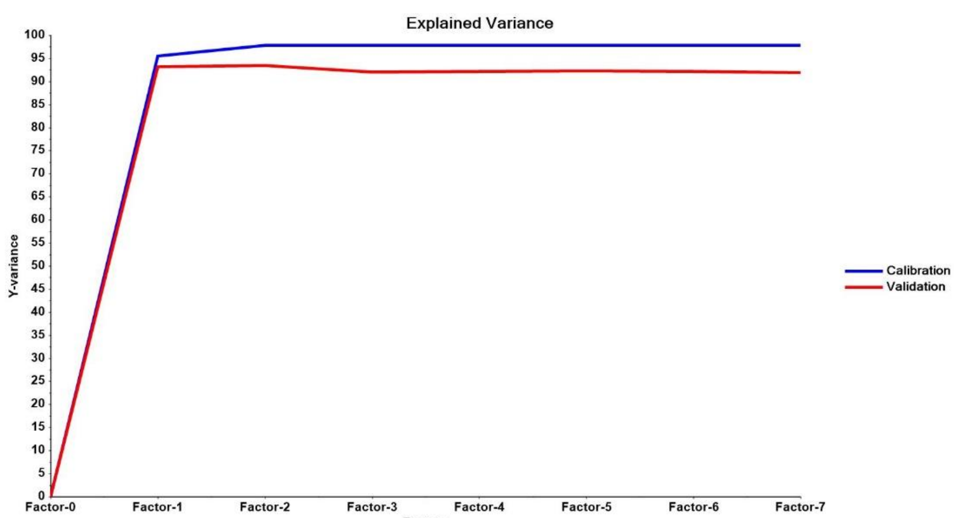

Figure B 26. Partial least squares regression explained variance graph for the D-0360 NPDES average potentiometric head model.

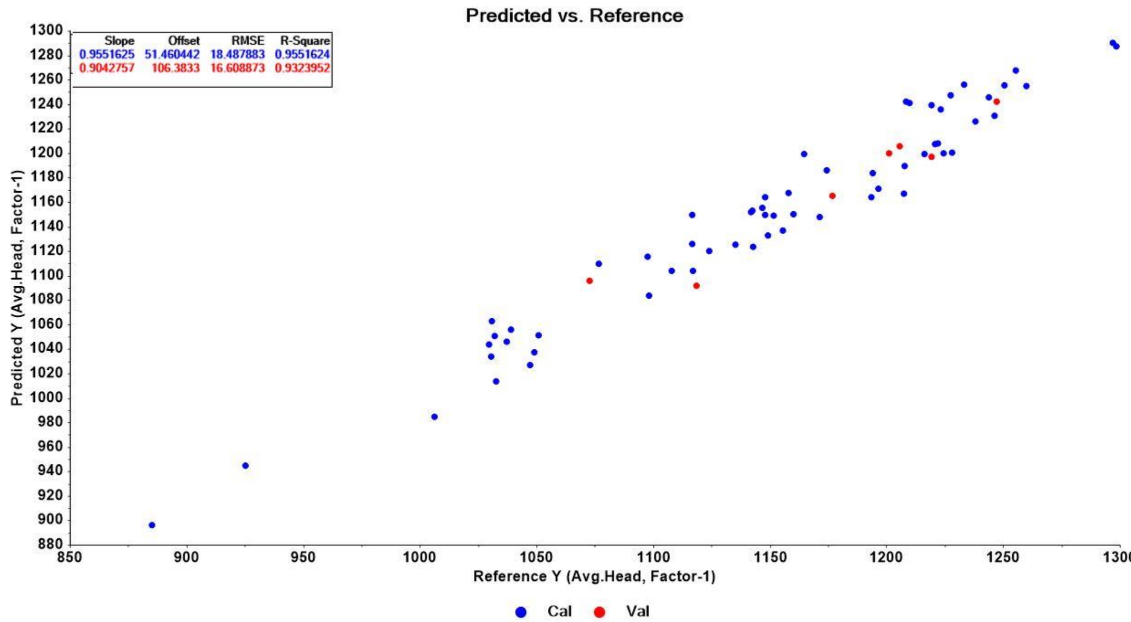

Figure B 27. Partial least squares regression predicted vs. reference plot for the D-0360 NPDES average potentiometric head model.

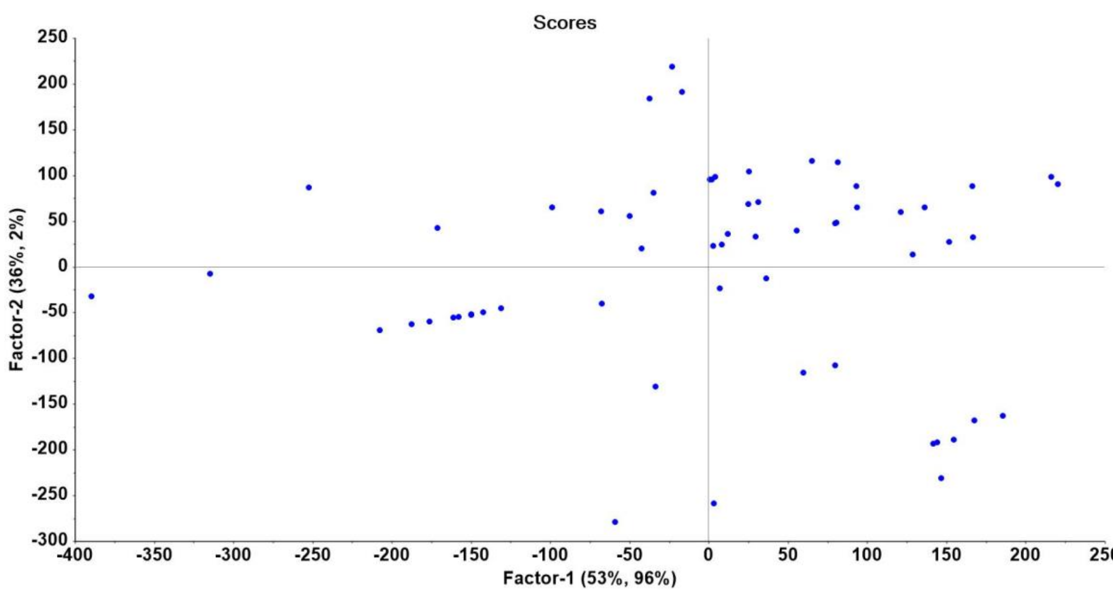

Figure B 28. Partial least squares regression scores plot for the D-0360 NPDES average potentiometric head model.

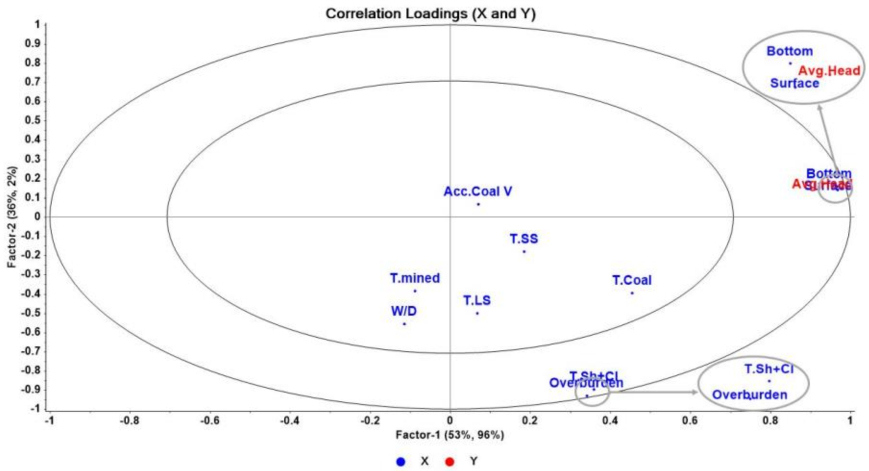

Figure B 29. Partial least squares regression correlation loadings plot for the correlation loadings plot for the D-0360 NPDES average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

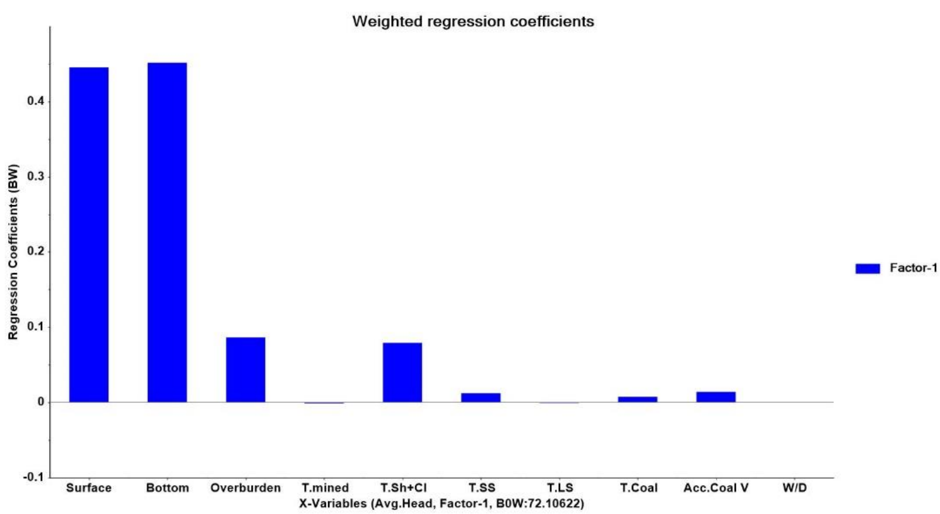

Figure B 30. Partial least squares regression weighted regression coefficients chart for the D-0360 NPDES average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

Table B 6. D-0360 all wells average potentiometric head model outlier.

Well
W21-165.04

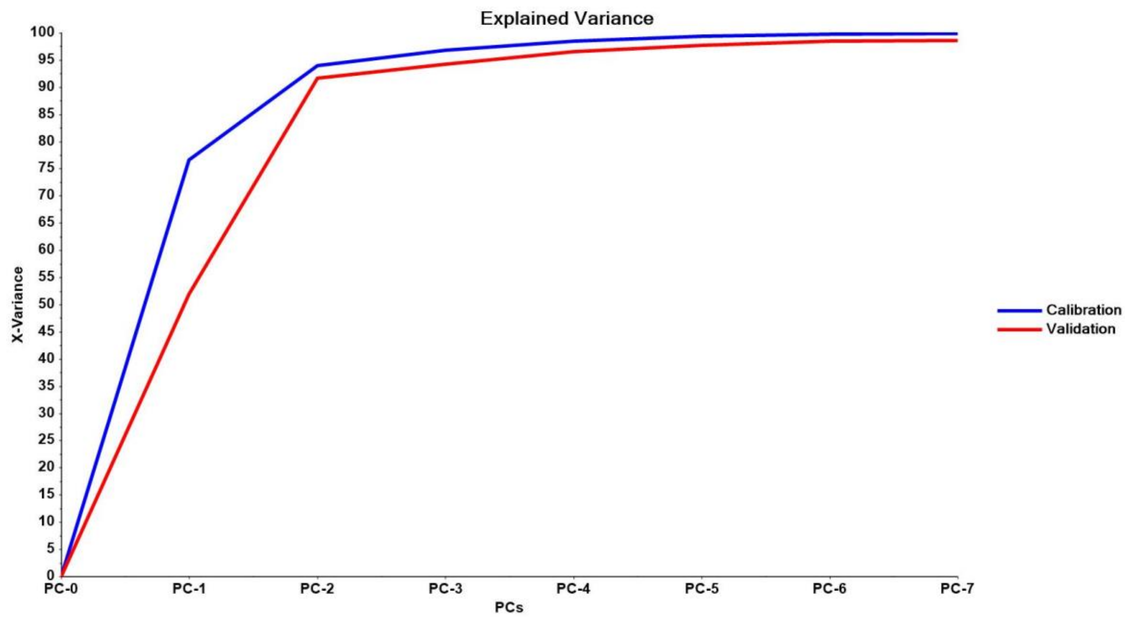

Figure B 31. Principal component analysis explained variance graph for the D-0360 all wells average potentiometric head model.

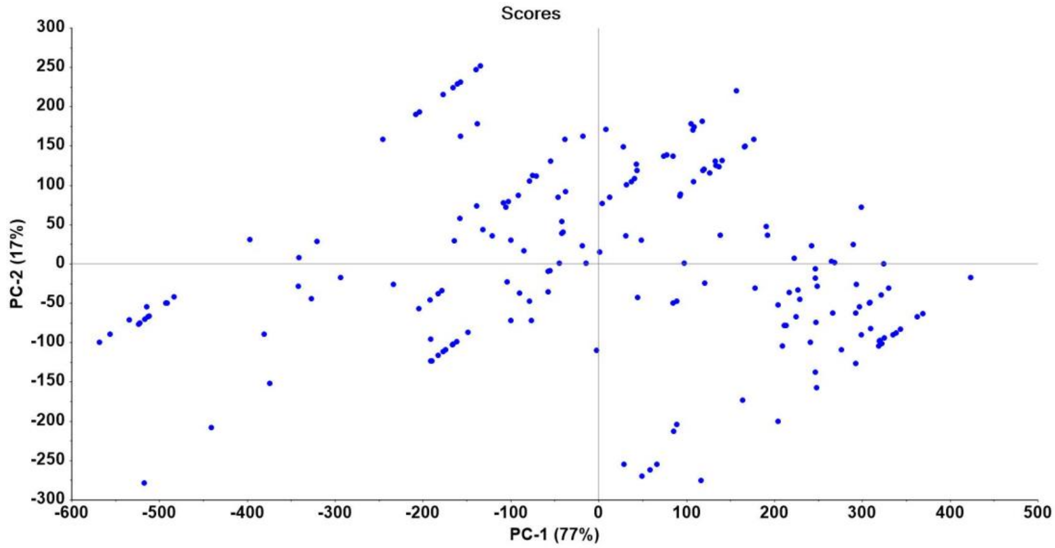

Figure B 32. Principal component analysis scores plot for the D-0360 all wells average potentiometric head model.

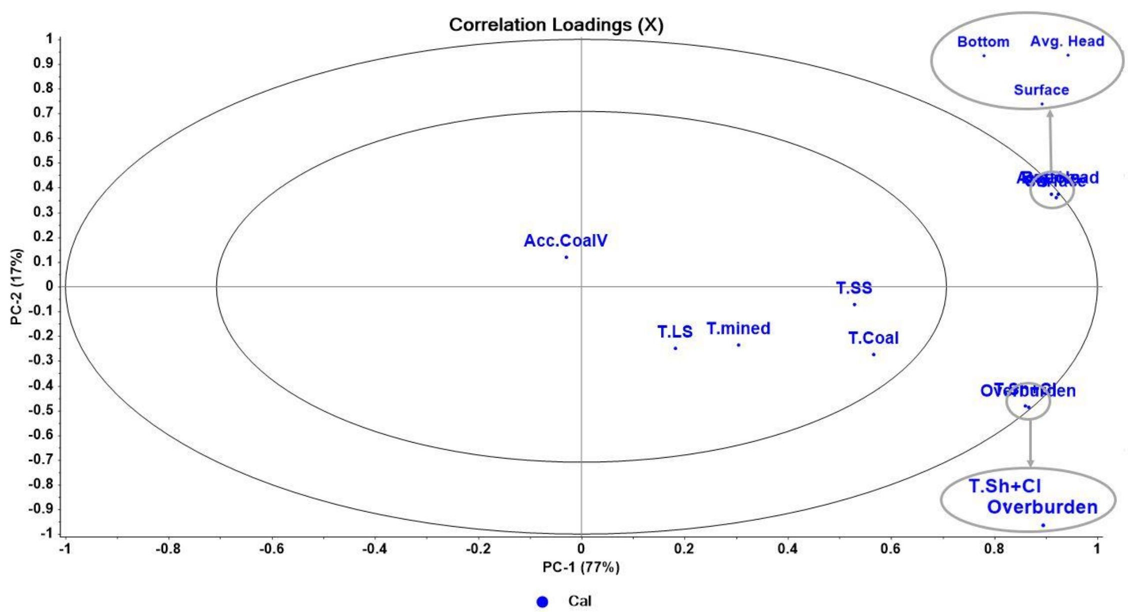

Figure B 33. Principal component analysis correlations loading plot for the D-0360 all wells average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

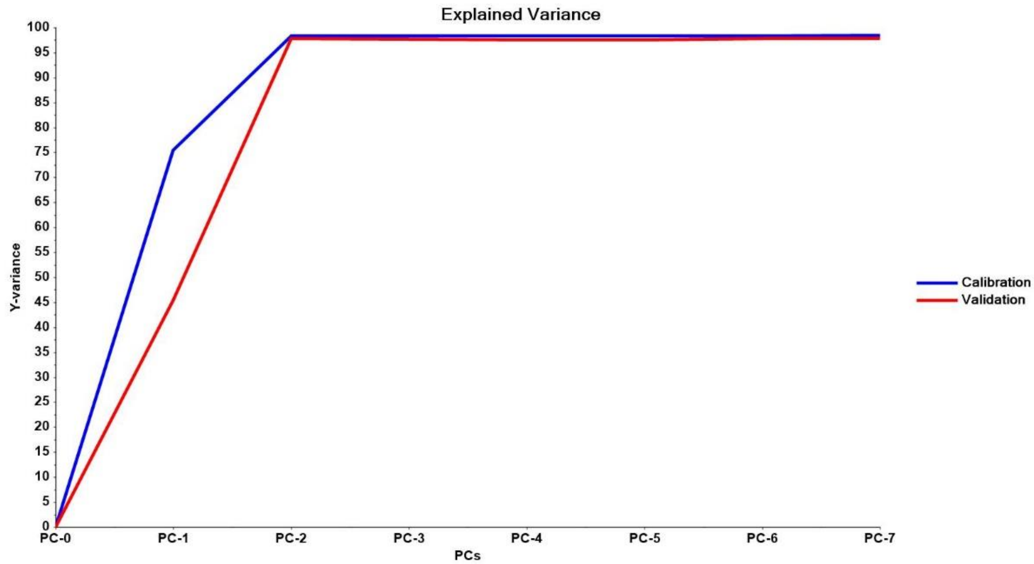

Figure B 34. Principal component regression explained variance graph for the D-0360 all wells average potentiometric head model.

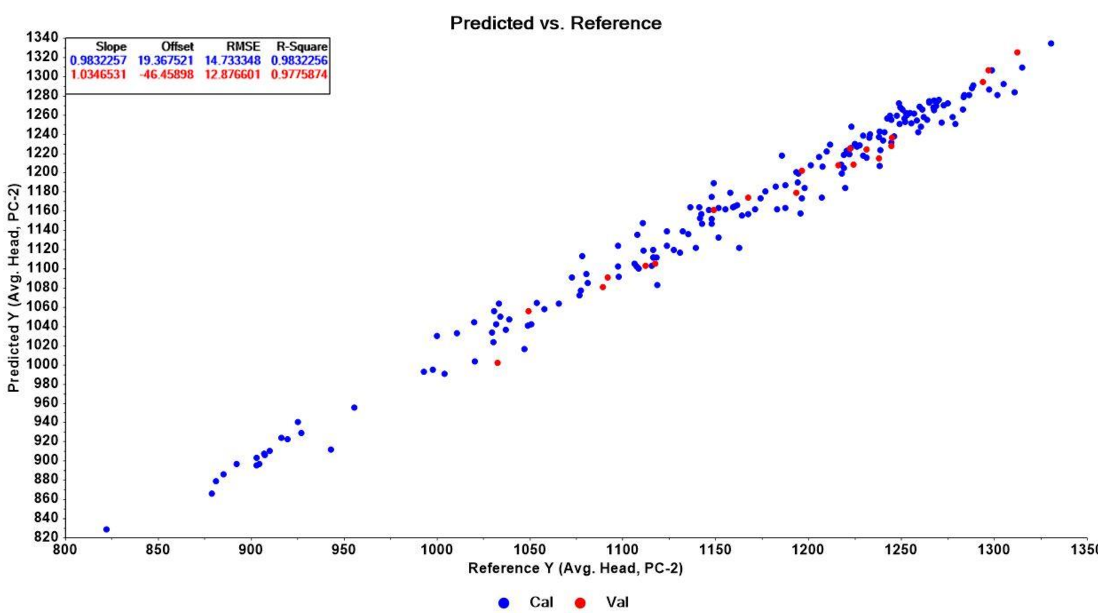

Figure B 35. Principal component regression predicted vs. reference plot for the D-0360 all wells average potentiometric head model.

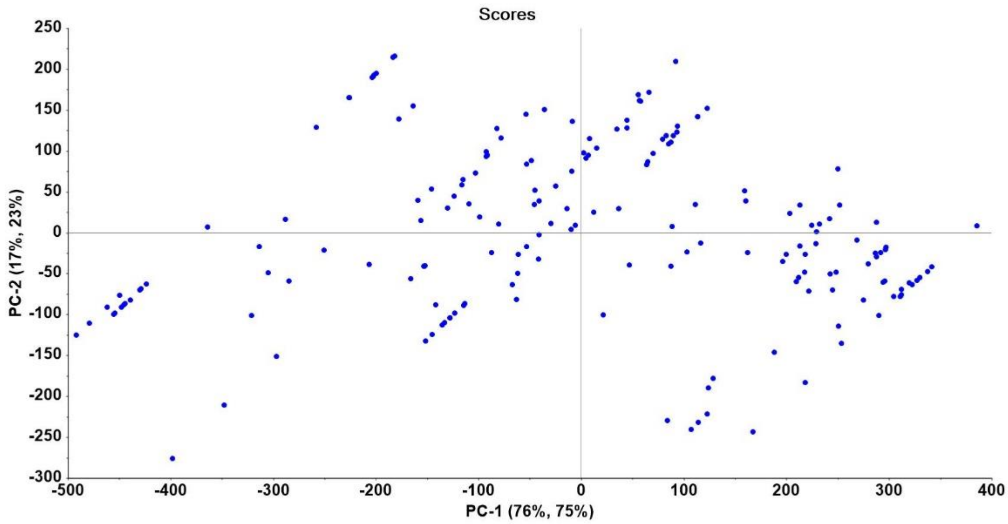

Figure B 36. Principal component regression scores plot for the D-0360 all wells average potentiometric head model.

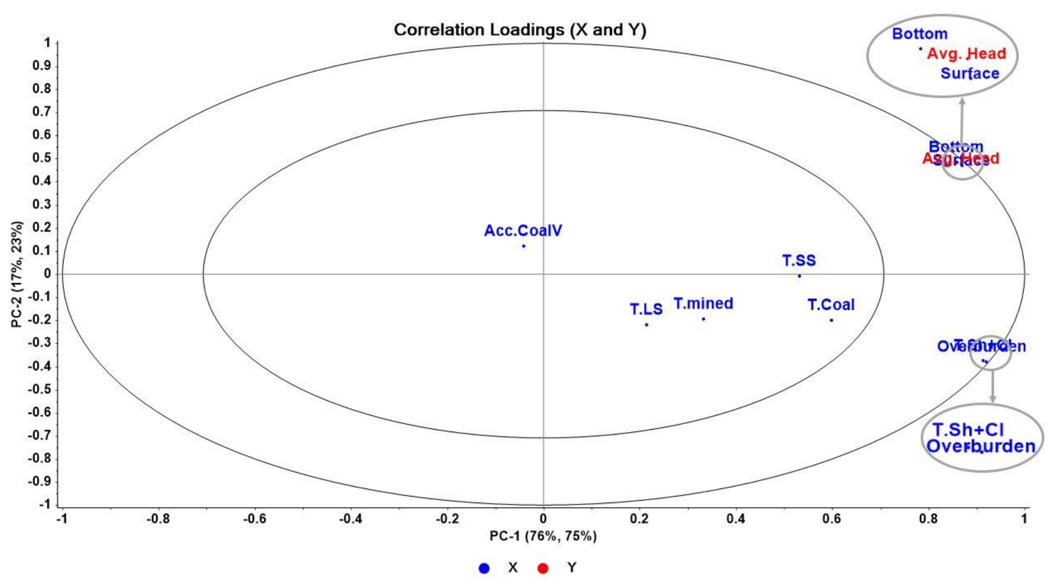

Figure B 37. Principal component regression correlation loadings plot for the D-0360 all wells model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

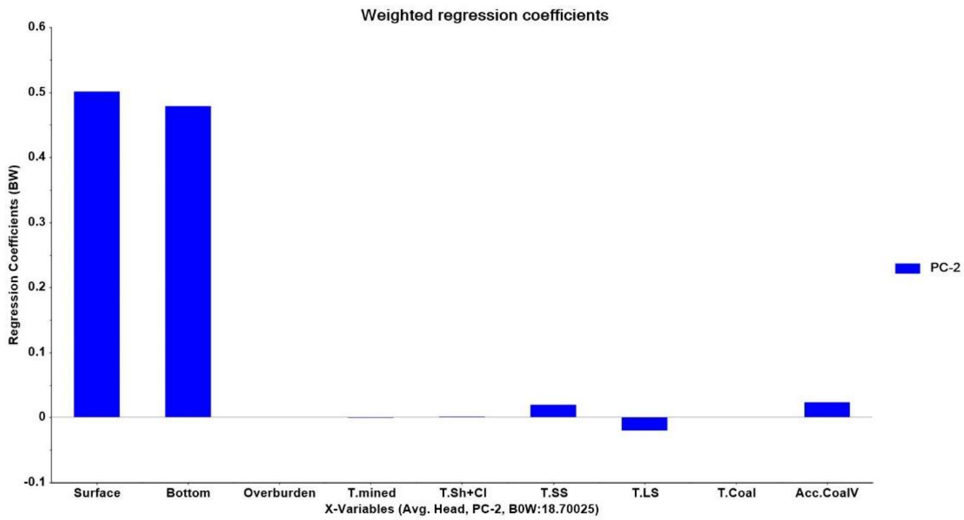

Figure B 38. Principal component regression weighted regression coefficients chart for the D-0360 all wells average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

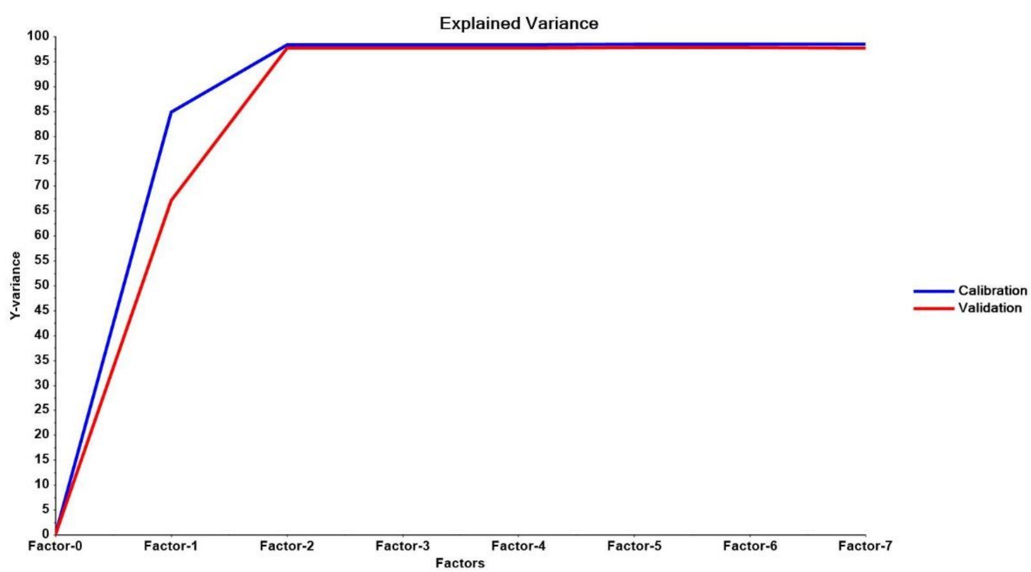

Figure B 39. Partial least squares regression explained variance graph for the D-0360 all wells average potentiometric head model.

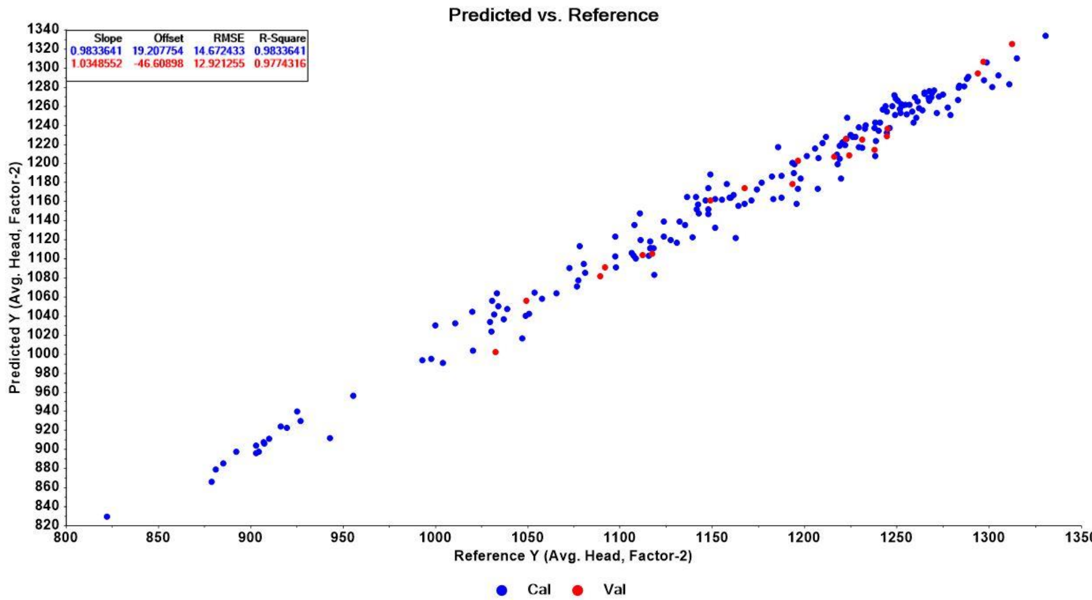

Figure B 40. Partial least squares regression predicted vs. reference plot for the D-0360 all wells average potentiometric head model.

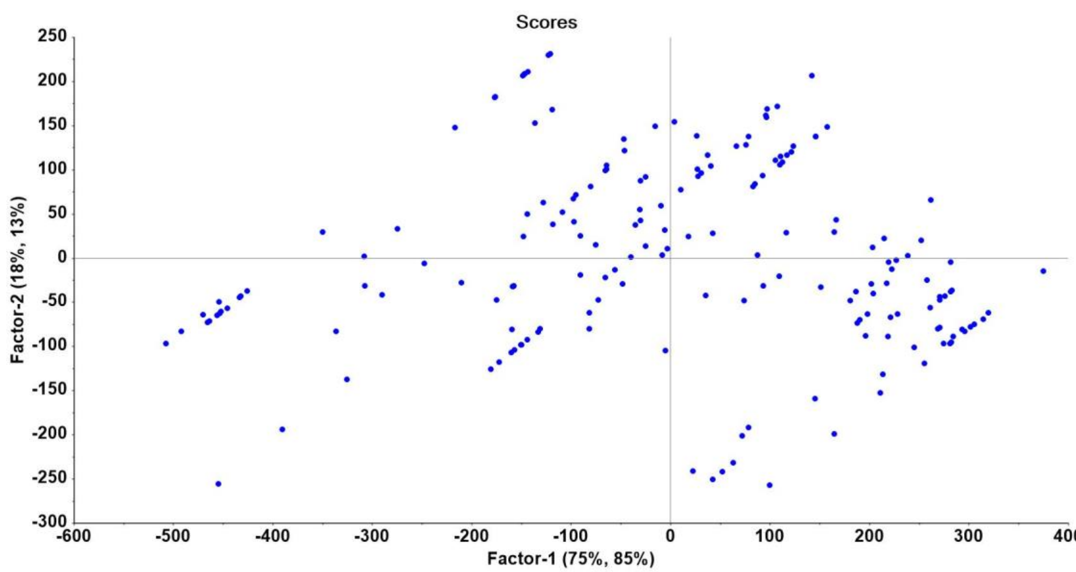

Figure B 41. Partial least squares regression scores plot for the D-0360 all wells average potentiometric head model.

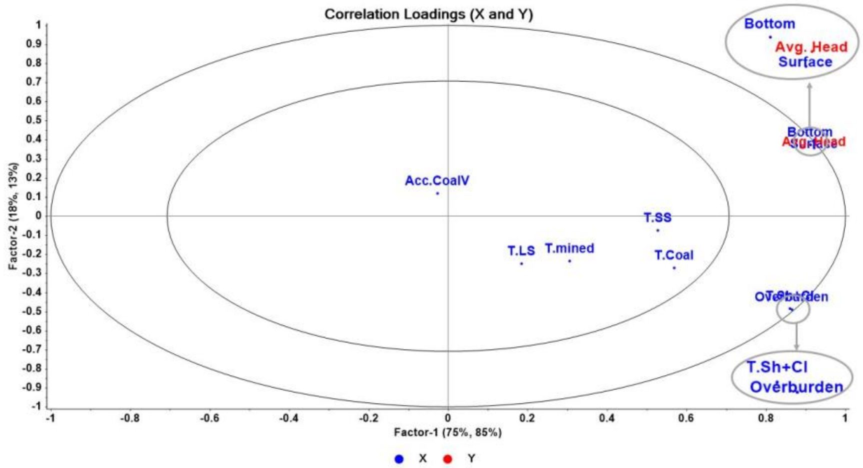

Figure B 42. Partial least squares regression correlation loadings plot for the D-0360 all wells average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

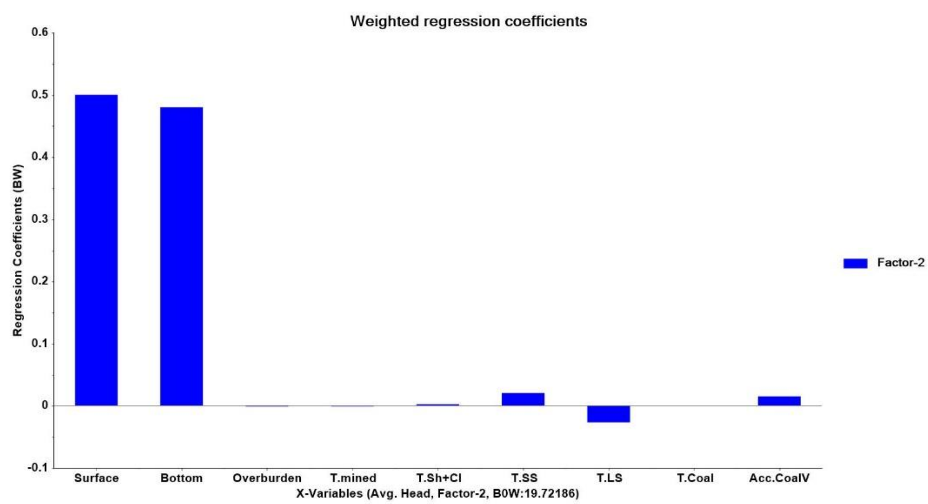

Figure B 43. Partial least squares regression weighted regression coefficients chart for the D-0360 all wells model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/month/ft).

APPENDIX C: MULTIVARIATE ANALYSIS MULTI-MINE MODELS DATA

Table C 1. Multi-mine without withdraw model data. ($1m^3 = 35.315ft^3$) ($1acre=43560ft^2$)

Mine	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4 mile buffer	Annual Average Precipitation (in)
D-0354	South Meins Shaft	1-28-08	12/8/16	285	475.45	430.49	457.17	781.68	304.53	470.69	6.46	217.43	204.83	9.48	9.67	39.63	10592.66	41.00
D-0354	Roving Crew	1/31/08	12/8/16	298	475.45	430.49	457.17	647.54	438.81	215.00	5.20	192.10	6.50	6.20	5.60	54.39	617.98	41.00
D-0354	Danville Shaft	1/28/08	6/30/11	154	475.48	445.49	460.08	735.03	442.37	292.66	4.46	214.92	52.25	14.33	5.71	54.39	617.98	41.00
D-0355	North East Intake	1/28/08	12/8/16	295	589.83	561.18	566.73	693.11	338.00	350.65	4.46	144.62	181.32	6.29	6.17	54.39	617.98	41.00
D-0355	Grange	1/28/08	12/8/16	294	585.83	552.19	557.92	735.03	442.37	292.66	4.46	214.92	52.25	14.33	5.71	54.39	617.98	41.00
D-0355	NW Shaft	1/28/08	12/8/16	292	586.00	551.86	557.51	693.11	338.00	350.65	4.46	144.62	181.32	6.29	6.17	54.39	617.98	41.00
D-0355	South Bleeder	1/28/08	12/8/16	301	605.67	552.14	557.90	771.22	443.10	278.48	4.53	55.51	208.50	4.08	4.53	54.39	617.98	41.00
D-0360	DW-118	10/24/90	3/20/91	6	1289.00	1287.00	1288.17	1305.00	1283.00	559.04	6.47	398.42	36.41	91.79	19.89	13.68	111048.55	40.50
D-0360	DW-122	10/26/90	3/20/91	6	1288.00	1284.00	1286.67	1302.00	1273.00	367.85	6.20	166.26	55.30	131.78	11.66	13.68	111048.55	40.50
D-0360	DW-126	10/25/90	3/20/91	6	1290.00	1288.00	1289.00	1311.00	1284.00	367.85	6.20	166.26	55.30	131.78	11.66	13.68	111048.55	40.50
D-0360	DW-129	10/25/90	3/20/91	6	1288.00	1282.00	1284.17	1305.00	1270.00	367.85	6.20	166.26	55.30	131.78	11.66	13.68	111048.55	40.50
D-0360	DW-161	10/30/90	4/24/91	6	1273.00	1273.00	1273.00	1290.00	1264.00	550.70	7.10	325.95	44.97	162.21	15.14	14.48	111048.55	40.50
D-0360	DW-162	11/27/90	4/24/91	6	1272.00	1269.00	1270.17	1296.00	1267.00	559.04	6.47	398.42	36.41	91.79	19.89	14.48	111048.55	40.50
D-0360	DW-169	11/2/90	4/8/91	6	1082.00	1081.00	1081.17	1100.00	1075.00	518.47	7.08	373.81	9.26	93.89	21.49	14.48	111048.55	40.50
D-0360	DW-178	11/6/90	4/9/91	6	1208.00	1186.00	1194.67	1225.00	1181.00	414.16	6.47	221.29	50.89	100.31	19.91	14.48	111048.55	40.50
D-0360	DW-180	11/14/90	4/16/91	6	1067.00	1064.00	1065.83	1083.00	1051.00	293.90	7.12	127.60	10.23	132.06	16.83	14.48	111048.55	40.50
D-0360	DW-196	11/14/90	4/17/91	6	1234.00	1228.00	1231.50	1240.00	1219.00	414.16	6.47	221.29	50.89	100.31	19.91	14.48	111048.55	40.50
D-0360	DW21-156.00	4/27/08	8/6/08	3	1222.00	1222.00	1222.00	1225.00	1219.00	274.25	5.45	194.05	15.51	61.90	11.27	98.01	111048.55	40.50
D-0360	DW21-190.00	4/27/08	8/22/08	3	1239.75	1236.20	1237.98	1248.00	1233.00	302.03	5.68	178.44	31.29	74.71	12.42	98.01	111048.55	40.50
D-0360	DW-22.004.00	10/23/08	3/9/09	3	1117.00	1117.00	1117.00	1125.00	1101.00	272.09	7.81	114.19	33.51	114.10	11.82	101.40	111048.55	40.50
D-0360	DW-22.008.05	10/8/08	3/11/09	3	1264.00	1257.00	1261.33	1285.00	1255.00	310.13	6.50	159.17	21.87	104.59	13.71	101.40	111048.55	40.50
D-0360	DW-318	11/30/93	4/28/94	6	1287.00	1276.00	1283.70	1294.00	1276.00	518.47	7.08	373.81	9.26	93.89	21.49	26.02	111048.55	40.50
D-0360	DW-324	11/14/95	2/3/1996	6	999.00	997.00	998.00	1000.00	991.00	209.68	4.28	93.70	32.00	105.70	7.82	35.38	111048.55	40.50
D-0360	DW-330	11/17/95	4/15/96	6	956.00	955.00	955.67	960.00	952.00	209.68	4.28	93.70	32.00	105.70	7.82	35.38	111048.55	40.50
D-0360	DW-331	11/20/95	4/15/96	6	928.00	926.00	927.00	935.00	924.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	DW-354	11/25/95	4/23/96	6	917.00	916.00	916.33	935.00	913.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	DW-356	11/28/95	4/23/96	6	1093.00	1091.00	1092.17	1100.00	1088.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50

Mine	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4 mile buffer	Annual Average Precipitation (in)
D-0360	DW-362	11/30/95	4/23/96	6	994.00	993.00	993.17	1000.00	989.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	DW-376	1/27/97	6/21/97	6	1246.00	1243.00	1244.83	1250.00	1220.00	471.79	5.29	321.05	61.70	78.55	18.20	40.52	111048.55	40.50
D-0360	DW-387	1/28/97	6/28/97	6	1241.00	1241.00	1241.00	1260.00	1236.00	287.45	6.85	195.67	43.79	129.97	13.52	40.52	111048.55	40.50
D-0360	DW-391	1/28/97	6/21/97	6	1098.00	1097.00	1097.67	1120.00	1090.00	287.45	6.85	195.67	43.79	129.97	13.52	40.52	111048.55	40.50
D-0360	DW-393	1/28/97	6/28/97	6	1318.00	1312.00	1315.00	1330.00	1300.00	433.09	5.12	321.97	32.71	69.59	16.17	40.52	111048.55	40.50
D-0360	DW-399	1/30/97	6/27/97	6	1296.00	1293.00	1294.17	1315.00	1285.00	291.50	6.25	177.75	23.01	71.99	15.15	40.52	111048.55	40.50
D-0360	DW-406	2/13/97	3/27/17	38	1302.00	1295.00	1298.95	1322.00	1298.00	291.50	6.25	177.75	23.01	71.99	15.15	146.18	111048.55	40.50
D-0360	DW-420	3/22/97	8/23/97	6	1225.00	1220.00	1222.67	1241.00	1218.00	291.50	6.25	177.75	23.01	71.99	15.15	41.98	111048.55	40.50
D-0360	DW-427	2/27/98	5/20/98	4	1231.00	1226.00	1229.50	1265.00	1224.00	562.20	5.50	277.65	65.48	204.97	11.83	46.09	111048.55	40.50
D-0360	DW-430	4/13/98	5/20/98	2	1254.00	1250.00	1252.00	1270.00	1246.00	335.45	7.45	211.84	21.69	92.72	12.98	46.09	111048.55	40.50
D-0360	DW-457	9/7/99	11/22/99	2	1050.00	1049.00	1049.50	1070.00	1045.00	287.45	6.85	195.67	43.79	129.97	13.52	52.95	111048.55	40.50
D-0360	DW-481	7/18/01	7/18/01	1	1148.00	1148.00	1148.00	1155.00	1143.00	241.40	2.31	140.36	34.51	73.45	10.11	59.37	111048.55	40.50
D-0360	DW502-338.08	10/29/08	3/9/09	3	1221.00	1215.70	1219.23	1230.00	1214.00	489.71	11.76	347.06	30.83	115.94	26.19	101.40	111048.55	40.50
D-0360	DW-679	1/21/14	4/15/14	4	1223.00	1219.00	1220.75	1235.00	1216.00	271.01	6.19	157.00	0.91	85.09	13.65	136.09	111048.55	40.50
D-0360	DW-702	8/7/03	2/25/04	3	1168.00	1167.00	1167.50	1190.00	1163.00	281.47	7.00	172.33	25.96	70.19	7.31	73.96	111048.55	40.50
D-0360	DW-717	7/22/03	2/19/04	3	1275.50	1275.00	1275.17	1280.00	1273.00	512.33	7.27	337.40	56.38	101.13	13.43	73.96	111048.55	40.50
D-0360	DW-719	7/26/03	3/13/17	21	1177.00	1172.00	1174.42	1178.00	1171.00	428.45	7.05	259.73	45.00	112.83	14.77	146.18	111048.55	40.50
D-0360	W-114	10/23/90	3/21/91	6	1266.00	1262.00	1264.17	1306.00	1213.00	559.04	6.47	398.42	36.41	91.79	19.89	13.68	111048.55	40.50
D-0360	W-125	10/25/90	12/27/90	3	1281.00	1276.00	1279.33	1299.00	1213.00	367.85	6.20	166.26	55.30	131.78	11.66	12.78	111048.55	40.50
D-0360	W-140	10/24/90	3/21/91	5	1269.00	1263.00	1265.00	1300.00	1256.00	559.04	6.47	398.42	36.41	91.79	19.89	13.68	111048.55	40.50
D-0360	W-153	10/27/90	3/21/91	6	1242.00	1240.00	1240.33	1269.00	1207.00	559.04	6.47	398.42	36.41	91.79	19.89	13.68	111048.55	40.50
D-0360	W-157	10/28/90	3/21/91	9	1263.00	1257.00	1259.33	1275.00	1219.00	514.70	7.57	350.60	23.74	78.65	19.66	13.68	111048.55	40.50
D-0360	W-159	10/30/90	4/10/91	6	1258.00	1244.00	1251.80	1290.00	1233.00	559.04	6.47	398.42	36.41	91.79	19.89	14.48	111048.55	40.50
D-0360	W-165	10/31/90	4/19/91	6	1111.00	1096.00	1107.50	1140.00	1069.00	559.04	6.47	398.42	36.41	91.79	19.89	14.48	111048.55	40.50
D-0360	W-166	11/2/90	4/8/91	6	1038.00	1023.00	1034.17	1106.00	998.00	293.90	7.12	127.60	10.23	132.06	16.83	14.48	111048.55	40.50
D-0360	W-170	11/2/90	4/8/91	6	1058.00	1052.00	1054.00	1105.00	1030.00	293.90	7.12	127.60	10.23	132.06	16.83	14.48	111048.55	40.50
D-0360	W-174	11/3/90	4/8/91	6	1054.00	1020.00	1033.67	1117.00	1016.00	293.90	7.12	127.60	10.23	132.06	16.83	14.48	111048.55	40.50
D-0360	W-175	11/8/90	4/9/91	6	1118.00	1117.00	1117.50	1132.00	1086.00	420.17	7.53	223.66	72.28	173.45	25.63	14.48	111048.55	40.50
D-0360	W-199	11/14/90	4/17/91	6	1187.00	1179.00	1183.08	1200.00	1133.00	143.32	3.00	15.48	0.00	96.63	9.60	14.48	111048.55	40.50
D-0360	W-2	2/24/84	2/24/84	1	822.20	822.20	822.20	834.90	819.90	263.05	7.55	115.24	35.79	109.05	13.01	1.52	111048.55	40.50
D-0360	W-202	11/15/90	4/17/91	6	1166.00	1158.00	1161.67	1210.00	1132.00	143.32	3.00	15.48	0.00	96.63	9.60	14.48	111048.55	40.50
D-0360	W-204	11/15/90	4/17/91	6	1190.00	1185.50	1187.58	1200.00	1136.00	143.32	3.00	15.48	0.00	96.63	9.60	14.48	111048.55	40.50
D-0360	W21-029.00	5/1/08	8/4/08	3	1235.00	1232.00	1233.33	1283.00	1204.00	490.16	5.17	323.67	11.34	108.77	13.68	98.01	111048.55	40.50

Mine	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4 mile buffer	Annual Average Precipitation (in)
D-0360	W21-043.00	5/1/08	8/14/08	3	1203.20	1198.50	1201.20	1242.00	1179.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	111048.55	40.50
D-0360	W21-045.01	5/1/08	8/6/08	3	1297.70	1295.80	1296.97	1340.00	1282.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	111048.55	40.50
D-0360	W21-057.00	5/3/08	8/12/08	3	1224.90	1223.50	1224.43	1260.00	1161.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	111048.55	40.50
D-0360	W21-059.00	5/3/08	8/9/08	3	1220.00	1210.50	1216.17	1255.00	1164.50	303.36	7.40	175.10	23.60	87.50	17.29	98.01	111048.55	40.50
D-0360	W21-064.00	5/2/08	8/13/08	3	1215.60	1199.60	1205.67	1260.00	1177.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	111048.55	40.50
D-0360	W21-066.00	5/1/08	8/21/08	3	1163.00	1162.50	1162.83	1165.00	1081.50	259.18	7.05	122.95	13.10	106.91	11.26	98.01	111048.55	40.50
D-0360	W21-080.00	5/3/08	8/18/08	3	1032.00	1029.30	1030.40	1045.00	1001.00	317.45	7.29	204.12	2.04	78.09	10.82	98.01	111048.55	40.50
D-0360	W21-083.00	5/2/08	8/8/08	3	1038.00	1035.70	1037.10	1055.00	1017.50	317.45	7.29	204.12	2.04	78.09	10.82	98.01	111048.55	40.50
D-0360	W21-087.00	5/5/08	8/11/08	3	1039.50	1038.80	1039.10	1068.00	1026.30	317.45	7.29	204.12	2.04	78.09	10.82	98.01	111048.55	40.50
D-0360	W21-087.01	5/5/08	8/11/08	3	1057.00	1045.80	1050.97	1068.00	1015.80	317.45	7.29	204.12	2.04	78.09	10.82	98.01	111048.55	40.50
D-0360	W21-095.00	5/2/08	8/9/08	3	1038.20	1019.30	1030.83	1100.00	1011.00	317.45	7.29	204.12	2.04	78.09	10.82	98.01	111048.55	40.50
D-0360	W21-106.00	5/3/08	8/11/2008	3	1048.60	1045.60	1047.33	1065.00	965.00	317.45	7.29	204.12	2.04	78.09	10.82	98.01	111048.55	40.50
D-0360	W21-110.01	5/9/08	8/8/08	3	1029.60	1029.60	1029.60	1050.00	1017.20	317.45	7.29	204.12	2.04	78.09	10.82	98.01	111048.55	40.50
D-0360	W21-111.00	5/2/08	8/8/08	3	1032.90	1032.20	1032.63	1040.00	961.00	317.45	7.29	204.12	2.04	78.09	10.82	98.01	111048.55	40.50
D-0360	W21-112.00	5/8/08	8/11/08	3	1032.40	1031.80	1032.07	1060.00	1023.40	317.45	7.29	204.12	2.04	78.09	10.82	98.01	111048.55	40.50
D-0360	W21-138.00	5/3/08	8/4/08	3	1215.40	1194.50	1207.30	1240.00	1109.70	303.36	7.40	175.10	23.60	87.50	17.29	98.01	111048.55	40.50
D-0360	W21-155.08	6/24/08	4/30/2008	3	1261.00	1259.00	1259.97	1300.00	1245.00	274.25	5.45	194.05	15.51	61.90	11.27	96.35	111048.55	40.50
D-0360	W21-160.00	4/30/08	8/6/08	3	1160.80	1159.40	1160.17	1220.00	1115.00	279.00	6.90	77.16	24.69	145.59	12.54	98.01	111048.55	40.50
D-0360	W21-165.04	5/3/08	8/23/08	3	1192.20	744.00	1042.07	1240.00	1100.00	253.20	9.20	50.40	31.39	165.59	12.60	98.01	111048.55	40.50
D-0360	W21-171.00	4/30/08	8/6/08	3	1180.00	1173.20	1176.93	1220.00	1147.00	279.00	6.90	77.16	24.69	145.59	12.54	98.01	111048.55	40.50
D-0360	W21-173.01	4/29/08	8/7/08	3	1211.00	1205.50	1207.83	1220.00	1201.50	279.00	6.90	77.16	24.69	145.59	12.54	98.01	111048.55	40.50
D-0360	W21-180.01	4/29/08	8/6/08	3	1194.20	1193.00	1193.63	1220.00	1144.50	279.00	6.90	77.16	24.69	145.59	12.54	98.01	111048.55	40.50
D-0360	W21-183.01	4/29/08	8/6/08	3	1195.60	1193.00	1194.20	1220.00	1164.00	302.03	5.68	178.44	31.29	74.71	12.42	98.01	111048.55	40.50
D-0360	W21-187.00	5/1/08	8/7/08	3	1220.60	1218.10	1219.23	1240.00	1173.50	302.03	5.68	178.44	31.29	74.71	12.42	98.01	111048.55	40.50
D-0360	W21-195.00	5/1/08	8/23/08	3	1227.50	1216.80	1223.37	1280.00	1221.00	302.03	5.68	178.44	31.29	74.71	12.42	98.01	111048.55	40.50
D-0360	W21-260.00	5/6/08	8/19/08	3	1142.90	1142.00	1142.47	1180.00	1137.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	111048.55	40.50
D-0360	W21-265.00	5/5/08	8/19/08	3	1148.20	1147.90	1148.03	1180.00	1127.50	303.36	7.40	175.10	23.60	87.50	17.29	98.01	111048.55	40.50
D-0360	W21-452.00	5/8/08	8/19/08	3	1156.80	1154.50	1155.50	1190.00	1137.00	156.50	7.10	92.72	0.00	41.26	9.32	98.01	111048.55	40.50
D-0360	W21-481.00	5/5/08	9/2/08	3	1150.00	1148.60	1149.13	1185.00	1143.00	148.57	6.55	43.93	0.00	95.92	9.60	98.01	111048.55	40.50
D-0360	W21-502.00	5/6/08	8/26/08	3	1143.90	1141.80	1142.85	1165.00	1132.00	156.50	7.10	92.72	0.00	41.26	9.32	98.01	111048.55	40.50
D-0360	W-22.007.00	10/29/08	3/20/17	16	1221.30	1204.00	1209.92	1250.00	1198.00	489.71	11.76	347.06	30.83	115.94	26.19	146.18	111048.55	40.50
D-0360	W-225	11/19/90	4/11/91	6	1141.00	1137.00	1139.33	1148.00	1102.00	311.66	5.89	203.68	6.59	88.74	15.19	14.48	111048.55	40.50
D-0360	W-226	11/20/90	4/11/91	6	1059.00	1057.00	1058.00	1080.00	1040.00	311.66	5.89	203.68	6.59	88.74	15.19	14.48	111048.55	40.50
D-0360	W-229A	1/26/91	6/14/91	6	1272.00	1250.00	1262.33	1305.00	1225.00	562.60	4.58	351.36	15.02	176.44	12.24	14.48	111048.55	40.50
D-0360	W231.356.00	10/27/08	3/10/09	3	1233.30	1160.00	1196.65	1280.00	1068.00	335.45	7.45	211.84	21.69	92.72	12.98	94.66	111048.55	40.50

Mine	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4 mile buffer	Annual Average Precipitation (in)
D-0360	W231.356.04	10/27/08	3/3/16	28	1267.00	1223.00	1246.36	1270.00	1209.70	335.45	7.45	211.84	21.69	92.72	12.98	144.60	111048.55	40.50
D-0360	W-289	11/15/93	4/29/94	6	1268.00	1266.00	1267.33	1300.00	1246.00	557.74	2.40	398.53	47.72	103.50	11.13	26.02	111048.55	40.50
D-0360	W-291	11/16/93	4/29/94	6	1273.00	1271.00	1271.83	1275.00	1240.00	542.40	5.04	412.92	16.15	92.07	13.88	26.02	111048.55	40.50
D-0360	W-292	11/16/93	4/29/94	6	1251.00	1232.00	1242.40	1310.00	1216.00	562.60	4.58	351.36	15.02	176.44	12.24	26.02	111048.55	40.50
D-0360	W-294	11/17/93	4/28/94	6	1083.00	1072.00	1080.50	1125.00	1068.00	518.47	7.08	373.81	9.26	93.89	21.49	26.02	111048.55	40.50
D-0360	W-295	11/17/93	4/29/94	6	1239.00	1228.00	1232.80	1264.00	1222.00	562.60	4.58	351.36	15.02	176.44	12.24	26.02	111048.55	40.50
D-0360	W-299	11/18/93	4/29/94	6	1254.00	1246.00	1249.40	1324.00	1221.00	542.40	5.04	412.92	16.15	92.07	13.88	26.02	111048.55	40.50
D-0360	W-312A	12/5/94	6/23/95	6	1255.00	1254.00	1254.67	1315.00	1220.00	550.70	7.10	325.95	44.97	162.21	15.14	30.70	111048.55	40.50
D-0360	W-314A	7/21/01	10/2/01	2	1234.00	1202.00	1218.00	1270.00	1132.00	542.40	5.04	412.92	16.15	92.07	13.88	63.00	111048.55	40.50
D-0360	W-316	11/29/93	4/28/94	6	1164.00	1151.00	1159.67	1203.00	1131.00	518.47	7.08	373.81	9.26	93.89	21.49	26.02	111048.55	40.50
D-0360	W-323	6/25/94	7/26/94	2	1079.00	1076.00	1077.50	1138.00	1018.00	518.47	7.08	373.81	9.26	93.89	21.49	27.47	111048.55	40.50
D-0360	W-325	11/14/95	4/23/96	6	947.00	935.00	943.17	975.00	846.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	W-327	11/17/95	4/24/96	6	904.00	902.00	903.17	910.00	880.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	W-333	11/20/95	4/24/96	6	905.00	904.00	904.33	908.00	885.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	W-334	11/20/95	4/24/96	6	908.00	906.00	907.17	913.00	901.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	W-335	11/20/95	4/24/96	6	909.00	903.00	907.50	918.00	893.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	W-336	11/20/95	4/24/96	6	905.00	898.00	903.17	918.00	888.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	W336.367.00	8/25/10	2/23/11	3	886.80	882.70	885.20	900.00	865.00	263.05	7.55	115.24	35.79	109.05	13.01	115.82	111048.55	40.50
D-0360	W336.375.00	1/27/12	12/1/16	34	928.00	923.00	925.35	1000.00	873.00	263.05	7.55	115.24	35.79	109.05	13.01	146.18	111048.55	40.50
D-0360	W-340	11/21/95	4/22/96	6	912.00	902.00	910.17	920.00	900.00	128.30	5.87	17.73	0.00	82.11	9.03	35.38	111048.55	40.50
D-0360	W-341	11/21/95	4/22/96	6	893.00	891.00	892.17	920.00	872.00	128.30	5.87	17.73	0.00	82.11	9.03	35.38	111048.55	40.50
D-0360	W-342	11/21/95	4/22/96	6	879.00	879.00	879.00	885.00	843.00	128.30	5.87	17.73	0.00	82.11	9.03	35.38	111048.55	40.50
D-0360	W-344	11/22/95	4/25/96	6	1166.00	1163.00	1164.33	1185.00	1131.00	414.16	6.47	221.29	50.89	100.31	19.91	35.38	111048.55	40.50
D-0360	W-345	11/22/95	4/18/96	6	1240.00	1237.00	1238.83	1270.00	1184.00	414.16	6.47	221.29	50.89	100.31	19.91	35.38	111048.55	40.50
D-0360	W-346	11/24/95	4/15/96	6	922.00	918.00	919.83	930.00	915.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	W-347	11/24/95	4/19/96	6	1097.00	1067.00	1078.50	1180.00	1050.00	311.66	5.89	203.68	6.59	88.74	15.19	35.38	111048.55	40.50
D-0360	W-350	11/24/95	4/19/96	6	1144.00	1133.00	1141.33	1218.00	1118.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50

Mine	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4 mile buffer	Annual Average Precipitation (in)
D-0360	W-353	11/24/95	4/24/96	6	1138.00	1135.00	1136.67	1210.00	1125.00	311.66	5.89	203.68	6.59	88.74	15.19	35.38	111048.55	40.50
D-0360	W-358	11/28/95	4/18/96	6	1201.00	1192.00	1196.50	1225.00	1190.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	W-359	11/29/95	4/19/96	6	1113.00	1104.00	1106.50	1118.00	1100.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	W-363	11/30/95	4/18/96	6	1001.00	999.00	1000.17	1095.00	965.00	209.68	4.28	93.70	32.00	105.70	7.82	35.38	111048.55	40.50
D-0360	W-365	11/30/95	4/26/96	6	1189.00	1179.00	1182.50	1240.00	1140.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	W-368	4/26/96	9/13/96	6	1140.00	1117.00	1132.33	1185.00	1100.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	W-374	1/15/97	6/27/97	6	1249.00	1246.00	1247.67	1290.00	1239.00	480.07	7.29	317.33	35.19	104.86	16.00	40.52	111048.55	40.50
D-0360	W-377	1/27/97	6/21/97	6	1253.00	1225.00	1245.17	1282.00	1196.00	471.79	5.29	321.05	61.70	78.55	18.20	40.52	111048.55	40.50
D-0360	W-378	1/27/97	6/21/97	6	1298.00	1296.00	1297.33	1325.00	1257.00	471.79	5.29	321.05	61.70	78.55	18.20	40.52	111048.55	40.50
D-0360	W-379	1/27/97	6/21/97	6	1247.00	1241.00	1244.00	1323.00	1203.00	433.09	5.12	321.97	32.71	69.59	16.17	40.52	111048.55	40.50
D-0360	W-382	1/27/97	6/21/97	6	1273.00	1265.00	1268.67	1350.00	1195.00	433.09	5.12	321.97	32.71	69.59	16.17	40.52	111048.55	40.50
D-0360	W-394	1/28/97	6/21/97	6	1233.00	1230.00	1231.33	1259.00	1179.00	433.09	5.12	321.97	32.71	69.59	16.17	40.52	111048.55	40.50
D-0360	W-396	1/30/97	6/27/97	6	1269.00	1266.00	1267.67	1305.00	1235.00	291.50	6.25	177.75	23.01	71.99	15.15	40.52	111048.55	40.50
D-0360	W-400	1/30/97	6/27/97	6	1271.00	1261.00	1267.83	1315.00	1245.00	291.50	6.25	177.75	23.01	71.99	15.15	40.52	111048.55	40.50
D-0360	W-401	1/30/97	6/28/97	6	1280.00	1276.00	1277.83	1318.00	1205.00	327.53	4.87	218.18	24.31	55.90	14.42	40.52	111048.55	40.50
D-0360	W-402	1/30/97	6/27/97	6	1260.00	1244.00	1252.67	1325.00	1206.00	327.53	4.87	218.18	24.31	55.90	14.42	40.52	111048.55	40.50
D-0360	W-403	1/31/97	6/28/97	6	1304.00	1298.00	1301.83	1345.00	1227.00	550.70	7.10	325.95	44.97	162.21	15.14	40.52	111048.55	40.50
D-0360	W-404	1/31/97	4/2001	8	1115.00	1111.00	1112.50	1130.00	1078.00	327.53	4.87	218.18	24.31	55.90	14.42	60.64	111048.55	40.50
D-0360	W-407	2/13/97	3/27/17	30	1250.00	1247.00	1248.83	1306.00	1243.00	518.47	7.08	373.81	9.26	93.89	21.49	146.18	111048.55	40.50
D-0360	W-410	2/13/97	3/20/17	38	1263.00	1237.00	1250.54	1310.00	1225.00	327.53	4.87	218.18	24.31	55.90	14.42	146.18	111048.55	40.50
D-0360	W-413	2/13/97	7/2008	41	1253.00	1240.00	1244.58	1280.00	1233.00	327.53	4.87	218.18	24.31	55.90	14.42	146.18	111048.55	40.50
D-0360	W-414	2/13/97	3/20/17	42	1267.00	1228.00	1249.27	1280.00	1225.00	327.53	4.87	218.18	24.31	55.90	14.42	146.18	111048.55	40.50
D-0360	W-415	2/13/97	7/2008	42	1115.00	1101.00	1108.67	1135.00	1063.00	327.53	4.87	218.18	24.31	55.90	14.42	146.18	111048.55	40.50
D-0360	W-417	2/24/97	7/19/97	6	1116.00	1106.00	1111.33	1165.00	1075.00	327.53	4.87	218.18	24.31	55.90	14.42	41.98	111048.55	40.50
D-0360	W-418	5/22/97	7/19/97	6	1171.00	1163.00	1167.83	1180.00	1139.00	327.53	4.87	218.18	24.31	55.90	14.42	41.98	111048.55	40.50
D-0360	W-423	1/23/98	6/10/98	6	1126.00	1122.00	1123.83	1200.00	1083.00	143.32	3.00	15.48	0.00	96.63	9.60	46.09	111048.55	40.50
D-0360	W-425	2/27/98	5/20/98	4	1228.00	1225.00	1226.25	1270.00	1193.00	335.45	7.45	211.84	21.69	92.72	12.98	46.09	111048.55	40.50
D-0360	W-426	2/27/98	5/22/98	4	1120.00	1117.00	1118.50	1160.00	1070.00	534.00	7.98	316.06	23.80	187.04	13.10	46.09	111048.55	40.50
D-0360	W-428	2/28/98	4/14/16	28	1234.00	1194.00	1211.64	1270.00	1195.00	540.40	5.50	336.95	11.82	178.25	12.88	145.62	111048.55	40.50
D-0360	W-429	2/28/98	5/22/98	4	1198.00	1194.00	1196.00	1210.00	1109.00	557.74	2.40	398.53	47.72	103.50	11.13	46.09	111048.55	40.50
D-0360	W-432	2/28/98	10/3/07	6	1193.00	1181.50	1185.83	1265.00	1179.00	562.20	5.50	277.65	65.48	204.97	11.83	93.06	111048.55	40.50
D-0360	W-438	10/28/98	1/24/99	4	1094.00	1085.00	1089.50	1145.00	1019.00	317.45	7.29	204.12	2.04	78.09	10.82	49.35	111048.55	40.50
D-0360	W-452	7/18/01	10/16/07	2	1155.50	1148.00	1151.75	1170.00	1097.00	241.40	2.31	140.36	34.51	73.45	10.11	93.06	111048.55	40.50
D-0360	W-455	3/27/99	4/30/99	2	1020.00	1020.00	1020.00	1080.00	1010.00	287.45	6.85	195.67	43.79	129.97	13.52	50.61	111048.55	40.50
D-0360	W501.077.00	7/23/07	2/1/17	33	1182.50	1097.00	1141.78	1210.00	1095.00	335.45	7.45	211.84	21.69	92.72	12.98	146.18	111048.55	40.50
D-0360	W501.077.01	4/30/07	12/1/16	27	1153.00	1034.00	1072.70	1180.00	997.50	335.45	7.45	211.84	21.69	92.72	12.98	146.18	111048.55	40.50

Mine	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4 mile buffer	Annual Average Precipitation (in)
D-0360	W501.343000	11/14/12	3/1/17	10	1125.00	1104.50	1116.63	1175.00	1045.00	431.50	6.60	236.12	77.80	118.08	12.12	146.18	111048.55	40.50
D-0360	W-53.01	11/4/05	3/16/12	3	1007.50	1000.00	1004.23	1010.00	969.00	181.70	7.40	100.39	2.00	91.20	12.29	122.05	111048.55	40.50
D-0360	W-568	1/21/14	3/12/14	3	1172.00	1171.00	1171.33	1222.00	1104.00	257.46	4.90	113.13	22.11	116.39	9.10	134.15	111048.55	40.50
D-0360	W-576	1/21/14	4/15/14	4	1149.00	1147.00	1148.00	1230.00	1121.00	271.01	6.19	157.00	0.91	85.09	13.65	136.09	111048.55	40.50
D-0360	W-583	1/21/14	3/12/14	3	1159.00	1157.00	1158.00	1245.00	1115.00	271.01	6.19	157.00	0.91	85.09	13.65	134.15	111048.55	40.50
D-0360	W-587	3/1/17	3/1/17	1	1238.20	1238.20	1238.20	1245.00	1189.00	261.34	4.91	129.00	22.85	104.89	13.16	146.18	111048.55	40.50
D-0360	W-609	1/21/14	9/21/15	20	1141.00	1094.00	1123.87	1162.00	1084.00	298.86	5.45	166.14	34.91	78.29	9.15	142.33	111048.55	40.50
D-0360	W-620	1/21/14	9/21/15	21	1150.00	1143.00	1146.64	1178.00	1146.00	298.86	5.45	166.14	34.91	78.29	9.15	142.33	111048.55	40.50
D-0360	W6-6	2/20/98	8/24/12	10	1235.00	1226.40	1229.54	1256.00	1184.00	263.05	7.55	115.24	35.79	109.05	13.01	125.58	111048.55	40.50
D-0360	W-660	1/14/14	4/7/15	16	1143.00	1129.00	1135.25	1170.00	1104.50	276.95	5.10	94.67	17.81	110.04	11.95	140.86	111048.55	40.50
D-0360	W-666	1/13/14	12/5/14	12	1055.00	1041.00	1049.08	1065.00	1012.00	263.35	7.00	108.55	53.31	84.24	5.91	138.08	111048.55	40.50
D-0360	W-671	1/15/14	9/3/14	9	1117.00	1079.00	1097.50	1183.00	1063.00	278.52	7.88	130.58	24.35	89.21	10.00	137.37	111048.55	40.50
D-0360	W-681	7/29/03	2/26/04	3	1259.50	1257.00	1258.50	1312.00	1203.00	404.43	7.01	276.76	17.32	84.19	12.07	73.96	111048.55	40.50
D-0360	W-683	7/29/03	2/23/04	3	1022.00	1020.00	1020.67	1030.00	977.00	171.63	5.20	65.90	1.30	100.36	11.56	73.96	111048.55	40.50
D-0360	W-690	7/31/03	2/24/04	3	1313.00	1312.00	1312.67	1366.00	1296.00	556.98	7.61	404.08	9.37	114.93	14.37	73.96	111048.55	40.50
D-0360	W-691	8/31/03	2/24/04	3	1263.00	1259.00	1260.67	1275.00	1229.00	428.45	7.05	259.73	45.00	112.83	14.77	73.96	111048.55	40.50
D-0360	W-694	4/23/07	3/20/17	16	1236.00	1208.00	1227.62	1260.00	1200.50	489.71	11.76	347.06	30.83	115.94	26.19	146.18	111048.55	40.50
D-0360	W-696	8/4/03	2/27/04	3	1194.50	1193.00	1193.50	1270.00	1136.00	428.45	7.05	259.73	45.00	112.83	14.77	73.96	111048.55	40.50
D-0360	W-701	8/5/03	2/26/04	3	1270.00	1269.00	1269.33	1320.00	1236.00	480.07	7.29	317.33	35.19	104.86	16.00	73.96	111048.55	40.50
D-0360	W-705	8/6/03	2/27/04	3	1224.00	1221.00	1222.93	1270.00	1187.00	480.07	7.29	317.33	35.19	104.86	16.00	73.96	111048.55	40.50
D-0360	W-706	8/8/03	2/26/04	3	1242.00	1233.90	1238.30	1290.00	1203.00	480.07	7.29	317.33	35.19	104.86	16.00	73.96	111048.55	40.50
D-0360	W-707	7/7/03	2/17/04	3	1226.00	1216.00	1220.00	1235.00	1140.00	233.13	7.55	117.80	5.49	98.95	10.71	73.96	111048.55	40.50
D-0360	W-709	7/7/03	3/13/17	6	1012.00	1010.00	1010.77	1085.00	977.00	171.63	5.20	65.90	1.30	100.36	11.56	146.18	111048.55	40.50
D-0360	W-716	7/23/03	2/19/04	3	1310.00	1295.00	1305.00	1320.00	1273.00	512.33	7.27	337.40	56.38	101.13	13.43	73.96	111048.55	40.50
D-0360	W-722	7/26/03	2/23/04	3	1332.00	1330.00	1330.67	1380.00	1300.00	556.98	7.61	404.08	9.37	114.93	14.37	73.96	111048.55	40.50
D-0360	W-723	7/11/03	2/7/04	3	1132.00	1130.00	1131.00	1180.00	1056.00	233.13	7.55	117.80	5.49	98.95	10.71	73.96	111048.55	40.50
D-0360	W-728	7/15/03	2/19/04	3	1116.00	1115.00	1115.67	1140.00	1070.00	233.13	7.55	117.80	5.49	98.95	10.71	73.96	111048.55	40.50
D-0360	W-734	7/18/03	2/19/04	3	1188.00	1187.00	1187.67	1205.00	1173.00	333.34	4.90	243.57	13.34	48.14	14.88	73.96	111048.55	40.50
D-0360	WL-113	11/18/98	11/18/98	1	1225.00	1225.00	1225.00	1280.00	1188.00	367.85	6.20	166.26	55.30	131.78	11.66	48.18	111048.55	40.50
D-0360	WL-116	10/23/90	3/21/91	5	1246.00	1244.00	1244.80	1260.00	1204.00	559.04	6.47	398.42	36.41	91.79	19.89	13.68	111048.55	40.50
D-0360	WL21-041.01	5/1/08	8/8/08	3	1258.40	1252.10	1255.37	1300.00	1210.00	490.16	5.17	323.67	11.34	108.77	13.68	98.01	111048.55	40.50
D-0360	WL231.362.00	8/25/10	3/1/17	40	1136.00	1100.00	1116.65	1170.00	1071.00	534.00	7.98	316.06	23.80	187.04	13.10	146.18	111048.55	40.50
D-0360	WL-301	11/18/93	4/29/94	6	1256.00	1249.00	1253.40	1303.00	1227.00	542.40	5.04	412.92	16.15	92.07	13.88	26.02	111048.55	40.50
D-0360	WL-319	1/26/94	12/15/94	6	1269.00	1261.00	1265.17	1325.00	1236.00	550.70	7.10	325.95	44.97	162.21	15.14	28.51	111048.55	40.50
D-0360	WL336.373.00	8/25/10	5/2/16	30	1085.00	1065.00	1076.71	1100.00	1046.00	534.00	7.98	316.06	23.80	187.04	13.10	145.62	111048.55	40.50
D-0360	WL-338	11/20/95	4/22/96	6	881.00	881.00	881.00	890.00	865.00	128.30	5.87	17.73	0.00	82.11	9.03	35.38	111048.55	40.50

Mine	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4 mile buffer	Annual Average Precipitation (in)
D-0360	WL-348	11/29/95	4/19/96	6	1117.00	1097.00	1110.83	1210.00	1090.00	311.66	5.89	203.68	6.59	88.74	15.19	35.38	111048.55	40.50
D-0360	WL-349	11/24/95	4/18/96	6	1111.00	1104.00	1108.00	1190.00	1085.00	311.66	5.89	203.68	6.59	88.74	15.19	35.38	111048.55	40.50
D-0360	WL-351	11/24/95	4/18/96	6	1203.00	1192.00	1198.17	1225.00	1152.00	143.32	3.00	15.48	0.00	96.63	9.60	35.38	111048.55	40.50
D-0360	WL-381	1/27/97	6/21/97	6	1285.00	1281.00	1283.17	1325.00	1213.00	471.79	5.29	321.05	61.70	78.55	18.20	40.52	111048.55	40.50
D-0360	WL-419	3/22/97	8/23/97	6	1243.00	1234.00	1238.33	1261.00	1160.00	291.50	6.25	177.75	23.01	71.99	15.15	41.98	111048.55	40.50
D-0360	WL-567	1/21/14	3/12/14	3	1152.00	1151.00	1151.67	1224.00	1104.00	257.46	4.90	113.13	22.11	116.39	9.10	134.15	111048.55	40.50
D-0360	WL-674	3/30/01	3/13/17	39	1103.00	1078.00	1098.00	1145.00	1036.00	238.05	6.60	146.59	0.00	68.14	11.96	146.18	111048.55	40.50
D-0360	WL-692	8/1/03	2/25/04	3	1312.00	1310.00	1311.00	1355.00	1220.00	556.98	7.61	404.08	9.37	114.93	14.37	73.96	111048.55	40.50
D-0360	WL-721	4/30/10	3/13/17	18	1150.00	1149.00	1149.20	1230.00	1150.00	428.45	7.05	259.73	45.00	112.83	14.77	146.18	111048.55	40.50
D-0360	WL-729	7/11/03	2/17/04	3	1132.00	1125.00	1127.67	1160.00	1083.00	274.30	7.64	160.72	7.90	89.41	14.94	73.96	111048.55	40.50
D-0360	WL-736	7/21/03	3/13/17	19	1130.87	1115.00	1118.74	1131.00	1031.00	333.34	4.90	243.57	13.34	48.14	14.88	146.18	111048.55	40.50
D-0360	WL-739	7/23/03	2/23/04	3	1258.00	1255.00	1257.00	1340.00	1190.00	500.76	7.61	275.70	57.23	136.09	33.23	73.96	111048.55	40.50
D-0360	WL-747	8/11/03	2/25/04	3	1219.00	1215.00	1217.67	1270.00	1150.00	520.40	6.58	417.07	32.62	64.63	15.68	73.96	111048.55	40.50
D-1019	W-100	2/19/96	2/19/96	1	1169.00	1169.00	1169.00	1225.00	1025.00	266.00	4.00	157.00	112.00	0.00	4.00	0.11	11184.92	38.00
D-1019	W-14	7/8/08	12/21/12	49	1164.00	1029.00	1066.93	1240.00	310.00	205.83	3.33	159.33	49.33	0.00	3.50	3.85	11184.92	38.00
D-1019	W-201	10/5/11	7/7/11	17	1224.00	1139.00	1202.74	1260.00	960.00	253.00	3.00	228.50	27.00	0.00	3.50	3.85	11184.92	38.00
D-1019	W-202	11/19/12	10/17/12	28	1267.00	1185.00	1223.25	1270.00	1189.00	253.00	3.00	228.50	27.00	0.00	3.50	3.85	11184.92	38.00
D-1019	W-242	5/2/12	1/20/10	4	1141.00	1137.00	1138.00	1190.00	986.00	253.00	3.00	228.50	27.00	0.00	3.50	3.85	11184.92	38.00
D-1019	WL-13	10/13/14	10/6/14	3	1254.00	1253.00	1253.67	1293.00	901.00	205.83	3.33	159.33	49.33	0.00	3.50	3.85	11184.92	38.00
D-1019	WL-14	7/8/08	12/21/12	49	1203.00	930.00	1064.75	1240.00	1130.00	266.00	4.00	157.00	112.00	0.00	4.00	1.71	11184.92	38.00
D-1019	WL-18	8/5/08	12/21/12	29	977.00	968.00	973.91	1005.00	910.00	266.00	4.00	157.00	112.00	0.00	4.00	3.85	11184.92	38.00
D-1019	WL-201	1/5/12	4/10/14	6	1223.00	1193.00	1217.14	1260.00	960.00	205.83	3.33	159.33	49.33	0.00	3.50	3.85	11184.92	38.00
D-1019	WL-3	5/13/96	1/11/02	35	1238.00	1133.00	1198.57	1260.00	1096.00	98.50	3.00	92.50	9.00	0.00	3.00	1.51	11184.92	38.00
D-1019	WL-39A	7/8/08	12/30/16	50	1218.00	1197.00	1212.56	1242.00	820.00	205.83	3.33	159.33	49.33	0.00	3.50	3.85	11184.92	38.00
D-1180-7	W-10	5/20/96	5/20/96	1	801.00	801.00	801.00	825.00	746.00	56.00	3.00	98.00	11.00	0.00	6.10	0.00	10262.20	37.00
D-1180-7	W-100	10/14/05	3/25/15	11	1092.40	1049.60	1079.38	1180.00	900.00	415.32	3.29	403.09	5.41	9.41	4.38	2.94	10262.20	37.00
D-1180-7	W-101	10/14/05	9/9/14	6	1162.00	1125.00	1141.93	1185.00	1100.00	413.50	2.50	333.50	126.00	0.00	5.50	2.78	10262.20	37.00
D-1180-7	W-102	10/14/05	12/11/14	7	1136.90	1128.30	1134.57	1180.00	955.00	410.00	3.08	390.50	66.00	0.00	6.00	2.88	10262.20	37.00
D-1180-7	W-23	5/20/96	3/25/15	11	1163.00	1144.00	1155.06	1200.00	1060.00	395.00	2.75	325.00	117.00	0.00	7.91	2.94	10262.20	37.00
D-1180-7	W-256	3/28/11	8/26/14	4	1135.60	1132.00	1134.40	1224.00	1085.00	534.66	3.50	466.43	41.58	18.76	4.63	2.78	10262.20	37.00
D-1180-7	W-277	9/7/12	5/22/13	3	1188.60	1183.60	1186.20	1260.00	1060.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	W-278	3/29/12	5/23/13	3	1183.60	1181.40	1182.77	1275.00	1175.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00

Mine	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4 mile buffer	Annual Average Precipitation (in)
D-1180-7	W-279	9/7/12	5/22/13	3	1173.60	1166.40	1171.00	1265.00	1040.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	W-285	3/20/12	8/26/14	2	1201.40	1201.00	1201.20	1240.00	1050.00	443.02	2.14	371.38	94.23	3.66	7.07	2.78	10262.20	37.00
D-1180-7	W-299	3/29/13	9/11/13	3	1124.80	1112.60	1120.67	1205.00	1080.00	443.02	2.14	371.38	94.23	3.66	7.07	2.46	10262.20	37.00
D-1180-7	W-3	5/20/96	5/20/96	1	1158.00	1158.00	1158.00	1198.00	986.00	416.00	5.00	326.00	133.00	0.00	9.00	0.00	10262.20	37.00
D-1180-7	W-30	6/20/01	11/25/14	7	1147.40	1131.00	1137.86	1225.00	1225.00	405.00	4.00	311.00	132.00	0.00	8.00	2.88	10262.20	37.00
D-1180-7	W-300	3/29/12	7/29/13	6	1170.20	1162.60	1166.33	1200.00	1055.00	443.02	2.14	371.38	94.23	3.66	7.07	2.78	10262.20	37.00
D-1180-7	W-305	7/29/13	7/29/13	1	1174.00	1151.40	1157.78	1202.00	1082.00	443.02	2.14	371.38	94.23	3.66	7.07	2.46	10262.20	37.00
D-1180-7	W-309	4/4/12	5/22/13	3	1152.40	1136.60	1142.53	1195.00	1085.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	W-311	4/4/12	7/30/13	3	1165.00	1164.60	1164.87	1235.00	1135.00	443.02	2.14	371.38	94.23	3.66	7.07	2.46	10262.20	37.00
D-1180-7	W-312	4/10/12	5/28/13	3	1210.00	1202.80	1206.93	1220.00	1070.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	W-312A	4/10/12	5/28/13	3	1209.00	1197.80	1204.60	1218.00	1068.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	W-315	4/2/12	6/3/13	3	1159.60	1158.40	1159.13	1202.00	1052.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	W-351	2/28/12	5/28/13	3	1159.60	1151.60	1154.97	1262.00	1104.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	W-352	4/20/12	8/31/12	3	1136.40	1134.20	1135.07	1200.00	1053.00	443.02	2.14	371.38	94.23	3.66	7.07	2.14	10262.20	37.00
D-1180-7	W-353	4/16/12	8/31/12	3	1192.60	1191.60	1192.07	1285.00	1085.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	W-358	3/6/12	8/31/12	3	1189.60	1186.40	1188.00	1265.00	1065.00	443.02	2.14	371.38	94.23	3.66	7.07	2.14	10262.20	37.00
D-1180-7	W-360	3/6/12	8/31/12	3	1184.60	1181.60	1183.20	1262.00	1087.00	443.02	2.14	371.38	94.23	3.66	7.07	2.14	10262.20	37.00
D-1180-7	W-361	3/6/12	8/31/12	3	1189.00	1185.80	1187.17	1255.00	1055.00	443.02	2.14	371.38	94.23	3.66	7.07	2.14	10262.20	37.00
D-1180-7	W-363	3/20/12	5/28/13	3	1203.60	1200.60	1202.27	1232.00	1117.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	W-5	5/20/96	5/20/96	1	1160.00	1160.00	1160.00	1220.00	1120.00	413.50	4.00	364.50	88.00	0.00	8.00	0.00	10262.20	37.00
D-1180-7	W-6	5/20/96	11/25/14	8	1195.00	1148.50	1179.66	1210.00	1100.00	395.00	2.75	325.00	117.00	0.00	7.91	2.88	10262.20	37.00
D-1180-7	W-9	5/20/96	3/23/15	6	1202.00	1172.40	1192.82	1265.00	1114.00	442.00	4.00	389.00	99.00	0.00	8.00	2.94	10262.20	37.00
D-1180-7	WL-101	12/11/14	3/27/15	2	1166.10	1164.50	1165.30	1185.00	1100.00	443.02	2.14	371.38	94.23	3.66	7.07	2.94	10262.20	37.00
D-1180-7	WL-102	3/27/15	3/27/15	1	1137.80	1137.80	1137.80	1180.00	955.00	443.02	2.14	371.38	94.23	3.66	7.07	2.94	10262.20	37.00
D-1180-7	WL-2	10/26/05	3/27/15	8	965.20	962.40	964.30	1000.00	919.00	360.83	6.00	400.00	3.00	0.00	9.33	2.94	10262.20	37.00

Mine	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4 mile buffer	Annual Average Precipitation (in)
D-1180-7	WL-200	1/18/05	2/14/17	13	821.00	813.00	816.32	830.00	745.00	443.02	2.14	371.38	94.23	3.66	7.07	3.18	10262.20	37.00
D-1180-7	WL-273	8/30/12	4/8/14	3	1255.60	1247.60	1250.60	1290.00	1159.00	443.02	2.14	371.38	94.23	3.66	7.07	2.68	10262.20	37.00
D-1180-7	WL-284	5/8/14	5/8/14	1	1177.00	1177.00	1177.00	1262.00	1076.00	443.02	2.14	371.38	94.23	3.66	7.07	2.78	10262.20	37.00
D-1180-7	WL-295	9/19/13	9/19/13	1	1156.00	1156.00	1156.00	1192.00	1048.00	443.02	2.14	371.38	94.23	3.66	7.07	2.46	10262.20	37.00
D-1180-7	WL-362	9/7/12	5/29/13	2	1168.50	1168.40	1168.45	1262.00	1155.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	WL-364	3/20/12	5/28/13	3	1194.60	1192.20	1193.40	1232.00	1117.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	WL-365	3/21/12	3/21/12	1	1160.80	1160.80	1160.80	1205.00	1070.00	443.02	2.14	371.38	94.23	3.66	7.07	1.99	10262.20	37.00
D-1180-7	WL-368	3/20/12	5/28/13	3	1121.60	1117.60	1119.20	1168.00	1008.00	443.02	2.14	371.38	94.23	3.66	7.07	2.36	10262.20	37.00
D-1180-7	WL-4	5/20/96	3/24/15	6	1160.40	1156.10	1159.07	1190.00	1090.00	416.00	5.00	326.00	133.00	0.00	9.00	2.36	10262.20	37.00
D-1180-7	WL-8	5/20/96	3/23/15	6	1169.80	1174.50	1184.00	1245.00	1135.00	390.00	3.00	319.00	69.00	0.00	3.00	2.94	10262.20	37.00
D-1180-6	W-10	5/20/96	5/20/96	1	801.00	801.00	801.00	825.00	746.00	109.00	3.10	98.00	11.00	0.00	6.10	0.00	10262.20	37.00
D-1180-6	W-100	10/14/05	3/25/15	11	1092.40	1049.60	1079.38	1180.00	900.00	415.32	3.29	403.09	5.41	9.41	4.38	1.59	10262.20	37.00
D-1180-6	W-101	10/14/05	9/9/14	6	1162.00	1125.00	1141.93	1185.00	1100.00	458.50	3.00	333.50	126.00	0.00	5.50	1.59	10262.20	37.00
D-1180-6	W-102	10/14/05	12/11/14	7	1136.90	1128.30	1134.57	1180.00	955.00	455.08	2.92	390.50	66.00	0.00	6.00	1.59	10262.20	37.00
D-1180-6	W-23	5/20/96	3/25/15	11	1163.00	1144.00	1155.06	1200.00	1060.00	442.75	3.16	325.00	117.00	0.00	7.91	1.59	10262.20	37.00
D-1180-6	W-256	3/28/11	8/26/14	4	1135.60	1132.00	1134.40	1224.00	1085.00	534.66	3.50	466.43	41.58	18.76	4.63	1.59	10262.20	37.00
D-1180-6	W-277	9/7/12	5/22/13	3	1188.60	1183.60	1186.20	1260.00	1060.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-278	3/29/12	5/23/13	3	1183.60	1181.40	1182.77	1275.00	1175.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-279	9/7/12	5/22/13	3	1173.60	1166.40	1171.00	1265.00	1040.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-285	3/20/12	8/26/14	2	1201.40	1201.00	1201.20	1240.00	1050.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-299	3/29/13	9/11/13	3	1124.80	1112.60	1120.67	1205.00	1080.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-3	5/20/96	5/20/96	1	1158.00	1158.00	1158.00	1198.00	986.00	462.00	4.00	326.00	133.00	0.00	9.00	0.00	10262.20	37.00
D-1180-6	W-30	6/20/01	11/25/14	7	1147.40	1131.00	1137.86	1225.00	1225.00	450.00	3.00	311.00	132.00	0.00	8.00	1.59	10262.20	37.00
D-1180-6	W-300	3/29/12	7/29/13	6	1170.20	1162.60	1166.33	1200.00	1055.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-305	7/29/13	7/29/13	1	1174.00	1151.40	1157.78	1202.00	1082.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00

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D-1180-6	W-309	4/4/12	5/22/13	3	1152.40	1136.60	1142.53	1195.00	1085.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-311	4/4/12	7/30/13	3	1165.00	1164.60	1164.87	1235.00	1135.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-312	4/10/12	5/28/13	3	1210.00	1202.80	1206.93	1220.00	1070.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-312A	4/10/12	5/28/13	3	1209.00	1197.80	1204.60	1218.00	1068.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-315	4/2/12	6/3/13	3	1159.60	1158.40	1159.13	1202.00	1052.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-351	2/28/12	5/28/13	3	1159.60	1151.60	1154.97	1262.00	1104.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-352	4/20/12	8/31/12	3	1136.40	1134.20	1135.07	1200.00	1053.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-353	4/16/12	5/28/13	3	1192.60	1191.60	1192.07	1285.00	1085.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-358	3/6/12	8/31/12	3	1189.60	1186.40	1188.00	1265.00	1065.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-360	3/6/12	8/31/12	3	1184.60	1181.60	1183.20	1262.00	1087.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-361	3/6/12	8/31/12	3	1189.00	1185.80	1187.17	1255.00	1055.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-363	3/20/12	5/28/13	3	1203.60	1200.60	1202.27	1232.00	1117.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	W-5	5/20/96	5/20/96	1	1160.00	1160.00	1160.00	1220.00	1120.00	457.50	3.00	364.50	88.00	0.00	8.00	0.00	10262.20	37.00
D-1180-6	W-6	5/20/96	11/25/14	8	1195.00	1148.50	1179.66	1210.00	1100.00	442.75	3.16	325.00	117.00	0.00	7.91	1.59	10262.20	37.00
D-1180-6	W-9	5/20/96	3/23/15	6	1202.00	1172.40	1192.82	1265.00	1114.00	489.00	4.00	389.00	99.00	0.00	8.00	1.59	10262.20	37.00
D-1180-6	WL-101	12/11/14	3/27/15	2	1166.10	1164.50	1165.30	1185.00	1100.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	WL-102	3/27/15	3/27/15	1	1137.80	1137.80	1137.80	1180.00	955.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	WL-2	10/26/05	3/27/15	8	965.20	962.40	964.30	1000.00	919.00	405.91	3.33	400.00	3.00	0.00	9.33	1.59	10262.20	37.00
D-1180-6	WL-200	1/18/05	2/14/17	13	821.00	813.00	816.32	830.00	745.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	WL-273	8/30/12	4/8/14	3	1255.60	1247.60	1250.60	1290.00	1159.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	WL-284	5/8/14	5/8/14	1	1177.00	1177.00	1177.00	1262.00	1076.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	WL-295	9/19/13	9/19/13	1	1156.00	1156.00	1156.00	1192.00	1048.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	WL-362	9/7/12	5/29/13	2	1168.50	1168.40	1168.45	1262.00	1155.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	WL-364	3/20/12	5/28/13	3	1194.60	1192.20	1193.40	1232.00	1117.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	WL-365	3/21/12	3/21/12	1	1160.80	1160.80	1160.80	1205.00	1070.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00

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D-1180-6	WL-368	3/20/12	5/28/13	3	1121.60	1117.60	1119.20	1168.00	1008.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-1180-6	WL-4	5/20/96	3/24/15	6	1156.10	1159.07	1190.00	1090.00	462.00	4.00	326.00	133.00	0.00	9.00	1.59	836.00	37.00	
D-1180-6	WL-8	5/20/96	3/23/15	6	1169.80	1174.50	1184.00	1245.00	1135.00	475.29	3.21	378.08	96.38	3.82	7.20	1.59	10262.20	37.00
D-2091	MW-8	2/16/17	2/16/17	1	1004.41	1004.41	1004.41	1006.74	992.74	343.10	3.01	163.03	137.67	36.34	3.92	1.72	11181.57	38.00
D-2091	MW-9	2/16/17	2/16/17	1	1007.80	1007.80	1007.80	1025.80	1002.80	343.10	3.01	163.03	137.67	36.34	3.92	1.72	11181.57	38.00
D-2091	W-10	10/14/96	2/27/04	2	1035.00	990.00	1012.50	1115.00	925.00	206.00	3.00	66.97	125.00	7.00	9.96	0.37	11181.57	38.00
D-2091	W-201	5/4/99	3/15/00	2	1145.00	1139.00	1142.00	1260.00	960.00	284.00	3.00	104.66	137.75	47.42	0.00	0.00	11181.57	38.00
D-2091	W-202	10/14/96	9/19/02	8	1222.00	1185.00	1216.28	1270.00	1189.00	284.00	3.00	104.66	137.75	47.42	0.00	0.01	11181.57	38.00
D-2091	W-26	3/11/16	11/29/16	4	1173.50	1123.00	1160.44	1185.00	1065.00	151.00	3.50	116.01	33.17	8.25	4.14	1.72	11181.57	38.00
D-2091	W-624	6/22/10	9/1/11	4	1011.50	1009.50	1010.50	1020.00	960.00	206.00	3.00	66.97	125.00	7.00	9.96	1.72	11181.57	38.00
D-2091	W-625	3/24/16	3/24/16	1	938.50	938.50	938.50	960.00	870.00	343.10	3.01	163.03	137.67	36.34	3.92	1.72	11181.57	38.00
D-2091	W-626	6/22/10	3/24/16	3	950.00	948.00	949.25	970.00	885.00	181.00	3.00	74.39	99.17	13.43	0.00	1.72	11181.57	38.00
D-2091	W-628	2/24/11	10/18/11	3	957.20	956.70	956.87	960.70	803.70	181.00	3.00	74.39	99.17	13.43	0.00	1.72	11181.57	38.00
D-2091	WL-113	4/21/11	10/6/11	3	1170.00	1170.00	1170.00	1215.00	1057.00	298.00	3.00	125.09	149.81	29.51	0.00	1.72	11181.57	38.00
D-2091	WL-18	2/16/17	2/16/17	1	975.00	975.00	975.00	1005.00	910.00	343.10	3.01	163.03	137.67	36.34	3.92	1.72	11181.57	38.00
D-2187-7	DW-6	4/10/06	10/14/06	3	840.00	838.00	838.67	845.00	815.00	354.30	3.30	350.00	48.00	0.00	6.33	0.00	14151.11	38.00
D-2187-7	MW1	5/17/12	5/2/13	8	969.75	940.00	945.22	970.00	918.50	279.61	2.90	240.91	81.25	0.37	5.40	0.88	14151.11	38.00
D-2187-7	W-2	4/16/02	7/31/03	3	1218.00	1217.00	1217.33	1260.00	1100.00	339.50	1.17	228.00	205.50	3.00	4.09	0.00	14151.11	38.00
D-2187-7	W-3	8/27/10	8/27/10	1	1210.00	1210.00	1210.00	1260.00	1096.00	279.61	2.90	240.91	81.25	0.37	5.40	0.38	14151.11	38.00
D-2187-7	W-303	1/6/10	3/9/15	47	1183.00	1170.00	1177.80	1220.00	140.00	279.61	2.90	240.91	81.25	0.37	5.40	1.54	14151.11	38.00
D-2187-7	W-352	7/31/03	4/8/04	2	1253.00	1250.00	1251.50	1290.00	1135.00	339.50	1.17	228.00	205.50	3.00	4.09	0.00	14151.11	38.00
D-2187-7	W-370	1/6/10	12/7/15	40	1213.50	1202.00	1207.61	1240.00	120.00	279.61	2.90	240.91	81.25	0.37	5.40	1.62	14151.11	38.00
D-2187-7	W-5	8/8/06	8/8/06	1	1162.00	1162.00	1162.00	1265.00	1100.00	238.50	3.00	217.50	25.00	0.00	3.00	0.00	14151.11	38.00
D-2187-7	W-8	4/24/03	9/2/15	20	1115.00	1101.00	1109.63	1150.00	80.00	380.00	2.50	383.50	19.00	0.00	5.83	1.59	14151.11	38.00
D-2187-7	WL-3	4/25/05	1/27/13	19	1231.00	1208.00	1213.53	1260.00	1096.00	238.50	3.00	217.50	25.00	0.00	3.00	1.08	14151.11	38.00
D-2187-7	WL-318	1/23/04	10/31/06	3	1199.00	1198.00	1198.50	1215.00	1135.50	361.00	3.33	257.00	161.00	0.00	6.30	0.00	14151.11	38.00
D-2187-6	DW-6	4/10/06	10/14/06	3	840.00	838.00	838.67	845.00	815.00	397.80	3.00	350.00	48.00	0.00	6.33	0.00	14151.11	38.00
D-2187-6	MW1	5/17/12	5/2/13	8	969.75	940.00	945.22	970.00	918.50	334.88	3.20	246.93	81.53	0.20	5.67	0.88	14151.11	38.00
D-2187-6	W-2	4/16/02	7/31/03	3	1218.00	1217.00	1217.33	1260.00	1100.00	438.67	2.92	228.00	205.50	3.00	4.09	0.00	14151.11	38.00

Mine	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4 mile buffer	Annual Average Precipitation (in)
D-2187-6	W-3	8/27/10	8/27/10	1	1210.00	1210.00	1210.00	1260.00	1096.00	334.88	3.20	246.93	81.53	0.20	5.67	0.38	14151.11	38.00
D-2187-6	W-303	1/6/10	3/9/15	47	1183.00	1170.00	1177.80	1220.00	140.00	334.88	3.20	246.93	81.53	0.20	5.67	1.54	14151.11	38.00
D-2187-6	W-352	7/31/03	4/8/04	2	1253.00	1250.00	1251.50	1290.00	1135.00	438.67	2.92	228.00	205.50	3.00	4.09	0.00	14151.11	38.00
D-2187-6	W-370	1/6/10	12/7/15	40	1213.50	1202.00	1207.61	1240.00	120.00	334.88	3.20	246.93	81.53	0.20	5.67	1.62	14151.11	38.00
D-2187-6	W-5	8/8/06	8/8/06	1	1162.00	1162.00	1162.00	1265.00	1100.00	334.88	3.20	246.93	81.53	0.20	5.67	0.00	14151.11	38.00
D-2187-6	W-8	4/24/03	9/2/15	20	1115.00	1101.00	1109.63	1150.00	80.00	433.00	3.33	417.00	19.00	0.00	5.83	1.59	14151.11	38.00
D-2187-6	WL-3	4/25/05	1/27/13	19	1231.00	1208.00	1213.53	1260.00	1096.00	334.88	3.20	246.93	81.53	0.20	5.67	1.08	14151.11	38.00
D-2187-6	WL-318	1/23/04	10/31/06	3	1199.00	1198.00	1198.50	1215.00	1135.50	417.33	3.00	257.00	161.00	0.00	6.30	0.00	14151.11	38.00
D-2223	DW-7	3/17/15	4/26/17	10	753.00	753.00	753.00	774.00	748.00	156.13	3.41	71.09	74.83	1.33	3.51	6.10	14067.46	40.00
D-2223	W-13	3/17/15	4/26/17	10	749.00	749.00	749.00	778.00	726.00	156.13	3.41	71.09	74.83	1.33	3.51	6.10	14067.46	40.00
D-2223	WL-936	3/17/15	4/26/17	10	746.00	746.00	746.00	820.00	686.00	65.00	4.20	13.90	39.70	0.00	4.20	6.10	14067.46	40.00
D-2317	DW-11A	4/30/06	11/1/06	3	575.00	575.00	575.00	585.00	570.00	240.10	5.25	188.65	56.10	0.00	5.25	0.00	2061.00	41.00
D-2317	DW-13	11/4/08	5/4/09	3	783.30	780.20	781.30	800.00	773.30	415.01	5.71	339.53	52.98	0.00	5.71	0.07	2061.00	41.00
D-2317	DW-21	4/25/07	8/29/07	3	668.00	665.50	666.33	678.00	658.50	127.75	3.85	62.90	72.25	0.00	3.85	0.00	2061.00	41.00
D-2317	DW-22	4/23/07	4/23/07	1	643.50	643.50	643.50	650.00	641.00	298.28	4.06	181.58	104.36	0.00	4.06	0.00	2061.00	41.00
D-2317	DW-22A	2/7/08	2/7/08	1	847.50	847.50	847.50	860.00	831.00	447.28	5.91	281.12	151.51	0.46	5.91	0.00	2061.00	41.00
D-2317	DW-22B	2/7/08	2/7/08	1	892.00	892.00	892.00	900.00	878.00	447.28	5.91	281.12	151.51	0.46	5.91	0.00	2061.00	41.00
D-2317	DW-23	4/23/07	4/23/07	1	624.20	624.20	624.20	630.00	613.00	229.70	4.00	156.00	60.00	0.00	4.00	0.00	2061.00	41.00
D-2317	DW-24	10/30/08	5/4/09	3	641.20	640.20	640.67	645.00	636.00	415.01	5.71	339.53	52.98	0.00	5.71	0.07	2061.00	41.00
D-2317	DW-406	12/5/07	9/2/08	3	693.30	690.00	691.27	700.00	682.00	379.35	3.60	266.90	109.50	0.00	3.60	0.00	2061.00	41.00
D-2317	DW-414	12/6/07	12/6/07	1	571.50	571.50	571.50	580.00	568.50	135.20	4.05	88.60	58.35	0.00	4.05	0.00	2061.00	41.00
D-2317	DW-42	4/25/07	8/28/07	3	876.90	876.50	876.63	882.00	871.50	447.28	5.91	281.12	151.51	0.46	5.91	0.00	2061.00	41.00
D-2317	DW-46	10/30/08	5/4/09	3	685.20	680.00	682.83	693.00	674.00	338.91	5.56	202.60	109.33	0.00	5.56	0.07	2061.00	41.00
D-2317	DW-602	12/7/17	12/7/17	1	635.09	635.09	635.09	640.00	632.00	229.70	4.00	156.00	60.00	0.00	4.00	1.60	2061.00	41.00
D-2317	M1A	5/15/13	11/26/16	12	648.00	646.00	647.00	749.00	636.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00
D-2317	M1B	5/15/13	11/26/16	12	686.00	685.00	685.67	749.00	659.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00
D-2317	M2A	5/15/13	11/26/16	12	647.00	645.00	645.83	720.00	620.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00
D-2317	M2B	5/15/13	11/26/16	12	648.00	646.00	646.83	720.00	643.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00
D-2317	M3B	8/27/13	11/26/16	3	645.00	645.00	645.00	660.00	643.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00
D-2317	W-10	4/30/06	10/17/06	3	540.00	540.00	540.00	600.00	500.00	240.10	5.25	188.65	56.10	0.00	5.25	0.00	2061.00	41.00
D-2317	W-125	4/17/07	4/17/07	1	584.50	584.50	584.50	590.00	524.50	293.46	4.28	161.81	133.11	0.00	4.28	0.00	2061.00	41.00
D-2317	W-134	5/6/09	5/6/09	1	601.80	601.80	601.80	639.00	536.50	240.10	5.25	188.65	56.10	0.00	5.25	0.07	2061.00	41.00
D-2317	W-18	4/30/06	10/17/06	3	545.00	545.00	545.00	665.00	515.00	182.95	3.93	95.70	80.37	0.00	3.93	0.00	2061.00	41.00
D-2317	W3	9/4/13	11/27/16	8	613.00	613.00	613.00	621.00	546.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00

Mine	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4 mile buffer	Annual Average Precipitation (in)
D-2317	W3.01	9/4/13	11/27/16	9	612.00	612.00	612.00	618.00	488.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00
D-2317	W-41	4/25/07	8/28/07	3	586.00	578.70	581.80	610.00	528.50	240.10	5.25	188.65	56.10	0.00	5.25	0.00	2061.00	41.00
D-2317	W41.01	8/27/13	11/27/16	9	759.00	721.00	737.89	784.00	299.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00
D-2317	W41.02	8/27/13	6/15/16	6	729.00	728.00	728.43	785.00	525.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00
D-2317	W-600	12/6/07	9/2/08	3	654.80	654.70	654.70	660.00	616.00	401.50	4.00	265.50	142.50	0.00	4.00	0.00	2061.00	41.00
D-2317	W-604	12/7/07	11/8/17	4	737.50	648.90	671.40	730.00	588.50	379.35	3.60	266.90	109.50	0.00	3.60	0.00	2061.00	41.00
D-2317	WL-1	8/25/05	4/2/06	3	665.00	665.00	665.00	705.00	275.00	340.95	3.90	245.05	94.05	0.00	3.90	0.00	2061.00	41.00
D-2317	WL-12	4/30/06	10/17/06	3	548.00	548.00	548.00	598.00	453.00	240.10	5.25	188.65	56.10	0.00	5.25	0.00	2061.00	41.00
D-2317	WL-154	10/30/08	5/6/09	3	537.00	537.00	537.00	602.00	502.00	160.16	5.00	91.16	72.50	0.00	5.00	0.07	2061.00	41.00
D-2317	WL-16	11/1/06	1/29/07	2	680.00	680.00	680.00	700.00	478.00	277.60	4.80	226.50	49.70	0.00	4.80	0.00	2061.00	41.00
D-2317	WL-21	9/12/05	4/3/06	3	575.00	575.00	575.00	600.00	492.00	193.58	5.92	139.18	63.90	0.00	5.92	0.00	2061.00	41.00
D-2317	WL-24C	7/9/17	7/9/17	1	507.00	507.00	507.00	545.00	500.00	293.46	4.28	161.81	133.11	0.00	4.28	1.60	2061.00	41.00
D-2317	WL-3	8/25/05	4/2/06	3	538.00	538.00	538.00	578.00	458.00	240.10	5.25	188.65	56.10	0.00	5.25	0.00	2061.00	41.00
D-2317	WL-4	10/17/06	10/17/06	1	400.00	400.00	400.00	580.00	380.00	262.35	4.10	164.55	68.35	0.00	4.10	0.00	2061.00	41.00
D-2317	WL-5	4/30/06	10/17/06	4	695.00	695.00	695.00	730.00	680.00	340.95	3.90	245.05	94.05	0.00	3.90	0.00	2061.00	41.00
D-2317	WL-601	12/6/07	9/2/08	3	640.60	639.80	640.22	648.00	618.00	229.70	4.00	156.00	60.00	0.00	4.00	0.00	2061.00	41.00
D-2317	WL-8	4/24/07	8/28/08	3	574.20	562.00	568.47	730.00	485.00	229.70	4.00	156.00	60.00	0.00	4.00	0.00	2061.00	41.00

Table C 2. Multi-mine without water withdraw average potentiometric head model outliers.

Permit	Well
D-0354	South Meins Shaft
D-0354	Roving Crew
D-0354	Danville Shaft
D-0355	South Bleeder
D-0355	Grange
D-0355	NW Shaft
D-0360	W21-165.04
D-2317	WL-4
D-1019	W-14
D-2187-7	W-8
D-2187-6	W-8
D-2187-7	W-370
D-2187-6	W-370
D-2187-7	W-303
D-2187-6	W-303
D-1019	WL-14
D-2317	W41.01
D-2317	WL-1
D-1019	WL-39A
D-1019	WL-13
D-1180-7	W-30
D-1180-6	W-30

Table C 3. Multi-mine without water withdraw maximum potentiometric head model outliers.

Permit	Well
D-0354	South Meins Shaft
D-0354	Roving Crew
D-0354	Danville Shaft
D-0355	South Bleeder
D-2317	WL-4
D-2187-7	W-8
D-2187-6	W-8
D-2187-7	W-370
D-2187-6	W-370
D-2187-7	W-303
D-2187-6	W-303
D-1019	W-14
D-2317	WL-8

Table C 4. Multi-mine without water withdraw minimum potentiometric head model outliers.

Permit	Well
D-0354	South Meins Shaft
D-0354	Roving Crew
D-0354	Danville Shaft
D-0355	South Bleeder
D-0360	W21-165.04
D-0360	WL-14
D-2187-7	W-8
D-2187-7	W-370
D-2187-6	W-370
D-2187-7	W-303
D-2187-6	W-303
D-1019	W-14

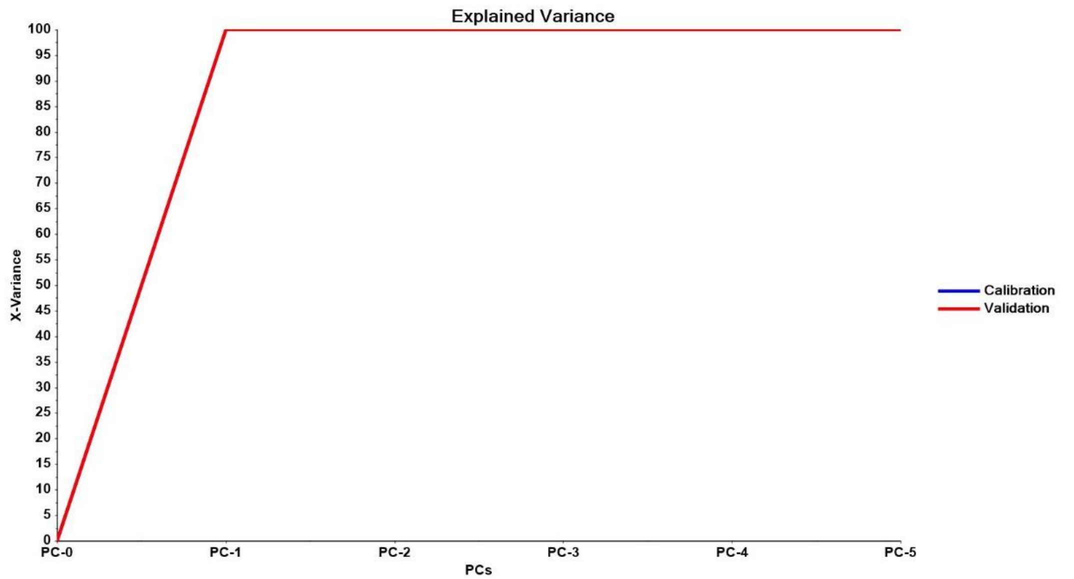

Figure C 1. Principal component analysis explained variance graph for the multi-mine without water withdraw average potentiometric head model.

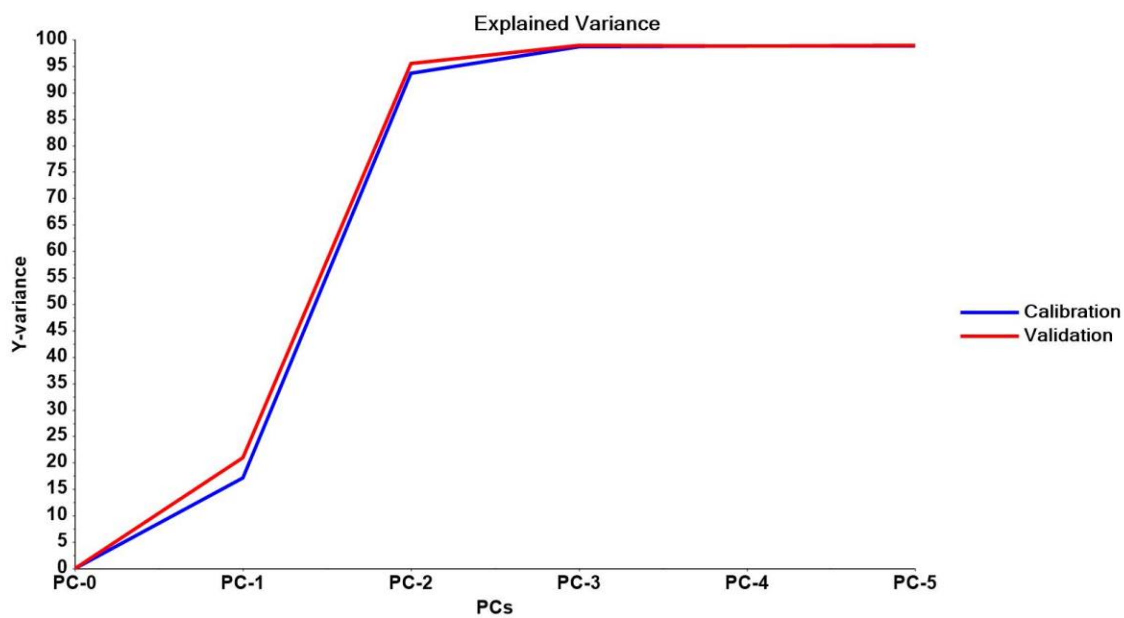

Figure C 2. Principal component regression explained variance graph for the multi-mine without water withdraw average potentiometric head model.

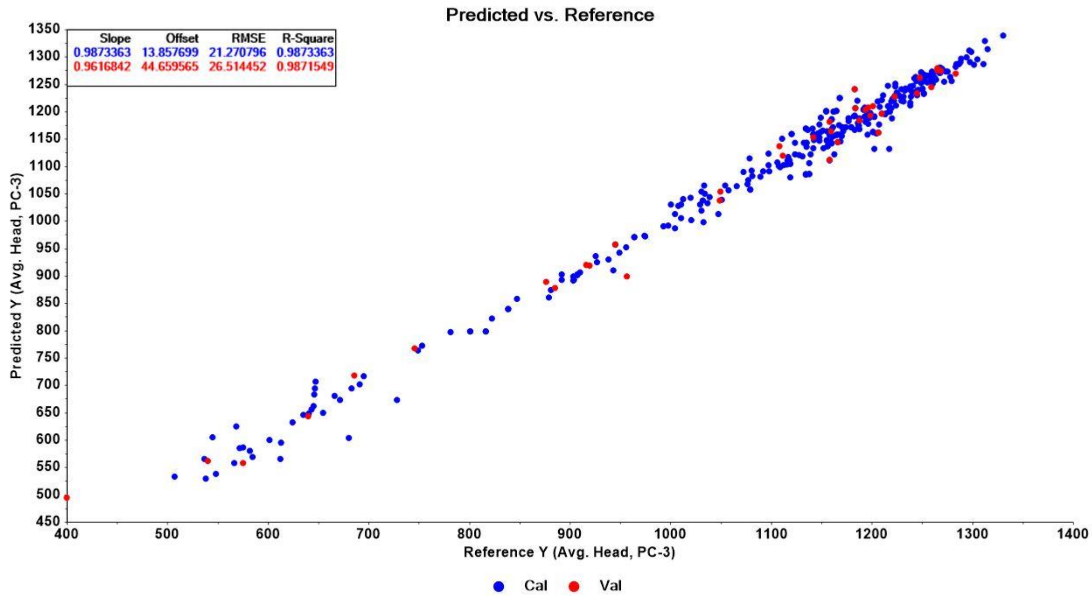

Figure C 3. Principal component regression predicted vs. reference plot for the multi-mine without water withdraw average potentiometric head model.

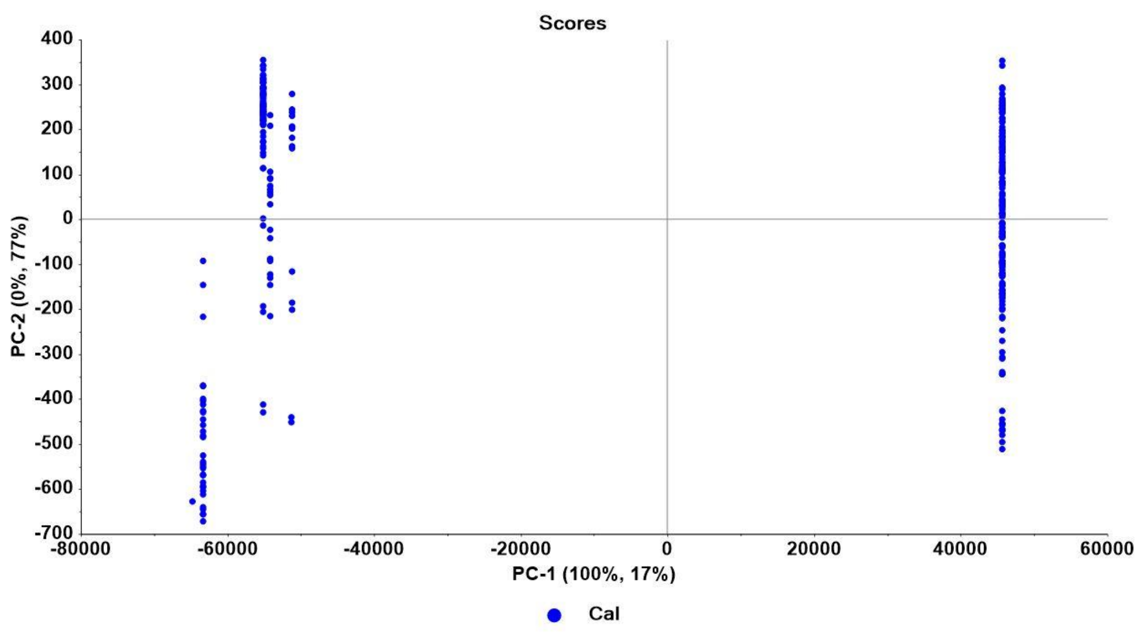

Figure C 4. Principal component regression scores plot for the multi-mine without water withdraw average potentiometric head model.

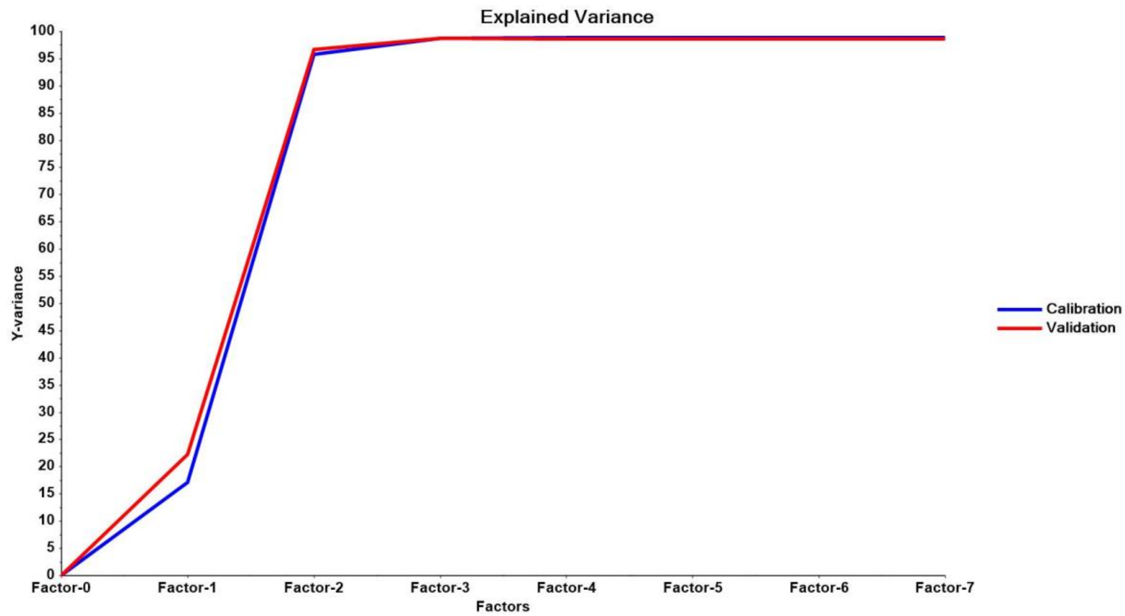

Figure C 5. Partial least squares regression explained variance graph for the multi-mine without water withdraw average potentiometric head model.

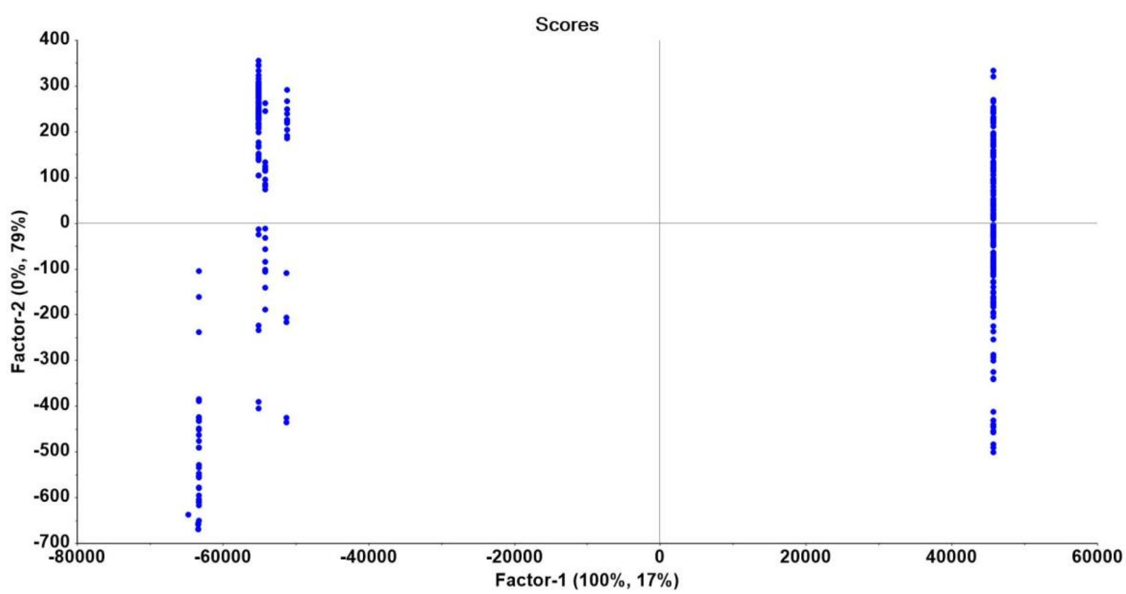

Figure C 6. Partial least squares regression scores plot for the multi-mine without water withdraw average potentiometric head model.

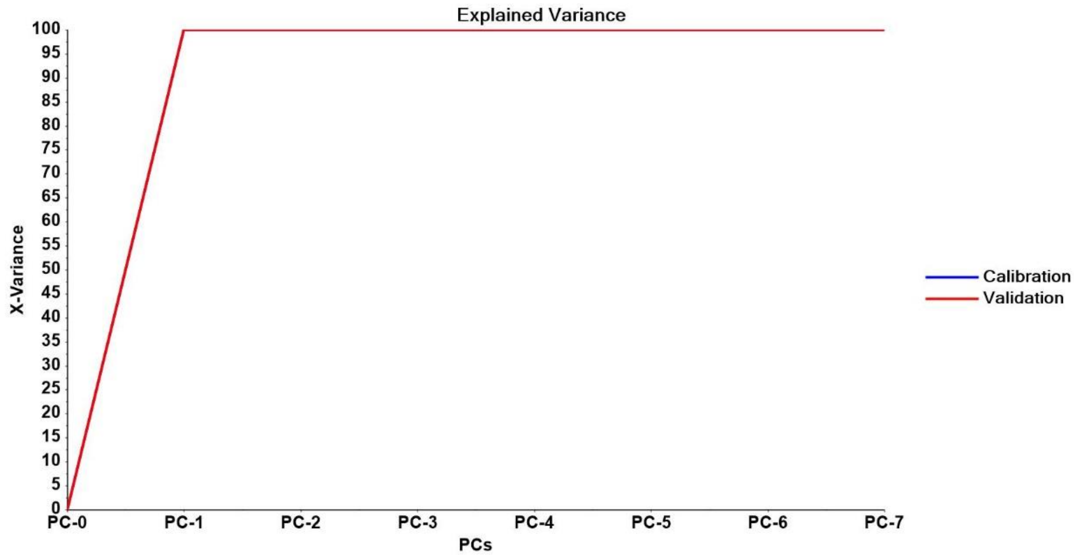

Figure C 7. Principal component analysis explained variance graph for the multi-mine without water withdraw maximum potentiometric head model.

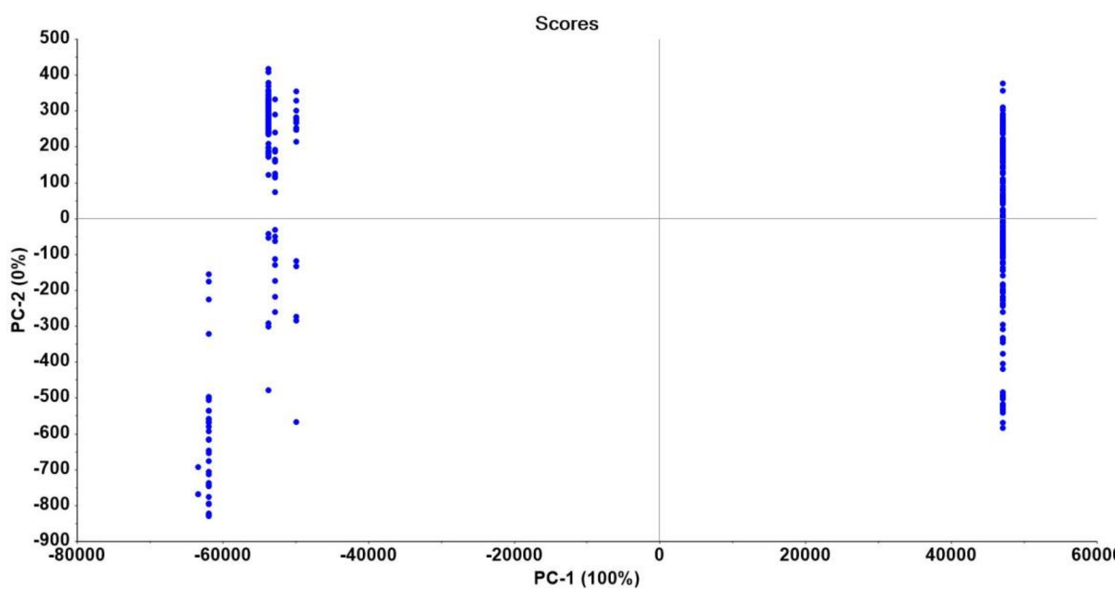

Figure C 8. Principal component analysis scores plot for the multi-mine without water withdraw maximum potentiometric head model.

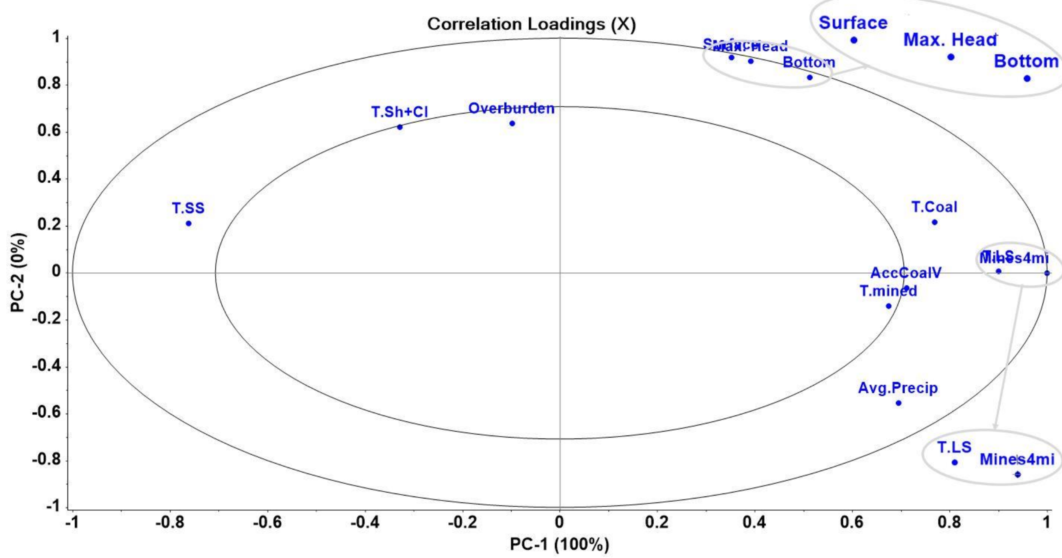

Figure C 9. Principal component analysis correlation loadings plot for the multi-mine without water withdraw maximum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

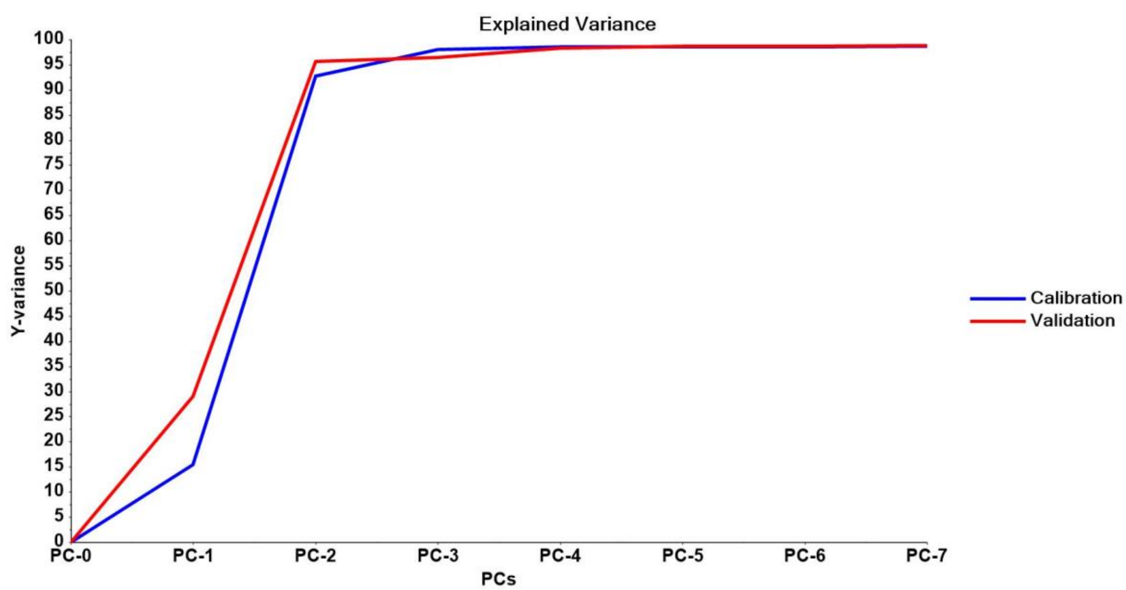

Figure C 10. Principal component regression explained variance graph for the multi-mine without water withdraw maximum potentiometric head model.

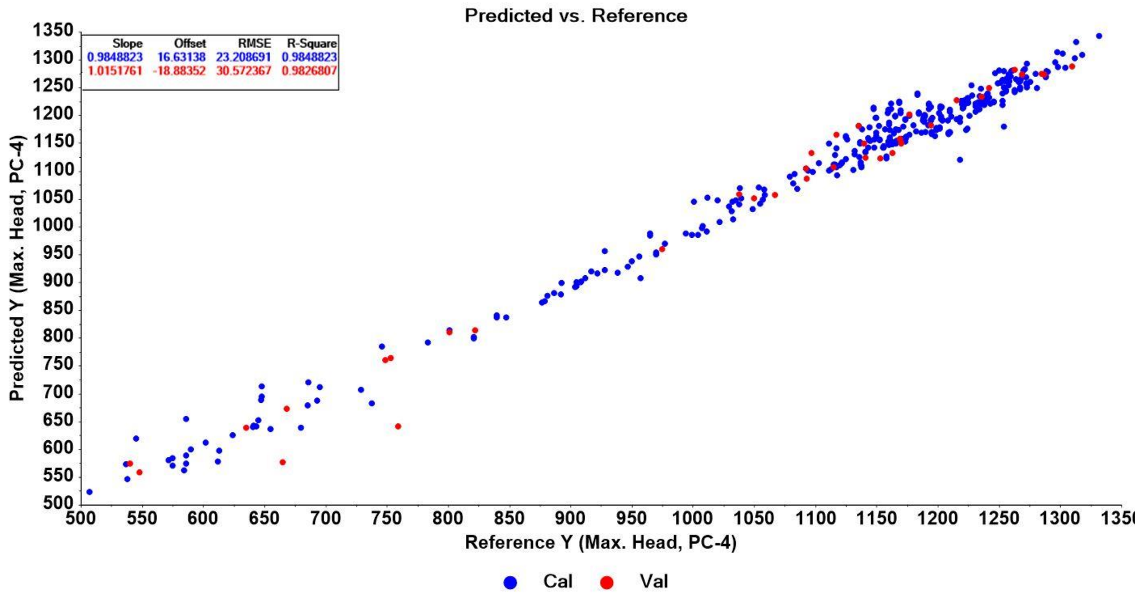

Figure C 11. Principal component predicted vs. reference plot for the multi-mine without water withdraw maximum potentiometric head model.

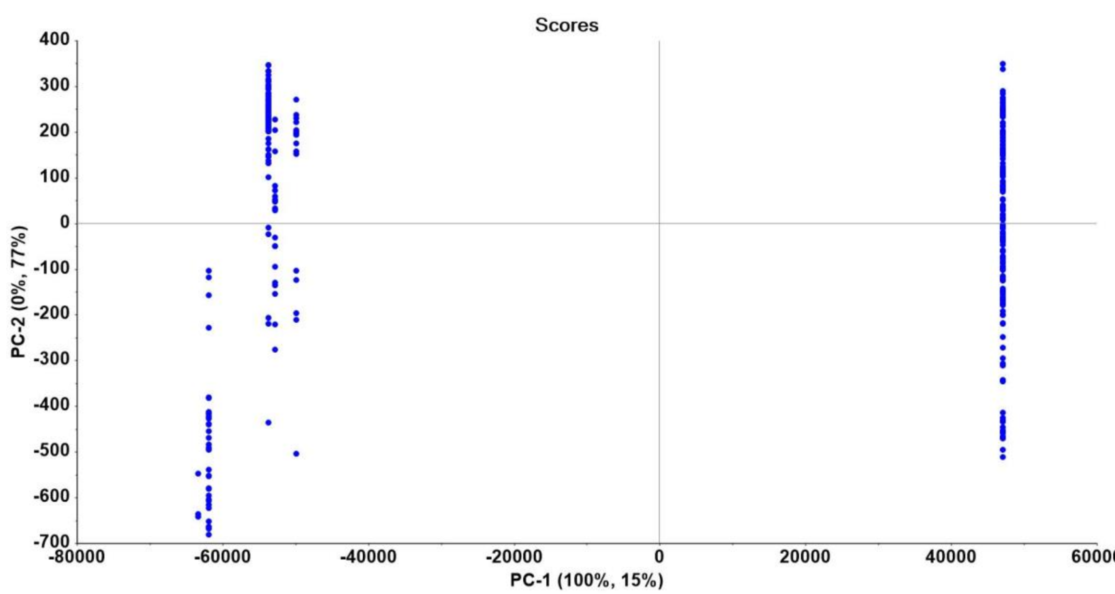

Figure C 12. Principal component regression scores plot for the multi-mine without water withdraw maximum potentiometric head model.

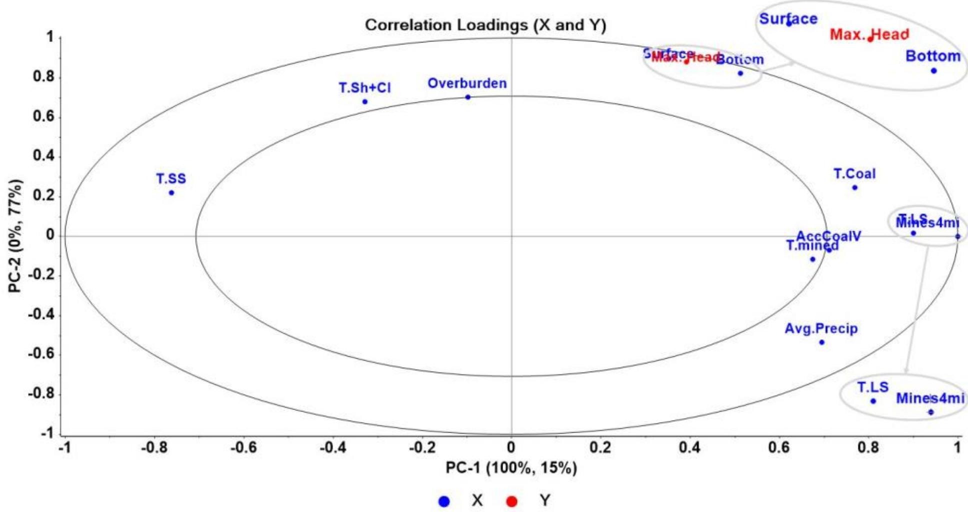

Figure C 13. Principal component regression correlation loadings plot for the multi-mine without water withdraw maximum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

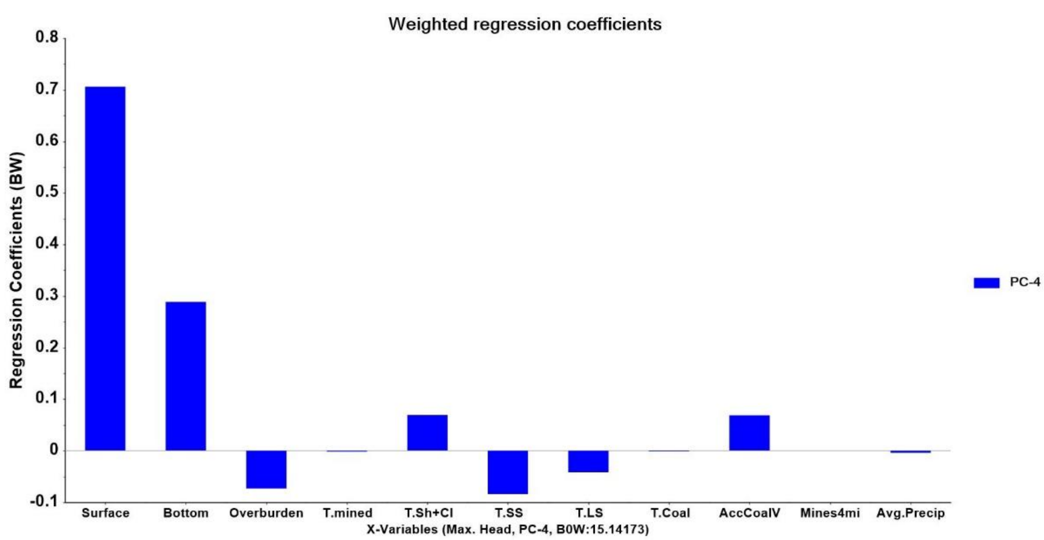

Figure C 14. Principal component regression weighted regression coefficients chart for the multi-mine without water withdraw maximum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

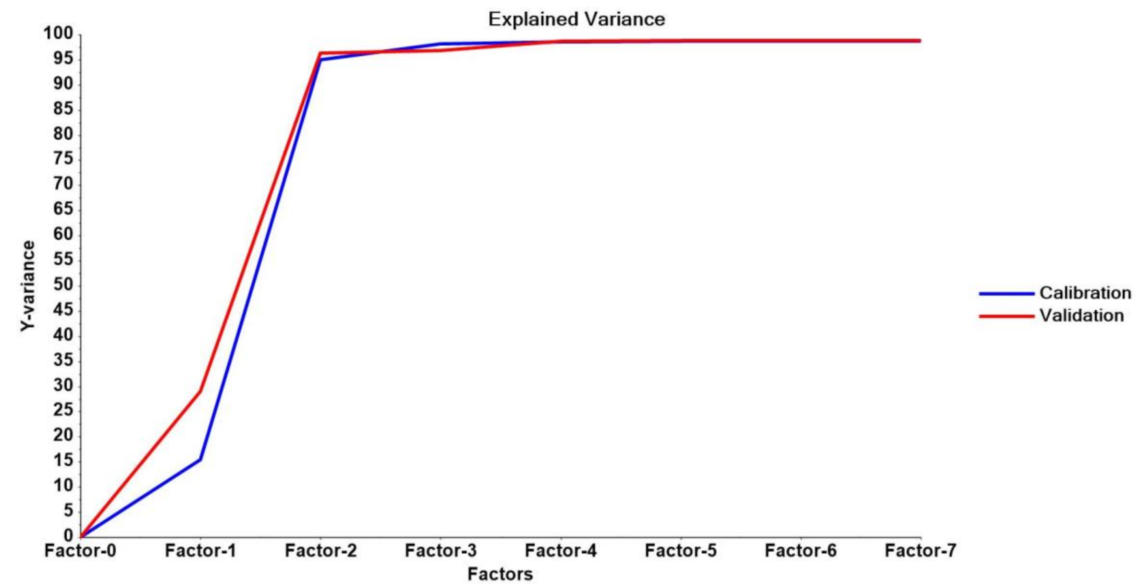

Figure C 15. Partial least squares regression explained variance graph for the multi-mine without water withdraw maximum potentiometric head model.

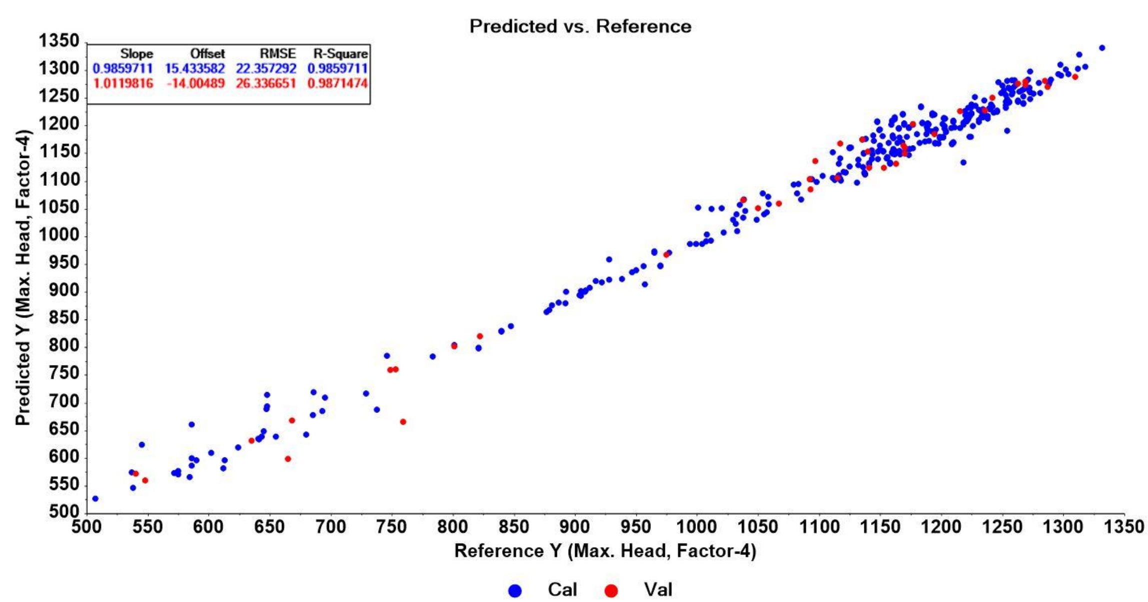

Figure C 16. Partial least squares regression predicted vs. reference plot for the multi-mine without water withdraw maximum potentiometric head model.

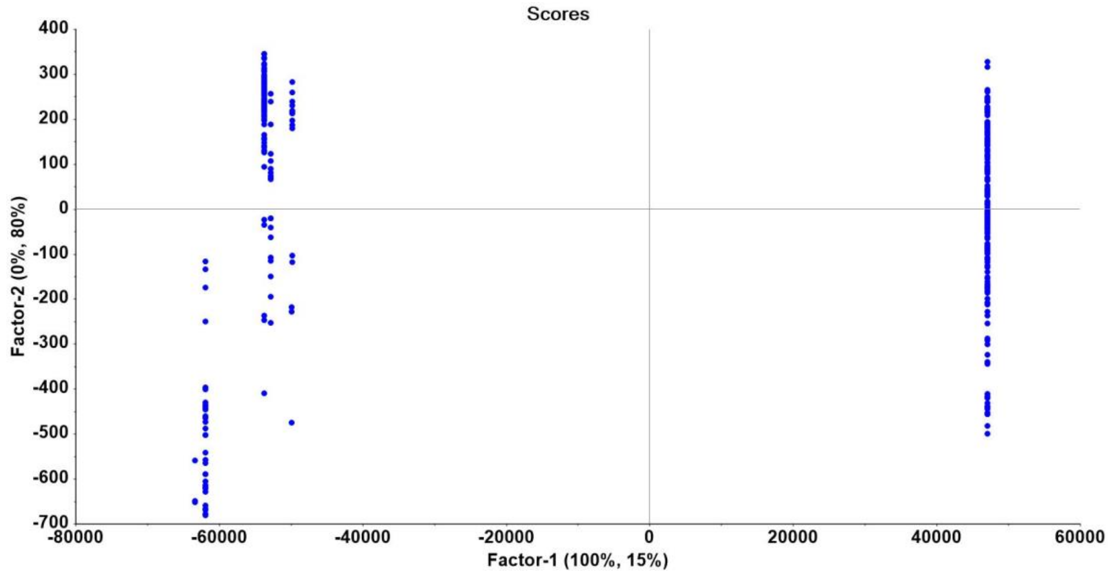

Figure C 17. Partial least squares regression scores plot for the multi-mine without water withdraw maximum potentiometric head model.

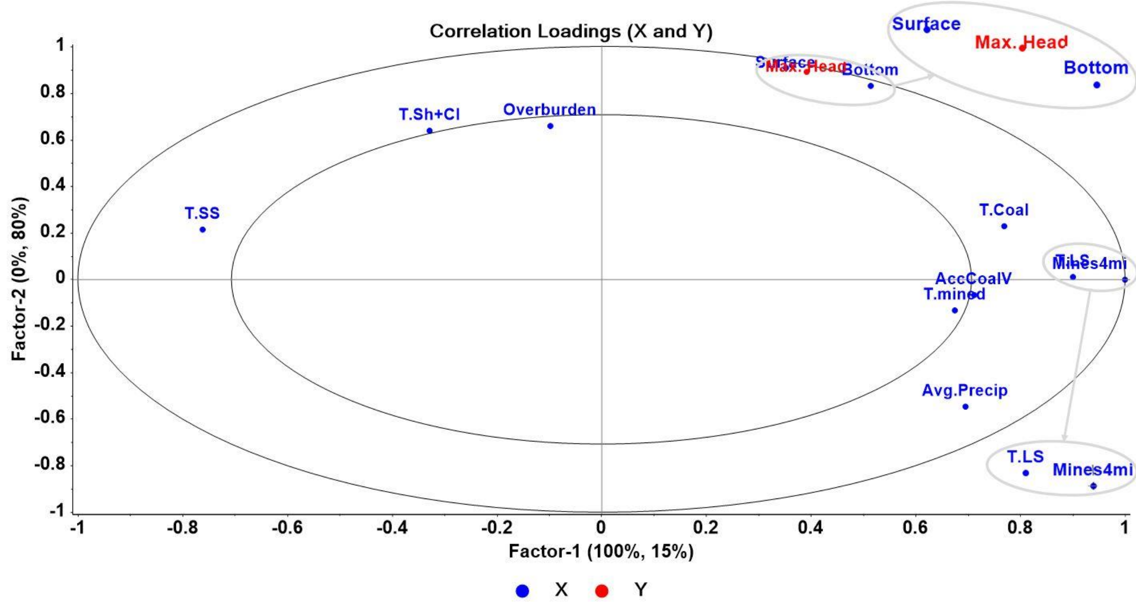

Figure C 18. Partial least squares regression correlation loadings plot for the multi-mine without water withdraw maximum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

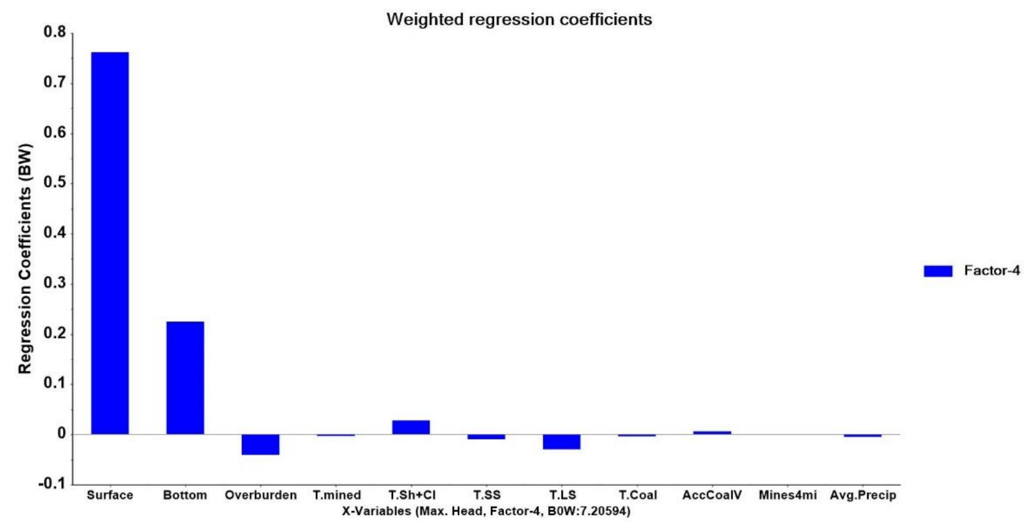

Figure C 19. Partial least squares regression weighted regression coefficients chart for the multi-mine without water withdraw maximum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

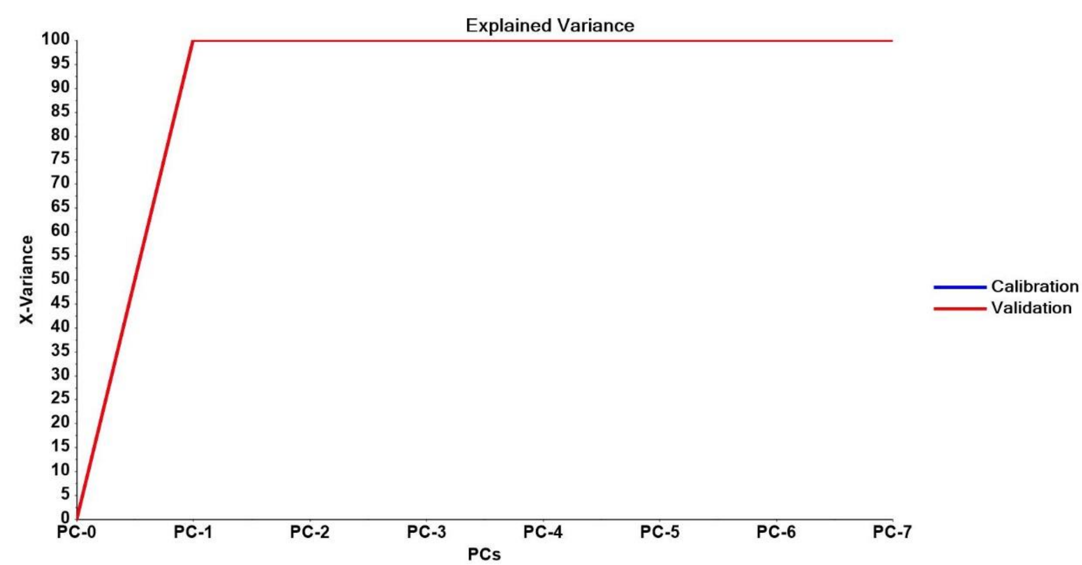

Figure C 20. Principal component analysis explained variance graph for the multi-mine without withdraw minimum potentiometric head model.

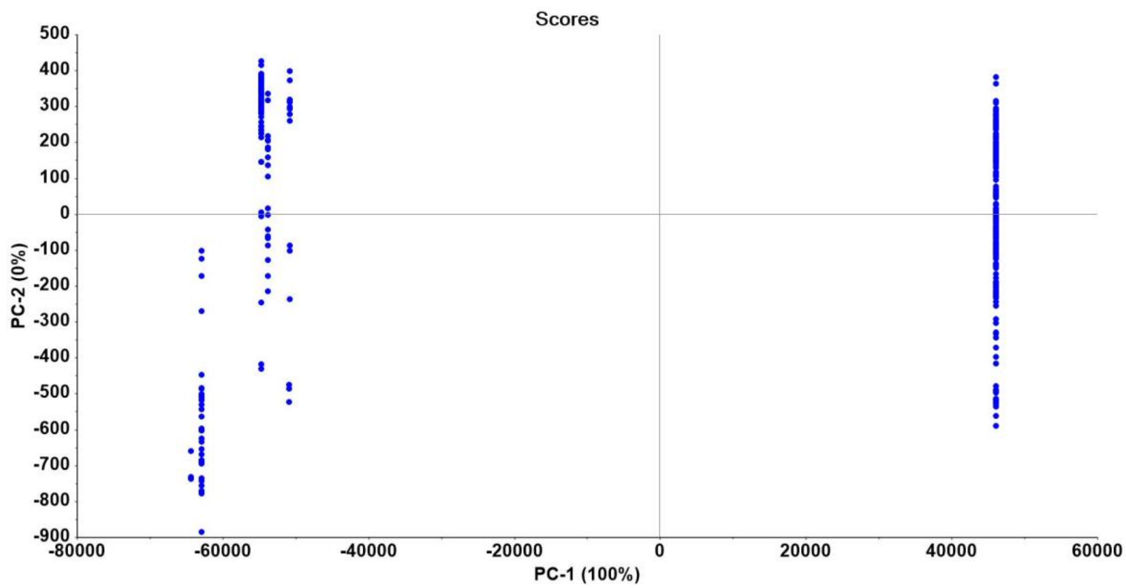

Figure C 21. Principal component analysis scores plot for the multi-mine without withdraw minimum potentiometric head model.

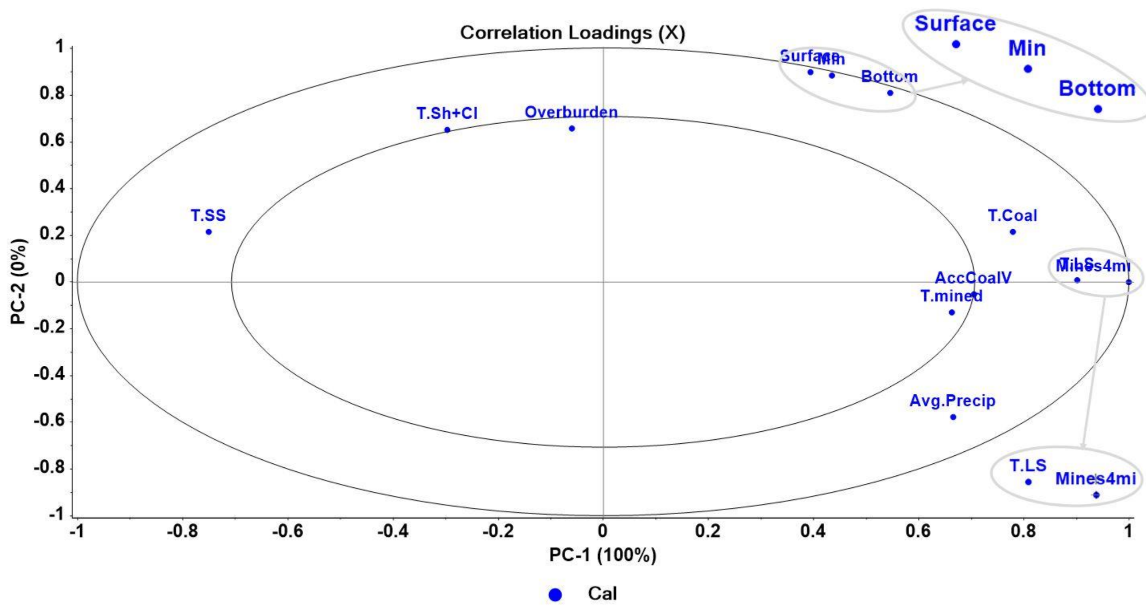

Figure C 22. Principal component analysis correlation loadings plot for the multi-mine without withdraw minimum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

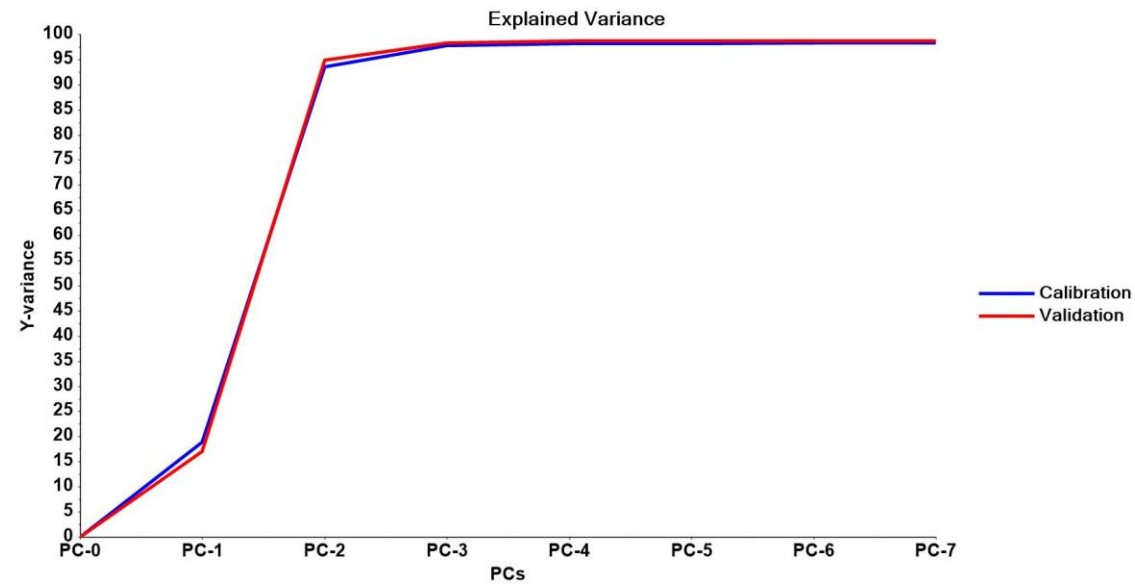

Figure C 23. Principal component regression explained variance graph for the multi-mine without withdraw minimum potentiometric head model.

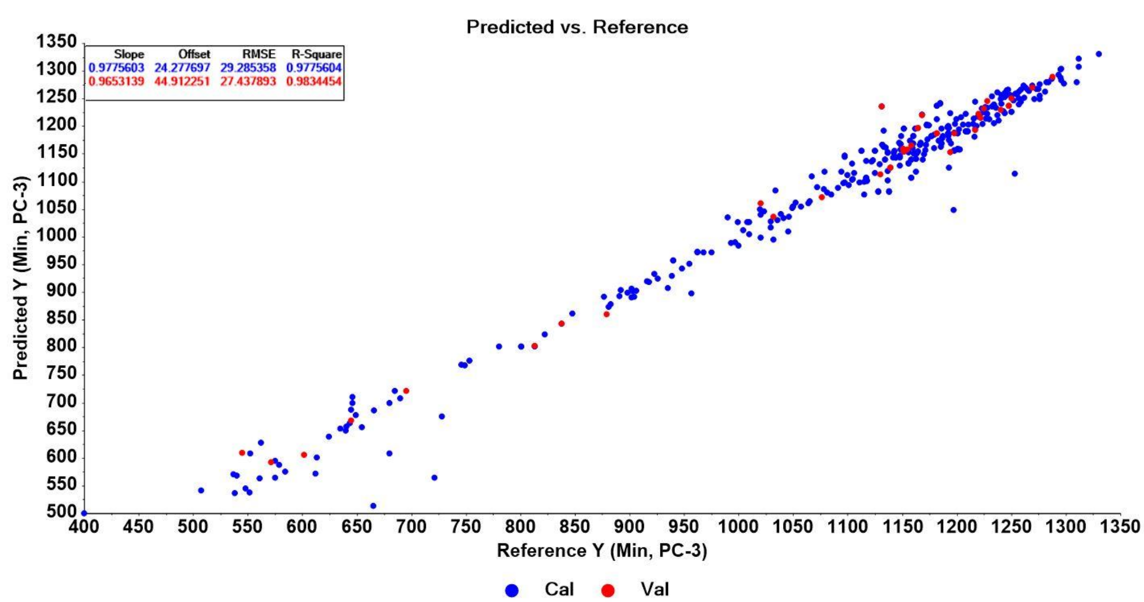

Figure C 24. Principal component analysis predicted vs. reference plot for the multi-mine without withdraw minimum potentiometric head model.

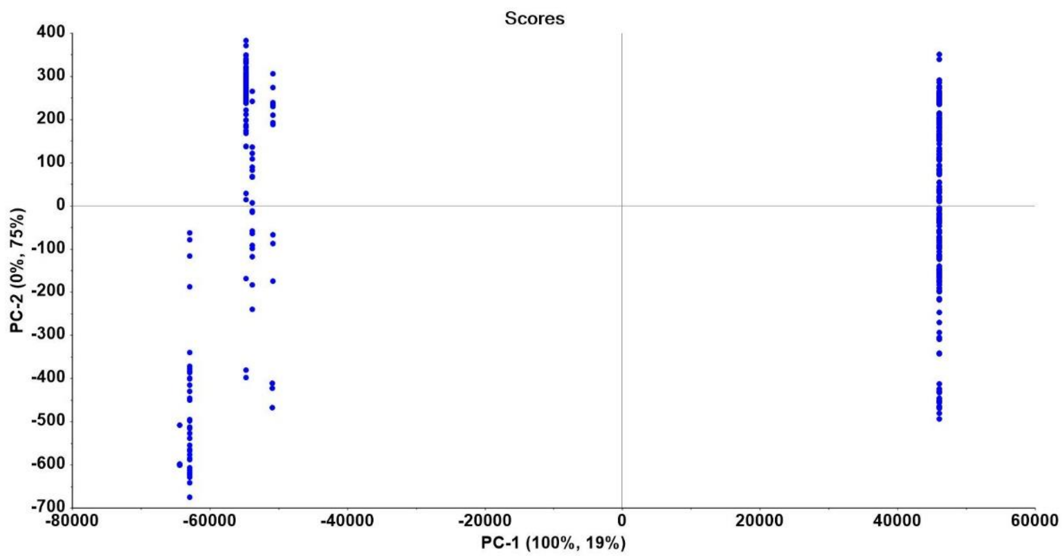

Figure C 25. Principal component regression scores plot for the multi-mine without withdraw minimum potentiometric head model.

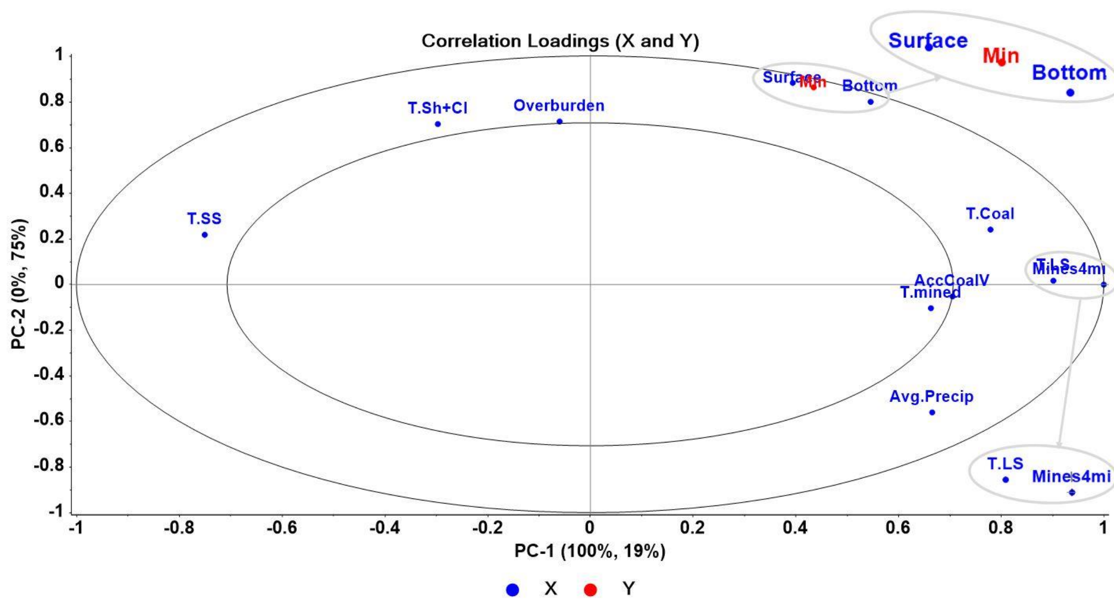

Figure C 26. Principal component regression correlation loadings plot for the multi-mine without withdraw minimum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

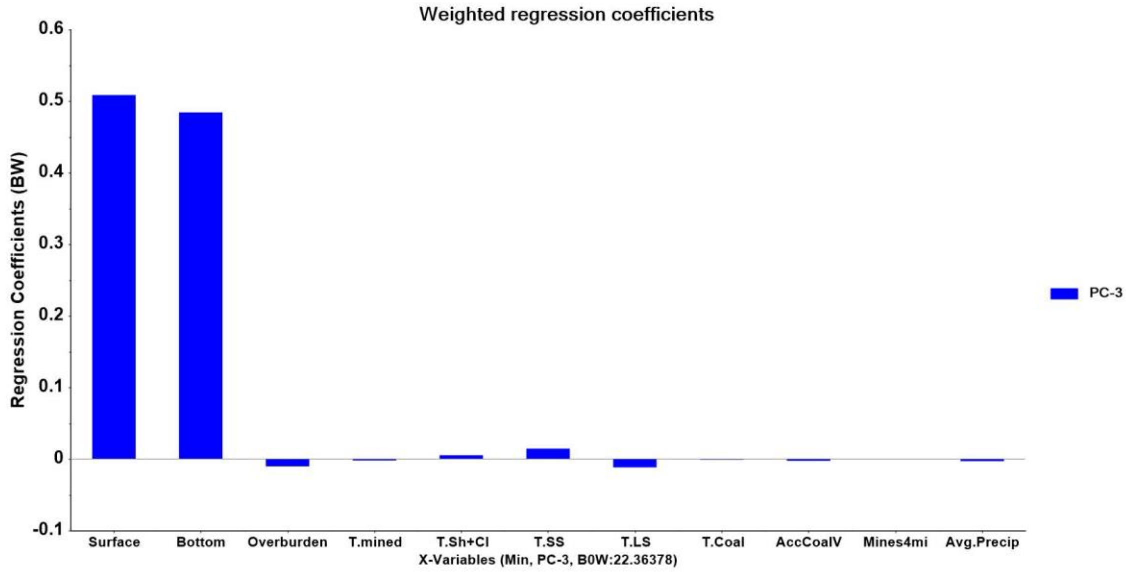

Figure C 27. Principal component regression weighted regression coefficients chart for the multi-mine without withdraw minimum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

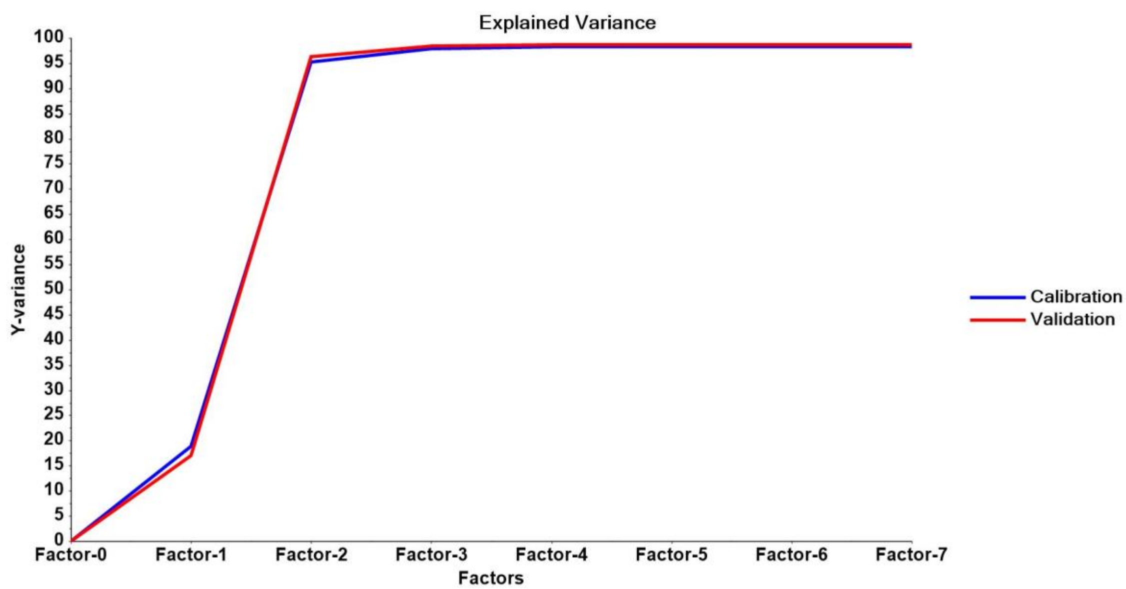

Figure C 28. Partial least squares regression explained variance graph for the multi-mine without withdraw minimum potentiometric head model.

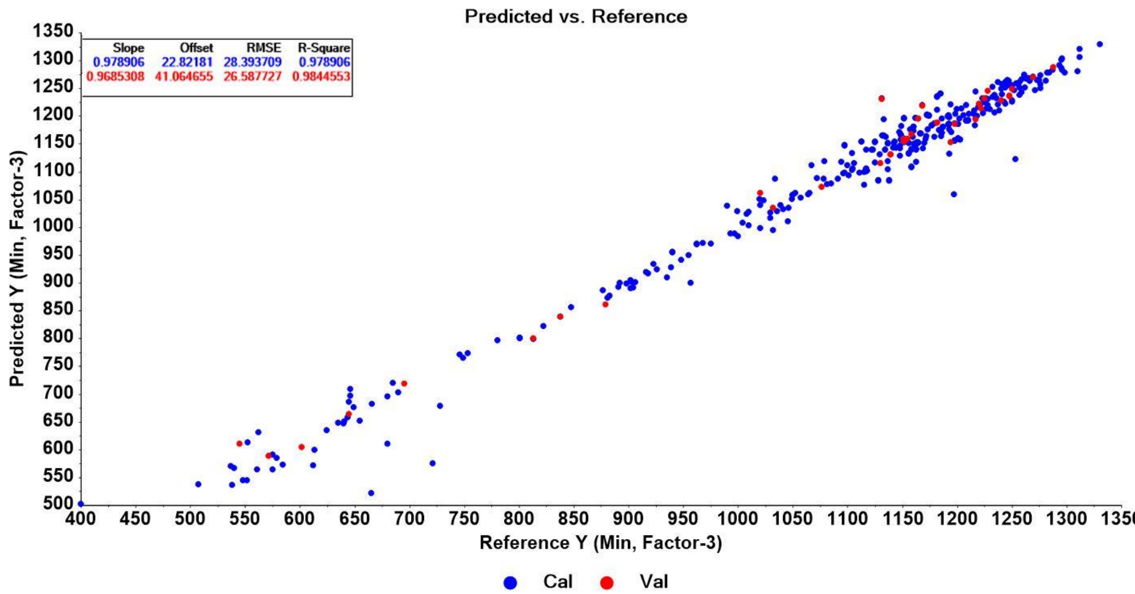

Figure C 29. Partial least squares regression predicted vs. reference plot for the multi-mine without withdraw minimum potentiometric head model.

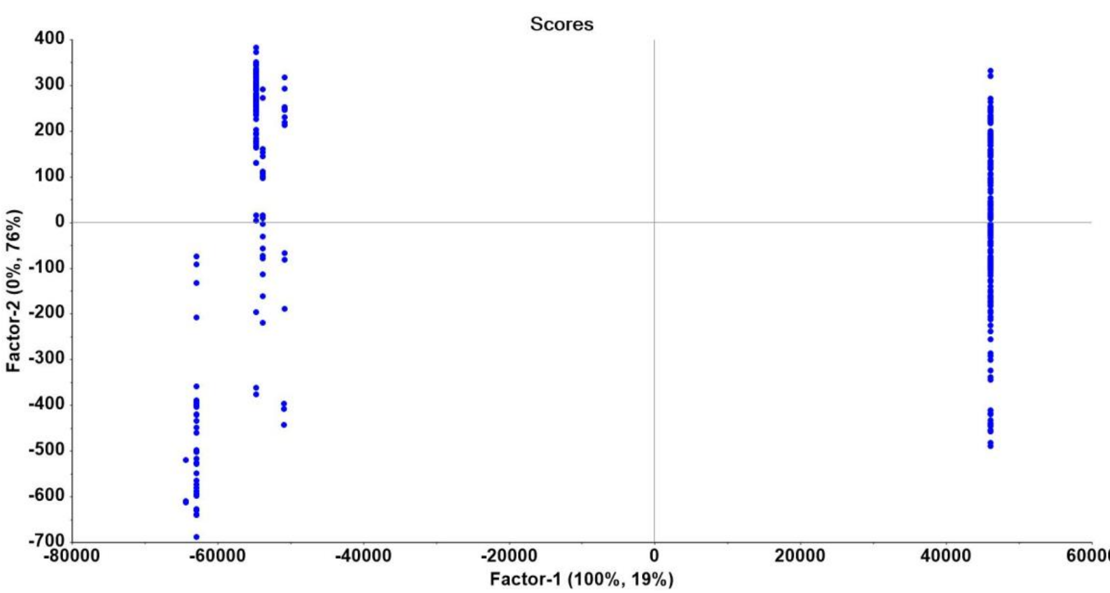

Figure C 30. Partial least squares regression scores plot for the multi-mine without withdraw minimum potentiometric head model.

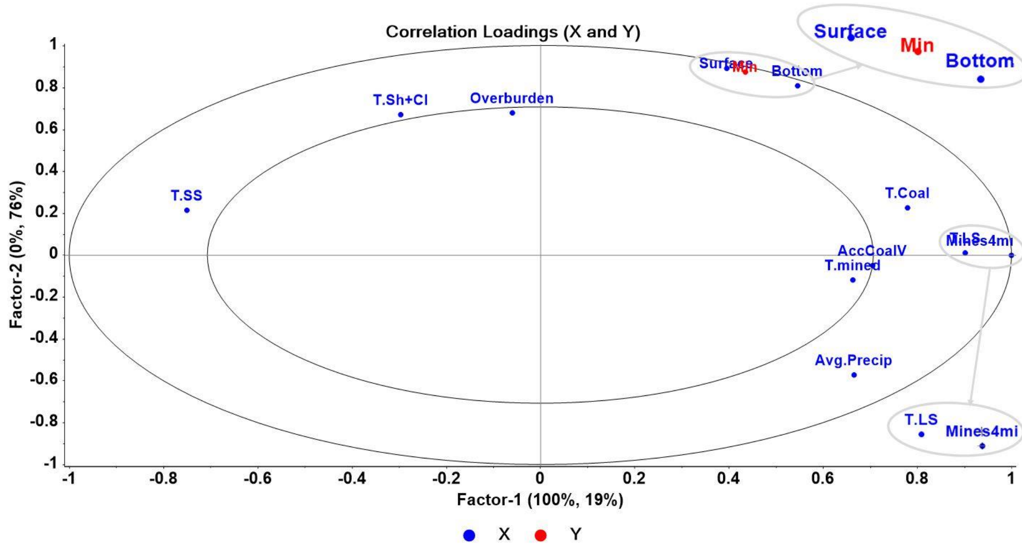

Figure C 31. Partial least squares regression correlation loadings for the multi-mine without withdraw minimum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

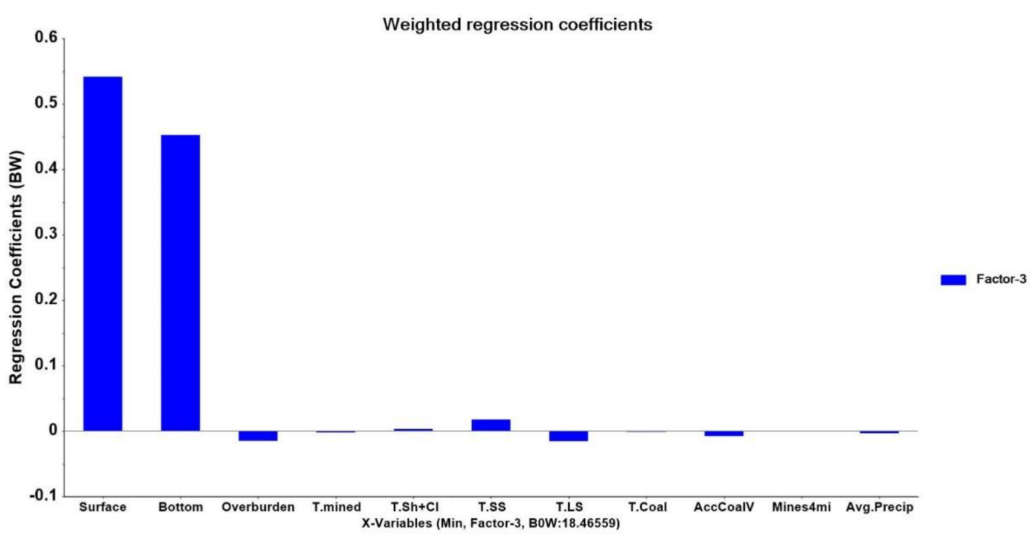

Figure C 32. Partial least squares regression weighted regression coefficients chart for the multi-mine without withdraw minimum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3).

Table C 5. Multi-mine without water withdraw maximum potentiometric head model regression coefficients.

Variable	PCR	PLS
β0	15.142	7.206
Surface elevation (msl)	0.706	0.762
Bottom elevation (msl)	0.289	0.225
Overburden thickness (ft)	-0.0730	-0.0403
Thickness of the mined coal seam (ft)	-1.53E-03	-2.83E-03
Thickness of shale + clay (ft)	0.0695	0.0282
Thickness of sandstone (ft)	-0.0838	-0.0096
Thickness of limestone (ft)	-0.0415	-0.0294
Total thickness of coal (ft)	-1.32E-03	-3.44E-03
Accumulative coal volume (Mm3)	0.0688	0.00632
Area of underground mines within a 4-mile buffer	-7.82E-05	2.73E-05
Annual Average Precipitation (in)	-3.69E-03	-4.52E-03

Table C 6. Multi-mine without water withdraw minimum potentiometric head model regression coefficients.

Variable	PCR	PLS
β0	22.364	18.466
Surface elevation (msl)	0.509	0.542
Bottom elevation (msl)	0.484	0.453
Overburden thickness (ft)	-0.0101	-0.0148
Thickness of the mined coal seam (ft)	-1.96E-03	-2.19E-03
Thickness of shale + clay (ft)	5.35E-03	3.40E-03
Thickness of sandstone (ft)	0.0146	0.0177
Thickness of limestone (ft)	-0.0116	-0.0152
Total thickness of coal (ft)	-7.87E-04	-1.04E-03
Accumulative coal volume (Mm3)	-2.33E-03	-7.66E-03
Area of underground mines within a 4-mile buffer	-1.62E-04	-1.35E-04
Annual Average Precipitation (in)	-2.84E-03	-3.08E-03

Table C 7. Multi-mine without water withdraw maximum potentiometric head model index values for Nash-Sutcliffe efficiency, percent bias, mean absolute error, volumetric efficiency, root mean square error and relative index of agreement.

	NSE	**PBIAS**	**MAE**	**VE**	**RMSE**	**rd**
Ideal value	**1**	**0**	**0**	**1**	**0**	**1**
PCR	0.985	3.47E-06	0.029	1.000	23.209	0.995
PLS	0.986	3.07E-06	0.019	1.000	22.357	0.995

Table C 8. Multi-mine without water withdraw minimum potentiometric head model index values for Nash-Sutcliffe efficiency, percent bias, mean absolute error, volumetric efficiency, root mean square error and relative index of agreement.

	NSE	**PBIAS**	**MAE**	**VE**	**RMSE**	**rd**
Ideal value	**1**	**0**	**0**	**1**	**0**	**1**
PCR	0.97756	6.57051E-07	0.00459	1	29.2854	0.99104
PLS	0.97891	4.78158E-07	0.01024	0.99999	28.3937	0.99149

Table C 9. Multi-mine with water withdraw model data. ($1m^3 = 35.315ft^3$) ($1acre=43560ft^2$)

Permit	Well	First Date	Last Date	Num. Measurements	Maximum Potentiometric Head (msl)	Minimum Potentiometric Head (msl)	Average Potentiometric Head (msl)	Surface elevation (msl)	Bottom elevation (msl)	Overburden thickness (ft)	Thickness of the mined coal seam (ft)	Thickness of shale + clay (ft)	Thickness of sandstone (ft)	Thickness of limestone (ft)	Total thickness of coal (ft)	Accumulative coal volume (Mm3)	Area of underground mines within a 4-mile buffer	Annual Average Precipitation (in)	Withdraw/Distance (Mgal/day/ft)
D-0354	South Meins Shaft	8/28/2008	12/8/2016	267	475.45	430.49	457.17	781.68	304.53	470.69	6.46	217.43	204.83	9.48	9.67	39.63	10592.66	41.00	1.09E-03
D-0354	Roving Crew	9/4/2008	12/8/2016	270	475.60	432.27	457.73	637.76	244.04	389.55	4.17	77.51	258.71	3.04	5.75	39.63	10592.66	41.00	1.72E-03
D-0354	Danville Shaft	9/4/2008	6/30/2011	137	475.48	452.99	460.73	743.09	498.59	242.25	2.25	111.00	96.34	6.58	6.79	39.63	10592.66	41.00	4.28E-04
D-0355	South Bleeder	11/6/2008	12/8/2016	261	605.67	552.14	557.61	771.22	443.10	278.48	4.53	55.51	208.50	4.08	4.53	54.39	617.98	41.00	2.32E-06
D-0355	North East Intake	11/6/2008	12/8/2016	257	589.83	561.18	566.57	647.54	438.81	215.00	5.20	192.10	6.50	6.20	5.60	54.39	617.98	41.00	4.04E-06
D-0355	Grange	11/6/2008	12/8/2016	257	585.83	552.19	557.64	735.03	442.37	292.66	4.46	214.92	52.25	14.33	5.71	54.39	617.98	41.00	8.73E-05
D-0355	NW Shaft	11/6/2008	12/8/2016	256	586.00	551.86	557.25	693.11	338.00	350.65	4.46	144.62	181.32	6.29	6.17	54.39	617.98	41.00	1.67E-08
D-0360	DW21-156.00	4/27/2008	8/6/2008	3	1222.00	1222.00	1222.00	1225.00	1219.00	274.25	5.45	194.05	15.51	61.90	11.27	13.68	111048.55	40.50	5.11E-05
D-0360	DW21-190.00	4/27/2008	8/22/2008	3	1239.75	1236.20	1237.98	1248.00	1233.00	302.03	5.68	178.44	31.29	74.71	12.42	13.68	111048.55	40.50	5.09E-05
D-0360	DW-22.004.00	10/23/2008	3/9/2009	3	1117.00	1117.00	1117.00	1125.00	1101.00	272.09	7.81	114.19	33.51	114.10	11.82	13.68	111048.55	40.50	4.50E-05
D-0360	DW-406	1/23/2014	12/26/2016	29	1301.00	1295.00	1298.43	1322.00	1298.00	291.50	6.25	177.75	23.01	71.99	15.15	14.48	111048.55	40.50	8.50E-05
D-0360	DW502-338.08	10/29/2008	3/9/2009	3	1221.00	1215.70	1219.23	1230.00	1214.00	489.71	11.76	347.06	30.83	115.94	26.19	14.48	111048.55	40.50	3.82E-05
D-0360	DW-679	1/21/2014	4/15/2014	4	1223.00	1219.00	1220.75	1235.00	1216.00	271.01	6.19	157.00	0.91	85.09	13.65	14.48	111048.55	40.50	6.62E-05
D-0360	DW-719	1/24/2007	12/22/2016	14	1177.00	1172.00	1174.32	1180.00	1173.00	428.45	7.05	259.73	45.00	112.83	14.77	14.48	111048.55	40.50	7.37E-05
D-0360	W21-029.00	5/1/2008	8/4/2008	3	1235.00	1232.00	1233.33	1283.00	1204.00	490.16	5.17	323.67	11.34	108.77	13.68	14.48	111048.55	40.50	6.78E-05
D-0360	W21-043.00	5/1/2008	8/14/2008	3	1203.20	1198.50	1201.20	1242.00	1179.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	111048.55	40.50	6.94E-05
D-0360	W21-045.01	5/1/2008	8/6/2008	3	1297.70	1295.80	1296.97	1340.00	1282.00	303.36	7.40	175.10	23.60	87.50	17.29	98.01	111048.55	40.50	9.41E-05
D-0360	W21-057.00	5/3/2008	8/12/2008	3	1224.90	1223.50	1224.43	1260.00	1161.00	303.36	7.40	175.10	23.60	87.50	17.29	101.40	111048.55	40.50	6.84E-05
D-0360	W21-059.00	5/3/2008	8/9/2008	3	1220.00	1210.50	1216.17	1255.00	1164.50	303.36	7.40	175.10	23.60	87.50	17.29	101.40	111048.55	40.50	6.48E-05
D-0360	W21-064.00	5/2/2008	8/13/2008	3	1215.60	1199.60	1205.67	1260.00	1177.00	303.36	7.40	175.10	23.60	87.50	17.29	26.02	111048.55	40.50	6.52E-05
D-0360	W21-066.00	5/1/2008	8/21/2008	3	1163.00	1162.50	1162.83	1165.00	1081.50	259.18	7.05	122.95	13.10	106.91	11.26	35.38	111048.55	40.50	6.09E-05
D-0360	W21-080.00	5/3/2008	8/18/2008	3	1032.00	1029.30	1030.40	1045.00	1001.00	317.45	7.29	204.12	2.04	78.09	10.82	35.38	111048.55	40.50	6.21E-05
D-0360	W21-083.00	5/2/2008	8/8/2008	3	1038.00	1035.70	1037.10	1055.00	1017.50	317.45	7.29	204.12	2.04	78.09	10.82	35.38	111048.55	40.50	6.06E-05

D-0360	W21-087.00	5/5/2008	8/11/2008	3	1039.50	1038.80	1039.10	1068.00	1026.30	317.45	7.29	204.12	2.04	78.09	10.82	35.38	111048.55	40.50	6.10E-05
D-0360	W21-087.01	5/5/2008	8/11/2008	3	1057.00	1045.80	1050.97	1068.00	1015.80	317.45	7.29	204.12	2.04	78.09	10.82	35.38	111048.55	40.50	6.04E-05
D-0360	W21-095.00	5/2/2008	8/9/2008	3	1038.20	1019.30	1030.83	1100.00	1011.00	317.45	7.29	204.12	2.04	78.09	10.82	35.38	111048.55	40.50	6.10E-05
D-0360	W21-106.00	5/3/2008	8/11/2008	3	1048.60	1045.60	1047.33	1065.00	965.00	317.45	7.29	204.12	2.04	78.09	10.82	40.52	111048.55	40.50	5.97E-05
D-0360	W21-110.01	5/9/2008	8/8/2008	3	1029.60	1029.60	1029.60	1050.00	1017.20	317.45	7.29	204.12	2.04	78.09	10.82	40.52	111048.55	40.50	5.94E-05
D-0360	W21-111.00	5/2/2008	8/8/2008	3	1032.90	1032.20	1032.63	1040.00	961.00	317.45	7.29	204.12	2.04	78.09	10.82	40.52	111048.55	40.50	5.91E-05
D-0360	W21-112.00	5/8/2008	8/11/2008	3	1032.40	1031.80	1032.07	1060.00	1023.40	317.45	7.29	204.12	2.04	78.09	10.82	40.52	111048.55	40.50	5.87E-05
D-0360	W21-138.00	5/3/2008	8/4/2008	3	1215.40	1194.50	1207.30	1240.00	1109.70	303.36	7.40	175.10	23.60	87.50	17.29	40.52	111048.55	40.50	5.84E-05
D-0360	W21-155.08	6/24/2008	4/30/2008	3	1261.00	1259.00	1259.97	1300.00	1245.00	274.25	5.45	194.05	15.51	61.90	11.27	146.18	111048.55	40.50	5.13E-05
D-0360	W21-160.00	4/30/2008	8/6/2008	3	1160.80	1159.40	1160.17	1220.00	1115.00	279.00	6.90	77.16	24.69	145.59	12.54	41.98	111048.55	40.50	5.09E-05
D-0360	W21-165.04	5/3/2008	8/23/2008	3	1192.20	744.00	1042.07	1240.00	1100.00	253.20	9.20	50.40	31.39	165.59	12.60	46.09	111048.55	40.50	5.92E-05
D-0360	W21-171.00	4/30/2008	8/6/2008	3	1180.00	1173.20	1176.93	1220.00	1147.00	279.00	6.90	77.16	24.69	145.59	12.54	46.09	111048.55	40.50	5.09E-05
D-0360	W21-173.01	4/29/2008	8/7/2008	3	1211.00	1205.50	1207.83	1220.00	1201.50	279.00	6.90	77.16	24.69	145.59	12.54	52.95	111048.55	40.50	5.26E-05
D-0360	W21-180.01	4/29/2008	8/6/2008	3	1194.20	1193.00	1193.63	1220.00	1144.50	279.00	6.90	77.16	24.69	145.59	12.54	59.37	111048.55	40.50	5.19E-05
D-0360	W21-183.01	4/29/2008	8/6/2008	3	1195.60	1193.00	1194.20	1220.00	1164.00	302.03	5.68	178.44	31.29	74.71	12.42	101.40	111048.55	40.50	5.30E-05
D-0360	W21-187.00	5/1/2008	8/7/2008	3	1220.60	1218.10	1219.23	1240.00	1173.50	302.03	5.68	178.44	31.29	74.71	12.42	136.09	111048.55	40.50	6.07E-05
D-0360	W21-195.00	5/1/2008	8/23/2008	3	1227.50	1216.80	1223.37	1280.00	1221.00	302.03	5.68	178.44	31.29	74.71	12.42	73.96	111048.55	40.50	6.01E-05
D-0360	W21-260.00	5/6/2008	8/19/2008	3	1142.90	1142.00	1142.47	1180.00	1137.00	303.36	7.40	175.10	23.60	87.50	17.29	73.96	111048.55	40.50	5.92E-05
D-0360	W21-265.00	5/5/2008	8/19/2008	3	1148.20	1147.90	1148.03	1180.00	1127.50	303.36	7.40	175.10	23.60	87.50	17.29	146.18	111048.55	40.50	5.89E-05
D-0360	W21-452.00	5/8/2008	8/19/2008	3	1156.80	1154.50	1155.50	1190.00	1137.00	156.50	7.10	92.72	0.00	41.26	9.32	13.68	111048.55	40.50	5.82E-05
D-0360	W21-481.00	5/5/2008	9/2/2008	3	1150.00	1148.60	1149.13	1185.00	1143.00	148.57	6.55	43.93	0.00	95.92	9.60	12.78	111048.55	40.50	5.58E-05
D-0360	W21-502.00	5/6/2008	8/26/2008	3	1143.90	1141.80	1142.85	1165.00	1132.00	156.50	7.10	92.72	0.00	41.26	9.32	13.68	111048.55	40.50	5.78E-05
D-0360	W-22.007.00	10/29/2008	12/21/2016	13	1221.30	1204.00	1209.92	1250.00	1198.00	489.71	11.76	347.06	30.83	115.94	26.19	13.68	111048.55	40.50	2.96E-04
D-0360	W231.356.00	10/27/2008	3/10/2009	3	1233.30	1160.00	1196.65	1280.00	1068.00	335.45	7.45	211.84	21.69	92.72	12.98	13.68	111048.55	40.50	9.88E-05
D-0360	W231.356.04	10/27/2008	3/3/2016	28	1267.00	1223.00	1246.36	1270.00	1209.70	335.45	7.45	211.84	21.69	92.72	12.98	14.48	111048.55	40.50	1.09E-04
D-0360	W336.367.00	8/25/2010	2/23/2011	3	886.80	882.70	885.20	900.00	865.00	263.05	7.55	115.24	35.79	109.05	13.01	14.48	111048.55	40.50	3.00E-04
D-0360	W336.375.00	1/27/2012	12/1/2016	34	928.00	923.00	925.35	1000.00	873.00	263.05	7.55	115.24	35.79	109.05	13.01	14.48	111048.55	40.50	1.85E-04

D-0360	W-410	1/23/2014	12/26/2016	29	1263.00	1237.00	1250.45	1310.00	1225.00	327.53	4.87	218.18	24.31	55.90	14.42	14.48	111048.55	40.50	8.07E-05
D-0360	W-413	7/2008	2/13/2014	32	1250.00	1240.00	1243.75	1280.00	1233.00	327.53	4.87	218.18	24.31	55.90	14.42	14.48	111048.55	40.50	8.48E-05
D-0360	W-414	1/23/2014	12/26/2016	33	1267.00	1228.00	1247.19	1280.00	1225.00	327.53	4.87	218.18	24.31	55.90	14.42	14.48	111048.55	40.50	9.03E-05
D-0360	W-415	1/23/2014	12/26/2016	33	1115.00	1101.00	1107.82	1135.00	1063.00	327.53	4.87	218.18	24.31	55.90	14.42	14.48	111048.55	40.50	8.45E-05
D-0360	W-428	2/20/2014	4/14/2016	24	1227.00	1194.00	1208.33	1260.00	1185.00	540.40	5.50	336.95	11.82	178.25	12.88	1.52	111048.55	40.50	1.45E-04
D-0360	W-452	10/16/2007	10/16/2007	1	1155.50	1155.50	1173.33	1160.00	1092.50	241.40	2.31	140.36	34.51	73.45	10.11	14.48	111048.55	40.50	5.20E-06
D-0360	W501.077.00	7/23/2007	12/2/2016	29	1182.50	1097.00	1141.78	1210.00	1095.00	335.45	7.45	211.84	21.69	92.72	12.98	14.48	111048.55	40.50	1.52E-04
D-0360	W501.077.01	4/30/2007	12/1/2016	27	1153.00	1034.00	1072.70	1180.00	997.50	335.45	7.45	211.84	21.69	92.72	12.98	98.01	111048.55	40.50	1.52E-04
D-0360	W501.343000	11/14/2012	6/7/2016	7	1125.00	1104.50	1116.63	1175.00	1045.00	431.50	6.60	236.12	77.80	118.08	12.12	98.01	111048.55	40.50	1.42E-04
D-0360	W-53.01	12/29/2011	3/16/2012	2	1007.50	1005.20	1006.35	1010.00	969.00	181.70	7.40	100.39	2.00	91.20	12.29	98.01	111048.55	40.50	1.36E-04
D-0360	W-568	1/21/2014	3/12/2014	3	1172.00	1171.00	1171.33	1222.00	1104.00	257.46	4.90	113.13	22.11	116.39	9.10	98.01	111048.55	40.50	7.68E-05
D-0360	W-576	1/21/2014	4/15/2014	4	1149.00	1147.00	1148.00	1230.00	1121.00	271.01	6.19	157.00	0.91	85.09	13.65	98.01	111048.55	40.50	6.50E-05
D-0360	W-583	1/21/2014	3/12/2014	3	1159.00	1157.00	1158.00	1245.00	1115.00	271.01	6.19	157.00	0.91	85.09	13.65	98.01	111048.55	40.50	1.07E-04
D-0360	W-609	1/21/2014	9/21/2015	20	1141.00	1094.00	1123.87	1162.00	1084.00	298.86	5.45	166.14	34.91	78.29	9.15	98.01	111048.55	40.50	6.01E-05
D-0360	W-620	1/21/2014	9/21/2015	21	1150.00	1143.00	1146.64	1178.00	1146.00	298.86	5.45	166.14	34.91	78.29	9.15	98.01	111048.55	40.50	5.92E-05
D-0360	W6-6	10/7/2009	8/24/2012	4	1231.30	1226.40	1228.18	1256.00	1184.00	263.05	7.55	115.24	35.79	109.05	13.01	98.01	111048.55	40.50	4.16E-05
D-0360	W-660	1/14/2014	4/7/2015	16	1143.00	1129.00	1135.25	1170.00	1104.50	276.95	5.10	94.67	17.81	110.04	11.95	98.01	111048.55	40.50	5.36E-05
D-0360	W-666	1/13/2014	12/5/2014	12	1055.00	1041.00	1049.08	1065.00	1012.00	263.35	7.00	108.55	53.31	84.24	5.91	98.01	111048.55	40.50	4.61E-05
D-0360	W-671	1/15/2014	9/3/2014	9	1117.00	1079.00	1097.50	1183.00	1063.00	278.52	7.88	130.58	24.35	89.21	10.00	98.01	111048.55	40.50	6.14E-05
D-0360	W-694	4/23/2007	12/22/2016	13	1236.00	1208.00	1227.62	1260.00	1200.50	489.71	11.76	347.06	30.83	115.94	26.19	98.01	111048.55	40.50	2.25E-04
D-0360	WL21-041.01	5/1/2008	8/8/2008	3	1258.40	1252.10	1255.37	1300.00	1210.00	490.16	5.17	323.67	11.34	108.77	13.68	98.01	111048.55	40.50	6.66E-05
D-0360	WL231.362.00	8/25/2010	12/1/2016	37	1136.00	1100.00	1116.65	1170.00	1070.50	534.00	7.98	316.06	23.80	187.04	13.10	98.01	111048.55	40.50	3.31E-04
D-0360	WL336.373.00	8/25/2010	5/2/2016	30	1085.00	1065.00	1076.71	1100.00	1050.50	534.00	7.98	316.06	23.80	187.04	13.10	98.01	111048.55	40.50	2.45E-04
D-0360	WL-567	1/21/2014	3/12/2014	3	1152.00	1151.00	1151.67	1224.00	1104.00	257.46	4.90	113.13	22.11	116.39	9.10	98.01	111048.55	40.50	7.71E-05
D-0360	WL-674	1/15/2014	12/1/2016	33	1103.00	1078.00	1098.18	1145.00	1036.00	238.05	6.60	146.59	0.00	68.14	11.96	96.35	111048.55	40.50	6.41E-05
D-0360	WL-721	4/30/2010	12/22/2016	15	1202.00	1157.00	1164.72	1230.00	1150.00	428.45	7.05	259.73	45.00	112.83	14.77	98.01	111048.55	40.50	1.42E-04
D-0360	WL-736	1/13/2016	12/22/2016	12	1130.87	1115.00	1118.57	1131.00	1031.00	333.34	4.90	243.57	13.34	48.14	14.88	98.01	111048.55	40.50	8.78E-05
D-1019	W-14	7/8/2008	11/9/2012	48	1164.00	1029.00	1066.93	1240.00	310.00	205.83	3.33	159.33	49.33	0.00	3.50	0.11	11184.92	38.00	1.06E-05

D-1019	W-201	7/8/2008	10/5/2011	13	1224.00	1210.00	1215.42	1260.00	960.00	253.00	3.00	228.50	27.00	0.00	3.50	3.85	11184.92	38.00	3.38E-06
D-1019	W-202	7/8/2008	11/19/2012	21	1267.00	1218.00	1226.02	1270.00	1189.00	253.00	3.00	228.50	27.00	0.00	3.50	3.85	11184.92	38.00	3.60E-06
D-1019	W-242	10/9/2008	5/2/2012	3	1137.00	1137.00	1137.00	1190.00	986.00	253.00	3.00	228.50	27.00	0.00	3.50	3.85	11184.92	38.00	4.72E-06
D-1019	WL-13	1/15/2014	10/13/2014	3	1254.00	1253.00	1253.67	1293.00	901.00	205.83	3.33	159.33	49.33	0.00	3.50	3.85	11184.92	38.00	1.80E-05
D-1019	WL-18	8/5/2008	12/21/2012	29	977.00	968.00	973.91	1005.00	910.00	266.00	4.00	157.00	112.00	0.00	4.00	3.85	11184.92	38.00	3.33E-05
D-1019	WL-201	1/5/2012	4/10/2014	7	1223.00	1193.00	1217.14	1260.00	960.00	205.83	3.33	159.33	49.33	0.00	3.50	1.71	11184.92	38.00	4.55E-06
D-1019	WL-39A	7/8/2008	12/30/2016	50	1218.00	1197.00	1212.56	1242.00	820.00	205.83	3.33	159.33	49.33	0.00	3.50	3.85	11184.92	38.00	2.35E-06
D-2091	MW-8	2/16/2017	2/16/2017	1	1004.41	1004.41	1004.41	1006.74	992.74	343.10	3.01	163.03	137.67	36.34	3.92	1.72	11181.57	38.00	0.00E+00
D-2091	MW-9	2/16/2017	3/11/2016	5	1007.80	1007.80	1007.80	1025.80	1002.80	343.10	3.01	163.03	137.67	36.34	3.92	1.72	11181.57	38.00	0.00E+00
D-2091	W-26	11/29/2016	3/11/2016	4	1173.50	1123.00	1160.44	1185.00	1065.00	151.00	3.50	116.01	33.17	8.25	4.14	1.72	11181.57	38.00	1.32E-06
D-2091	W-624	9/1/2011	6/22/2010	4	1011.50	1009.50	1010.50	1020.00	960.00	206.00	3.00	66.97	125.00	7.00	9.96	1.72	11181.57	38.00	9.79E-06
D-2091	W-625	3/24/2016	3/24/2016	1	938.50	938.50	938.50	960.00	870.00	343.10	3.01	163.03	137.67	36.34	3.92	1.72	11181.57	38.00	7.97E-06
D-2091	W-626	6/22/2010	3/24/2016	4	950.00	948.00	949.25	970.00	885.00	181.00	3.00	74.39	99.17	13.43	0.00	1.72	11181.57	38.00	6.79E-06
D-2091	W-628	2/24/2011	10/18/2011	3	957.20	956.70	956.87	960.70	803.70	181.00	3.00	74.39	99.17	13.43	0.00	1.72	11181.57	38.00	3.57E-06
D-2091	WL-113	4/21/2011	10/6/2011	3	1170.00	1170.00	1170.00	1215.00	1057.00	298.00	3.00	125.09	149.81	29.51	0.00	1.72	11181.57	38.00	1.12E-06
D-2091	WL-18	2/16/2017	2/16/2017	1	975.00	975.00	975.00	1005.00	910.00	343.10	3.01	163.03	137.67	36.34	3.92	1.72	11181.57	38.00	0.00E+00
D-2223	DW-7	6/14/2016	4/26/2017	6	753.00	753.00	753.00	774.00	748.00	156.13	3.41	71.09	74.83	1.33	3.51	6.10	14067.46	40.00	1.85E-05
D-2223	W-13	6/14/2016	4/26/2017	6	749.00	749.00	749.00	778.00	726.00	156.13	3.41	71.09	74.83	1.33	3.51	6.10	14067.46	40.00	1.76E-05
D-2223	WL-936	6/14/2016	4/26/2017	6	746.00	746.00	746.00	820.00	686.00	65.00	4.20	13.90	39.70	0.00	4.20	6.10	14067.46	40.00	8.63E-06
D-2317	WL-154	1/14/2009	5/6/2009	2	537.00	537.00	537.00	602.00	502.00	160.16	5.00	91.16	72.50	0.00	5.00	0.07	2061.00	41.00	1.61E-03
D-2317	W41.02	8/27/2013	6/15/2016	7	729.00	728.00	728.43	785.00	525.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00	1.28E-03
D-2317	W41.01	8/27/2013	11/27/2016	9	759.00	721.00	737.89	784.00	299.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00	2.09E-04
D-2317	W3.01	9/4/2013	11/27/2016	9	612.00	612.00	612.00	618.00	488.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00	2.04E-04
D-2317	W3	9/4/2013	11/27/2016	8	613.00	613.00	613.00	621.00	546.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00	1.83E-04
D-2317	W-134	5/6/2009	5/6/2009	1	601.80	601.80	601.80	639.00	536.50	240.10	5.25	188.65	56.10	0.00	5.25	0.07	2061.00	41.00	4.95E-03
D-2317	M3B	8/27/2013	11/26/2016	3	645.00	645.00	645.00	660.00	643.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00	1.77E-04
D-2317	M2B	5/15/2013	11/26/2016	12	648.00	646.00	646.83	720.00	643.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00	1.52E-05
D-2317	M2A	5/15/2013	11/26/2016	12	647.00	645.00	645.83	720.00	620.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00	1.51E-05

D-2317	M1B	5/15/2013	11/26/2016	12	686.00	685.00	685.67	749.00	659.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00	1.31E-05
D-2317	M1A	5/15/2013	11/26/2016	12	648.00	646.00	647.00	749.00	636.00	270.88	4.54	178.03	80.74	0.05	4.55	1.60	2061.00	41.00	1.30E-05
D-2317	DW-46	1/14/2009	5/4/2009	2	685.20	641.20	669.90	693.00	674.00	338.91	5.56	202.60	109.33	0.00	5.56	0.07	2061.00	41.00	1.38E-03
D-2317	DW-24	1/11/2009	5/4/2009	2	783.30	640.60	688.37	645.00	636.00	415.01	5.71	339.53	52.98	0.00	5.71	0.07	2061.00	41.00	5.24E-04
D-2317	DW-13	11/4/2008	5/4/2009	3	783.30	780.20	781.30	800.00	773.30	415.01	5.71	339.53	52.98	0.00	5.71	0.07	2061.00	41.00	6.14E-04

Table C 10. Multi-mine with water withdraw average potentiometric head model outliers.

Permit	Well
D-0354	South Meins Shaft
D-0354	Roving Crew
D-0354	Danville Shaft
D-0360	W-202
D-1019	WL-201
D-1019	W-14
D-1019	WL-39A
D-1019	WL-13
D-2091	W-26
D-2091	WL-113
D-2317	W41.01

Table C 11. Multi-mine with water withdraw maximum potentiometric head model outliers.

Permit	Well
D-0360	W-202
D-1019	W-14
D-1019	WL-39A
D-2317	W41.01

Table C 12. Multi-mine with water withdraw minimum potentiometric head model outliers.

Permit	Well
D-0354	South Meins Shaft
D-0354	Danville Shaft
D-0360	W-202
D-1019	W-14
D-1019	WL-39A
D-1019	WL-13
D-2317	W41.01

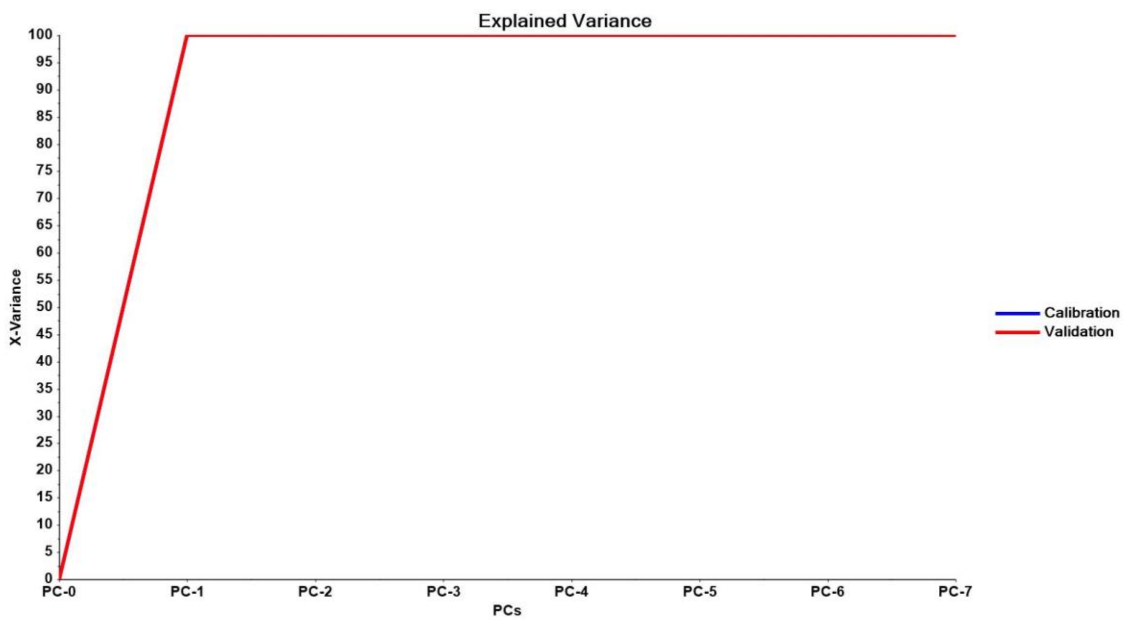

Figure C 33. Principal component analysis explained variance graph for the multi-mine with water withdraw average potentiometric head model.

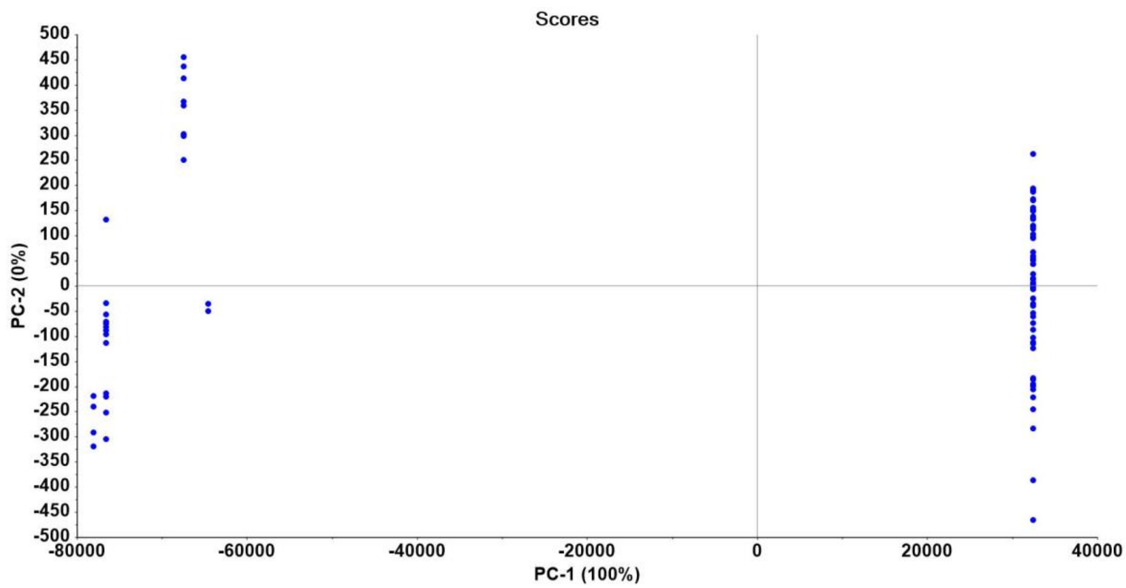

Figure C 34. Principal component analysis scores plot for the multi-mine with water withdraw average potentiometric head model.

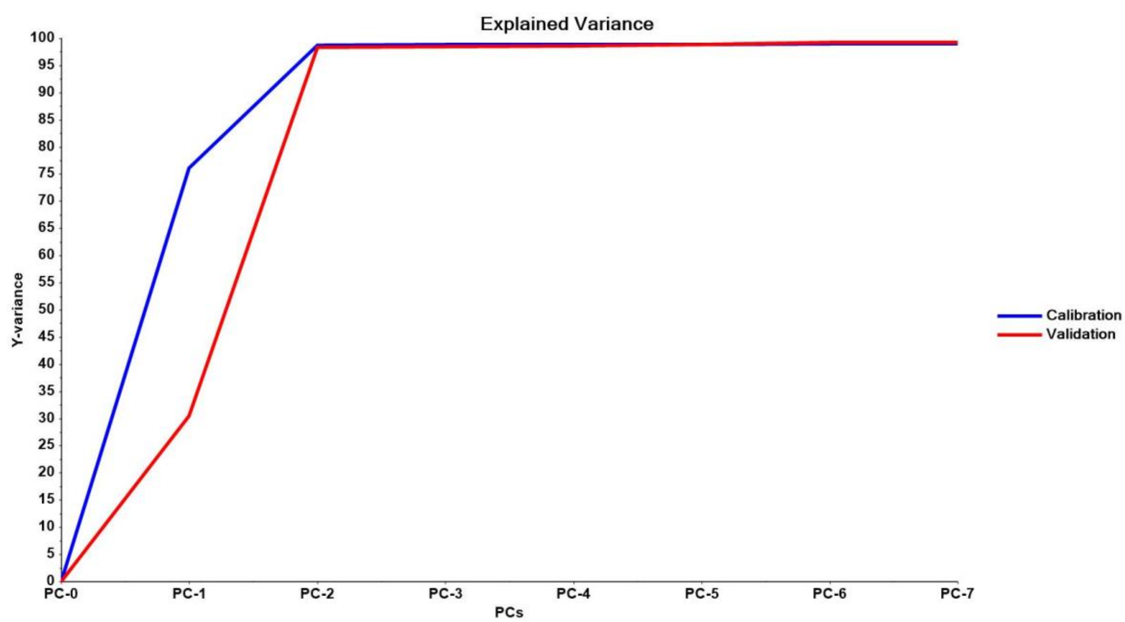

Figure C 35. Principal component regression explained variance graph for the multi-mine with water withdraw average potentiometric head model.

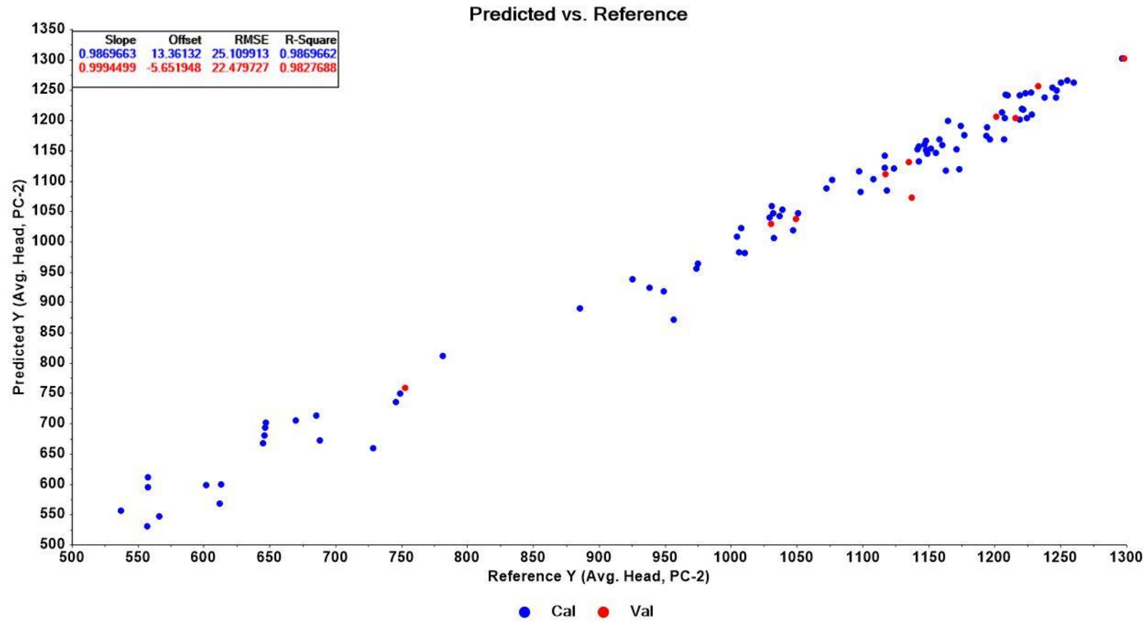

Figure C 36. Principal component regression predicted vs. reference plot for the multi-mine with water withdraw average potentiometric head model.

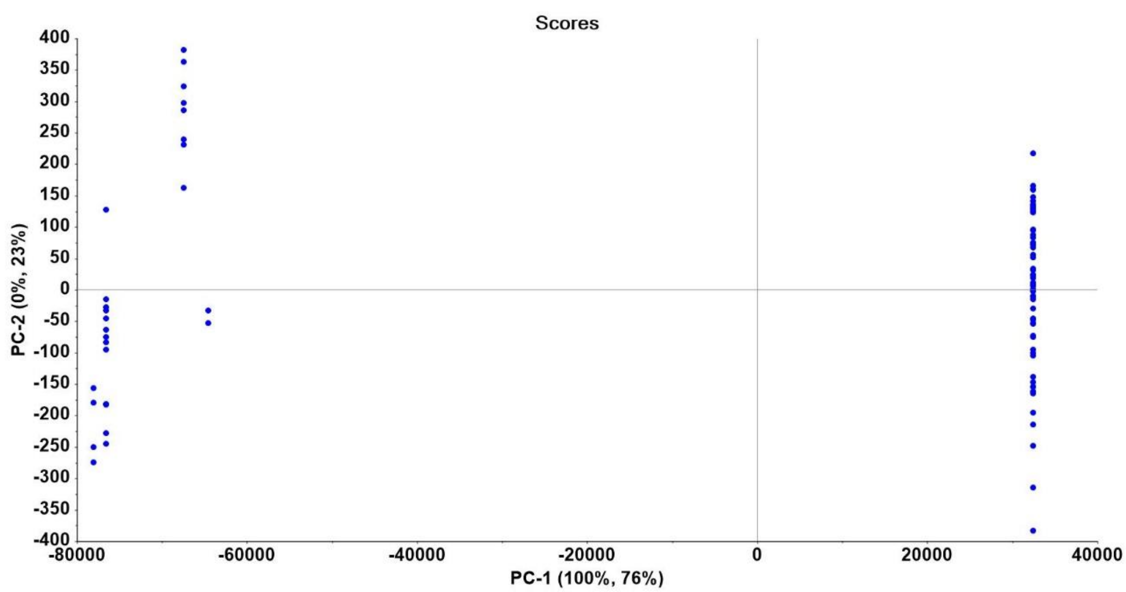

Figure C 37. Principal component regression scores plot for the multi-mine with water withdraw average potentiometric head model.

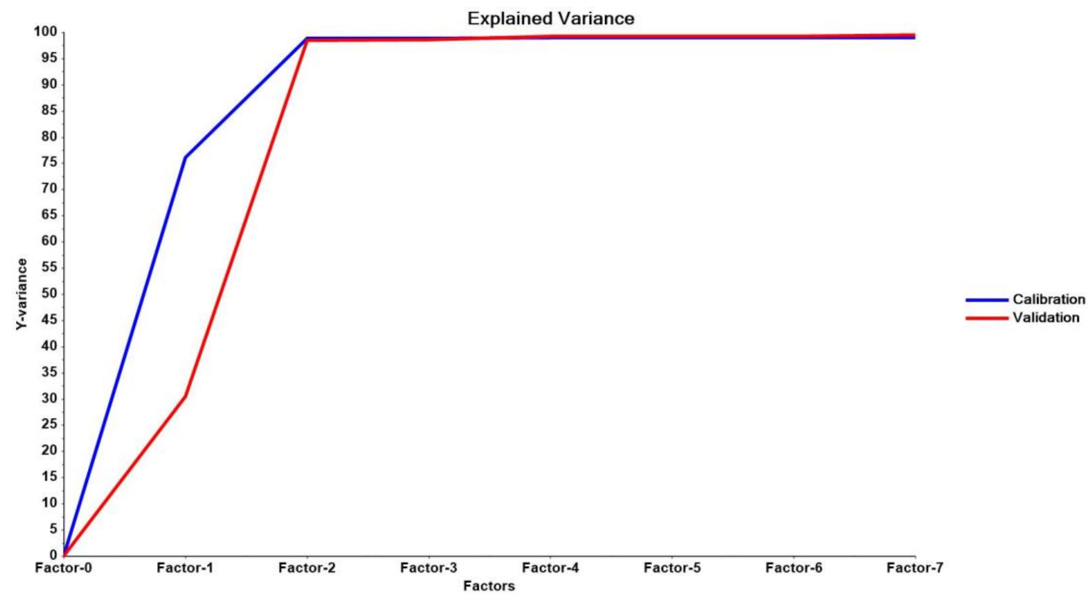

Figure C 38. Partial least squares regression explained variance graph for the multi-mine with water withdraw average potentiometric head model.

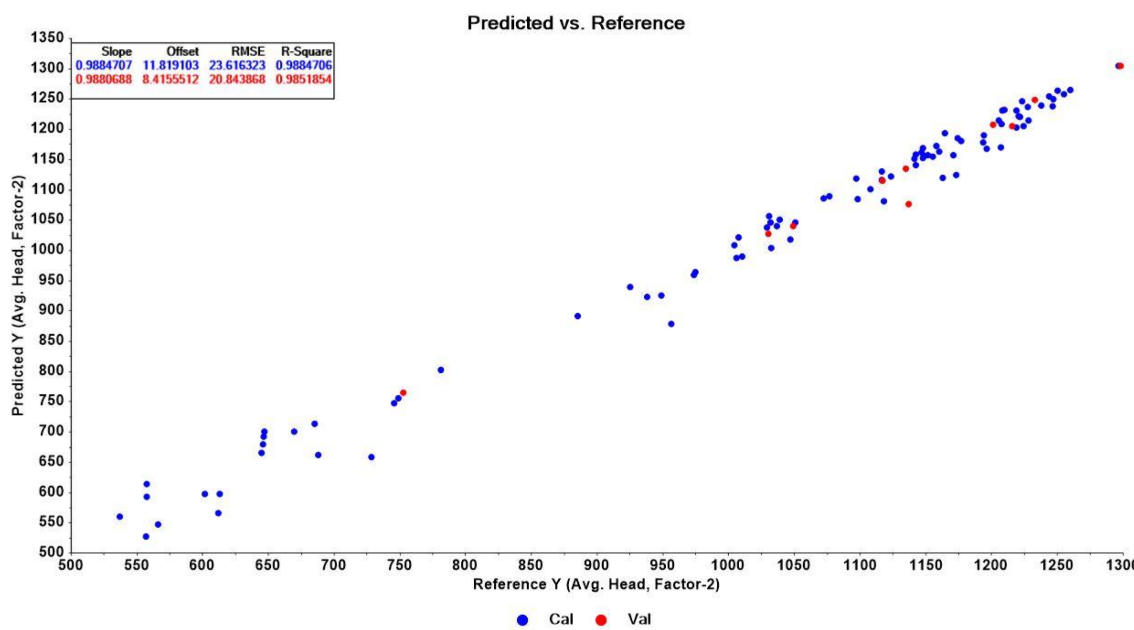

Figure C 39. Partial least squares regression predicted vs. reference plot for the multi-mine with water withdraw average potentiometric head model.

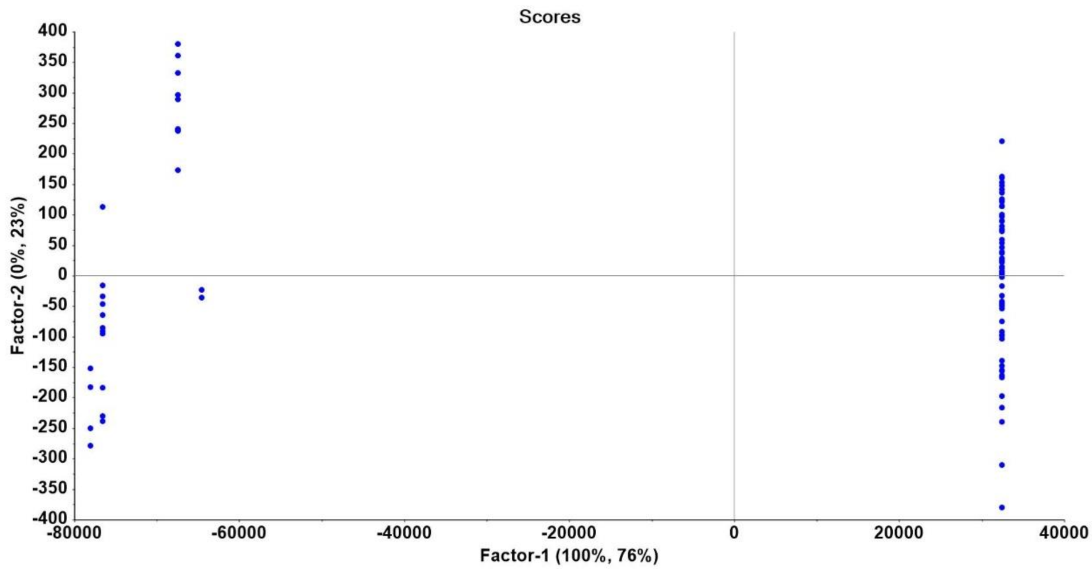

Figure C 40. Partial least squares regression scores plot for the multi-mine with water withdraw average potentiometric head model.

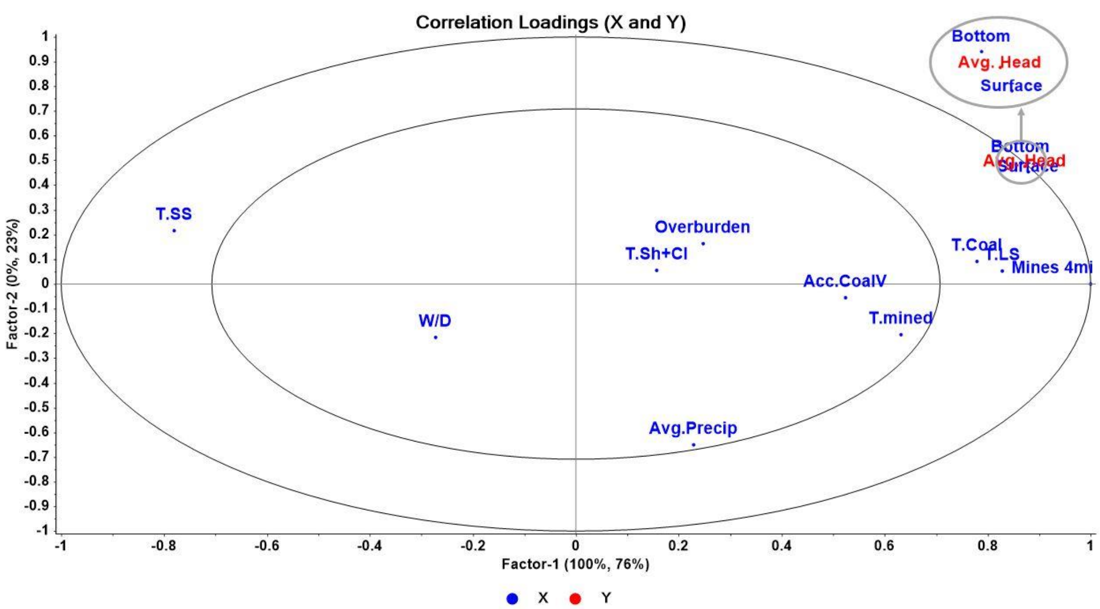

Figure C 41. Partial least squares regression correlation loadings plot for the multi-mine with water withdraw average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft).

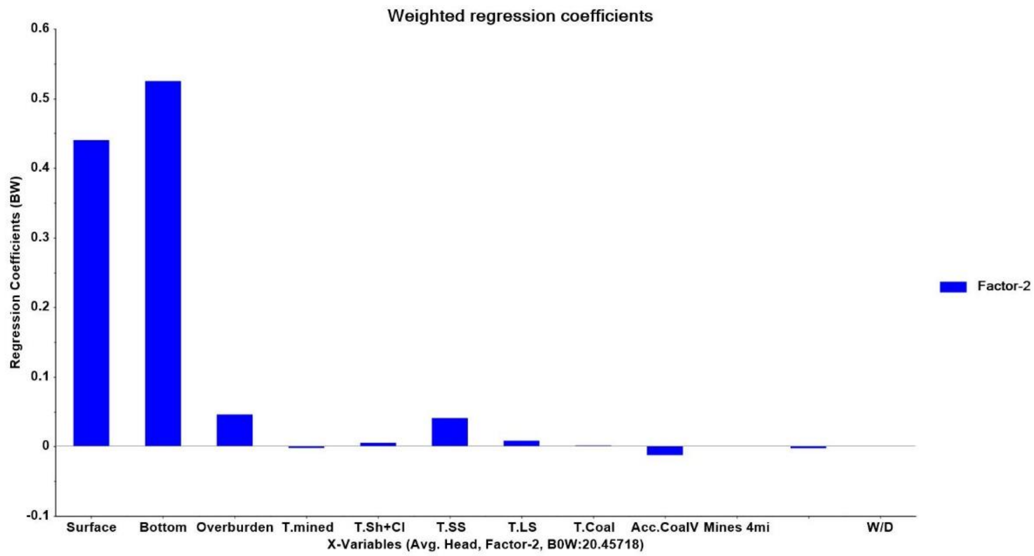

Figure C 42. Partial least squares regression weighted regression coefficients chart for the multi-mine with water withdraw average potentiometric head model. Partial least squares regression correlation loadings plot for the multi-mine with water withdraw average potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft).

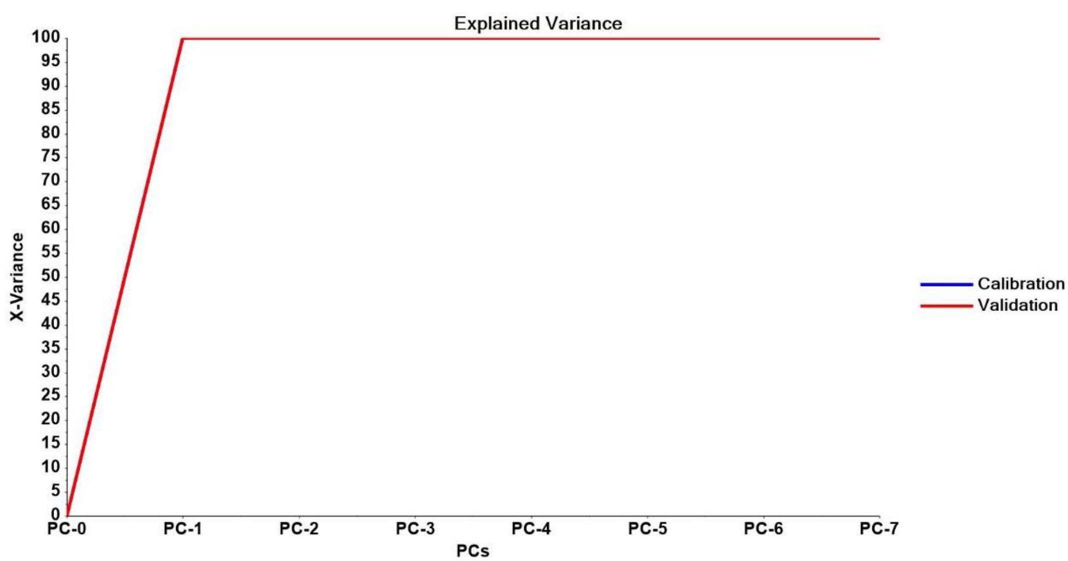

Figure C 43. Principal component analysis explained variance graph for the multi-mine with water withdraw maximum model.

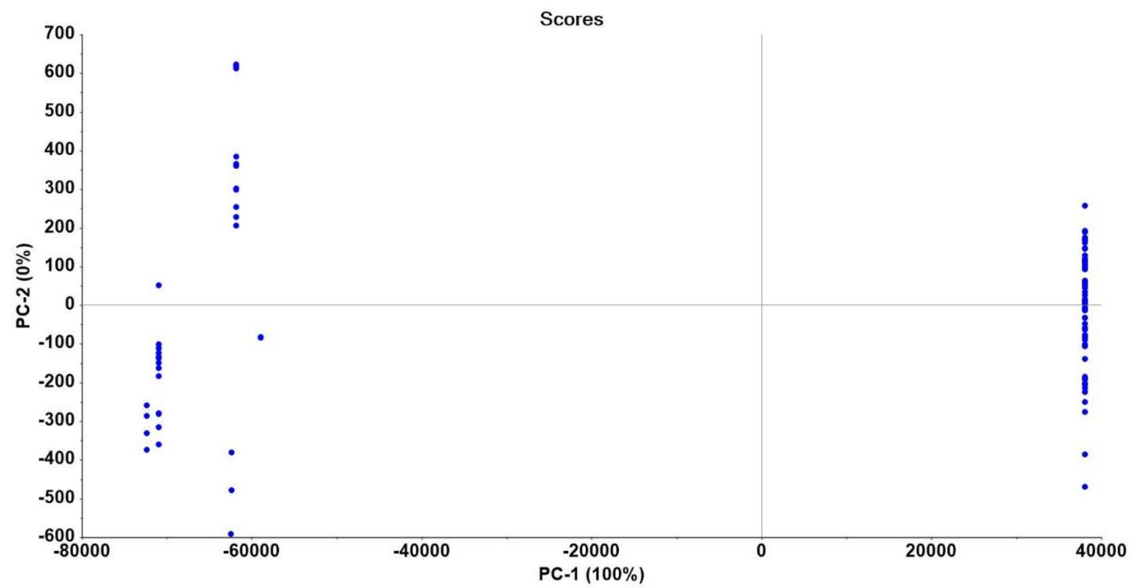

Figure C 44. Principal component analysis scores plot for the multi-mine with water withdraw maximum potentiometric head model.

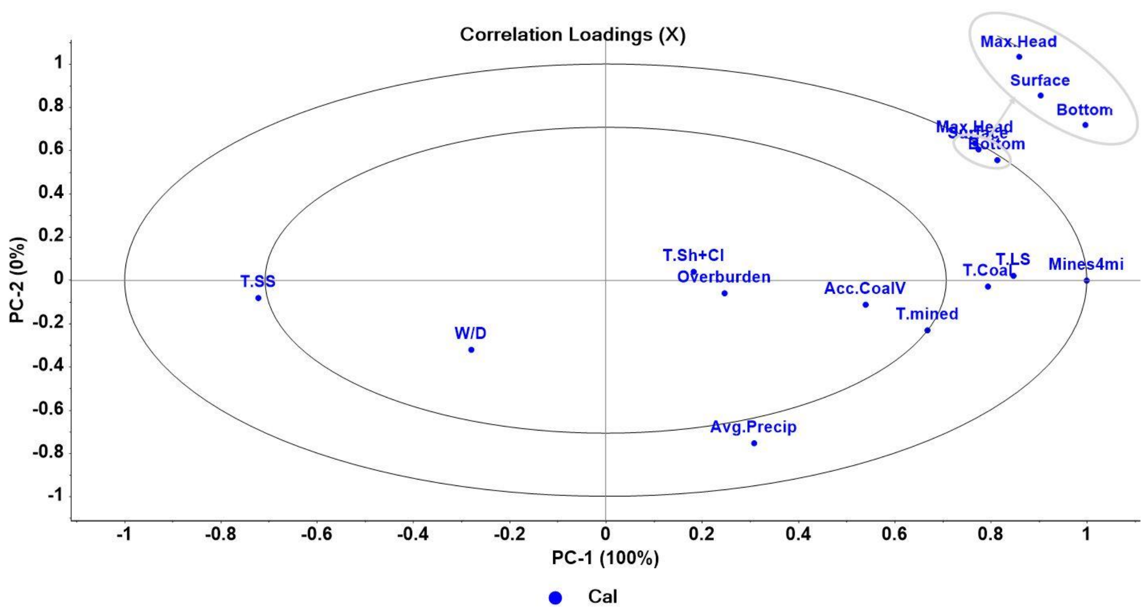

Figure C 45. Principal component analysis correlation loadings plot for the multi-mine with water withdraw maximum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft).

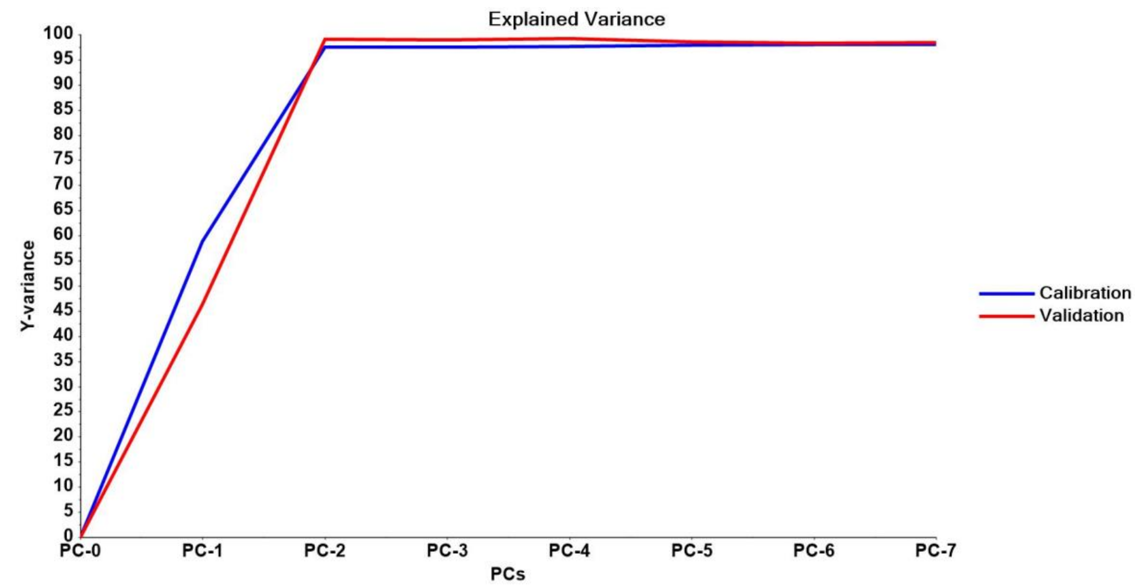

Figure C 46. Principal component regression explained variance graph for the multi-mine with water withdraw maximum potentiometric head model.

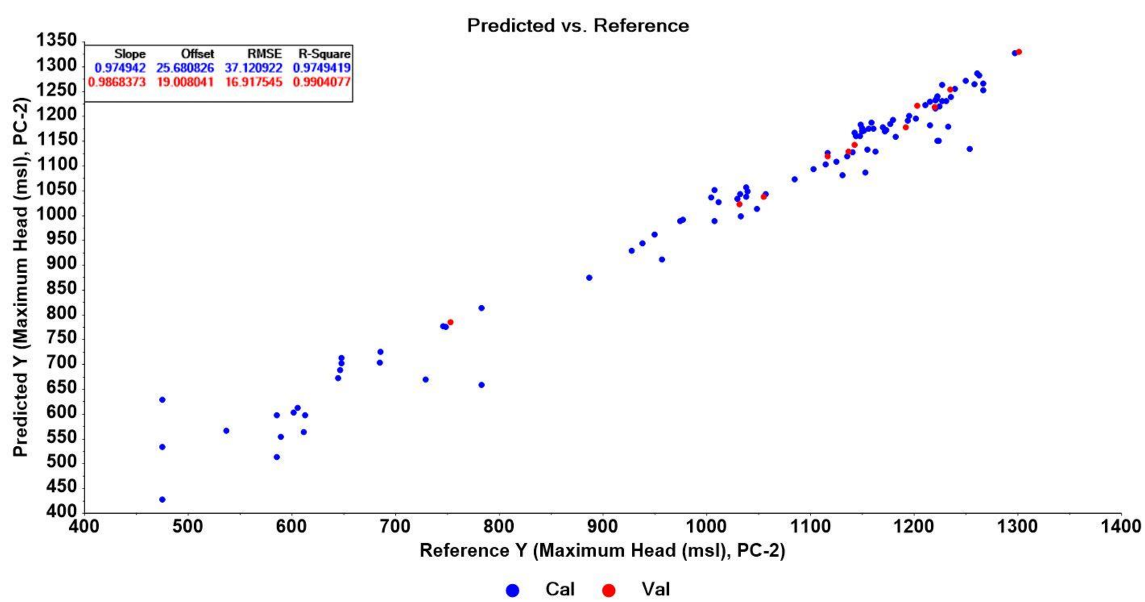

Figure C 47. Principal component regression predicted vs. reference plot for the multi-mine with water withdraw maximum potentiometric head model.

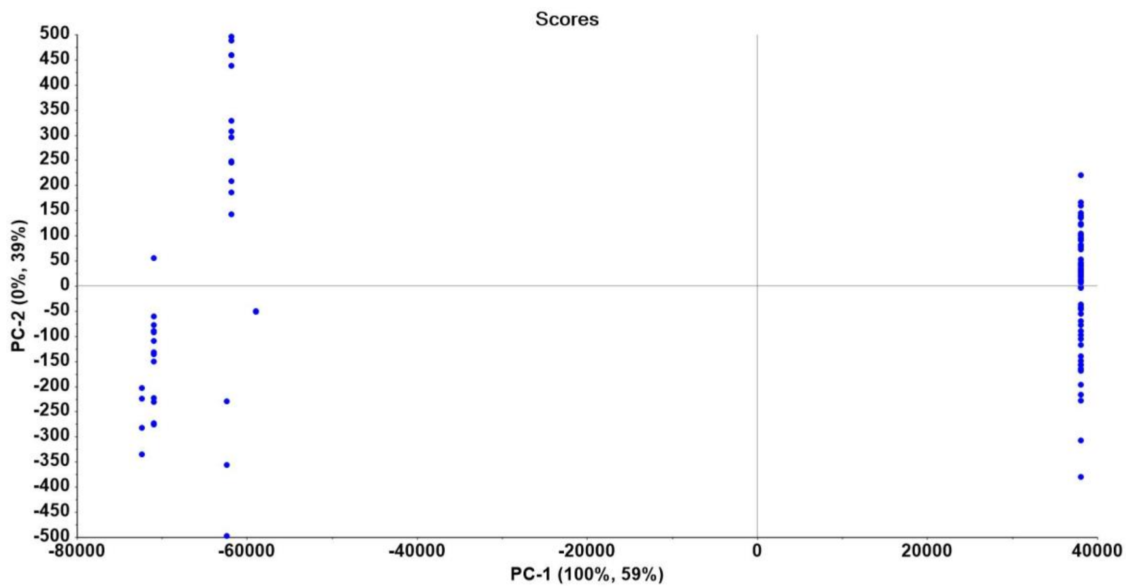

Figure C 48. Principal component regression scores plot for the multi-mine with water withdraw maximum potentiometric head model.

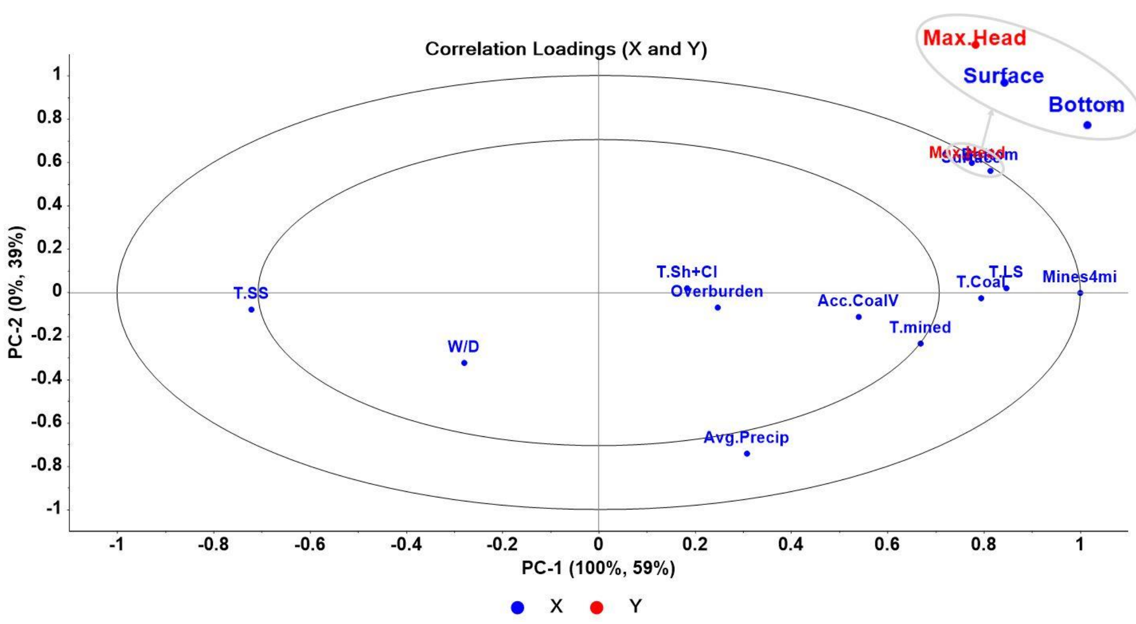

Figure C 49. Principal component regression correlation loadings plot for the multi-mine with water withdraw maximum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft).

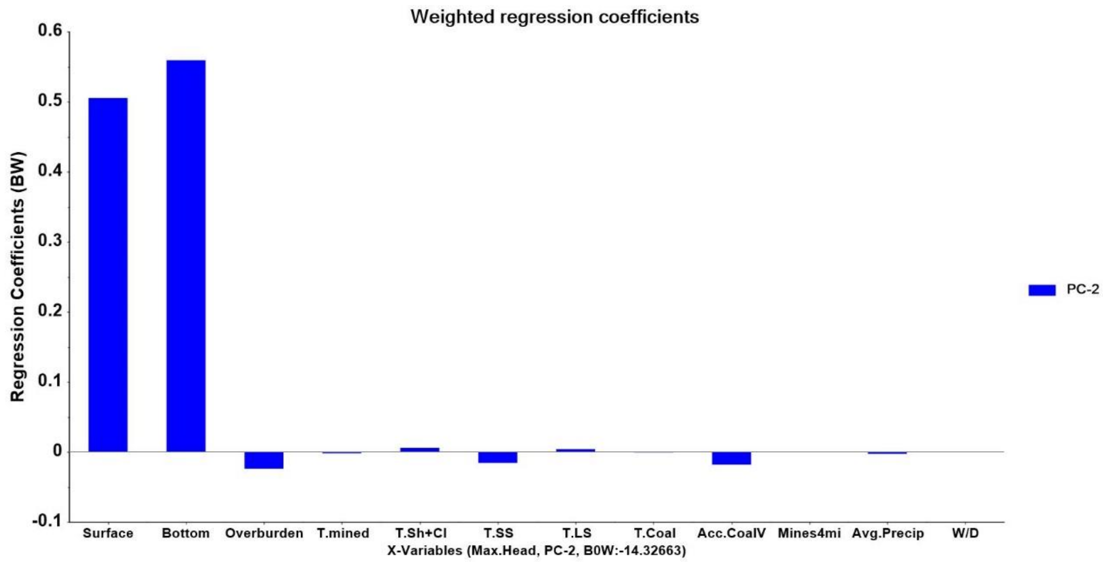

Figure C 50. Principal component regression weighted regression coefficients chart for the multi-mine with water withdraw maximum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft).

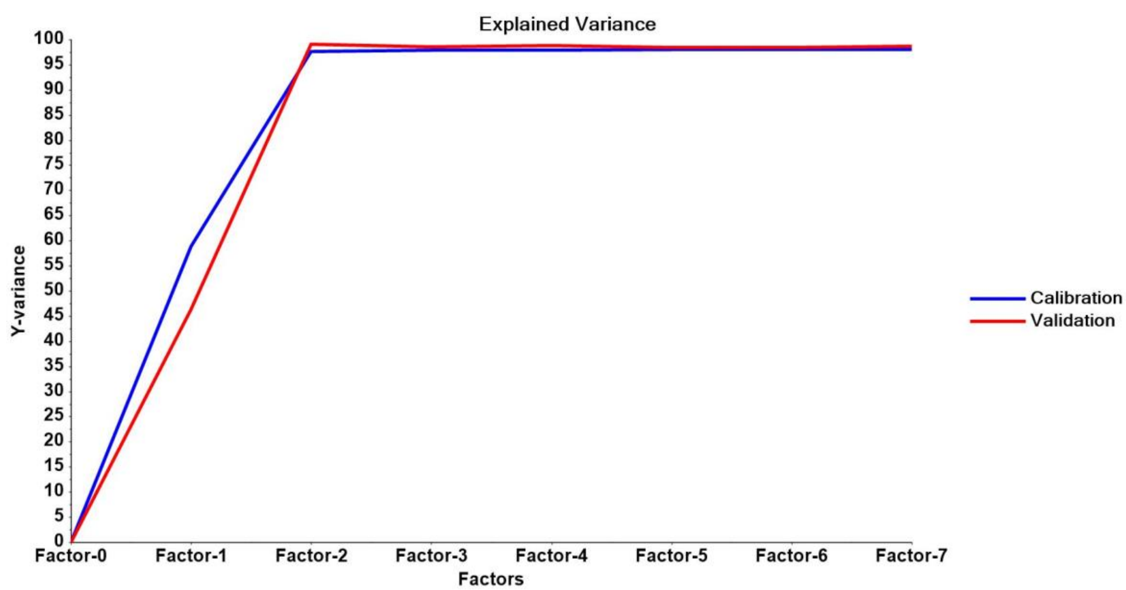

Figure C 51. Partial least squares regression explained variance graph for the multi-mine with water withdraw maximum potentiometric head model.

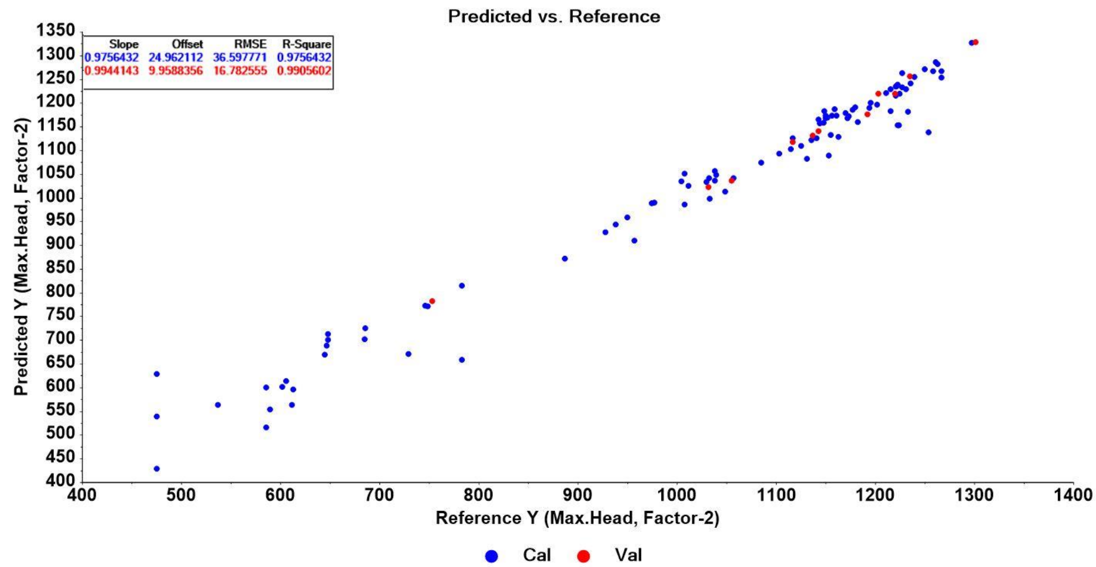

Figure C 52. Partial least squares regression predicted vs. reference plot for the multi-mine with water withdraw maximum potentiometric head model.

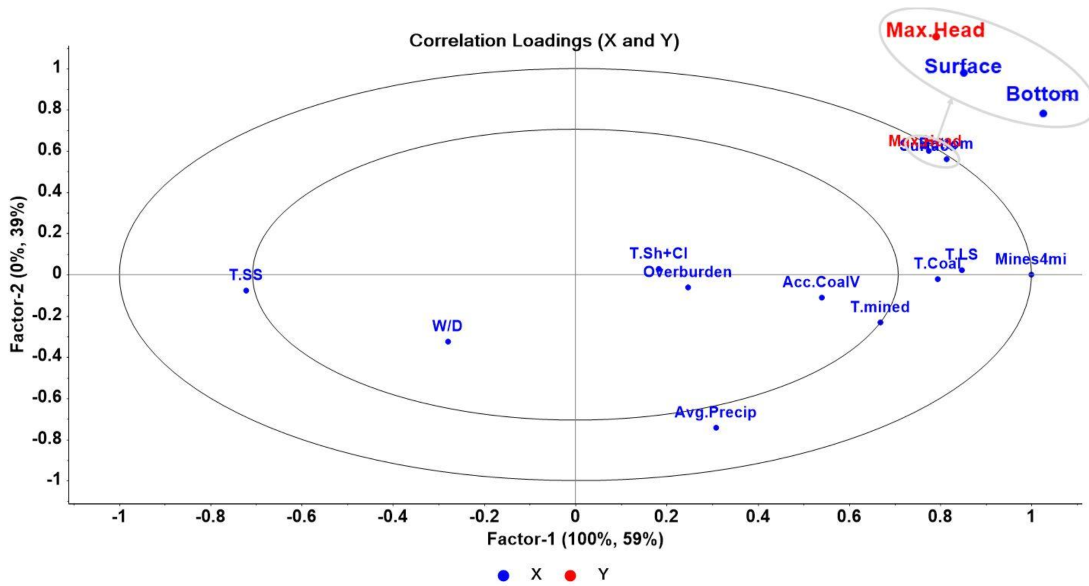

Figure C 53. Partial least squares regression correlation loadings plot for the multi-mine with water withdraw maximum model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft).

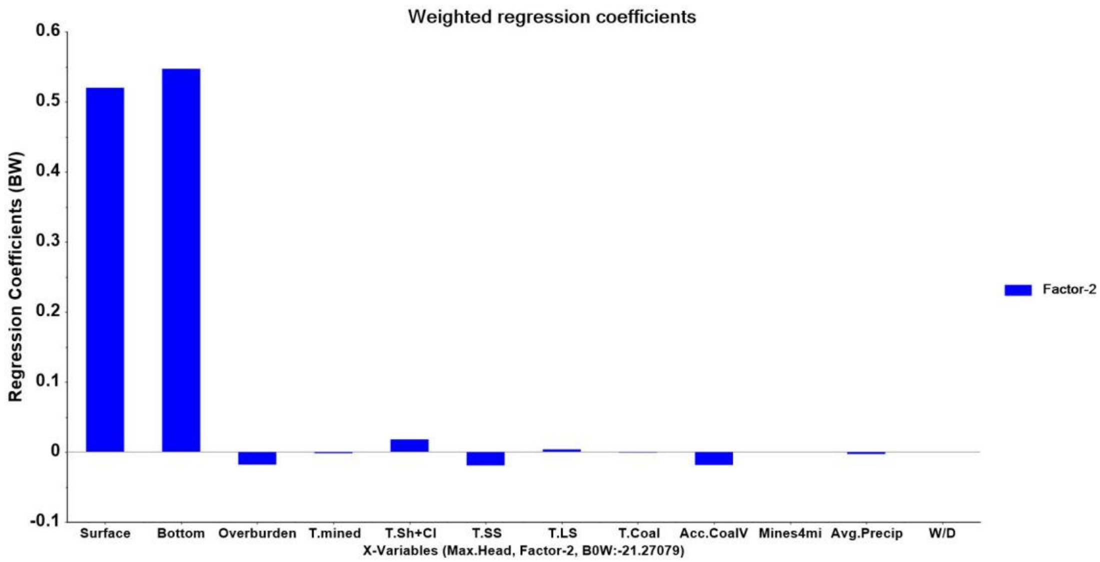

Figure C 54. Partial least squares regression weighted regression coefficients chart for the multi-mine with water withdraw maximum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft).

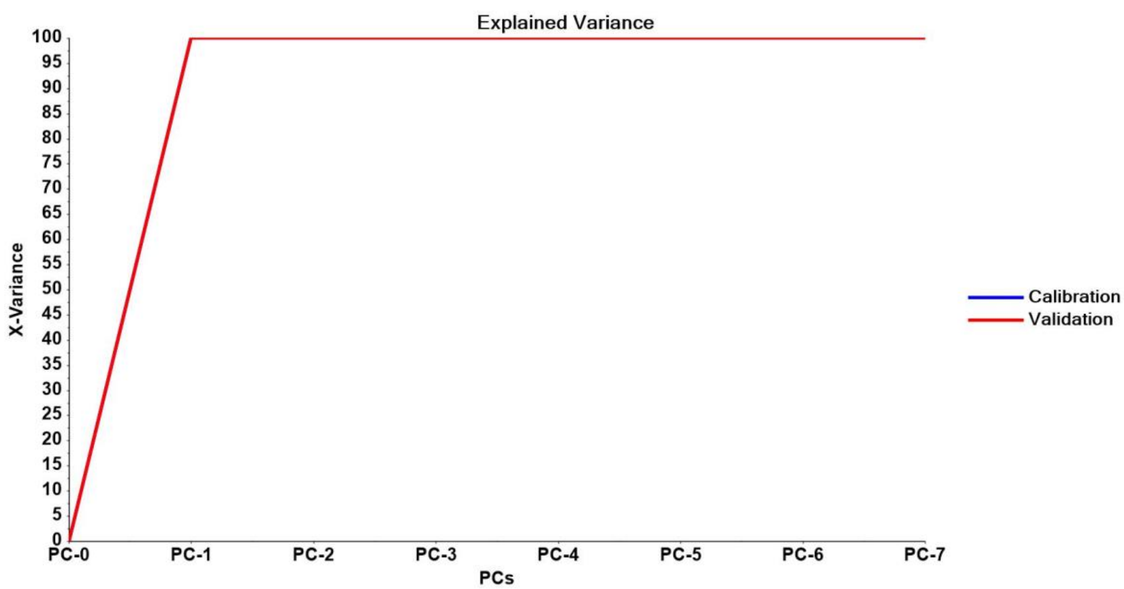

Figure C 55. Principal component analysis explained variance graph for the multi-mine with water withdraw minimum potentiometric head model.

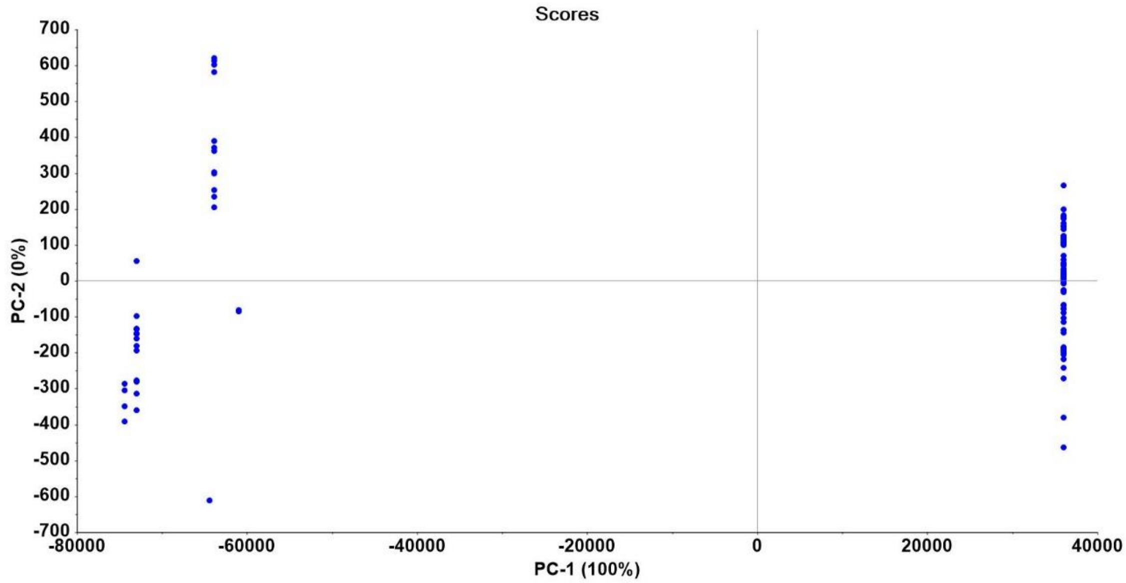

Figure C 56. Principal component analysis scores plot for the multi-mine with water withdraw minimum potentiometric head model.

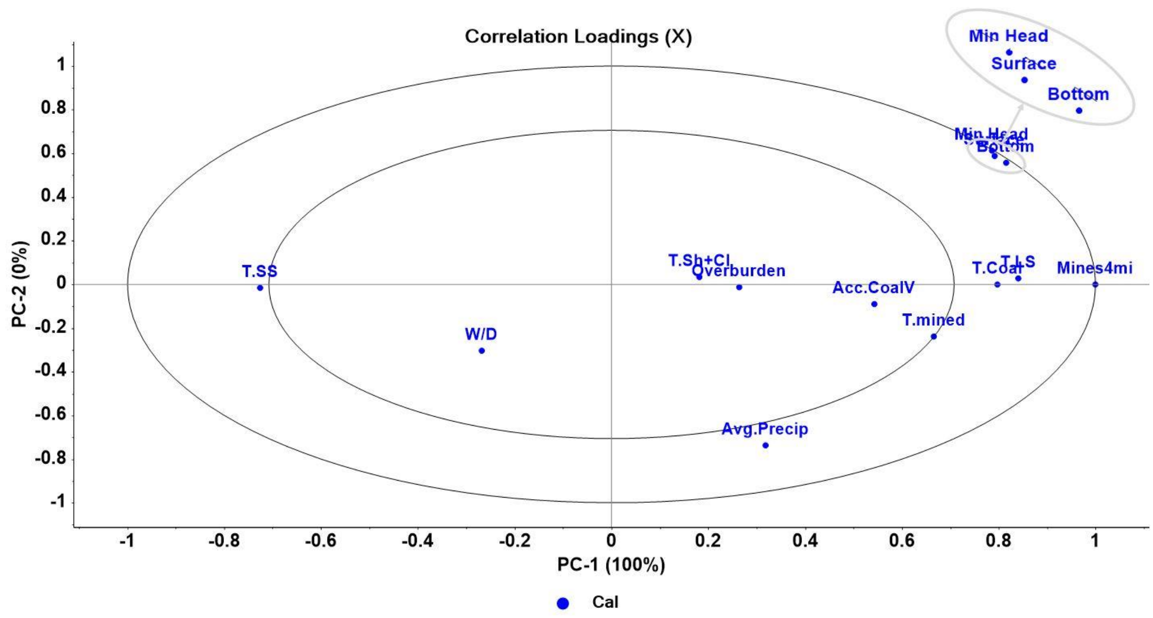

Figure C 57. Principal component analysis correlation loadings plot for the multi-mine with water withdraw minimum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft).

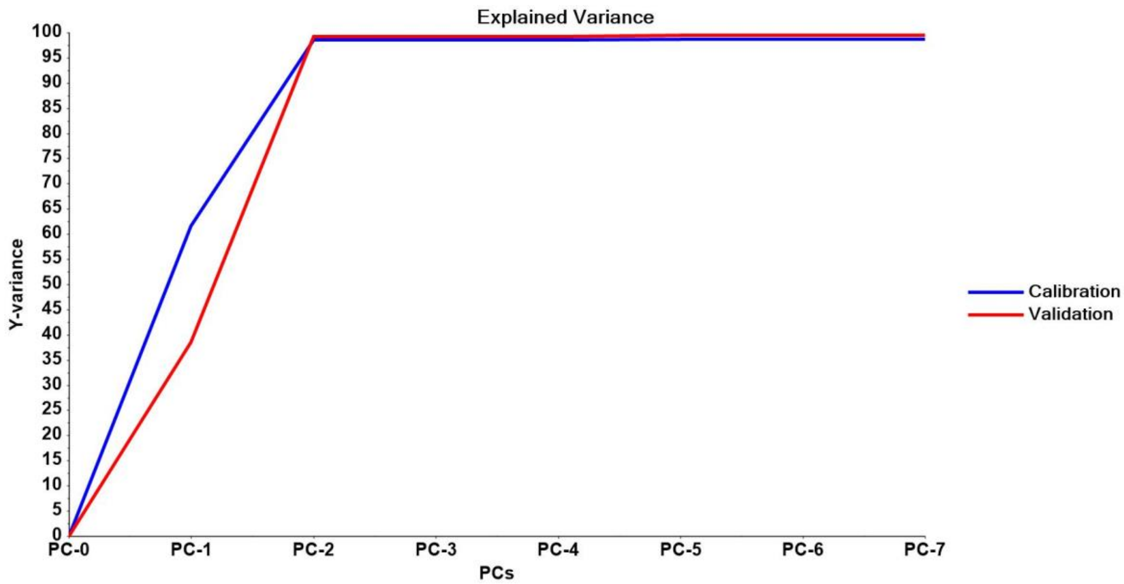

Figure C 58. Principal component regression explained variance graph for the multi-mine with water withdraw minimum potentiometric head model.

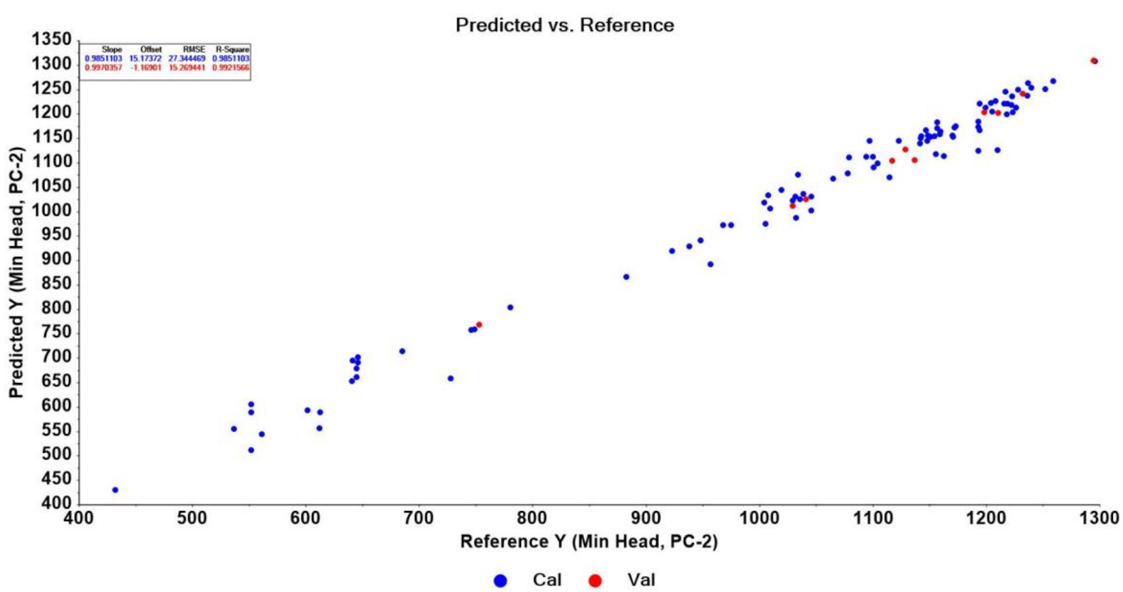

Figure C 59. Principal component regression predicted vs. reference plot for the multi-mine with water withdraw minimum potentiometric head model.

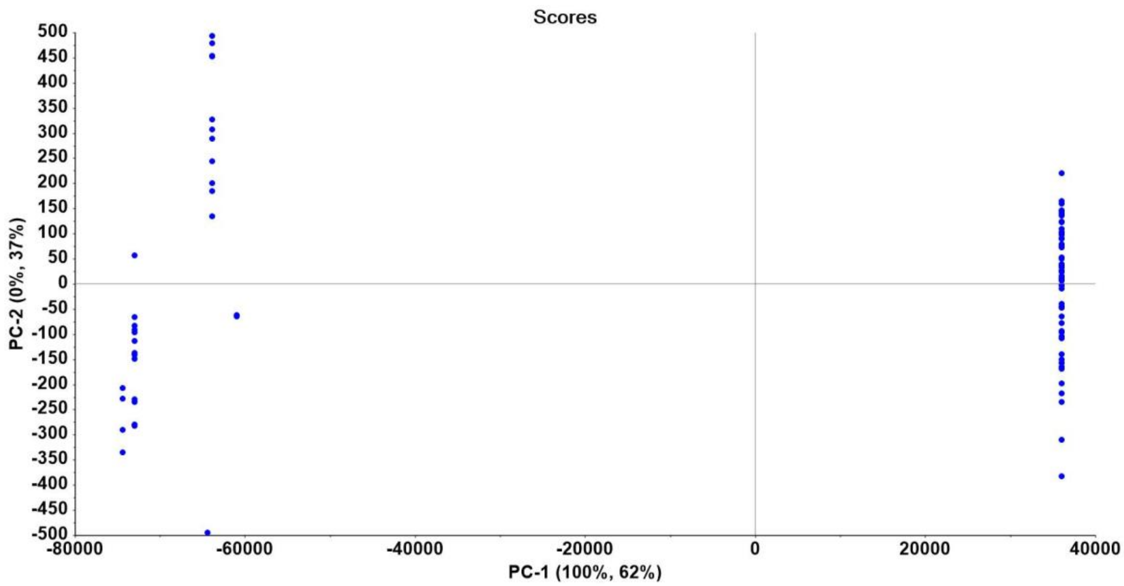

Figure C 60. Principal component regression scores plot for the multi-mine with water withdraw minimum potentiometric head model.

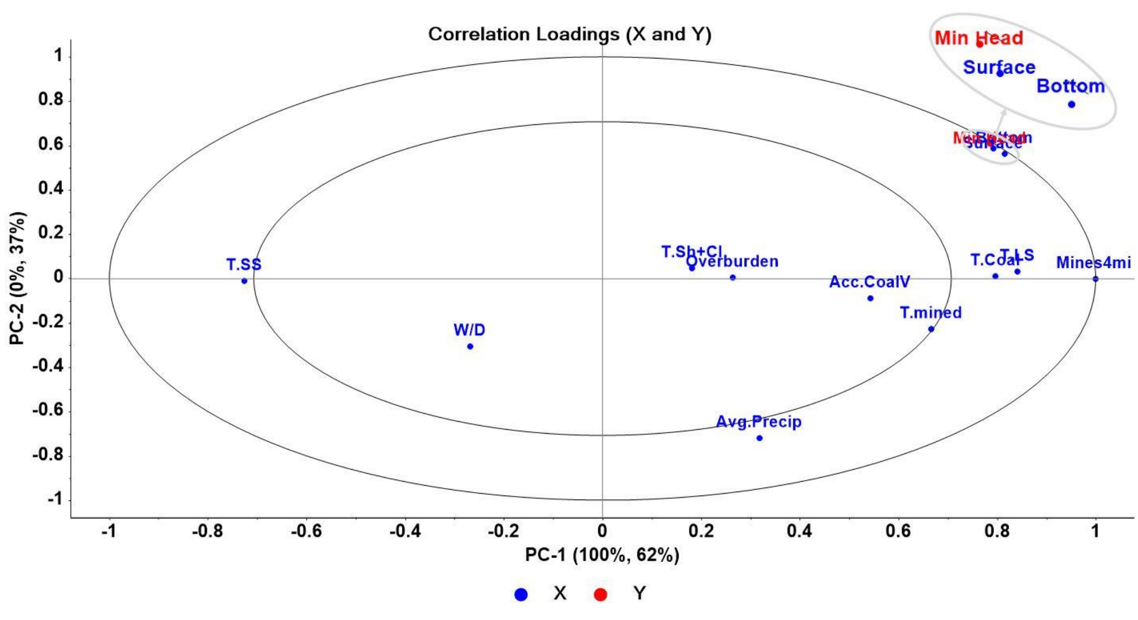

Figure C 61. Principal component regression correlation loadings plot for the multi-mine with water withdraw minimum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft).

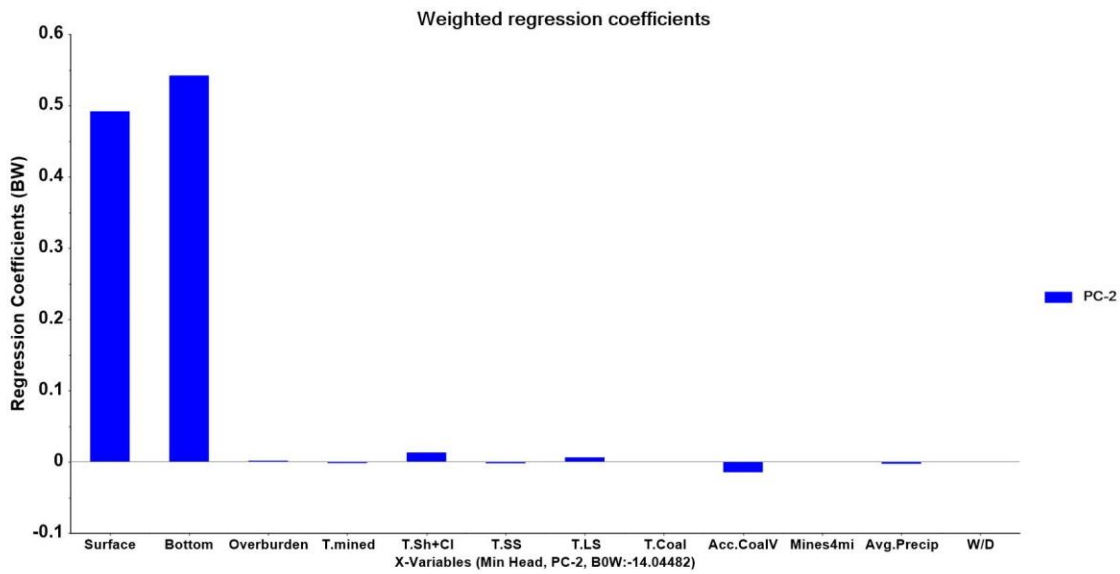

Figure C 62. Principal component analysis weighted regression coefficients chart for the multi-mine with water withdraw minimum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft).

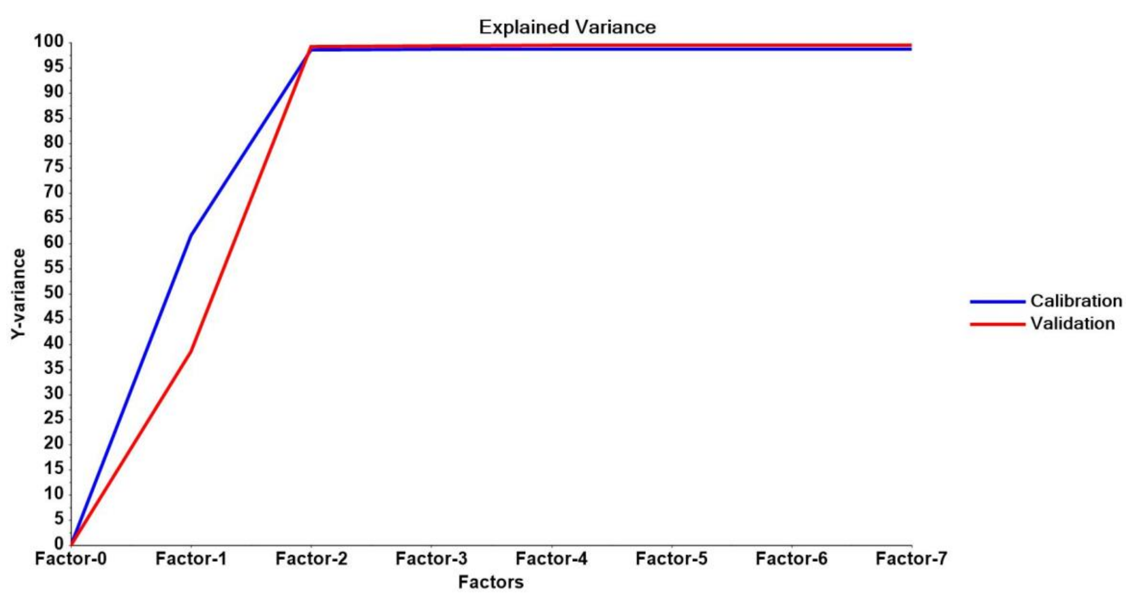

Figure C 63. Partial least squares regression explained variance graph for the multi-mine with water withdraw minimum potentiometric head model.

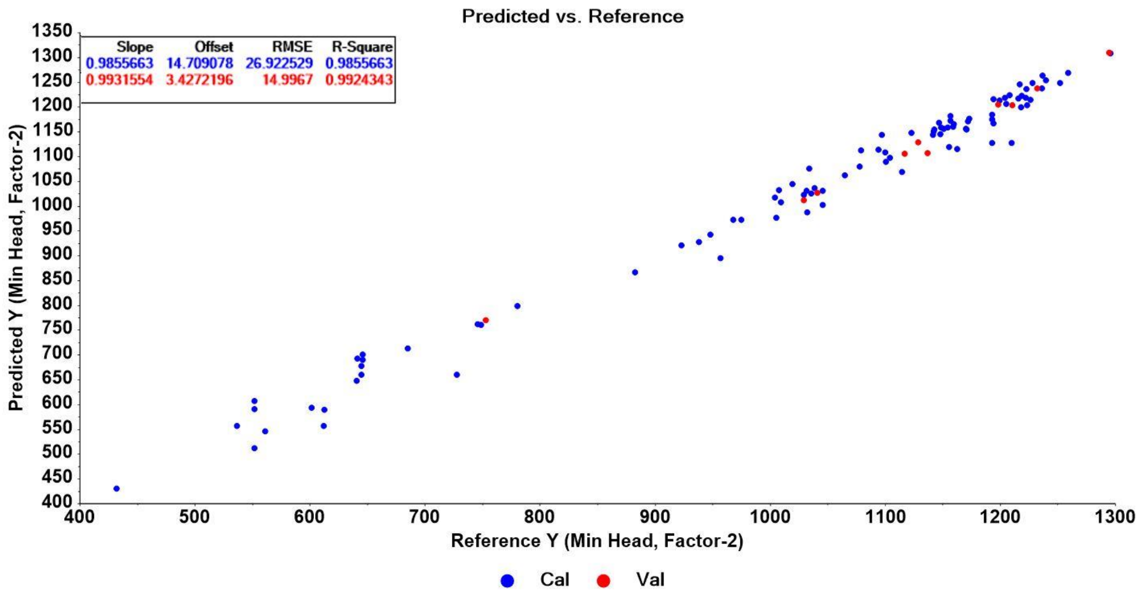

Figure C 64. Partial least squares regression predicted vs. reference plot for the multi-mine with water withdraw minimum potentiometric head model.

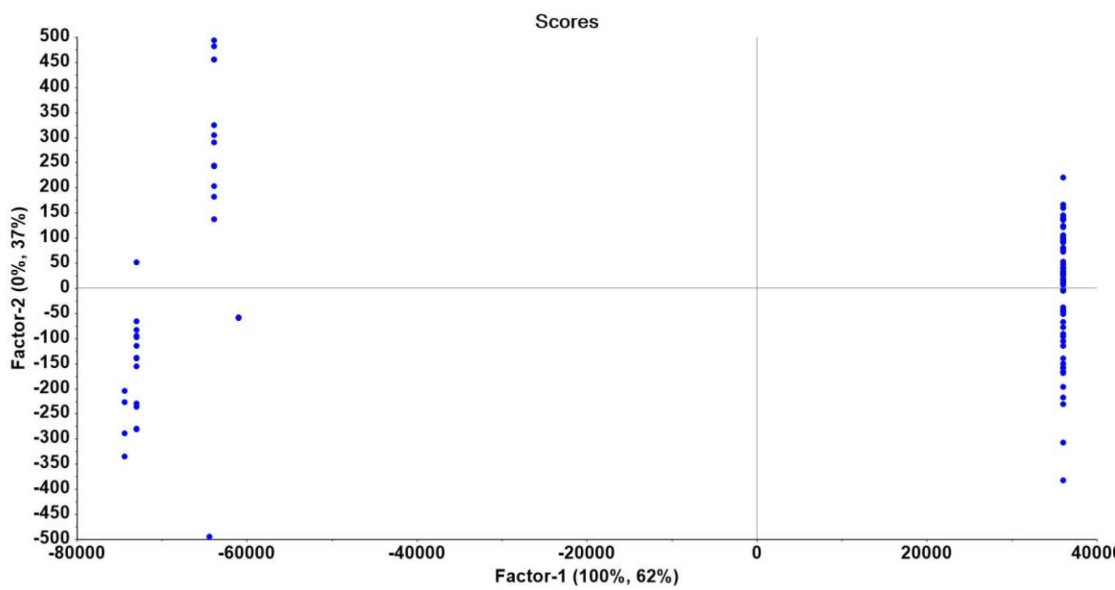

Figure C 65. Partial least squares scores plot for the multi-mine with water withdraw minimum potentiometric head model.

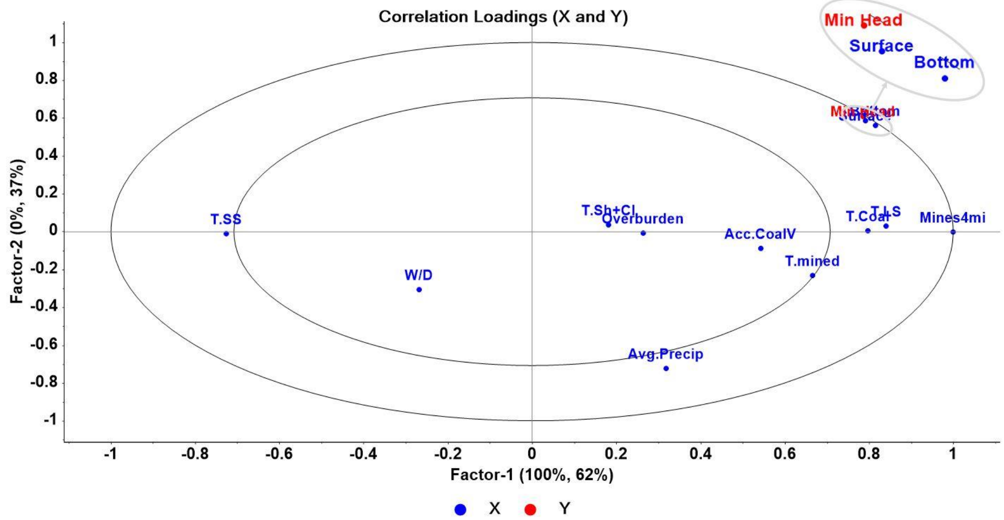

Figure C 66. Partial least squares regression correlation loadings plot for the multi-mine with water withdraw minimum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft).

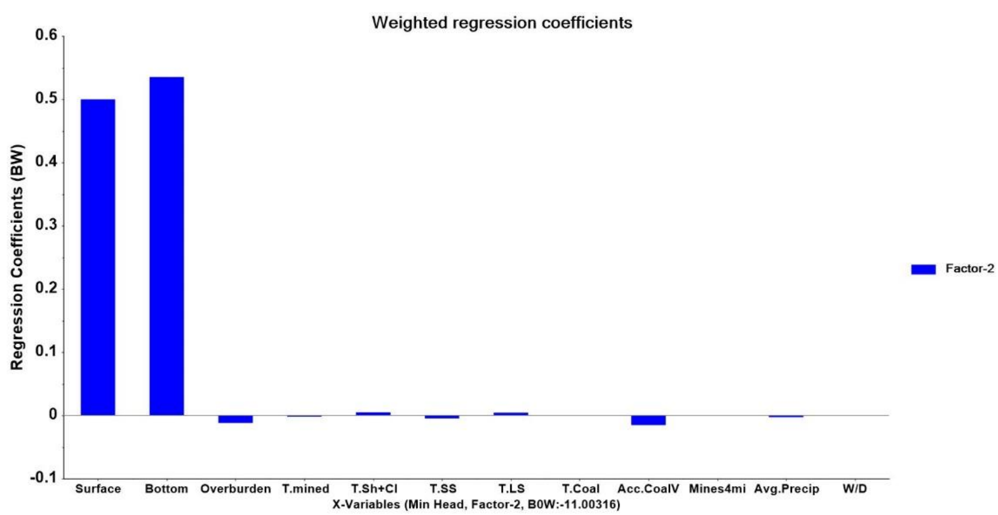

Figure C 67. Partial least squares regression weighted regression coefficients chart for the multi-mine with water withdraw minimum potentiometric head model. Parameters investigated: surface elevation (msl), bottom of well elevation (msl), thickness of shale + clay, sandstone, limestone, total coal, and mined coal seam (ft), overburden thickness (ft), accumulative coal volume (Mm^3), withdraw/distance (Mgal/day/ft)

Table C 13. Multi-mine with water withdraw maximum potentiometric head model regression coefficients.

Variable	PCR	PLS
β0	-14.327	-21.271
Surface elevation (msl)	0.505	0.520
Bottom elevation (msl)	0.559	0.547
Overburden thickness (ft)	-0.0241	-0.0181
Thickness of the mined coal seam (ft)	-1.74E-03	-1.67E-03
Thickness of shale + clay (ft)	5.97E-03	1.79E-02
Thickness of sandstone (ft)	-0.0154	-0.0192
Thickness of limestone (ft)	4.12E-03	3.88E-03
Total thickness of coal (ft)	-5.19E-04	-8.03E-04
Accumulative coal volume (Mm3)	-0.0180	-0.0184
Area of underground mines in a 4mile buffer (acres)	-4.01E-04	-4.07E-04
Average precipitation (in)	-2.67E-03	-2.80E-03
Withdrawal/Distance (Mgal/Day)/(ft)	-7.37E-07	-7.29E-07

Table C 14. Multi-mine with water withdraw minimum potentiometric head model regression coefficients.

Variable	PCR	PLS
β0	-14.045	-11.003
Surface elevation (msl)	0.492	0.500
Bottom elevation (msl)	0.542	0.535
Overburden thickness (ft)	0.0018	-0.0119
Thickness of the mined coal seam (ft)	-1.68E-03	-1.90E-03
Thickness of shale + clay (ft)	1.32E-02	5.07E-03
Thickness of sandstone (ft)	-2.01E-03	-4.81E-03
Thickness of limestone (ft)	6.22E-03	4.54E-03
Total thickness of coal (ft)	1.91E-04	-2.63E-04
Accumulative coal volume (Mm3)	-0.0146	-0.0152
Area of underground mines in a 4mile buffer (acres)	-3.07E-04	-3.00E-04
Average precipitation (in)	-2.55E-03	-2.72E-03
Withdrawal/Distance (Mgal/Day)/(ft)	-6.99E-07	-6.99E-07

Table C 15. Multi-mine with water withdraw maximum potentiometric head model goodness-of-fit index values for Nash-Sutcliffe efficiency, percent bias, mean absolute error, volumetric efficiency, root mean square error and relative index of agreement.

	NSE	PBIAS	MAE	VE	RMSE	rd
Ideal value	**1**	**0**	**0**	**1**	**0**	**1**
PCR	0.975	-1.45377E-06	1.594	0.998	37.121	0.987
PLS	0.976	-3.62899E-07	1.595	0.998	36.598	0.987

Table C 16. Multi-mine with water withdraw minimum potentiometric head model goodness-of-fit index values for Nash-Sutcliffe efficiency, percent bias, mean absolute error, volumetric efficiency, root mean square error and relative index of agreement.

	NSE	PBIAS	MAE	VE	RMSE	rd
Ideal value	**1**	**0**	**0**	**1**	**0**	**1**
PCR	0.985	-1.38292E-06	0.245	1.000	27.344	0.994
PLS	0.986	-2.51974E-07	0.201	1.000	26.923	0.995