GROUNDWATER MODEL UPDATE

DuPont Mine South Parcel Expansion Area

Project No. 040001-014 • June 2017

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Aspect CONSULTING

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1 Introduction

This report documents the updated analysis used to predict groundwater levels during and after the proposed dewatering and mining of the South Parcel at CalPortland's Pioneer Aggregate facility in DuPont, Washington.

The South Parcel is a proposed 171-acre mining expansion located west of the existing mine and south of the processing area (see Figure 1). Groundwater saturates the gravels of the South Parcel to within 20 feet of the ground surface. Mining will require pumping groundwater to dewater the gravels that are currently saturated. Dewatering and removal of the gravel will result in localized changes in groundwater elevations around the South Parcel.

The foundation of the groundwater analysis is a numerical groundwater model (DuPont model) developed specifically for the project. The DuPont model is based on the conceptual model for the groundwater system developed from extensive analysis of project-specific borings and investigations, as well as compilation and review of other geologic and hydrogeologic investigations in the DuPont area. After development, the model was calibrated to historically observed groundwater levels, then validated against additional historical data. Once the model was able to reliably reproduce historical conditions, the calibrated and validated model was then used to predict the changes in groundwater levels during and after the proposed expansion of mining.

This model represents an update to previous groundwater modeling analysis developed for the South Parcel (CH2M Hill 2003, Aspect 2004a, Aspect 2009a, Aspect 2009b, and Aspect 2014). It incorporates revisions to the mining plan, expansion of the model area, inclusion of seasonal and annual variability in climate and groundwater levels, and elements of the USGS groundwater model for the Chambers-Clover Creek watershed, including model boundary conditions and hydrogeologic layers at depth (Savoca et al., 2010; Johnson et al., 2011).

The model was first developed and calibrated to match existing measured conditions between 2004 and 2010, and then validated to the monitoring data collected through 2015. The model simulation of existing conditions formed the baseline from which changes in future groundwater levels under proposed scenarios can be measured. The model was then used in a series of predictive runs to simulate groundwater conditions at four different steps of dewatering during the proposed mining plan.

This report is organized into the following sections to reflect the process of model development, calibration, and use:

- Section 2 summarizes the groundwater modeling process.
- Section 3 presents a summary of the hydrogeologic conceptual model.
- Section 4 describes the model setup.
- Section 5 describes the model calibration and validation.

- Section 6 describes the DuPont model predictive analysis.
- Section 7 presents model predictions for future mining conditions.

2 Overview of Groundwater Modeling

This section provides an overview of general groundwater modeling methods and terminology, based on multiple sources (Fetter, 1994; Anderson and Woessner, 1992; Hill and Tiedeman, 2007).

Groundwater models are tools used to simulate and predict what cannot be measured directly. Groundwater models quantitatively simulate groundwater flow and groundwater levels using mathematical equations based on the well-established mechanics of fluid flow in porous media.

Generally, the process of developing and testing a robust groundwater model involves the following steps:

1) Monitor groundwater and surface water levels and compile information about area geology and hydrology from numerous sources.

2) Develop a conceptual model of area hydrogeology by interpreting the existing information.

3) Develop a numerical hydrogeologic model that represents the conceptual model.

4) Calibrate the numerical model to observed groundwater measurements.

5) Validate the numerical model with additional groundwater measurements.

6) Predict future groundwater conditions by simulating anticipated changes (e.g., adding pumping wells or changes in topography).

7) Update the model as new information is collected, and refine the model if necessary.

The foundation of a groundwater model is the “conceptual model” that describes the hydrogeologic system based on data collected during field investigations. The reliability of a groundwater model depends on the appropriate translation of the conceptual model into mathematical terms. For example, natural hydrogeologic systems typically include geologic layers with differing hydraulic characteristics (e.g., hydraulic conductivity, storage coefficient). A numerical groundwater model includes a three-dimensional (3-D) grid of cells. Layers with differing hydraulic parameters can be established within the 3-D model grid to best match the natural geologic layering. The influence of surface water features (e.g., creeks, lakes), and flow between groundwater and surface water, can also be simulated within the numerical groundwater model. Because natural hydrologic systems are always variable (heterogeneous) in both space and time, mathematic models are always simplifications of the natural system.

Groundwater models are evaluated based on how well they can reproduce historical observations. Adjustments to groundwater models are made during calibration to improve the comparison between observed and model-calculated conditions. In addition to the calibration process, there is a validation step that compares observed and model-calculated conditions outside the calibration timeframe. For a calibrated and validated model, the remaining differences between observed and model-calculated conditions are attributed to model bias and uncertainty, which are quantified using statistics.

Once calibrated and validated, the groundwater model is used to forecast conditions after incorporating anticipated hydrogeologic changes. The results of predictive models are interpreted within the context of the calibrated model bias and uncertainty. Post-modeling evaluation is used to provide more accurate forecasts of groundwater conditions, accounting for model bias to the extent practical, and identifying remaining prediction uncertainty.

The DuPont model is developed to predict groundwater level changes in response to the proposed mining plan, which includes active dewatering to accommodate mining, followed by cessation of pumping and establishment of a new hydrologic equilibrium condition. The results from the DuPont model are used for environmental evaluations and for design of the Monitoring Plan that will be followed during mining to directly measure groundwater level changes and thus allow ongoing assessment of, and adaptive response to, potential impacts. As described in this report, the DuPont model is a robust predictive tool developed based on hydrogeologic measurements collected from 2004 to 2015.

2.1 Model Setup

For three-dimensional, finite-difference groundwater models (like the DuPont model), the simulated aquifer system is digitized into a block of cells, including vertical layers of horizontal grids. Each cell is assigned information on cell dimensions, hydraulic conductivity, aquifer storage, and boundary conditions defined below:

- Cell dimensions are the length, width, and vertical thickness of the cell, which may vary with neighboring cells;
- Hydraulic conductivity describes the rate at which water can move through soils represented by the cell, typically distinguishing the horizontal and vertical values (in stratified soils, hydraulic conductivity is typically higher in the horizontal direction, along bedding, than vertically across the bedding);
- Aquifer storage describes the amount of water that can be stored in (or drained from) soils within the cell, typically distinguishing the confined and unconfined values; and
- Boundary conditions are the assigned mechanisms that result in cell-specific flux of water into or out of the model, and can change over time. Boundary conditions may include recharge from precipitation, groundwater underflow from outside the model domain, infiltration from surface water into the groundwater system, drainage from groundwater to surface water, well discharge, etc. Along the sides of a model domain that are parallel to the regional groundwater flow direction, no-flow boundary conditions can be established in a model; where used, no-flow boundary conditions are positioned far enough from areas within the model domain that are of primary interest for a project so that they do not artificially affect the model simulations in that area.

A “steady-state” model simulates average groundwater flow and levels assuming average hydrologic conditions over a specified time period without a change in aquifer storage –

it does not simulate changes over time. Conversely, a “transient” model simulates changes in aquifer storage, groundwater flow, and groundwater levels over time, based on specified changes in boundary conditions. Transient groundwater models are composed of multiple stress periods, and each boundary condition is specified for the length of each stress period. For example, each monthly stress period may specify a groundwater recharge rate based on the monthly rates of incident precipitation, runoff, and evapotranspiration.

A numerical groundwater model calculates a water balance for each cell within the model. For transient models, the water balance is calculated for each cell in each stress period. Because of the large number of calculations involved, groundwater models rely on numerical methods. These numerical methods allow for some small degree of approximation to provide a solution within a reasonable time. For example, a groundwater model may achieve a solution when the difference between calculated groundwater level changes is less than 0.01 foot, and the change in aquifer storage is less than 0.1 percent of the total calculated water balance.

2.2 Calibration

Model calibration is a standard component of groundwater modeling involving a systematic adjustment of cell-specific values assigned for less certain or spatially variable hydraulic parameters (such as hydraulic conductivity) to yield model-calculated groundwater levels that best match observed groundwater levels and minimize model bias. During calibration, adjusted parameter values should remain within a range that is considered reasonable based on the conceptual model.

When further parameter adjustment does not improve the model calibration, the remaining difference between calculated and observed groundwater levels, also called “residual,” is attributed to model bias. The uncertainty in model results are quantified using residual statistics, such as the mean residual, the standard deviation of residuals, and the root mean square error of residuals. These statistics may be applied to the entire set of available data to describe the overall model calibration, or applied to groups of available data to describe spatial and temporal differences in model calibration.

Calibrated model results may be further refined using residual statistics to offset model bias. Deterministic regression methods (e.g., well-specific trend-line analysis) may be used where there is sufficient observation data.

Model bias in a calibrated groundwater model is typically due to a combination of causes. These potential causes of model bias are described below.

Conceptual Model. A groundwater model is a mathematical representation of the conceptual model. Elements missing from the conceptual model are not simulated, and may present as potential model bias during calibration.

Model Discretization. A groundwater model is a collection of cells and stress periods, and the properties within these units are averaged over space and time. The cell size defines the “averaging volume”, while the stress period length defines the “averaging period”. Differences within an averaging volume or averaging period are not simulated, and may present as potential model bias during calibration.

Assumptions. A groundwater model requires assumptions beyond the available data. For example, a model requires information on subsurface conditions between and beyond a network of wells. Making informed hydrogeologic assumptions based on available data is an important element of the modeling process, and may present as potential model bias during calibration.

2.3 Validation

Model validation involves testing a calibrated model for a set of conditions outside the calibration period. The purpose of model validation is to demonstrate the reliability of model results and analysis.

During groundwater model validation, the cell dimensions, hydraulic conductivity, and aquifer storage parameters remain the same as determined in the calibration process. The boundary conditions are modified to reflect changes in recharge rates, groundwater underflow, and surface water infiltration. Then, the calculated and observed groundwater levels are compared to assess model bias, and model bias is evaluated for consistency between the calibration period and the validation period. If the residual statistics are sufficiently similar, then the model is considered validated for those conditions tested.

2.4 Model Bias and Uncertainty

A groundwater model is necessarily a simplified mathematical representation of complex subsurface physical conditions and does not perfectly represent the real-world groundwater behavior. As such, the use of any model introduces bias and uncertainty that the numeric results are exactly correct.

One measure of the uncertainty of a groundwater model is its ability to reproduce the observed data set used for validation. Systematic differences between observed and calculated conditions are due to model bias. For example, model bias helps explain why groundwater levels are generally calculated higher than observed at a given location, and we can objectively adjust model results to account for model bias. Model uncertainty is defined as the “random” differences between observed and model-calculated conditions. For example, model uncertainty helps explain why groundwater levels were calculated higher than observed during some periods, and lower during others. We don’t attempt to adjust model results for uncertainty, but it helps qualify the results. Model uncertainty can be expressed as a range around a specific model result that we can expect the actual groundwater levels to be within.

Additional uncertainty occurs when the model is used for predicting scenarios outside the range of observed baseline conditions. Some examples are:

- Spatial distance – there is greater uncertainty in model predictions for locations at greater distance from existing wells.
- Climatic conditions – there is greater uncertainty when climate conditions are different from those experienced in the calibration and validation periods.
- Decrease in water levels with dewatering – there is greater uncertainty where the decrease in water levels resulting from dewatering is beyond the range of observed water levels.

2.5 Predictive Analysis

Predictive groundwater models use the calibrated and validated model to forecast groundwater conditions associated with a change in hydrogeologic conditions. Some forecasted conditions, such as groundwater levels, can eventually be measured whereas others, such as surface water infiltration, cannot be directly measured. The results of the calibrated/validated model establish “baseline” conditions, and are compared with results from predictive models. This type of difference analysis is typically sufficient for most groundwater model applications (e.g., Johnson et al, 2011). Predictive model results should be interpreted within the context of model bias and uncertainty to make fully-informed decisions.

Predictive model results may be refined to offset model bias. Modified well-specific trend-line analysis, based on the calibrated and validated model refinement and informed by additional constraints, may be used to improve prediction accuracy. Model uncertainty may be quantified based on the calibrated and validated model residual statistics. When a predictive model calculates conditions outside the range of those observed, the model uncertainty increases.

3 Hydrogeologic Conceptual Model

The conceptual model describes the physical geologic and hydrologic conditions understood to exist around the proposed mine expansion. It forms the basis for the numerical model developed to predict groundwater changes as a result of the proposed mining project.

The following sections describe the conceptual understanding of the surface and groundwater system in the project area as it relates to the groundwater model development and predictive analyses. Figures 1, 2 and 3 provide, respectively, a plan map, geologic map and hydrogeologic cross-section for the project area.

3.1 Vashon Outwash Aquifer

The South Parcel expansion lies within a thick glacial outwash sequence near Puget Sound, just north of the Sequalitchew Creek canyon, and east-southeast of the existing mine (Figure 2). The outwash includes the surficial, coarse-grained Steilacoom Gravel flood deposits, overlying older Vashon outwash; the outwash sequence overlies the low-permeability Olympia Beds (Qob) interglacial unit.

The underlying Qob is absent west of a line (termed Qob Truncation and shown in purple on Figures 1 and 2) located on the order of 1,500 to 3,000 feet inland from the current Puget Sound shoreline. During the time of the Vashon glaciation, the Qob's western extent was the shoreline. The shoreline was extended westward to the current configuration during the waning stages of the Vashon glaciation, when glacial outburst flooding deposited a thick deltaic sequence of Steilacoom Gravels into ancestral Puget Sound. Consequently, Steilacoom Gravels extend from ground surface to below sea level west of the Qob Truncation.

The occurrence/non-occurrence of the Qob creates a unique hydrogeologic condition. Groundwater in the outwash east of the Qob Truncation is held up by the occurrence of the thick, low permeability Qob deposits. The cross section (Figure 3) illustrates the steep hydraulic gradient that occurs where the groundwater drops over this feature within the current mine site. As the groundwater flows westerly over the Qob Truncation, it drops roughly 160 feet in 800 feet (0.2 ft/ft) through the permeable gravels to near sea level. Therefore, the water table is found at relatively shallow depths of 15 to 25 feet in the South Parcel area. West of the Qob Truncation, the water table is found at a depth of roughly 190 feet in the existing mine.

Monitoring of groundwater levels began in 2000 with a series of groundwater monitoring wells installed within and around the South Parcel. Groundwater levels in the Vashon Aquifer typically fluctuate 6 to 8 feet in response to seasonal precipitation patterns and annual variations. However, groundwater levels in the central marsh area fluctuate over a more limited range of 2 to 3 feet, whereas monitoring well CHMW-3S, on the south end of the South Parcel, fluctuates greater than 15 feet of seasonally (Aspect 2007). In addition, monitoring conducted for the adjacent Fort Lewis Landfill 5 and DuPont Works Consent Decree area indicate groundwater level variations on the order of 10 feet (URS 2000; URS 2003).

Five pumping tests were conducted along the east side of the proposed South Parcel mine expansion area to determine hydraulic properties of the outwash aquifer throughout its depth (CH2M Hill, 2000). These testing data, along with studies conducted for Fort Lewis Landfill 5 (Woodward-Clyde Consultants, 1991) and the Former DuPont Works site (URS, 2003), provide baseline hydraulic parameters for the Vashon Aquifer used as a starting point in development of the numerical groundwater flow model.

The surficial Steilacoom Gravels are highly permeable and are known to rapidly infiltrate precipitation and stormwater; the veneer of topsoil covering the Gravels is finer grained (can contain volcanic ash) and thus has lower infiltration capacity. The gravels form a relatively flat outwash plain in the area, in the center of which is a series of large wetlands—referred to as Bell, McKay, Hamer, and Edmond Marshes (Figure 1). These wetlands occur in areas where large ice blocks, stranded during the glacial flood outbursts, later melted forming kettle depressions lined with finer-grained, lower-permeability materials. These features store water for a much longer time relative to the rapidly infiltrating gravel outwash around these features. The wetland sediments from throughout the wetland complex were sampled and lab tested for permeability, and these data were used for simulating the wetland areas in the numerical groundwater model.

For purposes of developing the numerical groundwater model, the Vashon Aquifer is represented by two principal zones with distinct permeabilities, separated by a relatively lower permeability zone. The upper zone is comprised of the Steilacoom Gravel, which occurs from groundwater surface to an elevation of approximately 180 to 168 feet above mean sea level and, based on model calibration, has a hydraulic conductivity ranging from 35 to 3,900 feet/day within the model area. At that elevation, there is a lithologic change sometimes indicated by a slightly siltier zone or a slight increase in density during drilling. Below this siltier zone lies the deeper portion of the Vashon Aquifer, comprised of sand and gravel that, based on model calibration, has a lower average permeability, ranging between 0.3 and 49 feet/day. The deeper outwash zone occurs to the depth of the Qob, which occurs at an average elevation of 110 to 120 feet. The two aquifer zones are differentiated on Figure 3 by a dashed line within the Vashon Aquifer in the area of the mine site.

3.2 Connection of Aquifer with Wetlands and Springs

The principal drainage features in the Sequalitchew Creek watershed include Sequalitchew Creek, the Fort Lewis Diversion Canal, and the series of interconnected wetlands through which these drainages flow (see Figure 1). The bulk of the surface water originates at Sequalitchew Lake and from several Fort Lewis stormwater facilities located on the southeast project boundary. The Diversion Canal drains excess surface water from Sequalitchew Lake and the upper marshes (Bell, Hamer and McKay) to Puget Sound, and Sequalitchew Creek provides additional drainage of Edmond Marsh and, to a limited degree, the upper marshes during high-precipitation periods.

Since 2000, monitoring data have been collected to understand the hydraulic connection of the groundwater system with the area wetlands and Sequalitchew Creek system. The monitoring data indicate hydraulic connection between surface water and groundwater through the wetland complex within the upper Sequalitchew Creek drainage. Hydraulic connection is observed by similar water elevations, fluctuations, and time-trends at paired surface water and groundwater monitoring stations. Hydraulic connection is also indicated in the middle reaches of Sequalitchew Creek where springs (groundwater) discharge to the ravine throughout most of the year. Sequalitchew Creek infiltrates water to the groundwater system in its lowermost reaches.

The monitoring data also indicate that the core wetland areas are generally underlain by fine-grained, low-permeability peat and silt deposits that hold water (Aspect, 2004). Where these peat deposits occur, the amount and rate of surface water that can leak into the groundwater system due to potential future groundwater drawdown would be limited by the natural low permeability of the underlying silts and peats. In other areas, development has removed the naturally low-permeability soils from historical wetland areas; the removal of peat and/or the natural heterogeneity of the soil materials, can create an avenue for greater hydraulic connection and thus wetland response to groundwater change. A summary of our understanding of the hydraulic connection of the groundwater system with the upstream marsh areas is provided below.

3.2.1 Sequalitchew Lake and East Edmond Marsh

The Sequalitchew Lake level is believed to be an expression of the water table, and the monitoring data at the outlet indicates year-round hydraulic connection between the surface water and groundwater in this area.

The principal water supply for Joint Base Lewis-McChord (JBLM) occurs on the eastern side of Sequalitchew Lake where Sequalitchew Springs are located, which are reported to yield as much as 9,000 gallons per minute (gpm) (approximately 20 cubic feet per second [cfs]). Most of the time the springs provide more flow that needed by JBLM for water supply, resulting in surface water outflow from the Lake passing over the Diversion Weir and into the Diversion Canal.

3.2.2 Upstream Marshes—Bell, Hamer and McKay

Surface water levels higher than groundwater levels indicate an influx of surface water in the wet season, with dropping surface water and groundwater levels in the dry season.

3.2.3 Edmond Marsh

Throughout Edmond Marsh, there is connection between surface water and groundwater; however, the connection is greater in the more easterly monitoring stations than in the west marsh area. In the central and eastern areas, stations EM-3 and EM-2 are located adjacent to roadways that, during their construction, may have excavated out the peat deposits. In addition, the creation and maintenances of a channel for Sequalitchew Creek through Edmond Marsh during the years when a fish hatchery operated in Sequalitchew Lake likely disturbed or removed portions of the peat deposits. The westernmost station EM-1 has the least amount of hydraulic connection, presumably because the underlying peat materials are still in place.

These monitoring data indicate an influx of stormwater in the wet season fills the wetland area. Beaver dams help to maintain marsh surface water levels higher than groundwater levels beneath the marshes during the wet season. During the dry season, the surface water and groundwater levels drop. The west end of Edmond Marsh completely dries each year by late spring.

3.2.4 Southern Lakes

A group of lakes (e.g., Grant Lake, Pond Lake, Old Fort Lake and several others) are located in the southwestern most study area. Monitoring data indicates these are water table lakes whose surfaces fluctuate with the groundwater level.

3.2.5 Groundwater Discharges to Sequalitchew Creek Ravine

Groundwater discharges from the Vashon Aquifer as springs in the Sequalitchew Creek ravine below elevations of approximately 195 feet down to the top elevation of the Qob deposits at elevation between approximately 100 to 120 feet, which spans a creek reach of approximately 0.7 miles. Based on stream gaging data, this groundwater discharge varies between approximately 0.5 cfs in the summer to 1.5 cfs in the winter. Progressing downstream past the Qob Truncation, Sequalitchew Creek becomes a losing stream as the water table drops through the outwash to near sea level.

3.3 Deeper Aquifers

Beneath the Qob is the regionally extensive and highly productive Sea Level Aquifer, which occurs throughout the DuPont area between elevations of roughly 50 and -100 feet relative to mean sea level. The Sea Level Aquifer is generally confined beneath the Qob aquitard, and has very limited hydraulic connection with the shallower Vashon Aquifer. West of the Qob Truncation, the Sea Level Aquifer becomes unconfined and its groundwater merges with flow from the Vashon Aquifer in the accumulation of Steilacoom Gravels extending below mean sea level (sometimes referred to as the unconfined Sea Level Aquifer; URS, 2003). Groundwater in the Sea Level Aquifer discharges to Puget Sound via intertidal and subtidal seeps. The Sea Level Aquifer is the City of DuPont’s primary water supply source, with their Bell Hill wells No. 1 and No. 3 and Hoffman Hill wells No. 1 and No. 2 completed in it.

Below the Sea Level Aquifer and underlying aquitard unit is a deeper glacial aquifer unit, sometimes termed the Lakewood Aquifer, in which the City of DuPont’s Bell Hill No. 2 is completed.

Below the Lakewood Aquifer, two deeper glacial aquifer units separated by interglacial aquitard units were observed during drilling of CalPortland’s 1,000-foot-deep water well for the aggregate processing plant. CalPortland’s well is completed in the deepest observed aquifer unit, screened between elevations of -685 and -770 feet.

4 Setup of Updated Model

The DuPont model represents a significant update to previous numerical groundwater models used on this project (CH2M Hill 2003, Aspect 2004a, Aspect 2009b)). The updates include changes to the model time period, structure and extent, calibration process, and mining plan scenarios.

Previous models were calibrated to an average “steady-state” condition. The updated model is a transient model calibrated to monthly hydrologic measurements collected from March 2004 through December 2010, and validated to measurements collected through December 2015. The model extent was also expanded to include the area west of the Olympia Beds (Qob) Truncation to Puget Sound to allow for simulation of groundwater discharges in the western portion of the project area. The model also now incorporates deeper geologic layers including the Sea Level Aquifer.

In 2010 and 2011, the USGS published a regional groundwater model that provides additional information outside the boundaries of the prior model, allowing us to supplement our site-specific hydrogeologic data with data from the greater Chambers-Clover Creek watershed (Savoca et al., 2010; Johnson et al., 2011). Elements of the USGS model were spatially correlated and numerically transcribed to the DuPont model.

The DuPont model was calibrated to groundwater conditions based on monitoring data from 2004 to 2010, and validated based on monitoring data through 2015. Overall, these 2004 to 2015 groundwater conditions are referred to as the “baseline.” The calibration process used a state-of-the-science parameter estimate program (PEST) and is discussed in Section 5.

The DuPont model was then used to predict groundwater conditions during and after mining. Predictive scenarios representing the major steps in mining and dewatering were developed based on the current mining plan, which differs from prior models in that it no longer includes construction of a north fork of Sequalitchew Creek. Four predictive scenarios representing the planned mining steps (hereafter referred to as Steps 1, 2, 3, and 4) were developed and simulated.

4.1 Model Code

Groundwater flow equations were calculated using the program MODFLOW-SURFACT, version 3 (Hydrogeologic, 2012). This program is better suited than traditional MODFLOW programs for simulating the partially saturated flow conditions that are anticipated will be caused by the proposed mining of the South Parcel. An earlier version of the same software was used for previous modeling efforts.

The DuPont model was developed using an industry-standard computer program, Groundwater Vistas, version 6 (ESI, 2011), as a pre- and post-processor. An earlier version of the same software was used for previous modeling efforts.

The DuPont model was setup to minimize numerical error and provide for a practical computational run time. The head convergence criterion was set to 0.01 feet, which is a setting typical for groundwater models. The cumulative mass balance error was limited to 0.02 percent, which is more stringent than the 0.1 percent criterion for an “ideal” model

(Anderson and Woessner, 1992). The DuPont model requires up to 18 hours for a computational run.

4.2 Model Extent and Grid

Relative to earlier versions of the model, the DuPont model was expanded to simulate boundaries further from the South Parcel, so as to reduce the effects of model boundaries on the central area of interest. The model extent is shown on Figure 4 and the inset shows the DuPont model extent within the context of the regional USGS model extent. Compared to previous models, the DuPont model was expanded to the northwest to include the area beyond (downgradient of) the Qob Truncation. Inactive cells along the northeast and southeast model extents were converted to active cells to include a portion of American Lake as a well-defined surface water boundary condition. Model results for areas closer to the model extents are considered less accurate due to the proximity of model boundaries.

The DuPont model grid coordinate system was updated to be consistent with the project coordinate system and to provide quality assurance for model construction and interpretation of model results. The model horizontal datum is NAD 83 State Plane South in feet. The model vertical datum is NGVD 29 in feet. The model was rotated and offset to better align with the predominant groundwater flow direction. The grid was rotated 44.45 degrees counter-clockwise; and model x,y coordinates were offset 1,097,483 feet east and 653,755 feet north, respectively. The model coordinate, elevation, and offset information allows for georeferencing of model results.

The grid in the DuPont model was refined to reduce potential numerical error and allow greater spatial resolution in results. Grid spacing in the DuPont model was halved from previous models, with a range from 50-foot spacing across the mine property up to a maximum of 250-foot spacing at the model boundaries. This spacing resulted in 268 rows and 198 columns across the DuPont model domain, creating 53,064 cells in each layer and a total of 477,576 cells in the model.

4.3 Model Layers

The DuPont model was constructed with nine layers to simulate five hydrostratigraphic units, which is consistent with the upper five hydrostratigraphic units identified in the USGS model (Johnson et al., 2011). The five hydrostratigraphic units simulated in the DuPont model are, from the surface down:

- Steilacoom Gravel;
- Upper Confining Unit;
- Vashon Outwash;
- Olympia Beds; and
- Sea Level Aquifer.

Table 1 provides a brief description of the hydrostratigraphic units simulated in the model. Figure 7a through 7e provides the thickness and extent of the five hydrostratigraphic units. Other reports provide a more detailed description of the hydrogeologic conceptual model for the project area, including the hydrostratigraphic units (Aspect, 2004a; Savoca et al., 2010; Johnson et al., 2011). Each hydrostratigraphic unit was simulated as two layers in the model, except the Upper Confining Unit, which was simulated with one layer. Using two model layers allowed integrating the information from co-located monitoring wells into the calibration of vertical hydraulic conductivity within a hydrostratigraphic unit.

4.3.1 Model Top Elevation

The ground surface elevation, shown on Figure 5, was based on available LiDAR surveys and represents the top elevation used in the DuPont model. This surface topography was used in the baseline and predictive simulations of future mining Steps 1 through 3. For future mining Step 4, the surface topography was modified within the South Parcel as shown in Figure 6 to reflect the changes from mining.

4.3.2 Hydrostratigraphic Units

The hydrostratigraphic units and their contact elevations were inferred from the network of mine exploration borings, off-property monitoring well logs, and area-wide cross sections including those developed for the DuPont Mine (Aspect 2004b) and the USGS model (Savoca et al., 2010; Johnson et al., 2011). Where a hydrostratigraphic unit is simulated using two layers, each layer is of equal thickness.

Model Layers 1 and 2 generally simulated the Steilacoom Gravel across the model extent, except where it was inferred to be absent. The areas of greater hydraulic conductivities in Layers 1 and 2 reflect Steilacoom Gravel, whereas areas of lesser hydraulic conductivities reflect glacial till deposits at the surface (Burke Hill, for example) or erosion through deeper hydrostratigraphic units (Sequalitchew Ravine, for example) (Figure 7a). The Steilacoom Gravel was simulated in all layers west of the Qob Truncation, where the main flow channel for the glacial outburst floods was inferred to have discharged.

East of the Qob Truncation, Layer 3 generally simulates a thin layer of finer-grained material (relative to the Steilacoom Gravel above and Vashon Outwash below), and is referred to as the Upper Confining Unit in this report. The lack of obvious till in the borings from the DuPont Mine led us to infer that the Steilacoom Gravel flood outwash may have eroded away most, if not all, of the till within the main flow channel. This is consistent with the hydrogeologic interpretation established for Parcel 1 of the Former DuPont Works Site located south of Sequalitchew Creek (URS, 2003). The USGS mapped till deposits on either side of the main flow channel, and we included that till in our model (see Figure 21 in Johnson et al., 2011). During model calibration, the model did not replicate observed water levels in the Steilacoom Gravel without a finer-grained layer within the flow channel, consistent with the USGS geologic interpretation. Figure 7b shows the Upper Confining Unit east of the Qob Truncation, and Steilacoom Gravel west of the Qob Truncation.

Layers 4 and 5 simulate the Vashon Outwash east of the Qob Truncation, as shown in Figure 7c. Layers 6 and 7 simulate the Olympia Beds east of the Qob Truncation, as shown in Figure 7d. Layers 8 and 9 simulate the Sea Level Aquifer east of the Qob Truncation, as shown in Figure 7e.

The Sequalitchew Creek ravine is an erosional feature created after deposition of the Steilacoom Gravel. As such, the ravine was simulated as cutting through the hydrostratigraphic layers as it descends toward sea level.

In the predictive model simulating the post-mining condition, the hydrostratigraphic units are modified to reflect the effects of mining as described in Section 5.

4.4 Aquifer Parameters

An initial range in aquifer parameter values (including horizontal hydraulic conductivity, vertical hydraulic conductivity, specific yield, and specific storage) was defined for each hydrostratigraphic unit based on data developed in previous studies (Aspect, 2004a; Aspect, 2004b). Aquifer parameter values for the model layers were calibrated using the process described in Section 5 to minimize the difference between observed and model-calculated groundwater levels. The calibrated average values are provided in Table 1.

The DuPont model was updated to allow spatial differences in hydraulic conductivity within a hydrostratigraphic unit. Allowing hydraulic conductivity to vary in this updated model permitted better calibration to the observed transient conditions (note that prior models were steady state and assumed homogeneous hydraulic conductivity within each hydrostratigraphic unit). The spatial distribution of final calibrated hydraulic conductivity is shown for the Steilacoom Gravel hydrostratigraphic unit, the Upper Confining Unit hydrostratigraphic unit, and the deeper Vashon Outwash hydrostratigraphic unit on Figure 8a through 8d.

Other parameters (specific yield, specific storage, and vertical anisotropy—the ratio of vertical to horizontal hydraulic conductivity) were held spatially constant within a hydrostratigraphic unit, as they had been in prior models. Vertical conductivity is calculated based on the horizontal conductivity, which varies spatially, and the vertical anisotropy, which does not. As such, vertical conductivity varies spatially within a hydrostratigraphic unit.

4.5 Model Calibration and Validation Timeframes

The DuPont model calibration timeframe was updated to simulate the period of monitoring from March 2004 through December 2010. The DuPont model simulates 82 monthly stress periods[1], preceded by one "lead-in" period of average conditions for the entire period. The first stress period was included to simulate steady-state average conditions, similar to previous models, and improve the model calibration process.

The roughly 6-year model calibration timeframe is robust in comparison with prior versions of the model and the recent work by USGS. The transient USGS model simulated the 24-month period from September 2006 to August 2008, which was preceded by a 3-year lead-in period.

[1] Stress periods are a time interval within the model when conditions change. Stress periods include multiple time steps for computational purposes, but conditions such as precipitation, pumping rates, or lake water levels only change at the beginning of the stress period.

The DuPont model validation timeframe was updated to simulate the period of monitoring from March 2004 through December 2015, or 142 monthly stress periods. This longer timeframe provided the baseline groundwater conditions for predictive analysis.

The validation timeframe overlaps the calibration timeframe because of a change in the precipitation data source. The model was calibrated using precipitation data from McMillin Reservoir, but beginning in 2012 this data source became unreliable, with significant gaps in coverage. For model validation, the precipitation data source was changed to the PRISM estimates for the McMillin Reservoir (details are presented in Section 4.6.1) for the entire validation period (2004-2015). Using the full period of record for validation allows for validation of the change in precipitation source as well as validating the model in additional years.

The validation period reflects a range of weather conditions, including both relatively wet and relatively dry years, as shown on Figure 9. Figure 9 shows the DuPont model timeframe compared to the USGS model timeframe, within the context of historical annual precipitation. The predictive models used the same 2004 to 2015 timeframe as the baseline model, but with different boundary conditions as noted below. Predictive models simulated dewatering and/or surface drainage during the initial stress period, so as to provide the maximum predicted change in groundwater levels for each phase of mining.

4.6 Boundary Conditions

Model boundary conditions were assigned to best simulate the observed or inferred hydrogeologic conditions, as described below. The predictive models used boundary conditions identical to the baseline model, except as noted below.

4.6.1 Recharge—Net Precipitation

Monthly-variable and spatially-variable recharge values were based on values assigned in the USGS transient model (see Figures 4 and 6 in Johnson et al., 2011; Savoca et al., 2010), which included net precipitation recharge after accounting for runoff, evapotranspiration, and other surficial processes. Figure 10 shows the distribution of average recharge rates across the model extent.

For the calibration time periods outside the USGS model timeframe, recharge values were correlated with precipitation data at the McMillin Reservoir (NWS station 455224), the nearest long-term weather station with a long-term record (active since 1941). The precipitation record for McMillin Reservoir became less reliable in 2012, with more frequent breaks in data collection.

Since the McMillin Reservoir observations no longer had good coverage for the entire model timeframe, a predicted monthly time series for the McMillin Reservoir location from the Oregon State University PRISM Climate Group (OSU 2017) was used instead of the actual weather station observations.

Figure 9 shows a collection of graphs with the following information:

- Annual precipitation (upper left): compares the annual precipitation at McMillin Reservoir with PRISM data, and shows the average annual precipitation with PRISM data and the groundwater model timeframes;

- Annual precipitation exceedance plot (lower left): shows the probability distribution of annual precipitation, highlighting the years during the validation period;
- Monthly precipitation and recharge (upper right): compares the monthly precipitation (bars) and recharge (lines) during the validation period, and shows the model timeframes; and
- Precipitation by month (lower right): shows the range in historical (1942 to 2015) monthly precipitation (high/low lines) and the monthly precipitation during the validation period (scatter plot).

The McMillin Reservoir and PRISM precipitation data sets compare closely with each other, and the switch to using PRISM data for modeling was seamless. The validation period for the DuPont model represents a wide-range in the precipitation recharge, including both relatively wet and relatively dry years and months.

4.6.2 Groundwater Inflow

Groundwater inflow to the model domain was simulated as occurring in three locations: 1) from American Lake, 2) across a portion of the northeast model boundary, and 3) across the southeast model boundary. Figure 11 shows the location of model boundary conditions, including groundwater inflow. The American Lake boundary was defined by monthly-variable specified head cells based on reported and/or precipitation-correlated water levels (Johnson et al., 2011). Groundwater underflow across the northeast model boundary occurs in the Steilacoom Gravel hydrostratigraphic unit (Layer 2) and was defined in the model by monthly-variable specified head cells based USGS model results (Johnson et al., 2011). Groundwater underflow across the southeast model boundary occurs in the Sea Level Aquifer (Layer 9) and was defined by monthly-variable specified head cells based on USGS model results (Johnson et al., 2011). For the period after the USGS model timeframe, specified heads were assigned based on correlations with precipitation patterns. Figure 12 shows a graph of specified heads over time assigned to the groundwater inflow boundaries of the DuPont model.

4.6.3 Infiltration from Wetlands

Wetlands simulated in the DuPont model include Bell Marsh, McKay Marsh, Hamer Marsh, and the Edmond Marsh complex (Table 2). In addition, the channel flowing through East Edmond Marsh was simulated distinctly from the surrounding wetland areas to reflect the “cookie cutter” dredging that occurred in the 1970s to 1990s.

Each wetland area, including the Sequalitchew Creek channel, was treated as a distinct head-dependent boundary condition within the model, as shown on Figure 11.

In a few areas, wetland soils have been removed during historical development activities within the Edmond Marsh complex. Specifically, it was assumed that wetland soils were removed and replaced with sand and gravel fill at the former railroad grade at the Robinson Trail, and along the DuPont-Steilacoom Road. These areas were not included as wetland boundary conditions.

Wetland boundary conditions (drains and rivers) used monthly-variable and spatially-variable heads based on observed staff gage readings during the period of monitoring. Graphs of wetland water depths over time are shown on Figure 13, calculated from observed staff gage readings and the estimated bottom elevation of the wetland. When wetland stages were observed to be dry, the model simulated no water depth. Perched wetland conditions, where the wetland may have surface water ponded above the groundwater table (see Figure 15; Aspect, 2004a), were not simulated with the DuPont model because that water is not in direct hydraulic connection with the groundwater system being simulated.

The connection between the wetlands and the aquifer was defined by river cells with calibrated conductance values simulating a 5-foot-thick layer of peat forming the wetland bottom (see Figure 15; Aspect, 2004a). The wetland properties assigned in the model are summarized in Table 2. Wetland conductance values[2] were calibrated such that the area-weighted average vertical hydraulic conductivity was 0.034 feet per day. This value was consistent with previous peat testing results, which averaged in the range of 0.03 to 0.08 feet per day.

For predictive modeling, the wetland stages were maintained at baseline conditions.

4.6.4 Discharge to Surface Water

Groundwater-to-surface water discharge was simulated for the Joint Base Lewis-McChord (JBLM) water supply overflow, Sequalitchew Lake, the Diversion Canal and drainage, the wetlands complex, and the Sequalitchew Creek ravine. The locations of these boundary conditions are shown on Figure 11, and each is described below. The groundwater model simulates groundwater discharge to surface water, and does not simulate surface water flow due to runoff.

We assumed that groundwater discharged to surface water travels directly to Puget Sound, without potential for re-infiltration to the groundwater system. This assumption may result in the model overestimating drawdown effects from mine dewatering, especially in the area of the Diversion Canal and the Sequalitchew Creek ravine.

4.6.4.1 Joint Base Lewis-McChord Water Supply Overflow

Overflow from the spring water supply for JBLM at the east end of Sequalitchew Lake was simulated to evaluate changes in overflow throughout the mining process. The overflow was defined with a drain cell based on the overflow elevation. Groundwater discharged to this drain cell was assumed to subsequently discharge to Puget Sound via Sequalitchew Lake and the Diversion Canal, without potential for re-infiltration to the groundwater system.

4.6.4.2 Sequalitchew Lake

Sequalitchew Lake was simulated as a reflection of the groundwater table, and was defined by drain cells with monthly-variable heads based on observed lake levels at

[2] Wetland conductance (C) is a model-specific value that depends on the cell dimensions, as shown in the following equation: $C = Kv*L*W/m$, where Kv is vertical hydraulic conductivity (ft/d), L is cell length (ft), W is cell width (ft), and m is the peat thickness (ft). A higher conductance value allows greater hydraulic connection between wetland surface water and underlying groundwater, and vice versa.

monitoring well MW-SL-1, which is located at the west shore of Sequalitchew Lake. Groundwater discharging to Sequalitchew Lake was assumed to travel directly to Puget Sound via the Diversion Canal, without potential for re-infiltration to the groundwater system.

4.6.4.3 Diversion Canal and Drainage

The Diversion Canal, and the drainage associated with JBLM North were defined by drain cells with heads assigned at the elevation of the ground surface. Losing reaches of the Diversion Canal to the aquifer were not simulated with the DuPont model because that water is not in direct hydraulic connection with the groundwater system being simulated. Except near Sequalitchew Lake, the bottom of the Diversion Canal is generally above the water table, and proposed mining will not affect the flow in the canal or the seepage rates from the canal.

Groundwater model results indicate a shallow water table in the vicinity of JBLM North. We assumed that groundwater discharging to channels or other surface water features on JBLM North travels via the Diversion Canal directly to Puget Sound, without potential for re-infiltration to the groundwater system.

4.6.4.4 Wetlands Complex

Surface water discharge from the wetlands was defined by drain cells with conductance values greater than values for the river cells simulating wetland infiltration. We assumed that surface water discharged from the wetlands was subsequently discharged to Puget Sound via the Diversion Canal or the Sequalitchew Creek ravine, without re-infiltration within the wetlands. Re-infiltration of water to the aquifer from the losing reach of Sequalitchew Creek near Edmonds Marsh was not simulated because of the complexity of surface water/groundwater interaction in this area. This is a conservative assumption because it reduces the amount of water infiltrating to the aquifer along the losing reach, and may result in overestimating the effects of mine dewatering in the vicinity of the losing reach.

Infiltration from the wetlands is discussed in Section 4.6.3.

4.6.4.5 Sequalitchew Creek Ravine

Seepage within the Sequalitchew Creek ravine was defined by drain cells with heads assigned to ground surface to simulate gaining conditions. We assumed that groundwater discharged to these drain cells was subsequently discharged to Puget Sound via Sequalitchew Creek.

4.6.5 Discharge from Dewatering Wells

Dewatering wells were included in the predictive scenarios for future mining Steps 1 through 3. These mining steps represent the phased increase in dewatering efforts through planning, preparation, and execution of mining:

- Step 1 – Initial Dewatering Test
- Step 2 – Preparation for Mining/Expanded Dewatering Test
- Step 3 – Active Dewatering During Mining

Dewatering wells are not included in Step 4 – Cessation of Active Dewatering – because, at that point, all dewatering wells will have been turned off allowing groundwater seeps to develop at the toe of the mined slope. Additional detail about the dewatering plan is presented in the main body of the Monitoring Plan (Aspect, 2017).

The DuPont model was used to simulate the effects of dewatering as though each dewatering step occurred throughout the 11-year baseline period. This approach simulates the effects of the dewatering activities under the range of weather conditions represented by the baseline period.

The DuPont model simulated 10, 24, and 66 dewatering wells along the eastern mine property boundary for Steps 1, 2, and 3, respectively. Figure 14 shows the locations of the proposed dewatering wells during the progressive mining Steps. The simulated wells were screened across multiple model layers for the aquifer above the Olympia Beds, with pumping rates of up to 1 cfs per well. The MODFLOW-SURFACT model code automatically re-allocates pumping to lower layers as upper layers are dewatered, and automatically reduces the pumping rate as the water level approaches the bottom of the well.

Planned re-infiltration of pumped water to the floor of the existing mine will discharge to Puget Sound via the Sea Level Aquifer, and thus will not influence upgradient effects of dewatering and mining in the Vashon Outwash. Simulation of the re-infiltration of the dewatering discharge was not included in the DuPont model as it would occur west of the truncation of the Olympia Beds and thus would not affect water levels in the Vashon Aquifer.

4.6.6 Discharge to the Mined Slope

Groundwater discharge along the toe of the newly mined slope in the South Parcel was simulated for future mining Step 4, and was defined by drain cells with heads assigned at the elevation of the toe of the proposed mine slope (see Figure 5 for post-mining elevations).

4.6.7 Groundwater Outflow

Submarine groundwater outflow to Puget Sound was simulated using drain cells with heads assigned to mean sea level. The locations of boundary conditions, including groundwater outflow, is provided on Figure 11.

4.6.8 No-Flow Boundaries

No-flow boundaries were assigned at the edges of the DuPont model where groundwater flow was inferred to be relatively parallel with the model boundary (Figure 4). This included the bottom of the model (bottom of Sea Level Aquifer), and the sides of the model perpendicular to the shore of Puget Sound, except in layers where information was available to specify head.

5 Model Calibration and Validation

The DuPont model was calibrated by adjusting parameter values to minimize the difference between observed and calculated hydrogeologic conditions. The DuPont model was calibrated to the monitoring data from March 2004 through December 2010. The DuPont model was then updated with monitoring data from January 2011 through December 2015 and validated to the entire March 2004 to December 2015 period.

Similar to the USGS model, the DuPont model was calibrated using a specialized program called PEST, version 12 (Dougherty, 2011), which optimizes a parameter estimation method to provide the best fit within the limits of the available data and assumptions used in the numerical model. Jim Rumbaugh, the software developer for Groundwater Vistas, assisted Aspect with calibrating the DuPont model.

The raw calibration results statistically indicated a good calibration, and were further refined using trend-line analysis to improve matching observed and calculated water levels. The model calibration process is described below, including establishing calibration targets, defining the calibration method, providing the calibration and validation results, and post-processing the model results.

5.1 Calibration Targets

Observed groundwater levels were assigned to the DuPont model as transient calibration targets at the mid-point elevation of the monitoring well screen. Head targets, drawdown targets, and head-difference targets were set up using the same observed water levels, but provide different information to PEST during model calibration. Targets, and their primary calibration parameters, are summarized below:

- Head targets (1,467 total during calibration; 2,503 total during validation) primarily informed the calibration of horizontal hydraulic conductivity values. Head targets were used during validation to calculate residual statistics.
- Drawdown targets (1,467 total) primarily informed the calibration of aquifer storage parameters. In this case, “drawdown targets” applied the same information used for head targets to reflect seasonal changes in water levels (not drawdown due to a pumping well). Drawdown targets were calculated as the arithmetic average water level minus the observed water level on a given date. Drawdown targets were not used during validation.
- Head-difference targets (414 total) primarily informed the calibration of vertical hydraulic conductivity where shallow and deep wells were co-located. In this case, head-difference targets applied the same information used for head targets to reflect the vertical hydraulic gradient. Head-difference targets were not used during validation.

Observed and calculated groundwater levels over time at monitoring wells are presented on Figure 15 (top graphs). Wells with more observations had greater influence on model calibration than those with fewer observations.

Select single-observation targets in the area south of Sequalitchew Creek were used to inform model calibration. These calibration data were assigned for the first stress period to represent average conditions and included the following:

- Groundwater level data from 1994 at monitoring wells that were part of the Remedial Investigation of the Former DuPont Works Site (URS, 2003); and
- Surface water levels from August 2004 at Wetland 8, Wetland 10, Strickland Lake, Grant Lake, and Old Fort Lake (Aspect, 2004b).

5.2 Calibration Methods

Calibration methods followed the guidance provided for highly parameterized inversion (Doherty and Hunt, 2010; Doherty, et al., 2010). Essentially, this guidance allows back-calculating multiple model parameters to result in a best-fit with observed data, while maintaining parameter values within an expected range.

Table 3 provides a list of the model parameters adjusted during the calibration process. The DuPont model calibration was conducted in two stages, as described below:

- The first stage of model calibration refined aquifer parameters and wetland conductance values using zones or reaches of piecewise constancy. Calibration results were used to focus efforts on the most sensitive parameters. Calibrated aquifer parameters included horizontal and vertical hydraulic conductivities, and unconfined and confined aquifer storage values.
- The second stage of model calibration involved refinements to the spatial distribution of hydraulic conductivity within the Steilacoom Gravel, the Upper Confining Unit, and the deeper Vashon Outwash. Calibration methods included the following:
  - Regularization with pilot points, allowing hydraulic conductivity values to vary one order of magnitude from the value determined during the first stage. Previously determined vertical: horizontal anisotropy was maintained. As shown in Table 1, the maximum and minimum calibrated hydraulic conductivity values for a hydrostratigraphic unit are within two orders of magnitude.
  - Singular value decomposition, which internalized sensitivity analysis and reduced the time required for calibration. The calibration process was concluded when successive iterations showed limited improvement in residual statistics (discussed below).

5.3 Calibration Results

The calibrated DuPont model provided a good “fit” between calculated and observed groundwater levels. Consistent with model calibration guidance (Anderson and Woessner, 1992; Hill and Tiedemann, 2007), we evaluated the sufficiency of DuPont model calibration based on comparing observed and calculated groundwater levels from multiple perspectives. First, we evaluated the overall model calibration. Then, we evaluated the transient model calibration for potential trends. Last, we evaluated the model calibration for each monitoring well. Additional discussion of each step is provided below.

5.3.1 Overall Groundwater Level Calibration

We characterized the DuPont model as calibrated when additional adjustment in model parameters did not improve overall residual statistics, within the constraints of the model setup (Section 3) and the calibration targets and methods (Section 4.1 and 4.2).

A quantitative calibration evaluation, based on statistical analysis, met accepted industry standards for overall model comparison. The overall groundwater level calibration for the DuPont model was quantitatively evaluated using residual statistics for head targets (Table 4). Overall residual statistics were also calculated for drawdown (i.e., seasonal change in water levels) and head-difference targets, and we describe the level of calibration for these targets within the context of head targets for clarity and consistency. A description of common residual statistics is provided below:

- The overall **mean** residual reflects that calculated groundwater levels were 1.8 feet less than observed, on average.
- The overall **standard deviation** of residuals reflects that calibrated water levels were generally within 2.7 feet of the observed value.
- The **sum of squared** residuals is used for identification of specific targets which affect the overall model calibration, discussed further in Section 5.3.3.
- The overall **root mean square error** incorporates information on both the mean and standard deviation, and reflects that calibrated groundwater levels were generally within 3.2 feet of the observed value.

Thus, a broad interpretation of the mean and standard deviation is that the model-calculated groundwater levels across the entire model domain were 1.8 feet less than observed groundwater levels on average, and were usually within 2.7 feet of observed groundwater levels.

Consistent with model calibration guidance, selected residual statistics were scaled to the range of observed groundwater levels to compare with industry standards. The DuPont model calibration focused on groundwater conditions east of the Qob truncation, where the difference between the maximum and minimum observed groundwater levels was approximately 31 feet. The range in simulated groundwater elevations spanned approximately 230 feet (from American Lake to Puget Sound). The scaled standard deviation and root mean square error "*should be less than 10 to 15 percent for a good calibration*" (ESI, 2011). A description of the scaled residual statistics is provided below:

- The scaled standard deviation of residuals was less than 9 percent (2.7 feet / 31 feet) of the observed range.
- The scaled root mean square error of residuals was less than 11 percent (3.2 feet / 31 feet) of the observed range.

Thus, we interpreted the DuPont model as meeting industry standards, and as having a good calibration over the 6 years of observations covering a range of climatic conditions.

Residual statistics were calculated for drawdown (i.e. seasonal change in water levels) and head-difference targets (Table 4). Low values of scaled standard deviation indicate a good model fit. The overall scaled standard deviation of residuals for drawdown was 12 percent of the observed range, and for head-difference was 14 percent of the observed range.

A qualitative evaluation of the overall model calibration showed good agreement between calculated and observed groundwater levels and ranges based on mapped comparisons (Figures 16 and 17). The map on Figure B-13 compares measured to model-calculated water table elevation contours for May 2010. This qualitative calibration evaluation shows good agreement between water table elevation contours across most of the model domain within the context of seasonal variability, with the best agreement in the vicinity of the wetlands that are areas of primary interest for the project. The map on Figure 17 compares the seasonal range in model-calculated and observed groundwater levels. The range in model-calculated groundwater levels (contours) were approximately 86 percent of the observed values (posted values), on average.

5.3.2 Calibration of Groundwater Levels over Time

The DuPont model head calibration results were consistently good during seasonal and annual hydrologic cycles. Transient head calibration results were evaluated over two time scales, monthly and annual, as listed in Table 4, to evaluate if there were temporal trends in the accuracy of the model calibration.

The time-related residual statistics indicate a good annual model calibration with the scaled standard deviation between 8 to 12 percent. There is no discernible trend in the annual residual statistics, which suggests that the model calibration is consistently good during dry and wet years. The monthly residual statistics also indicate a consistently good calibration during dry and wet months, with the scaled standard deviation between 8 and 11 percent.

5.3.3 Calibration of Groundwater Levels at Individual Wells

Overall, individual monitoring wells selected for DuPont model calibration showed good model fit. The calibration was evaluated at individual wells to determine if there were spatial trends in model performance. Calibration at individual wells is summarized in a scatter plot (Figure 18, upper graph), which compares the observed and calibrated groundwater level elevations. Most wells fall close to the 1:1 line that represents the "perfect" model fit.

Based on the validation model results, head target residual statistics for individual wells are provided in Table 5, and are described in more detail below:

- Monitoring wells with fewer observations provided less information for the PEST calibration than other wells. These wells included 88-2-VD and MW-PL-1.
- All monitoring wells had mean residuals that were less than the range of observed values, except 88-2-VD.
- The standard deviation of residuals at any individual well was less than approximately 1.7 feet.

- The sum of squared residuals clearly identifies those wells most influencing the overall model calibration. The shallow and deep monitoring wells at MW-EM-1, CHMW-2, and CHMW-3 have greater mean residuals, and greater sum of squared residuals, than other locations. Although the offset at 88-2-VD is larger than other monitoring wells, the sum of squared residuals is limited by the relatively small number of observations.
- The root mean square error combines the mean and standard deviation of residuals. Based on this statistic, the calibration is better at monitoring wells MW-EM-3, MW-EM-2s and -2d, MW-SRC-2, and MW-HM-1 than at other locations.

The potential causes for poorer calibration at selected wells, identified by greater mean residual, are as follows:

- MW-EM-1S and MW-EM-1D appear to be sensitive to the groundwater and wetland interactions at the discharge point of West Edmond Marsh. Re-infiltration of surface water was not simulated at this location based on limited information for flow rates; ignoring re-infiltration is a conservative assumption with respect to predicting hydrogeologic impacts (see Section 4.6.4.5). Also, surface water was inferred to be seasonally perched above the water table (see Figure 15, Aspect 2004a), and the groundwater model was setup to simulate typical groundwater conditions.
- The shallow and deep monitoring wells at CHMW-2 and CHMW-3 are close to the Qob truncation, and are in areas with greater hydraulic gradients (inferred and calculated) than other monitoring wells. Groundwater levels at these monitoring wells appear to be sensitive where the curving water table crosses hydrostratigraphic contacts near the Qob truncation.

In summary, areas with the best model fit are the central portion of the Edmond Marsh Complex (MW-EM-2s, MW-EM-2d, and MW-EM-3) and the eastern boundary of the South Parcel (CHMW-1 and CHMW-4d) based on the residual statistics shown in Table 5. These areas are also the focus of attention for predicting the effects of proposed mining activities, and model predictions in these areas are considered more reliable than areas with poorer calibration.

5.4 Validation Results

Model validation was conducted, without changing the model construction (model grid/layering and aquifer parameters, to demonstrate that the validity of using PRISM data to assign recharge distribution. We characterized the DuPont model as validated because of the similarity between the calibration and validation residual statistics, as explained in further detail below.

5.4.1 Overall Groundwater Level Validation

The summary table below compares overall residual statistics between model calibration and model validation.

Type (Period)	Mean Residual (feet)	Standard Deviation of Residuals (feet)
Calibration (2004 to 2010)	1.8	2.7
Validation (2004 to 2010)	1.9	2.7
Validation (2011 to 2015)	1.8	2.5

The calibration and validation residual statistics for the period 2004 to 2010 compare closely, and demonstrate that the use of the PRISM data source, in place of the McMillin Reservoir data, was valid. The residual statistics for the period from 2011 to 2015 compares closely to the earlier period, and validates the model results for the conditions simulated.

Table 6 shows the residual statistics for head targets during model validation, and can be compared to Table 4 which provides statistics for head targets during model calibration. Specifically, the residual statistics for the model validation meets the industry standard for a reliable groundwater model.

5.4.2 Validation of Groundwater Levels over Time

Similar to calibration evaluation, the DuPont model head results were consistently validated over two time scales, monthly and annual, as listed in Table 6. Similar residual statistics over time indicated no temporal trends, and validated the model accuracy.

5.4.3 Validation of Groundwater Levels at Individual Wells

Overall, individual monitoring wells in the DuPont model showed good model fit for the validation period. Based on the validation model results, head target residual statistics for individual wells are provided in Table 7. The validation results provided similar well-specific residual statistics as the model calibration results.

The top graphs on Figure 15 show observed and calculated groundwater levels over time at individual monitoring wells. The middle graphs on Figure 15 compare the calculated and observed groundwater levels at individual wells. These graphs illustrate the offset and scatter described in the residual statistics, as well as the ranges in observed and calculated groundwater levels.

5.5 Further Refinement of Model Results

During calibration, the DuPont model was updated by including additional hydrologic complexity to better simulate the observed groundwater conditions. Some real-world complexity could not be incorporated in the model, and resulted in model bias quantified in the residual statistics. Therefore, the raw model results were refined to reduce model bias in groundwater levels calculated at individual wells using deterministic regression methods (Hill and Tiedeman, 2007). Similar methods were also used to improve the accuracy of the predicted groundwater levels (Xu et al., 2012; Doherty and Cristensen, 2011) for individual wells discussed in Section 6.

The trend-line analysis used to refine the model-calculated groundwater levels is shown on Figure 15 for each monitoring well (except 88-2-VD). To avoid introducing additional bias by refining groundwater level results for only wells with poorer calibration, trend-line analysis was performed for all wells. The top plot for each well on Figure 15 shows observed and validated groundwater water levels over time. The middle plot for each well on Figure 15 shows the trend-line analysis for observed and calculated water levels to determine the best-fit line, or "refinement trend line". The best-fit line also accounts for local hydrogeology by establishing a control point at elevation 120 feet NGVD29, which is the approximate contact elevation between the Vashon Outwash and the Olympia Beds. This allows for correlation of model-predicted results outside the range of observed water levels, and is most applicable for wells CHMW-1, CHMW-2, CHMW-3, and CHMW-4. The refined baseline groundwater levels have been corrected for the offset and slope in the refinement trend line, but do not account for the scatter around the 1:1 line. The bottom plot for each well on Figure 15 shows the observed and refined baseline groundwater levels.

Post-model refinement statistics for individual wells are provided in Table 7, and are described in more detail below:

- The refined mean residual was zero for all monitoring wells because the refinement method accounts for the well-specific offset.
- The refined standard deviation of residuals for all monitoring wells was similar to, and less than, the raw calibrated value.
- The refined sum of squared residuals was less than the calibrated value.
- The refined root mean square error was less than the calibrated value, and similar to the refined standard deviation of residuals.

Table 7 provides the refined range in groundwater levels, for comparison with the validation results and observed values. The trend-line analysis results in a range in groundwater levels of approximately 104 percent of observed values, on average.

In summary, the refinement method greatly improves the accuracy of model results, as measured by mean residual and other residual statistics. The refinement method is limited to the model-calculated groundwater levels at head targets, and does not extend to other model results such as groundwater balance analysis.

5.6 Groundwater Balance Analysis

The groundwater balance for the calibrated DuPont model provides baseline conditions to be used for comparison with the predictive future mining. The groundwater balance provides information on water inputs, outputs, and changes in aquifer storage during the model timeframe. Analysis of the components of the DuPont model groundwater balance allows comparison of baseline conditions to predicted conditions during the mining process.

The average values from the models (not including the first stress period) were used for the analysis. The results of the water balance analysis are presented below for the overall model and for the wetland complex. Observed flows in the Diversion Canal and Sequalitchew Creek ravine were compared to model results.

The trend-line analysis used to refine model-calculated groundwater levels was not applied to the model-calculated groundwater balance. Groundwater balance elements were not monitored directly, and did not serve as model calibration targets.

5.6.1 Overall Groundwater Balance Analysis

The overall groundwater balance is consistent with the description of model boundary conditions above, and is expressed by the following equation:

$$R + GWin + WLinf = Dsw + Dwell + Dmine + GWout + \Delta S$$

Where:

R is recharge to groundwater from precipitation;

GWin is groundwater inflow to the model area;

WLinf is wetland infiltration to groundwater;

Dsw is groundwater discharge to surface water;

Dwell is groundwater discharge from dewatering wells (future mining Steps 1, 2, and 3 only);

Dmine is groundwater discharge into the mine (future mining Step 4 only);

GWout is groundwater outflow from the model area; and

ΔS is change in aquifer storage.

All terms in the water balance equation have units of cubic feet per second (cfs).

Time-averaged groundwater balances are presented on Figure 19, which shows a column chart and a table with rates provided in cfs. For the baseline model:

- Recharge and groundwater inflow represented approximately 13 and 83 percent of all model inflows, on average.
- The average infiltration from the wetland complex was approximately 5 cfs, and represented approximately 3.4 percent of all model inflows.
- The average change in aquifer storage was slightly positive, reflecting the transient boundary conditions assigned in the model, and represented 0.2 percent of all model inflows.
- Average groundwater outflow along the Puget Sound shoreline represented approximately 91 percent of all model outflows.
- Discharge to surface water (e.g., Sequalitchew Lake, wetlands, Sequalitchew Creek, Diversion Canal) represented the balance of model outflows (approximately 9 percent, on average). Dewatering wells were not simulated in the baseline model.

Figure 20 shows a line chart of the baseline model groundwater balance over the model timeframe, with rates provided in cfs. The monthly variability in recharge is largely balanced by changes in aquifer storage and discharge to surface water.

5.6.2 Wetland Complex Groundwater Balance Analysis

For the purposes of the groundwater balance analysis, wetlands were grouped consistent with the previous water balance analysis (Aspect, 2004a) as follows:

- Bell, Hamer, and McKay (BHM) Marshes
- East Edmond Marsh (East EM)
- West Edmond Marsh (West EM)

Time-averaged infiltration and discharge rates for the wetland complex are presented on Figure 21. For the baseline model:

- Infiltration in BHM Marshes represented approximately 29 percent of the total wetland infiltration, on average.
- Average infiltration in East EM, with the peat removed from the “cookie cutter” channel, represented approximately 68 percent of the total wetland infiltration.
- Average infiltration in West EM represented approximately 3 percent of the total wetland infiltration.
- For the combined wetlands, the average groundwater-to-surface water discharge was approximately 19 percent of infiltration from the wetlands.
- Average groundwater-to-surface water discharge rates to the BHM Marshes, East EM, and West EM were approximately 66, 26, and 7 percent, respectively, of total groundwater-to-surface water discharge within the wetlands.

Figure 22 shows a line chart of the infiltration and discharge for the wetland groups under baseline conditions, as well as the net wetland flow. Infiltration rates at the West EM were the lowest, occurred with the lowest frequency, and were the least sensitive to seasonal precipitation patterns, compared to the other wetland groups.

6 Model Predictions for Future Mining Conditions

Following calibration and validation, the DuPont model was used to predict decreases in groundwater conditions during the four sequential future steps of proposed dewatering and mining activity in the South Parcel. As described in Section 4.6.5, dewatering Steps 1, 2, and 3 simulated 10, 24, and 66 active dewatering wells, respectively. Step 4 simulated the post-mining condition with pumping terminated and groundwater passively discharging at the toe of the newly mined slope. For direct comparison with baseline model results, predictive models used the same baseline boundary conditions as the validation model, except for pumping at active dewatering wells.

Model results indicate that pumping rates will equilibrate within one month, and water levels will largely equilibrate within 60 days of a change in pumping rates. For the purposes of this modeling effort, we assumed surface water levels in the wetlands will be similar to historical conditions.

Results of the predictive models are discussed below by dewatering phase, in terms of predicted decreases in groundwater levels. To support the discussion, predicted decreases in groundwater levels are presented in a table, graphs, and maps. Baseline groundwater levels are sensitive to seasonal and longer-term precipitation patterns (e.g., see Figure 15), and groundwater levels during the four dewatering phases are predicted to likewise remain sensitive to precipitation patterns.

For each of the monitoring wells and each of the dewatering steps, Table 8 provides the maximum decrease in groundwater level based on refined model results, with and without including model uncertainty. For the purposes of communicating refined model results, we focus on the maximum decrease in groundwater level without including model uncertainty represented by the values on the left half of Table 8. Additional discussion of model uncertainty is provided in Section 6.5.

Figure 23 provides a collection of graphs comparing groundwater levels (elevations) for each dewatering step by well. The upper graphs on Figure 23 compare baseline groundwater levels and predicted groundwater levels for each of the four dewatering phases. The error bars illustrate the minimum groundwater levels at the 95-percent confidence interval, as a measure of model uncertainty. The 95-percent confidence interval was calculated using the 1-tailed test and the well-specific standard deviation of residuals from the residual statistics for the entire 11-year model validation period. For predictive model results, the 95-percent confidence interval was increased proportional to the average water level decrease at that location. Additional discussion of model uncertainty is provided in Section 6.5.

The middle graphs on Figure 23 show the ranges in monthly groundwater level elevations for baseline conditions and each of the four dewatering phases. The color bars reflect the potential effects of annual hydrologic variability. As described above, the error bars illustrate the minimum groundwater level at the 95-percent confidence interval, as a measure of model uncertainty.

The lower graphs on Figure 23 show the range in monthly groundwater levels decrease from baseline for each of the four dewatering steps. The color bars reflect the potential effects of annual hydrologic variability. As described above, the error bars illustrate the minimum groundwater level at the 95-percent confidence interval, as a measure of model uncertainty.

Figure 24a through Figure 24d shows maps of predicted maximum groundwater level decreases from baseline conditions for each of the four dewatering steps. The contour lines on Figure 24a through Figure 24d are lines of equal groundwater level decrease. Predicted groundwater level decreases during the planned four mining steps are described below.

6.1 Future Mining Step 1: Initial 10-well Dewatering Test

Step 1 dewatering will include 10 active wells located in the northern portion of the South Parcel, as shown on Figure 14. To simulate Step 1, the validated model was modified by adding 10 wells screened across the Steilacoom Gravels and Vashon Outwash. Wells were simulated to pump up to 1 cfs each unless the available drawdown in the well limited the pumping rate. After the first month of pumping all 10 wells, the combined pumping rate is predicted to be approximately 3.6 cfs, on average, and up to approximately 5.5 cfs during the wet season.

Groundwater level decreases are predicted to stabilize within approximately 60 days after pumping starts based on model results. During Step 1, the model-predicted decreases in groundwater levels are most evident at monitoring wells CHMW-2s and CHMW-2D, which are the closest monitoring wells to the proposed location of the Step 1 dewatering wells (see Figure 24a through Figure 24d; monitoring well locations are depicted on Figure 4). At more distant monitoring wells, the predicted groundwater level decreases are less than half the observed range in baseline groundwater levels. The maximum groundwater level decrease at CHMW-2D is predicted to be approximately 8.8 feet. The maximum groundwater level decrease at upgradient monitoring well MW-D-3 (adjacent to the Diversion Canal east of the mine expansion) is predicted to be approximately 1.8 feet. The maximum groundwater level decrease at monitoring wells MW-EM-1D and MW-EM-2D (in Edmonds Marsh) is predicted to be approximately 0.5 foot and 0.1 foot, respectively.

During Step 1, little or no effects on wetlands or groundwater discharge to Sequalitchew Creek were predicted by the model. The overall average wetland infiltration rate is predicted to remain similar to baseline conditions (Figure 19). The predicted average rates of wetland infiltration to groundwater, and discharge from wetland to surface water, are similar to baseline conditions (Figure 21). The timing of net wetland flow (wetland infiltration to groundwater and discharge from the wetland to surface water) is predicted to be approximately the same as baseline conditions (Figure 22). During Step 1, the JBLM water supply overflow showed no significant change in flow rates compared to baseline conditions.

6.2 Future Mining Step 2: Active Dewatering In Preparation for Mining

During Step 2, the dewatering well network will be expanded to the south along the South Parcel mine perimeter as well as adding a few wells in the interior as shown in Figure 14. To simulate Step 2, the validated model was modified by adding 24 wells screened across the Steilacoom Gravels and Vashon Outwash. The dewatering wells are arranged in two lines on either side of the initial mine trough, with 19 boundary wells and 5 inner wells. Wells were simulated to pump up to 1 cfs each unless the available drawdown in the well limited the pumping rate. After the first month of pumping all 24 wells, the combined pumping rate is predicted to be approximately 5.2 cfs, on average, and up to approximately 8.8 cfs during the wet season.

Groundwater level decreases at upgradient monitoring wells are predicted to stabilize within approximately 60 days after pumping starts based on model results. During Step 2, the maximum groundwater level decreases at CHMW-2D and CHMW-1 are predicted to be approximately 45 feet and 5.2 feet, respectively (see Table 8 and Figures 23 and 24). At this step, monitoring well CHMW-2D will be interior to the dewatering well network. The maximum groundwater level decrease at upgradient monitoring well MW-D-3 is predicted to be approximately 4.3 feet. The maximum groundwater level decreases at MW-EM-1D and MW-EM-2D are predicted to be approximately 1.5 feet and 0.2 feet, respectively.

During Step 2, the predicted overall wetland infiltration rate will be approximately 0.2 cfs greater than baseline conditions (Figure 19), assuming wetland water levels are maintained. Most of the predicted changes in infiltration will occur in the East Edmond Marsh area (Figure 21). The predicted timing of net wetland flow will remain approximately the same as baseline conditions (Figure 22). Groundwater discharge to Sequalitchew Creek during Step 2 is predicted to remain similar to baseline conditions. During Step 2, the JBLM water supply overflow showed no significant change in flow rates compared to baseline conditions.

6.3 Future Mining Step 3: Active Dewatering During Mining

Step 3 dewatering was simulated with 66 active wells along the eastern and southern South Parcel mine boundary, as shown in Figure 14. The dewatering wells are arranged in two lines on either side of the initial mine trough, with 54 boundary wells and 12 interior wells. The combined pumping rate is predicted to be approximately 6.9 cfs, on average, and up to approximately 12.2 cfs during the wet season. It may not be necessary to operate all dewatering wells as the final mine trough progresses, once an alternative (passive) dewatering system is in place. However, for the purposes of evaluating the maximum effects of dewatering during Step 3, the DuPont model simulated all dewatering wells operating simultaneously as a conservative assumption.

Groundwater level decreases are predicted to stabilize within approximately 60 days after pumping starts based on model results. During Step 3, the maximum groundwater level decreases at CHMW-2D, CHMW-1, CHMW-4D, and CHMW-3D are predicted to be approximately 51 feet, 60 feet, 15 feet, and 57 feet, respectively (see Table 8 and Figures 23 and 24). The maximum groundwater level decreases at MW-EM-1D and MW-EM-2D are predicted to be approximately 5.1 feet and 0.4 feet, respectively. The maximum groundwater level decreases at upgradient monitoring wells MW-D-3 and MW-93-MFS-C-5 are predicted to be approximately 7.7 feet and 4.2 feet, respectively. The groundwater levels during Step 3 are predicted to be approximately 10 to 20 feet above the Olympia Beds along the mine trough.

During Step 3, the predicted overall wetland infiltration rate will be approximately 0.6 cfs greater than baseline conditions (Figure 19), assuming wetland water levels are constant. Most of the predicted changes in infiltration will occur in the East Edmond Marsh area (Figure 21). Based on model results, the lower groundwater levels under West Edmond Marsh will reduce groundwater discharge to surface water during Step 3 (Figure 22). Groundwater discharge to Sequalitchew Creek during Step 3 is predicted to be 0.5 cfs less than baseline conditions, on average, with the greatest decreases during the wet season. As with Steps 1 and 2, the JBLM water supply overflow showed no significant change in flow rates in Step 3 compared to baseline conditions.

6.4 Future Mining Step 4: Post-Mining Conditions

During Step 4, pumping from the dewatering well network will cease, groundwater will emanate from the toe of the mined slope, forming wetlands along the toe of the slope and on portions of the mine floor of the South Parcel. Overflow from the wetlands will be collected and conveyed to an infiltration pond on the floor of the existing mine, . As described in Section 4.3.1, the Step 4 ground surface (model top) elevation was modified to reflect the final mine grade (Figure 6) to simulate passive groundwater discharge into the mine. The flow rate of groundwater discharging into the mine is predicted to be 6.9 cfs, on average, and up to 13.7 cfs during the wet season. Collected groundwater discharging into the mine will be re-infiltrated in the western portion of the mine area. The re-infiltration of collected groundwater seeping into the mine will recharge the Sea Level Aquifer and will not affect groundwater levels in the Vashon Outwash aquifer. As such, re-infiltration was not simulated in the DuPont model.

Groundwater level decreases are predicted to stabilize within approximately 60 days after pumping stops based on model results. Groundwater levels will recover slightly relative to the active pumping of Step 3. During Step 4, the maximum groundwater level decreases at monitoring wells along the mine trough (CHMW-2D, CHMW-1, CHMW-4D, and CHMW-3S), are predicted to be approximately 32 feet, 30 feet, 14.0 feet, and 50 feet, respectively. The maximum groundwater level decreases at upgradient monitoring wells MW-D-3 and MW-93-MFS-C-5 are predicted to be approximately 6.6 feet and 3.6 feet, respectively. The maximum groundwater level decreases at MW-EM-1D and MW-EM-2D are predicted to be approximately 4.7 feet and 0.4 feet, respectively (see Figures 23 and 24).

During Step 4, the predicted overall wetland infiltration rate will be approximately 0.5 cfs greater than baseline conditions (Figure 19), assuming stream restoration efforts maintain wetland water levels. Most of the predicted changes in infiltration will occur in East Edmond Marsh area (Figure 21). Based on model results, the result of lower groundwater levels under West EM will reduce groundwater discharge to surface water during Step 4 than during Baseline conditions (Figure 22). Groundwater discharge to Sequalitchew Creek during Step 4 is predicted to be 0.5 cfs less than baseline conditions, on average, with the greatest decreases during the wet season.

During Step 4, the JBLM water supply overflow showed no significant change in flow rates compared to baseline conditions (Figure 19).

6.5 Quantifying Model Uncertainty

All predictions of any groundwater model, including the DuPont model, are subject to uncertainty – for example, in the model parameters and boundary conditions, conceptual model construction, and future conditions. While these some of these uncertainties can be controlled through the robustness of the data collection, calibration, and validation process, they cannot be eliminated and some uncertainties, particularly related to future conditions, are not knowable.

One method for acknowledging uncertainty in model predictions is to quantify the knowable components (i.e., model bias) and incorporate it into the evaluation of future conditions. We can calculate a lower confidence limit on the predicted groundwater levels, then perform environmental evaluations based on those lower limits. If the environmental analyses are still favorable, then we can have increased confidence in the groundwater model and a smaller chance of an adverse outcome.

We calculated a measure of overall model bias based on the scaled standard deviation of the differences between the validated model water levels and the measured water levels at each groundwater monitoring location over the validation period. The scaled standard deviation is the standard deviation divided by the range in the observed water levels. This analysis used the raw validation results, before application of post-modeling refinement. As such, this analysis incorporates uncertainty from the model validation (baseline conditions, without dewatering) and application of the model to the future dewatering scenarios.

A lower 95-percent confidence interval for predicted water levels was calculated by multiplying the scaled standard deviation by the sum of the range in future water levels and the drawdown and the z-value corresponding to a one-tailed 95-percent confidence interval for a normal distribution (i.e., z = 1.28). Expressed mathematically, this uncertainty is equal to:

1.28 * (scaled standard deviation) * (maximum drawdown + observed range).

As an example of this approach, consider monitoring well CHMW-2D. The observed range in water levels from 2004 to 2015 was 6.89 feet at CHMW-2D, and the standard deviation of the validated model is 0.66 feet (Table 7). Thus, the scaled standard deviation is 9.6 percent (0.66 feet/6.89 feet).

The maximum drawdown at CHMW-2D during Step 1 is predicted to be 8.8 feet (Table 8), based on refined model results. The model uncertainty is therefore approximately 1.9 feet (1.28 * 9.5% * (8.8 ft + 6.89 ft). Thus, the maximum predicted drawdown, including model uncertainty, is predicted to be approximately 10.7 feet (Table 8).

Similar calculations were made for each well in each month in each dewatering step, and are the basis for the minimum groundwater levels described in the following section.

6.6 Minimum Groundwater Levels in Each Dewatering Step

A primary use of the output from the predictive model runs is to establish minimum groundwater levels at the various monitoring wells for each dewatering step. These minimum water levels will be evaluated to determine environmental impacts, and if acceptable relative to the mitigation provided by the Restoration Plan, will be used as performance thresholds for the dewatering program. Measured groundwater levels below the performance threshold would trigger adaptive management, as described in the South Parcel Monitoring Plan (Aspect, 2017).

The minimum groundwater levels for each monitoring well, in each month, in each dewatering step are provided in Table 9. These minimum groundwater levels are the 95% lower confidence interval for the groundwater level predicted by the DuPont Model, and have been calculated for each existing monitoring well for each month of each dewatering step. Minimum groundwater levels can be calculated with the DuPont Model for any new monitoring wells once the location has been determined.

Steps 1 and 2 will not last through all months of a year, but precise starting months and duration are not firmly established. Minimum groundwater levels were calculated for all months to allow flexibility in the future.

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Limitations

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Tables

Table 1: Summary of Hydrostratigraphic Units and Calibrated Parameter Values

Project #040001 -South Parcel Mine Expansion
Dupont, WA

Hydrostratigraphic Unit in DuPont Model	Correlated USGS Hydrogeologic Unit and Partial Description	Principal Layers in DuPont Model	Horizontal Hydraulic Conductivity (feet/day)					Vertical Anisotropy (-)	Specific Yield (-)	Specific Storage (1/foot)
			Max.	75 percentile	Average	25 percentile	Min.	horizontal: vertical		
Steilacoom Gravel	A1 – "recessional outwash…sand and gravel deposited by large meltwater streams…"	1,2	3,900	1,600	1,100	350	36	2.7	0.07	6.1E-05
Upper Confining Unit	A2 – "low-permeability unit composed of Vashon till and lesser amounts of ice-contact, moraine and fine-grained glaciolacustrine deposits…"	3	1.61	0.47	0.33	0.16	0.017	1.0	0.07	5.0E-05
Vashon Outwash	A3 – "aquifer composed of Vashon advance outwash…"	4,5	49	11	7.7	2.4	0.27	15.1	0.09	2.7E-05
Olympia Beds (Qob)	B – "low-permeability unit composed of fine-grained silts and clays deposited during the Olympia interglacial…"	6,7	0.018 (uniform)					10.0	0.09	1.1E-04
Sea Level Aquifer	C – "aquifer composed of pre-Olympia glacial drift deposits consisteing of sand and gravel…"	8,9	690 (uniform)					6.3	0.18	6.0E-05

Table 2: Summary of Wetland Properties used in Model

Project #040001 -South Parcel Mine Expansion
Dupont, WA

Wetland	Drain and River Cells			River Cells Only			
	Area In Model (acres)	Staff Gage(s) used to Establish Stage	Average Stage (feet)	Average Vertical K (feet/day)	Average Bottom Elevation (feet)	Wetland Water Depth (feet)	
						Average	Standard Deviation
Bell Marsh	11	SG-BM-1	218.4	0.55	215.6	2.8	1.0
McKay Marsh	35	SG-MKM-1	215.2	0.0086	213.6	1.6	1.1
Hamer Marsh	67	SG-HM-1	213.7	0.0090	211.7	2.0	0.9
East Edmond Marsh (JBLM)	25	SG-EM-3E, SG-SCM-1	212.1	0.020	210.0	2.1	0.5
East Edmond Marsh (JBLM) - Channel	10		212.1	11	210.0	2.1	0.5
East Edmond Marsh	27	SG-EM-2E, SG-EM-3W	211.9	0.0013	210.0	1.9	0.5
East Edmond Marsh - Channel	8		211.9	39	210.0	1.9	0.5
West Edmond Marsh - Eastern	29	SG-EM-2W, SG-EM-1/1A	210.4	0.0010	207.7	2.7	0.4
West Edmond Marsh - Middle	25		208.9	0.0026	206.6	2.2	1.1
West Edmond Marsh - Western	7		207.4	0.0015	205.8	1.6	1.4

Notes:

Wetlands were simulated with drains cells (for surface runoff) and river cells (for connection with aquifer) across the same areas, and with the same stage values.

The wetland area was assigned based on historical aerial photos.

Monthly-variable stages were assigned based on staff gage observations. Where two staff gages were used, stages were linearly interpolated.

Drain cells were uniformly assigned a vertical hydraulic conductivity (vertical K) of 10 feet per day.

Vertical K for river cells was calibrated.

The wetland bottom elevation was estimated.

The wetland peat was assigned a thickness of 1 foot.

The wetland water depth provides information on seasonal differences in water levels.

Table 3: Parameters Adjusted during Calibration

Project #040001 -South Parcel Mine Expansion
Dupont, WA

Hydraulic Conductivity		
Hydrostratigraphic Unit	***Horizontal Hydraulic Conductivity***	***Vertical Hydraulic Conductivity***
Steilacoom Gravel	Regularization with Pilot Points	Anisotropy Maintained
Upper Confining Unit	Regularization with Pilot Points	Anisotropy Maintained
Vashon Outwash	Regularization with Pilot Points	Anisotropy Maintained
Olympia Beds	Piecewise Constancy	Anisotropy Maintained
Sea Level Aquifer	Piecewise Constancy	Anisotropy Maintained
Storage Coefficients		
Hydrostratigraphic Unit	***Specific Yield***	***Specific Storage***
Steilacoom Gravel	Piecewise Constancy	Piecewise Constancy
Upper Confining Unit	Piecewise Constancy	Piecewise Constancy
Vashon Outwash	Piecewise Constancy	Piecewise Constancy
Olympia Beds	Piecewise Constancy	Piecewise Constancy
Sea Level Aquifer	Piecewise Constancy	Piecewise Constancy

River Cells	
Wetland	***Conductance***
Bell Marsh	Piecewise Constancy
McKay Marsh	Piecewise Constancy
Hamer Marsh	Piecewise Constancy
East Edmond Marsh (JBLM)	Piecewise Constancy
East Edmond Marsh (JBLM) - Channel	Piecewise Constancy
East Edmond Marsh	Piecewise Constancy
East Edmond - Channel	Piecewise Constancy
West Edmond Marsh - Eastern	Piecewise Constancy
West Edmond Marsh - Middle	Piecewise Constancy
West Edmond Marsh - Western	Piecewise Constancy

Table 4: Model Calibration - Residual Statistics - Overall and Over Time

Project #040001 -South Parcel Mine Expansion
Dupont, WA

		Residual Statistics					Range in Observed Values [Max. - Min.] (feet)	Scaled Statistics	
		Number of Observations	Mean (feet)	Standard Deviation (feet)	Sum of Squares	Root Mean Squared Error (feet)		Standard Deviation	Root Mean Square Error
Overall Model Fit									
Head Targets		1,467	1.77	2.71	15,382	3.24	30.81	9%	11%
Drawdown Targets		1,467	1.17	1.40	4,874	1.82	11.51	12%	16%
Head Difference Targets		414	0.11	1.80	1,343	1.80	13.14	14%	14%
Model Fit By Calendar Year									
Head Targets	2004	192	1.63	3.40	2,709	3.76	27.52	12%	14%
	2005	208	1.90	2.69	2,251	3.29	29.98	9%	11%
	2006	205	1.99	2.55	2,135	3.23	30.81	8%	10%
	2007	212	1.88	2.47	2,040	3.10	29.51	8%	11%
	2008	228	1.75	2.65	2,294	3.17	30.16	9%	11%
	2009	209	1.61	2.61	1,961	3.06	29.58	9%	10%
	2010	213	1.60	2.61	1,992	3.06	28.8	9%	11%
Model Fit By Month									
Head Targets	January	103	2.41	2.73	1,358	3.63	25.82	11%	14%
	February	102	2.14	2.73	1,222	3.46	26.43	10%	13%
	March	133	2.10	3.06	1,823	3.70	27.09	11%	14%
	April	134	2.37	3.01	1,959	3.82	27.86	11%	14%
	May	121	1.91	2.84	1,409	3.41	27.81	10%	12%
	June	122	1.74	2.66	1,223	3.17	28.12	9%	11%
	July	130	1.61	2.51	1,146	2.97	28.38	9%	10%
	August	124	1.41	2.43	976	2.81	28.26	9%	10%
	September	103	1.21	2.40	736	2.67	28.87	8%	9%
	October	148	0.90	2.52	1,055	2.67	29.92	8%	9%
	November	124	1.67	2.52	1,126	3.01	28.53	9%	11%
	December	123	1.92	2.71	1,348	3.31	27.54	10%	12%

Table 5: Model Calibration - Residual Statistics By Well

Project #040001 -South Parcel Mine Expansion
Dupont, WA

	Calibration Results						
	Residual Statistics (residual = observed - calculated)					Range in Observed Water Levels [Max. - Min.] (feet)	Range in Calculated Water Levels [Max. - Min.] (feet)
Well ID	Number of Observations	Mean (feet)	Standard Deviation (feet)	Sum of Squares	Root Mean Squared Error (feet)		
MW-EM-1s	79	5.26	1.50	2,362	5.47	7.02	7.50
MW-EM-1d	85	4.95	0.99	2,168	5.05	6.91	7.92
MW-EM-2s	82	0.23	0.35	14	0.42	2.28	2.39
MW-EM-2d	85	0.39	0.30	20	0.49	2.39	2.39
MW-EM-3	85	0.10	0.14	2	0.17	2.49	2.01
CHMW-1	85	-0.69	0.91	110	1.14	9.48	6.75
CHMW-2S	85	3.30	0.62	955	3.35	6.84	5.77
CHMW-2D	85	3.65	0.62	1,168	3.71	6.81	5.74
CHMW-3S	85	5.25	1.60	2,562	5.49	10.8	5.90
CHMW-3D	83	6.05	1.55	3,232	6.24	10.43	5.94
CHMW-4S	85	1.41	0.99	251	1.72	9.54	7.70
CHMW-4D	85	-0.18	0.90	72	0.92	9.40	7.57
MW-SRC-2	79	0.17	0.61	31	0.63	6.61	4.25
MW-D-3	81	2.11	1.05	450	2.36	7.77	5.49
MW-93-MFS-C5-3	83	-2.92	0.97	787	3.08	7.26	4.55
88-2-VD	10	-7.49	0.74	565	7.52	2.85	0.75
MW-BM-1	80	2.39	0.51	477	2.44	5.45	6.47
MW-HM-1	80	0.49	0.43	34	0.65	4.79	4.52
MW-PL-1	45	0.27	1.65	123	1.66	6.04	10.27

Notes:
1. Model results and statistics are presented at the typical field-measurement precision (0.01 ft).

Table 6: Model Validation - Residual Statistics Overall and Over Time

Project #040001 -South Parcel Mine Expansion
Dupont, WA

		Residual Statistics					Range in Observed Values [Max. - Min.] (feet)	Scaled Statistics	
		Number of Observations	Mean (feet)	Standard Deviation (feet)	Sum of Squares	Root Mean Squared Error (feet)		Standard Deviation	Root Mean Square Error
Overall Model Fit									
Head Targets		2,503	1.86	2.65	26,217	3.24	31.08	9%	10%
Model Fit By Calendar Year									
Head Targets	2004	193	1.66	3.38	2,732	3.76	27.52	12%	14%
	2005	208	2.04	2.72	2,394	3.39	29.98	9%	11%
	2006	205	2.17	2.58	2,317	3.36	30.81	8%	11%
	2007	212	2.06	2.52	2,242	3.25	29.51	9%	11%
	2008	228	1.87	2.67	2,417	3.26	30.16	9%	11%
	2009	209	1.69	2.62	2,023	3.11	29.58	9%	11%
	2010	213	1.88	2.64	2,239	3.24	28.8	9%	11%
	2011	203	1.58	2.48	1,751	2.94	29.26	8%	10%
	2012	206	1.89	2.47	1,991	3.11	29.44	8%	11%
	2013	208	1.68	2.54	1,918	3.04	28.76	9%	11%
	2014	209	1.85	2.55	2,066	3.14	28.65	9%	11%
	2015	209	1.92	2.55	2,128	3.19	29.8	9%	11%

Table 6: Model Validation - Residual Statistics Overall and Over Time

Project #040001 -South Parcel Mine Expansion
Dupont, WA

		Residual Statistics					Range in Observed Values [Max. - Min.] (feet)	Scaled Statistics	
		Number of Observations	Mean (feet)	Standard Deviation (feet)	Sum of Squares	Root Mean Squared Error (feet)		Standard Deviation	Root Mean Square Error
Overall Model Fit									
Head Targets		2,503	1.86	2.65	26,217	3.24	31.08	9%	10%
Model Fit By Month									
Head Targets	January	187	2.31	2.74	2,399	3.58	26.7	10%	13%
	February	154	2.21	2.73	1,893	3.51	26.51	10%	13%
	March	217	2.28	2.89	2,925	3.67	27.21	11%	13%
	April	252	2.39	2.84	3,464	3.71	28.3	10%	13%
	May	208	1.99	2.73	2,363	3.37	28.51	10%	12%
	June	193	1.84	2.60	1,953	3.18	28.99	9%	11%
	July	197	1.69	2.47	1,760	2.99	29.18	8%	10%
	August	231	1.51	2.35	1,802	2.79	29.29	8%	10%
	September	171	1.48	2.33	1,295	2.75	29.23	8%	9%
	October	253	1.33	2.57	2,116	2.89	30.78	8%	9%
	November	230	1.56	2.52	2,013	2.96	28.83	9%	10%
	December	209	1.86	2.69	2,230	3.27	27.69	10%	12%

Table 7: Model Calibration - Residual Statistics By Well

Project #040001 -South Parcel Mine Expansion
Dupont, WA

Well ID	Validation Results							Post-Model Refinement Results				
	Residual Statistics (residual = observed - calculated)					Range in Observed Water Levels [Max. - Min.] (feet)	Range in Calculated Water Levels [Max. - Min.] (feet)	Residual Statistics (residual = observed - calculated)				Range in Calculated Water Levels [Max. - Min.] (feet)
	Number of Observations	Mean (feet)	Standard Deviation (feet)	Sum of Squares	Root Mean Squared Error (feet)			Mean (feet)	Standard Deviation (feet)	Sum of Squares	Root Mean Squared Error (feet)	
MW-EM-1s	136	4.99	1.75	3,799	5.29	7.56	10.44	0.00	1.74	411	1.74	9.65
MW-EM-1d	131	4.97	0.98	3,355	5.06	7.9	10.92	0.00	0.94	115	0.94	9.43
MW-EM-2s	140	0.24	0.35	25	0.42	2.39	2.90	0.00	0.23	7	0.23	1.75
MW-EM-2d	144	0.38	0.30	34	0.48	2.54	2.91	0.00	0.20	6	0.20	1.94
MW-EM-3	144	0.11	0.14	5	0.18	3	2.59	0.00	0.13	3	0.13	2.88
CHMW-1	143	-0.55	0.92	163	1.07	9.48	9.08	0.00	0.88	109	0.87	10.63
CHMW-2S	145	3.46	0.71	1,804	3.53	7.55	7.16	0.00	0.70	71	0.70	7.63
CHMW-2D	145	3.79	0.66	2,141	3.84	6.89	7.14	0.00	0.65	61	0.65	7.56
CHMW-3S	145	5.41	1.55	4,596	5.63	10.8	8.15	0.00	1.33	253	1.32	12.54
CHMW-3D	143	6.17	1.51	5,771	6.35	10.43	8.17	0.00	1.23	216	1.23	13.00
CHMW-4S	145	1.37	1.03	425	1.71	9.54	10.49	0.00	1.02	150	1.02	11.25
CHMW-4D	145	-0.11	0.92	124	0.92	9.40	10.30	0.00	0.90	117	0.90	11.26
MW-SRC-2	138	0.28	0.61	62	0.67	6.7	5.17	0.01	0.49	32	0.49	5.84
MW-D-3	141	2.36	0.97	920	2.55	7.77	6.54	0.00	0.96	128	0.95	7.42
MW-93-MFS-C5-3	142	-2.76	1.01	1,229	2.94	7.26	5.34	0.00	0.91	118	0.91	7.68
88-2-VD	10	-7.45	0.69	559	7.47	2.85	0.86	0.00	0.48	2	0.46	2.42
MW-BM-1	140	2.39	0.46	831	2.44	5.72	7.53	0.00	0.45	29	0.45	6.95
MW-HM-1	139	0.83	0.59	142	1.01	5.95	4.51	0.00	0.54	40	0.54	5.66
MW-PL-1	86	0.56	1.55	231	1.64	6.04	10.70	0.00	0.84	59	0.83	5.05

Notes:
1. Model results and statistics are presented at the typical field-measurement precision (0.01 ft).

Table 8: Well-Specific Maximum Water Level Changes

Project #040001 -South Parcel Mine Expansion
Dupont, WA

		Predictive Model Results							
		Maximum Decrease in Water Level based on Refined Model Results				Maximum Decrease in Water Level based on Refined Model Results, and includes Model Uncertainty			
		Step 1	Step 2	Step 3	Step 4	Step 1	Step 2	Step 3	Step 4
Well ID	MW-EM-1s	0.50	1.61	5.44	5.00	2.90	4.33	9.29	8.73
	MW-EM-1d	0.47	1.51	5.12	4.71	1.81	3.01	7.20	6.72
	MW-EM-2s	0.06	0.15	0.35	0.33	0.52	0.63	0.87	0.84
	MW-EM-2d	0.07	0.17	0.39	0.36	0.46	0.58	0.83	0.80
	MW-EM-3	0.01	0.02	0.02	0.02	0.20	0.21	0.21	0.21
	CHMW-1	1.30	5.23	59.79	30.47	2.64	7.06	68.41	35.44
	CHMW-2S	7.37	45.45	50.98	29.92	9.17	51.82	58.01	34.43
	CHMW-2D	8.80	45.20	50.79	31.76	10.71	51.55	57.83	36.47
	CHMW-3S	0.83	3.24	53.86	52.76	2.97	5.82	65.73	64.43
	CHMW-3D	0.10	2.70	57.02	50.29	2.05	5.14	69.56	61.57
	CHMW-4S	0.95	3.14	14.33	13.79	2.40	4.90	17.64	17.02
	CHMW-4D	0.76	2.96	15.03	14.01	2.03	4.51	18.10	16.95
	MW-SRC-2	0.29	0.33	0.30	0.34	1.11	1.15	1.12	1.16
	MW-D-3	1.79	4.27	7.68	6.55	3.33	6.20	10.16	8.85
	MW-93-MFS-C5-3	1.40	2.73	4.21	3.63	2.96	4.52	6.27	5.58
	88-2-VD	0.40	0.57	1.41	1.35	1.41	1.63	2.72	2.64
	MW-BM-1	0.21	0.35	0.39	0.74	0.83	0.98	1.03	1.41
	MW-HM-1	0.25	0.41	0.27	0.41	1.03	1.21	1.05	1.22
	MW-PL-1	0.10	0.35	1.10	1.01	2.11	2.45	3.44	3.33

Notes:
1. Model predictions are presented at the typical field-measurement precision (0.01 ft).
2. Maximum Change in Water Level based on refined model results.
3. Maximum Change in Water Level calculated for 95% lower confidence interval for 1-tailed test.
4. Shaded values indicate forecasted change in water level exceeds half the range in observed values.

Table 9 - Minimum Predicted Groundwater Levels for Each Dewatering Step

South Parcel Mine Expansion, Proj. No. 040001

Step 1 - Initial Pumping Test

Well	Groundwater Elevation in Feet (NGVD 29)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MW-EM-1S	203.6	202.4	202.9	202.2	202.3	201.4	200.4	200.4	199.5	199.5	202.1	202.9
MW-EM-1D	204.6	203.4	203.9	203.2	203.3	202.5	201.5	201.5	200.7	200.7	203.1	203.9
MW-EM-2S	210.6	210.3	210.4	210.3	210.2	210.0	209.7	209.6	209.3	209.5	210.2	210.4
MW-EM-2D	210.8	210.4	210.6	210.5	210.4	210.2	209.8	209.7	209.4	209.6	210.4	210.5
MW-EM-3	212.1	211.9	211.8	211.9	212.0	211.6	211.4	210.8	210.2	210.3	211.5	211.9
MW-SRC-2	213.2	212.4	212.7	212.6	212.8	212.0	211.4	210.2	209.6	210.5	212.3	212.7
MW-BM-1	218.0	217.0	216.6	217.4	217.3	216.6	216.1	213.1	213.3	214.2	216.8	217.4
MW-HM-1	214.2	213.5	213.3	213.8	213.6	212.7	211.8	211.2	210.6	211.1	213.1	213.6
MW-PL-1	200.8	200.1	200.4	200.1	200.0	199.4	198.6	198.7	198.0	197.7	199.6	200.2
CHMW-1	191.3	189.9	190.4	189.6	189.7	189.0	188.1	188.0	187.4	187.5	190.0	190.7
CHMW-2S	184.6	183.3	183.7	183.0	183.0	182.5	181.7	181.6	181.2	181.4	183.5	184.0
CHMW-2D	183.4	181.8	182.4	181.4	181.5	180.8	179.8	179.7	179.3	179.4	182.1	182.7
CHMW-3S	193.3	191.7	192.4	191.3	191.5	190.6	189.6	189.5	188.7	188.8	191.7	192.6
CHMW-3D	193.2	191.5	192.2	191.1	191.3	190.4	189.2	189.1	188.3	188.4	191.5	192.5
CHMW-4S	196.1	194.7	195.3	194.4	194.6	193.7	192.7	192.6	191.9	191.9	194.6	195.5
CHMW-4D	194.3	192.9	193.5	192.6	192.7	191.9	190.9	190.8	190.1	190.1	192.8	193.6
MW-D-3	196.5	195.3	195.7	195.0	195.1	194.6	193.9	193.7	193.3	193.5	195.6	195.9
MW-93-MFS-C5-3	192.3	191.2	191.7	191.0	191.0	190.5	190.0	189.9	189.5	189.8	191.6	191.7

Table 9 - Minimum Predicted Groundwater Levels for Each Dewatering Step

South Parcel Mine Expansion, Proj. No. 040001

Step 2 - Preparation for Mining/Expanded Dewatering Test

Well	Groundwater Elevation in Feet (NGVD 29)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MW-EM-1S	202.3	201.1	201.6	200.9	201.1	200.1	199.1	199.2	198.4	198.3	200.8	201.5
MW-EM-1D	203.4	202.3	202.8	202.2	202.3	201.4	200.5	200.5	199.7	199.7	202.0	202.7
MW-EM-2S	210.6	210.2	210.3	210.2	210.1	210.0	209.6	209.5	209.2	209.4	210.1	210.3
MW-EM-2D	210.8	210.4	210.5	210.4	210.3	210.1	209.7	209.6	209.3	209.5	210.3	210.5
MW-EM-3	212.1	211.9	211.8	211.9	212.0	211.6	211.4	210.8	210.2	210.3	211.5	211.9
MW-SRC-2	213.2	212.4	212.6	212.6	212.8	212.0	211.4	210.2	209.5	210.5	212.0	212.7
MW-BM-1	218.0	217.0	216.5	217.3	217.2	216.6	216.1	213.0	213.3	214.1	216.8	217.3
MW-HM-1	214.2	213.4	213.3	213.8	213.6	212.7	211.8	211.2	210.5	211.1	213.0	213.6
MW-PL-1	200.4	199.7	200.1	199.8	199.8	199.1	198.2	198.4	197.7	197.4	199.2	199.8
CHMW-1	187.0	185.7	186.3	185.5	185.6	184.9	184.0	184.0	183.3	183.4	185.8	186.4
CHMW-2S	143.8	141.4	142.2	141.0	141.0	140.1	139.1	138.9	138.3	138.6	141.8	142.9
CHMW-2D	142.5	141.0	141.6	140.7	140.7	140.0	139.1	138.9	138.3	138.5	141.2	141.9
CHMW-3S	190.6	189.0	189.8	188.8	189.0	188.1	187.0	187.0	186.2	186.2	189.0	189.8
CHMW-3D	190.2	188.6	189.4	188.3	188.5	187.5	186.3	186.3	185.4	185.3	188.4	189.3
CHMW-4S	193.7	192.3	193.0	192.1	192.3	191.4	190.4	190.4	189.6	189.6	192.2	193.0
CHMW-4D	191.8	190.5	191.2	190.3	190.5	189.6	188.6	188.6	187.8	187.8	190.4	191.1
MW-D-3	193.7	192.5	193.0	192.3	192.3	191.9	191.2	191.1	190.7	190.9	192.9	193.4
MW-93-MFS-C5-3	190.8	189.8	190.3	189.6	189.6	189.1	188.7	188.5	188.2	188.5	190.2	190.5

Table 9 - Minimum Predicted Groundwater Levels for Each Dewatering Step

South Parcel Mine Expansion, Proj. No. 040001

Step 3 - Active Dewatering during Mining

Well	Groundwater Elevation in Feet (NGVD 29)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MW-EM-1S	197.5	196.4	196.9	196.4	196.5	195.6	194.7	194.8	194.1	194.1	196.1	196.8
MW-EM-1D	199.4	198.4	198.9	198.3	198.4	197.6	196.8	196.9	196.2	196.2	198.1	198.7
MW-EM-2S	210.3	210.0	210.1	209.9	209.9	209.7	209.4	209.3	209.0	209.2	209.9	210.0
MW-EM-2D	210.5	210.1	210.3	210.1	210.0	209.8	209.5	209.4	209.1	209.3	210.0	210.2
MW-EM-3	212.1	211.9	211.8	211.9	212.0	211.6	211.4	210.8	210.2	210.3	211.5	211.8
MW-SRC-2	213.2	212.4	212.7	212.6	212.8	212.0	211.4	210.2	209.5	210.5	212.0	212.7
MW-BM-1	217.8	216.8	216.4	217.2	217.1	216.4	215.9	212.8	213.1	213.9	216.7	217.2
MW-HM-1	214.2	213.4	213.3	213.8	213.6	212.7	211.8	211.2	210.4	211.1	213.0	213.6
MW-PL-1	199.4	198.7	199.0	198.8	198.7	198.0	197.1	197.3	196.6	196.2	198.1	198.8
CHMW-1	129.8	129.1	129.4	128.9	128.9	128.5	127.8	127.8	127.3	127.4	129.2	129.5
CHMW-2S	136.0	134.5	135.0	134.1	134.1	133.5	132.9	132.8	132.3	132.5	134.9	135.5
CHMW-2D	135.9	134.7	135.1	134.3	134.2	133.7	133.1	132.9	132.4	132.6	134.9	135.5
CHMW-3S	131.1	128.4	130.3	128.9	129.2	127.9	126.6	127.0	126.2	126.3	129.0	130.2
CHMW-3D	128.3	127.4	127.9	127.6	127.6	126.8	125.8	126.1	125.4	125.1	127.0	127.6
CHMW-4S	181.0	179.7	180.4	179.6	179.7	178.8	177.7	177.8	176.9	176.9	179.5	180.3
CHMW-4D	178.5	177.3	178.0	177.1	177.3	176.4	175.3	175.4	174.5	174.4	177.1	177.8
MW-D-3	189.9	188.6	189.1	188.4	188.4	187.9	187.4	187.3	186.9	187.3	189.1	189.6
MW-93-MFS-C5-3	189.5	188.5	189.0	188.4	188.3	187.9	187.5	187.4	187.2	187.5	189.0	189.3

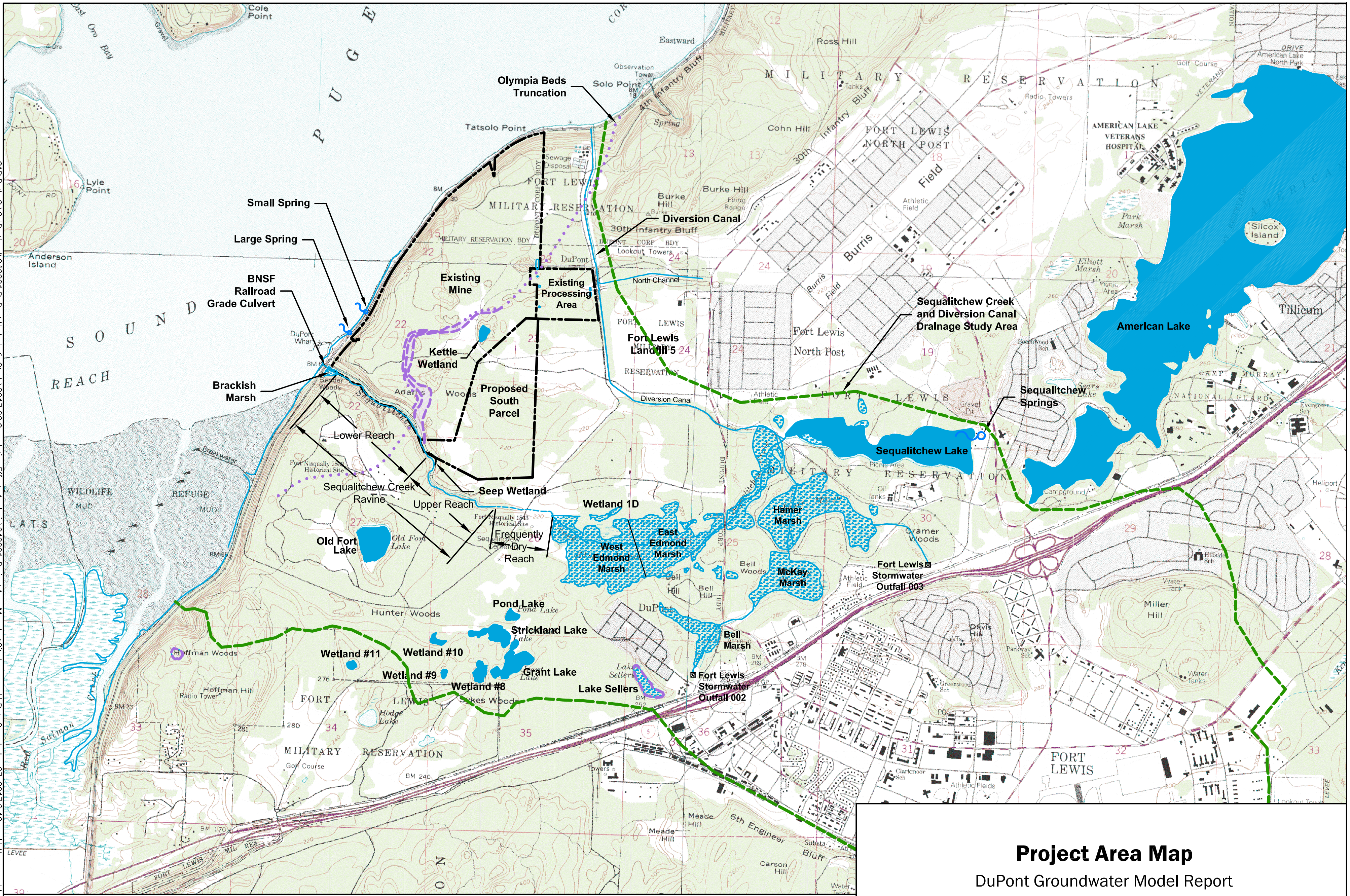
Table 9 - Minimum Predicted Groundwater Levels for Each Dewatering Step

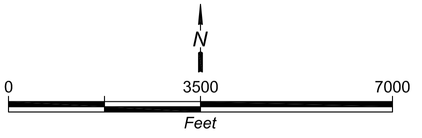
South Parcel Mine Expansion, Proj. No. 040001

Step 4 - Cessation of Active Dewatering

Well	Groundwater Elevation in Feet (NGVD 29)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MW-EM-1S	198.1	197.0	197.6	197.0	197.1	196.2	195.4	195.3	194.8	194.7	196.8	197.4
MW-EM-1D	199.9	198.9	199.4	198.8	199.0	198.2	197.3	197.3	196.7	196.7	198.7	199.3
MW-EM-2S	210.3	210.0	210.1	210.0	209.9	209.7	209.4	209.3	209.0	209.2	209.9	210.1
MW-EM-2D	210.5	210.2	210.3	210.1	210.1	209.9	209.5	209.4	209.1	209.3	210.1	210.2
MW-EM-3	212.1	211.9	211.8	211.9	212.0	211.6	211.4	210.8	210.2	210.3	211.5	211.8
MW-SRC-2	213.2	212.4	212.7	212.6	212.8	212.0	211.4	209.9	209.4	210.4	212.0	212.7
MW-BM-1	217.9	216.9	216.4	217.2	217.1	216.5	216.0	212.3	213.0	213.8	216.7	217.2
MW-HM-1	214.2	213.4	213.3	213.8	213.6	212.7	211.8	211.0	210.3	211.1	213.0	213.6
MW-PL-1	199.5	198.8	199.2	198.9	198.9	198.2	197.3	197.5	196.8	196.4	198.2	198.9
CHMW-1	163.2	162.7	162.9	162.7	162.6	162.4	162.1	162.1	161.8	162.0	162.9	163.1
CHMW-2S	169.3	165.0	168.1	163.2	162.8	158.9	157.1	157.2	156.2	156.9	167.9	168.8
CHMW-2D	160.3	158.5	159.2	158.1	157.9	156.9	155.4	155.5	154.6	155.2	159.1	159.8
CHMW-3S	140.4	140.2	140.3	140.2	140.2	140.0	139.7	139.7	139.5	139.7	140.3	140.3
CHMW-3D	141.9	141.6	141.8	141.6	141.6	141.4	141.1	141.1	140.9	141.0	141.6	141.8
CHMW-4S	183.0	181.9	182.5	181.8	181.9	181.3	180.5	180.5	179.9	180.0	181.9	182.4
CHMW-4D	181.0	180.0	180.6	179.9	180.0	179.4	178.7	178.7	178.2	178.2	180.0	180.5
MW-D-3	191.4	190.2	190.7	190.0	189.9	189.5	188.9	188.8	188.5	188.9	190.7	191.1
MW-93-MFS-C5-3	190.1	189.1	189.5	188.9	188.8	188.4	187.9	187.9	187.6	188.0	189.6	189.9

Figures





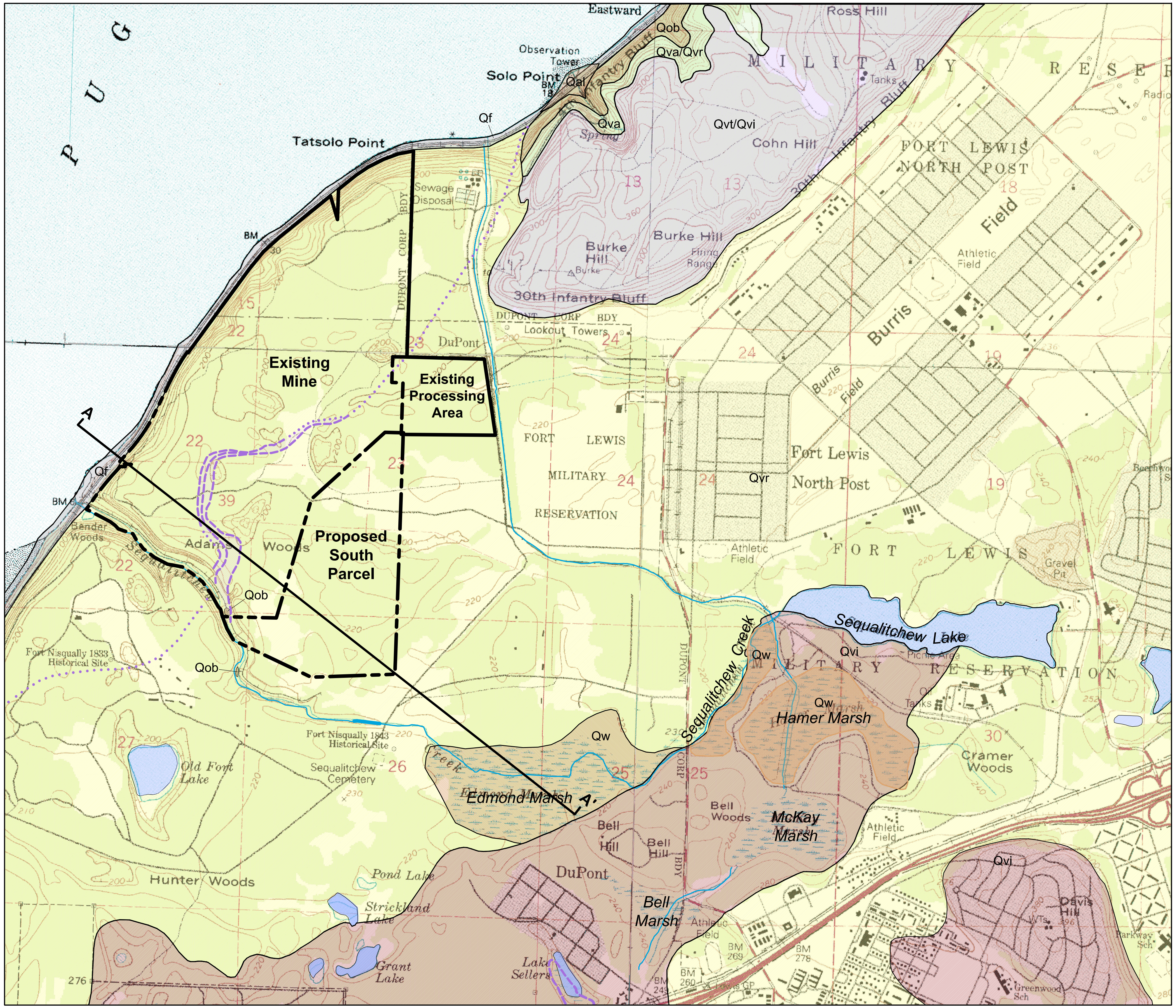
Project Area Map

DuPont Groundwater Model Report

DuPont, Washington

Aspect CONSULTING

Jun-2017	BY: OGR/SCC	FIGURE NO.
PROJECT NO. 040001-014	REVISED BY: SCC	1



Legend

Qf	**Qf (Fill)** Artificial fill. Likely consists primarily of crushed rock and rip-rap placed for railroad embankment.
Qw	**Qw (Wetland Deposits)** Peat, organic-rich muck, silt and clay.
Qal	**Qal (Recent Alluvium)** Silt, sand, gravel, and peat deposited in stream beds and estuaries, includes some lacustrine and beach deposits.
Qvr	**Qvr (Vashon Recessional Glacial Outwash)** Medium dense to dense, slightly silty to clean sand and gravel. Includes some silty beds. The majority of near-surface Vashon recessional outwash on the Project Site is made up of the Steilacoom Gravel member, which is composed of sandy gravel and gravelly sand, with minor amounts of silt.
Qvi	**Qvi (Ice-Contact Deposits)** Water-worked sands and gravels with interbeds and lenses of silty, till-like deposits.
Qvt/Qvi	**Qvt/Qvi (Till and Ice Contact Deposits)** Dense to very dense discontinuous layers of silty, sandy, and gravelly basal till. Ice contact deposits contain water-worked sands and gravels with interbeds and lenses of silty, till-like deposits.
Qva	**Qva (Vashon Advance Glacial Outwash)** Sand and gravel, and lacustrine clay, silt, and sand of northern source, deposited during Vashon glacial advance.
Qob	**Qob (Olympia Beds)** The Olympia Beds Qob unit is generally composed of interbedded lacustrine silt and clay and fluvial deposits.
- - -	**Olympia Beds Truncation (Surface Projection)** Approximate surface projection line showing the northwestward lateral subcrop extent of the Olympia Beds unit. Dashed where approximate, dotted where inferred.

Note: Map modified based on subsurface data and geologic interpretation from Walsh, Logan and Polenz 2003; Walsh et al. 2003, Walters and Kimmel, 1968, and Troost, Booth, and Borden, in review.

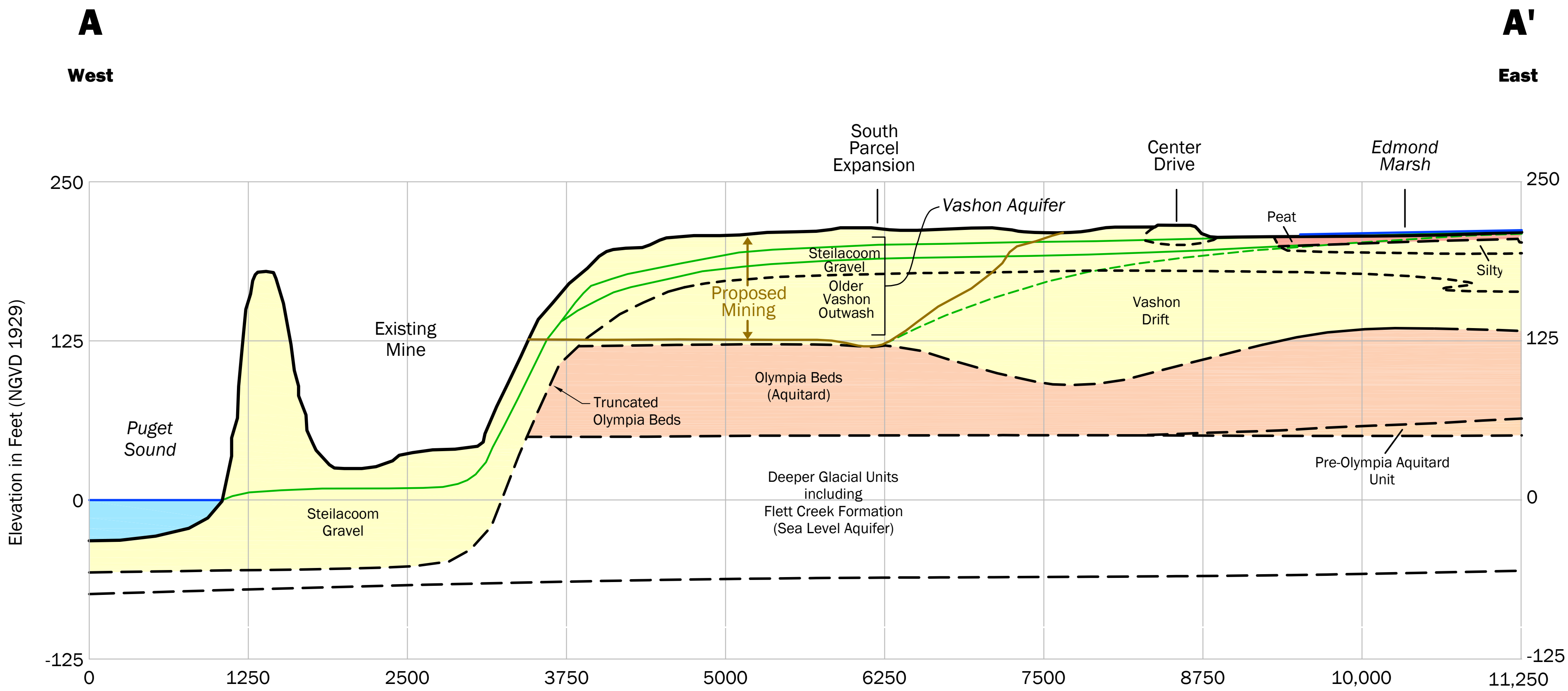
N

0 2000 4000
Feet

Geologic Map

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	Jun-2017	BY: DFR/SCC	FIGURE NO.
	PROJECT NO. 040001-014	REV BY: SCC	2



Predicted Water Table Change

Water Table Elevation February 2008
(Range at TW-4 shown for 2003-2008)

Note: 10x Vertical vs. Horizontal Exaggeration for Illustration

Horizontal Scale: 0 – 1250 Feet

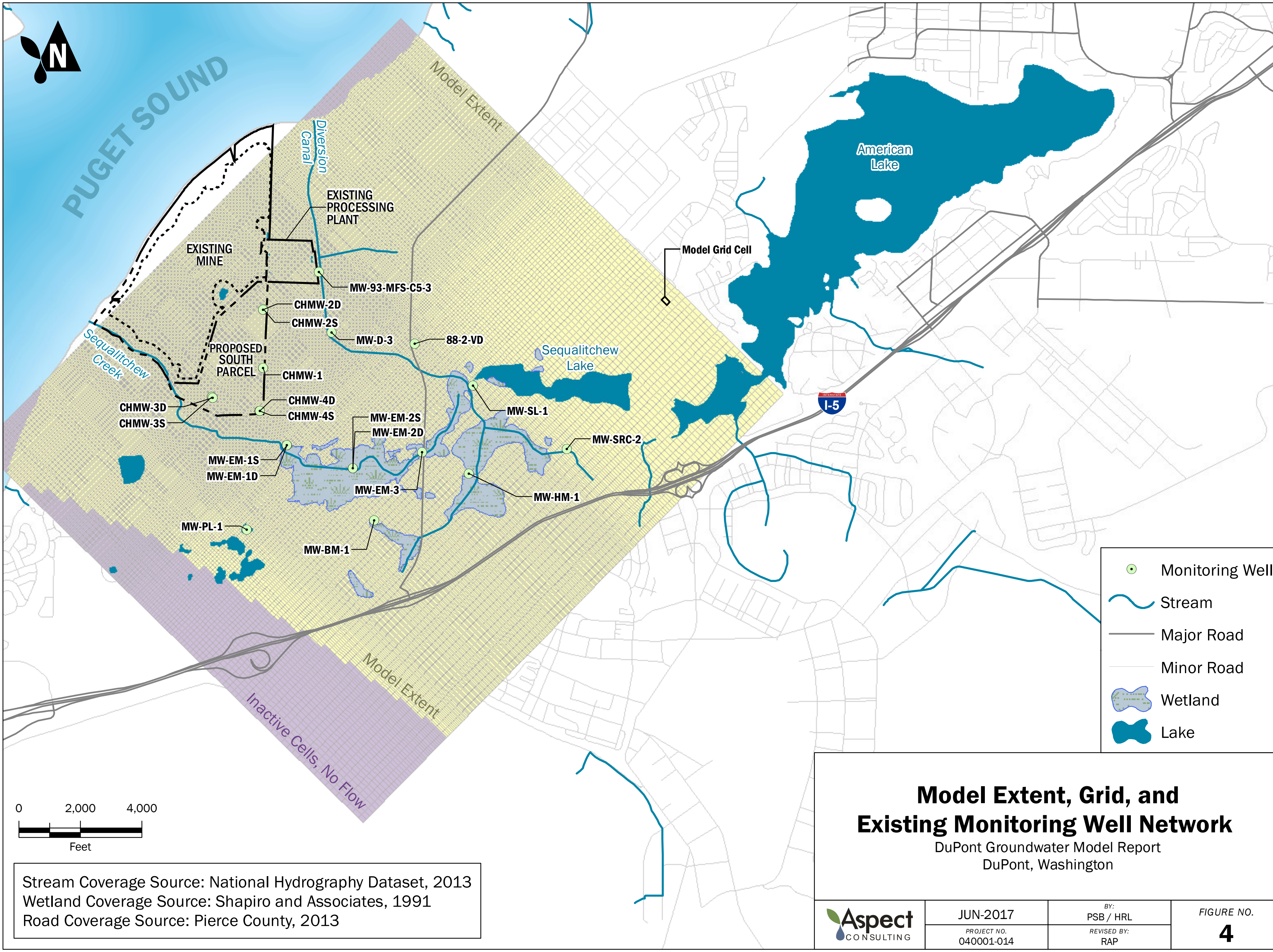
Vertical Scale: 0 – 125 Feet

Hydrogeologic Cross Section

CalPortland DuPont South Parcel
Groundwater Modeling
DuPont, Washington

Aspect CONSULTING	DEC-2014	BY: OGR/SCC	FIGURE NO. 3
	PROJECT NO. 040001-014	REVISED BY: -	

CAD Path: Q:\CalPortland\040001 DuPont Hydrologic Study\2014-12 South Parcel Monitoring Plan\040001-06 South Parcel Geologic Units.dwg 11x17 Landscape || Date Saved: Nov 13, 2014 2:14pm || User: scudd

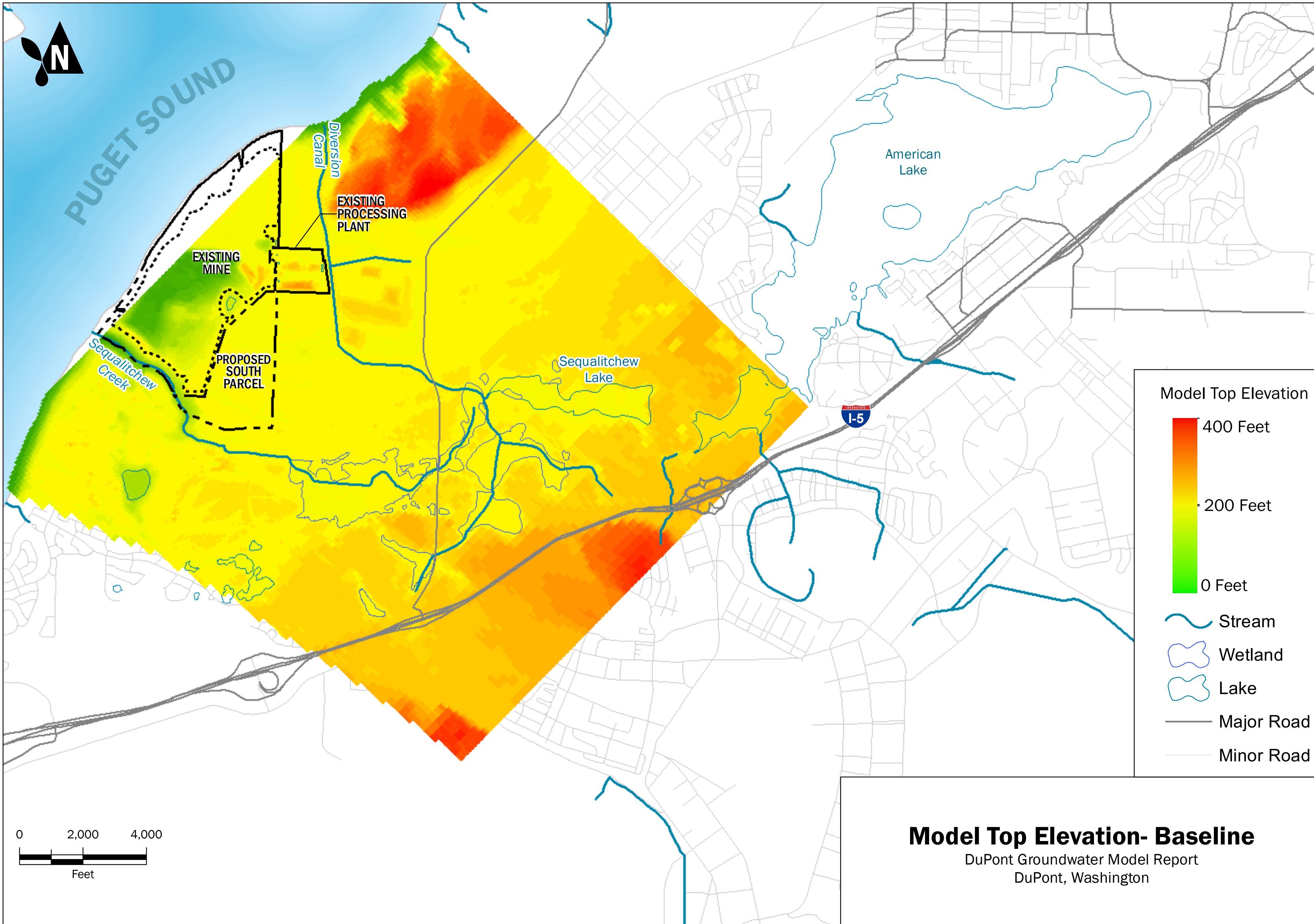


Stream Coverage Source: National Hydrography Dataset, 2013
Wetland Coverage Source: Shapiro and Associates, 1991
Road Coverage Source: Pierce County, 2013

Model Extent, Grid, and Existing Monitoring Well Network

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO. 4
	PROJECT NO. 040001-014	REVISED BY: RAP	



Notes: Topography from LiDAR study

Model Top Elevation- Baseline
DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO. 5
	PROJECT NO. 040001-014	REV BY: KES	

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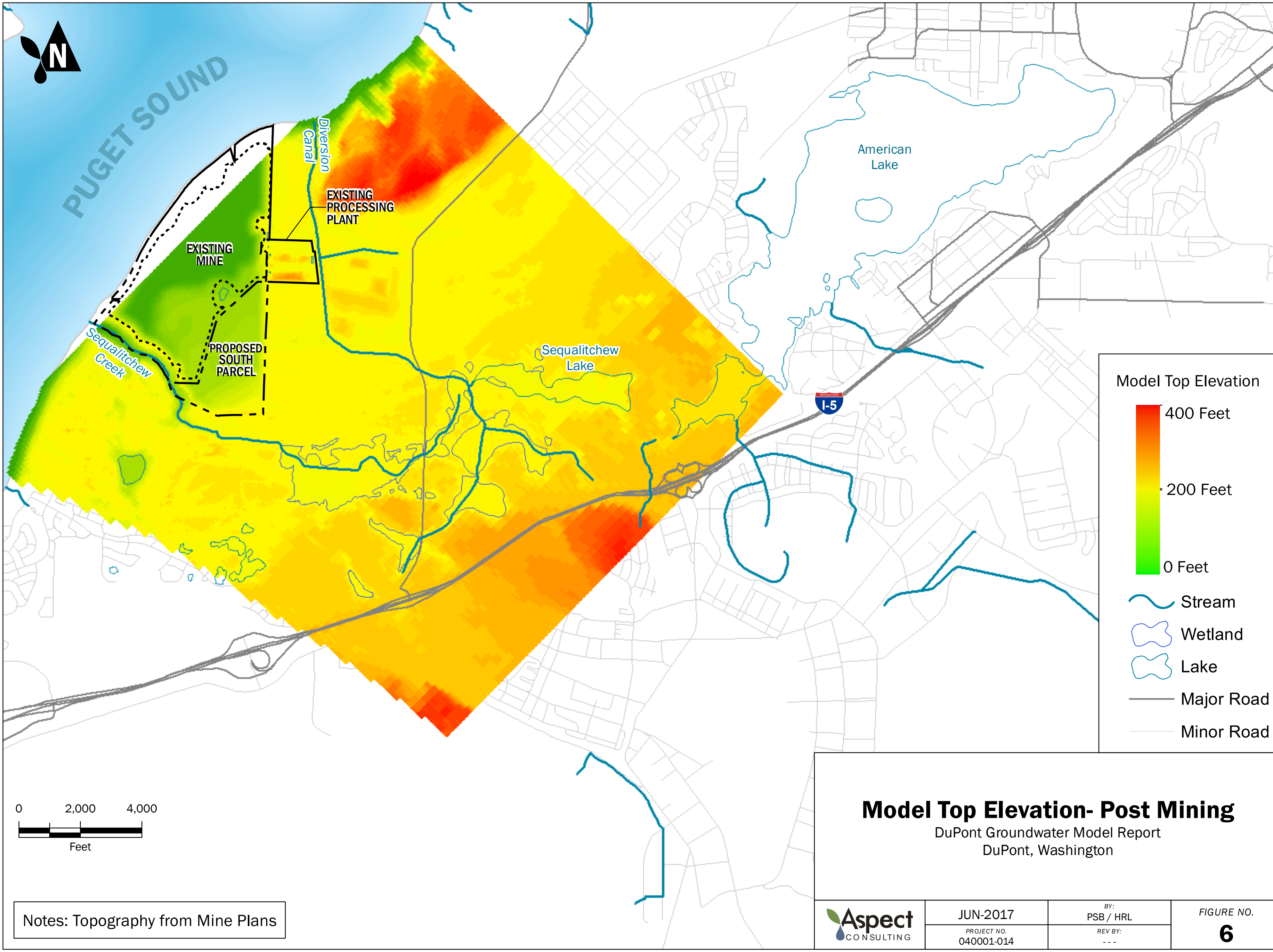

Model Top Elevation- Post Mining

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO. 6
	PROJECT NO. 040001-014	REV BY: - - -	

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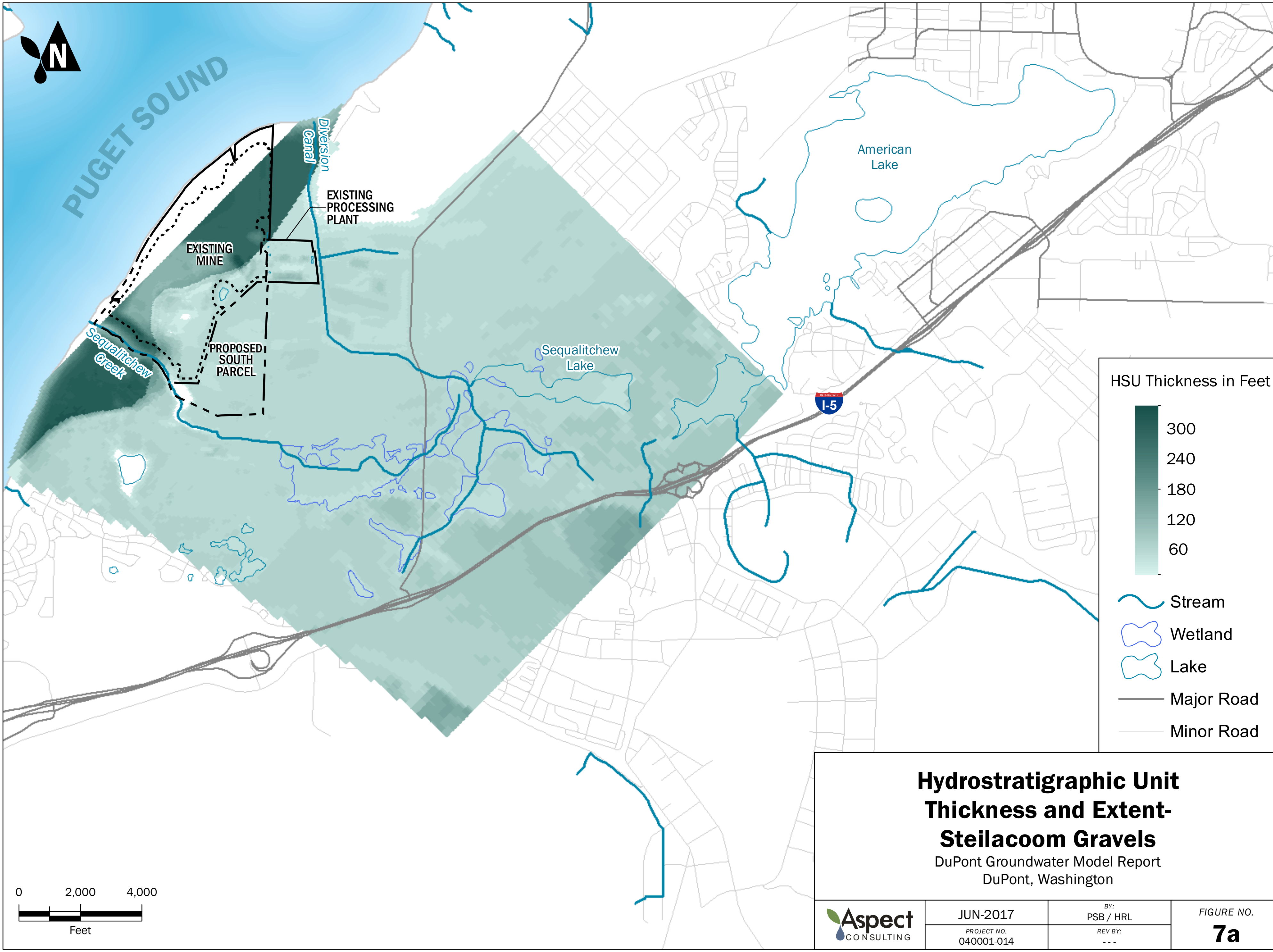

Hydrostratigraphic Unit Thickness and Extent- Steilacoom Gravels

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO.
	PROJECT NO. 040001-014	REV BY: - - -	7a

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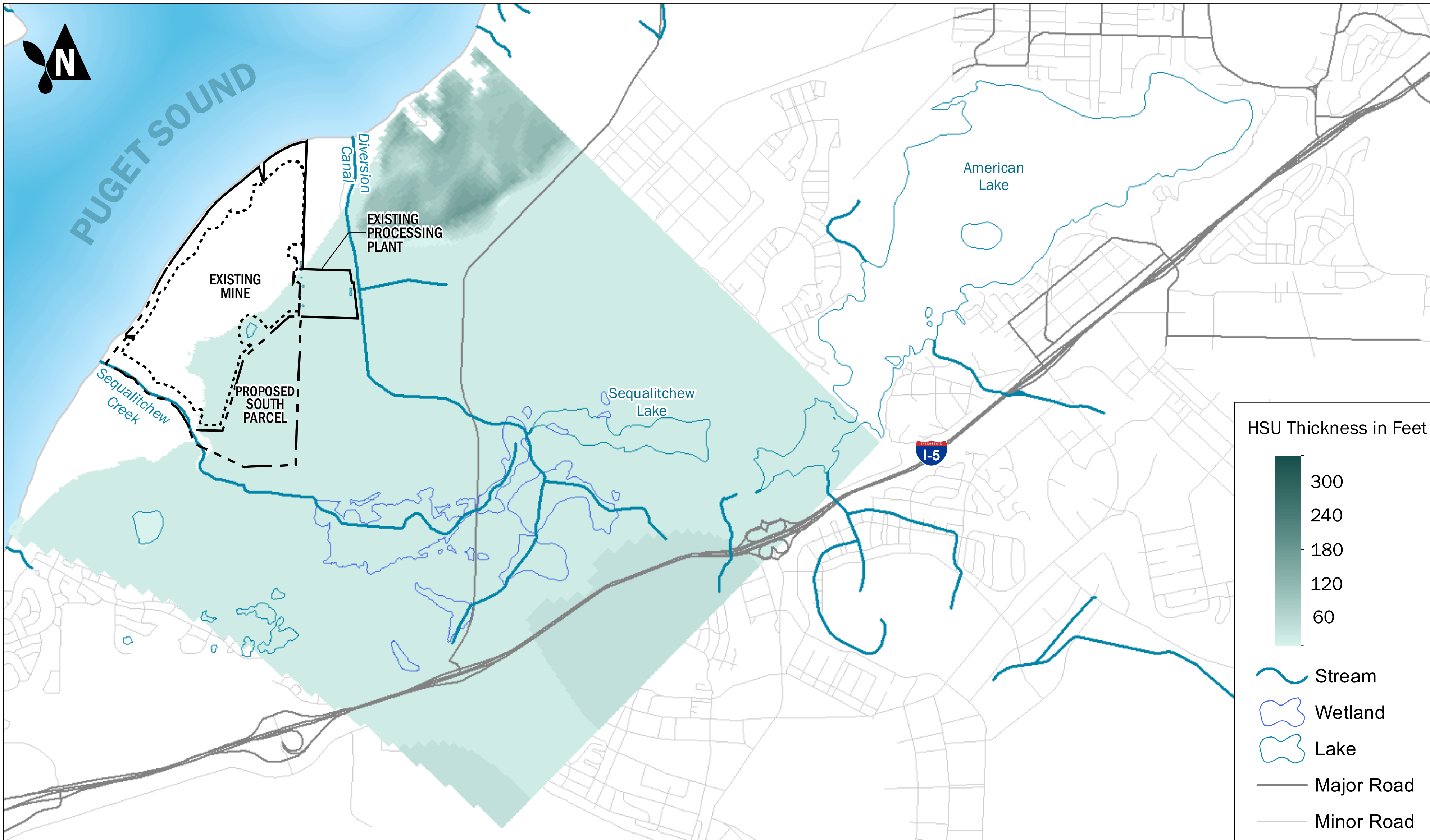

Hydrostratigraphic Unit Thickness and Extent-Upper Confining Unit

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING

JUN-2017	BY: PSB / HRL	FIGURE NO.
PROJECT NO. 040001-014	REV BY: - - -	7b

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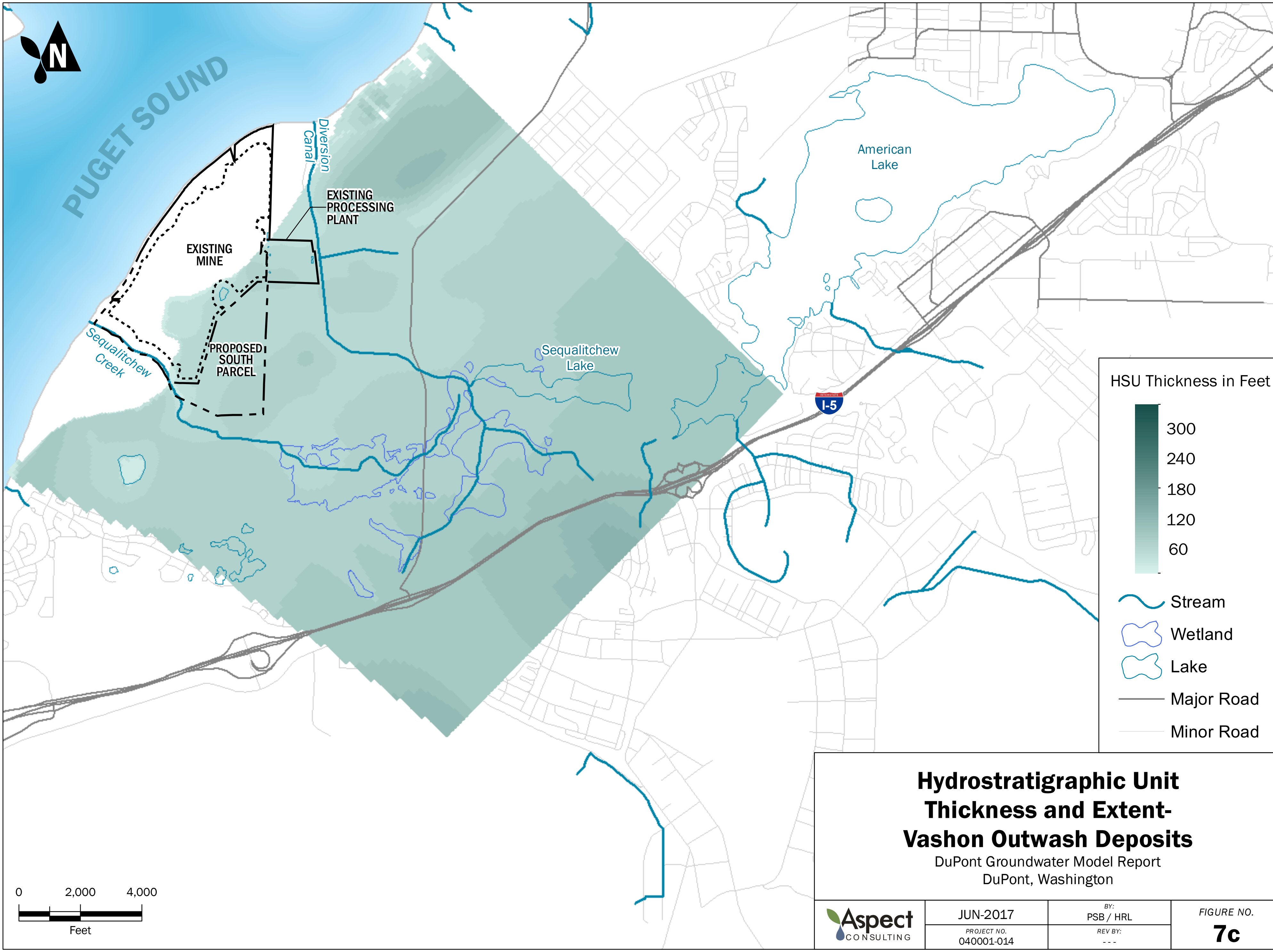

Hydrostratigraphic Unit Thickness and Extent-Vashon Outwash Deposits

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO. 7c
	PROJECT NO. 040001-014	REV BY: - - -	

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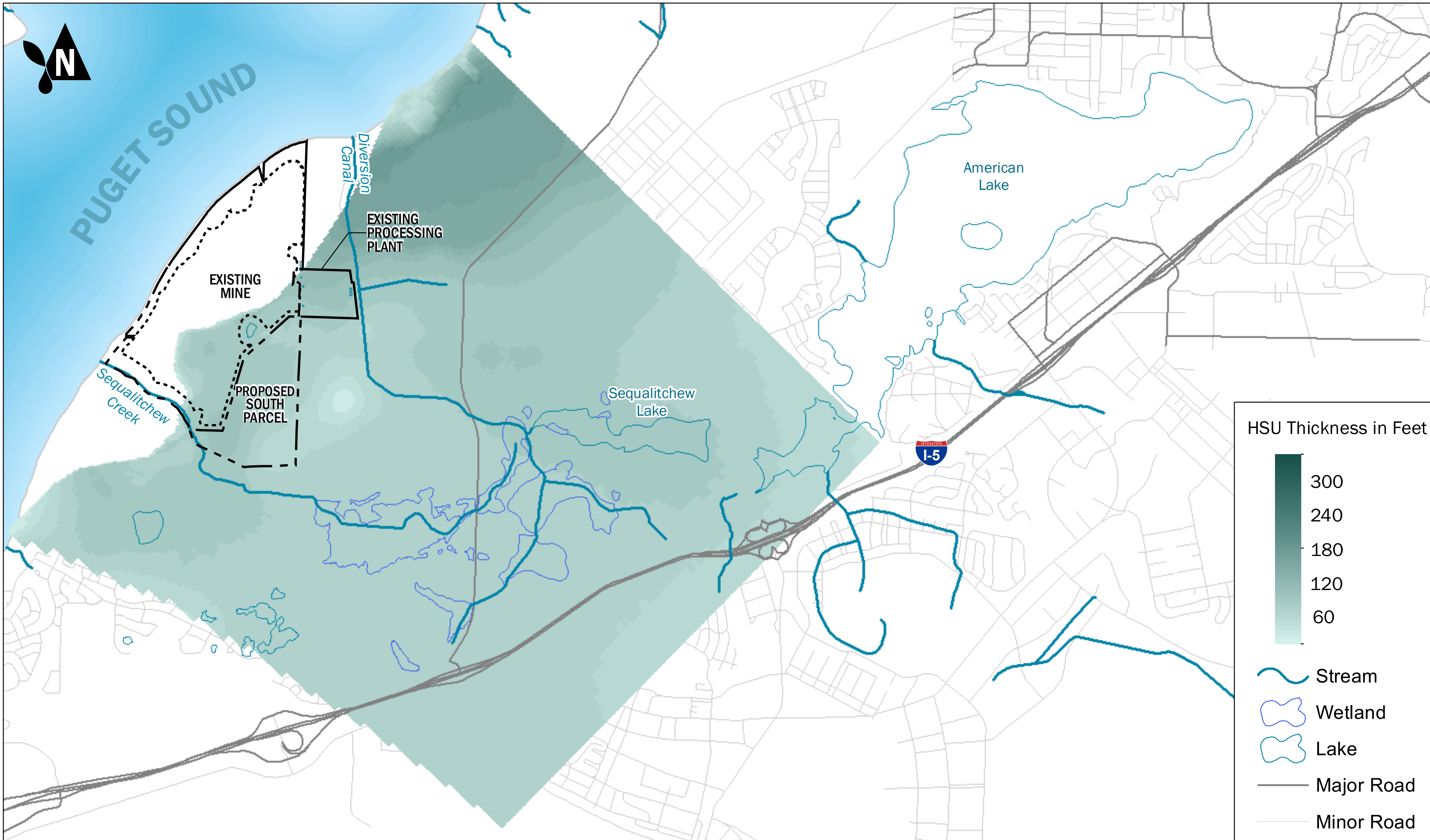
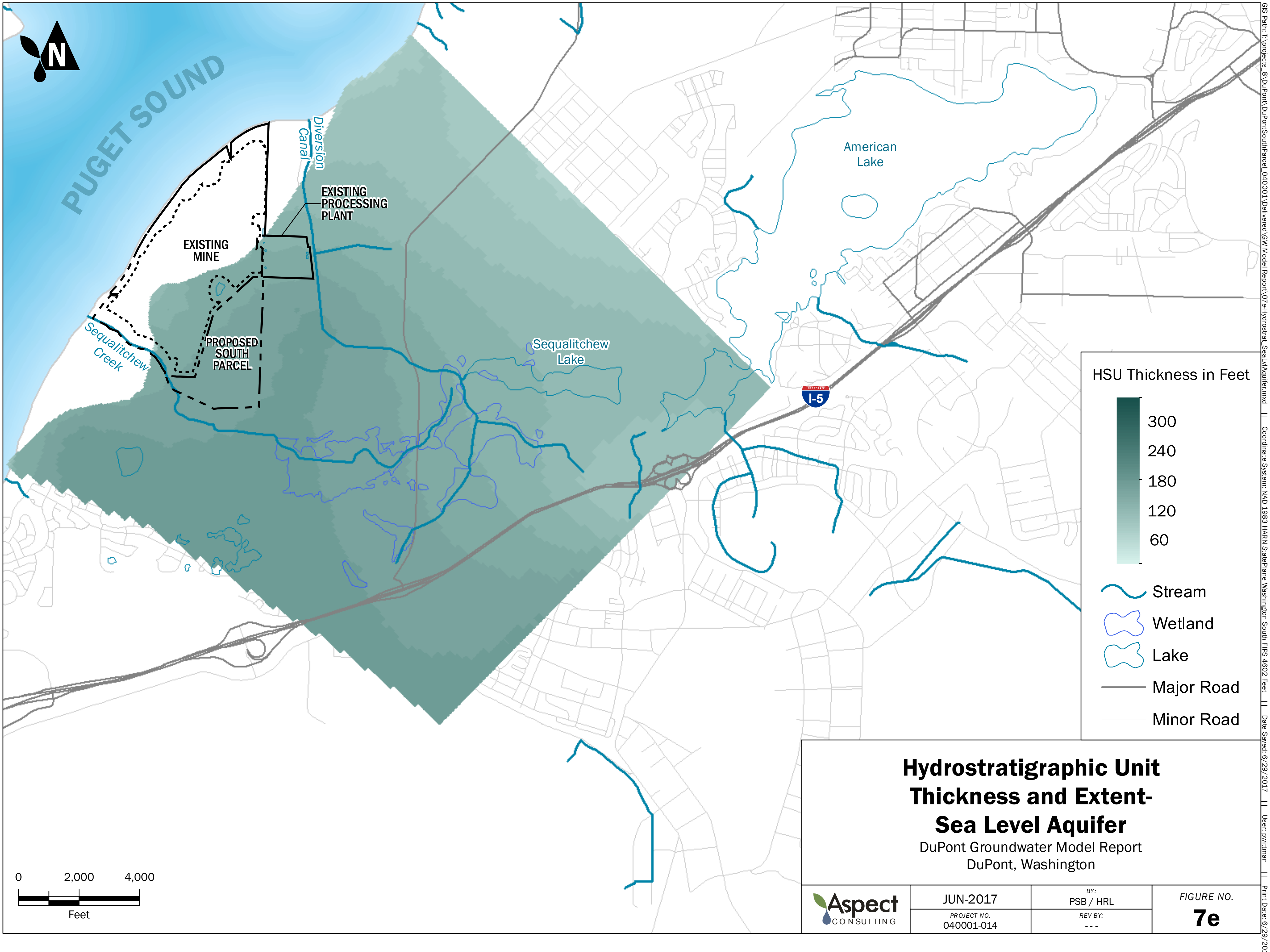


Hydrostratigraphic Unit Thickness and Extent-Olympia Beds

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING

JUN-2017	BY: PSB / HRL	FIGURE NO.	
PROJECT NO. 040001-014	REV BY: - - -	7d	



Hydrostratigraphic Unit Thickness and Extent-Sea Level Aquifer
DuPont Groundwater Model Report
DuPont, Washington

Hydraulic Conductivity by Hydrostratigraphic Unit- Steilacoom Gravel

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO.
	PROJECT NO. 040001-014	REV BY: - - -	8a

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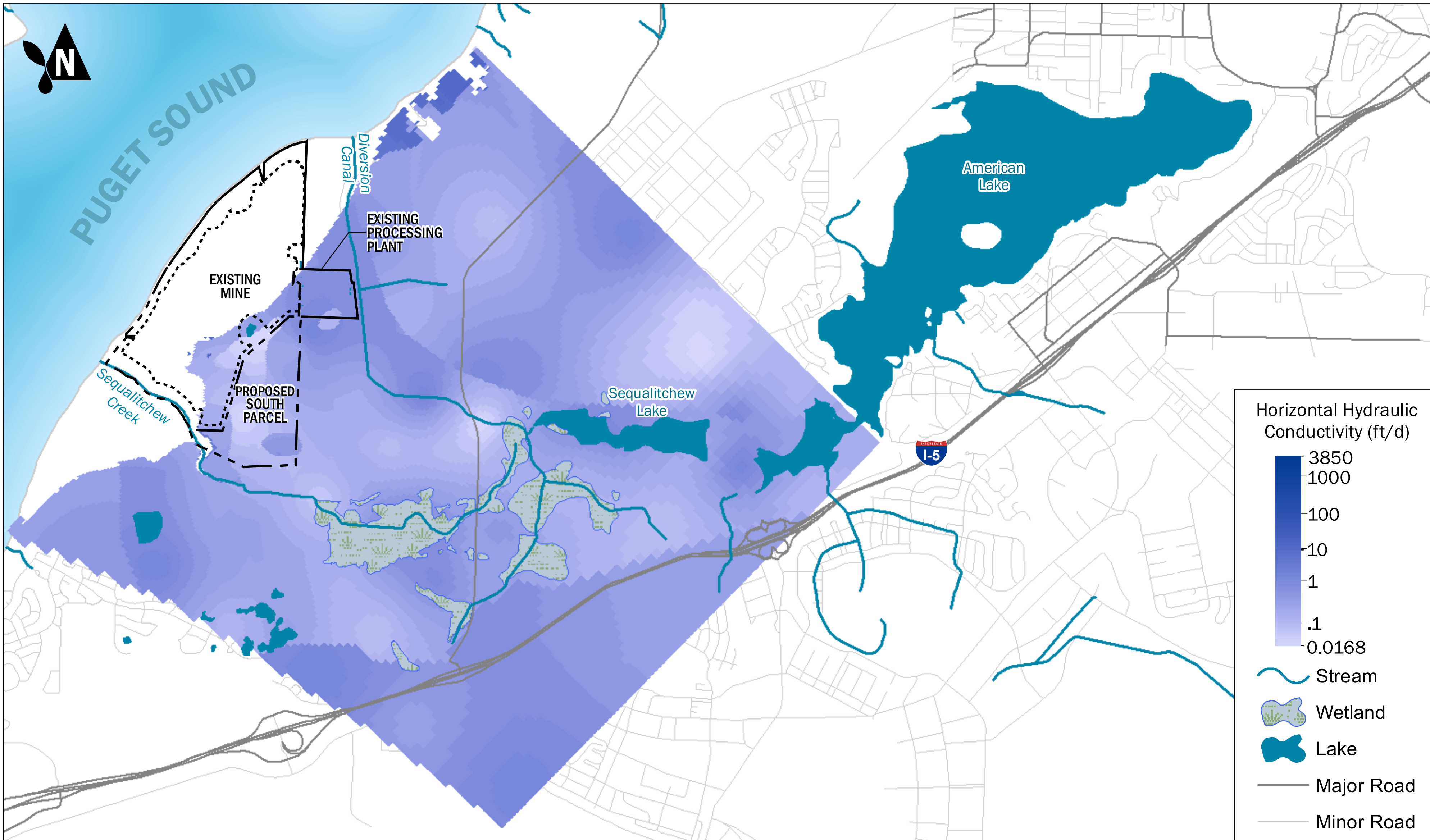

Hydraulic Conductivity by Hydrostratigraphic Unit- Upper Confining Unit

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO.
	PROJECT NO. 040001-014	REV BY: - - -	8b

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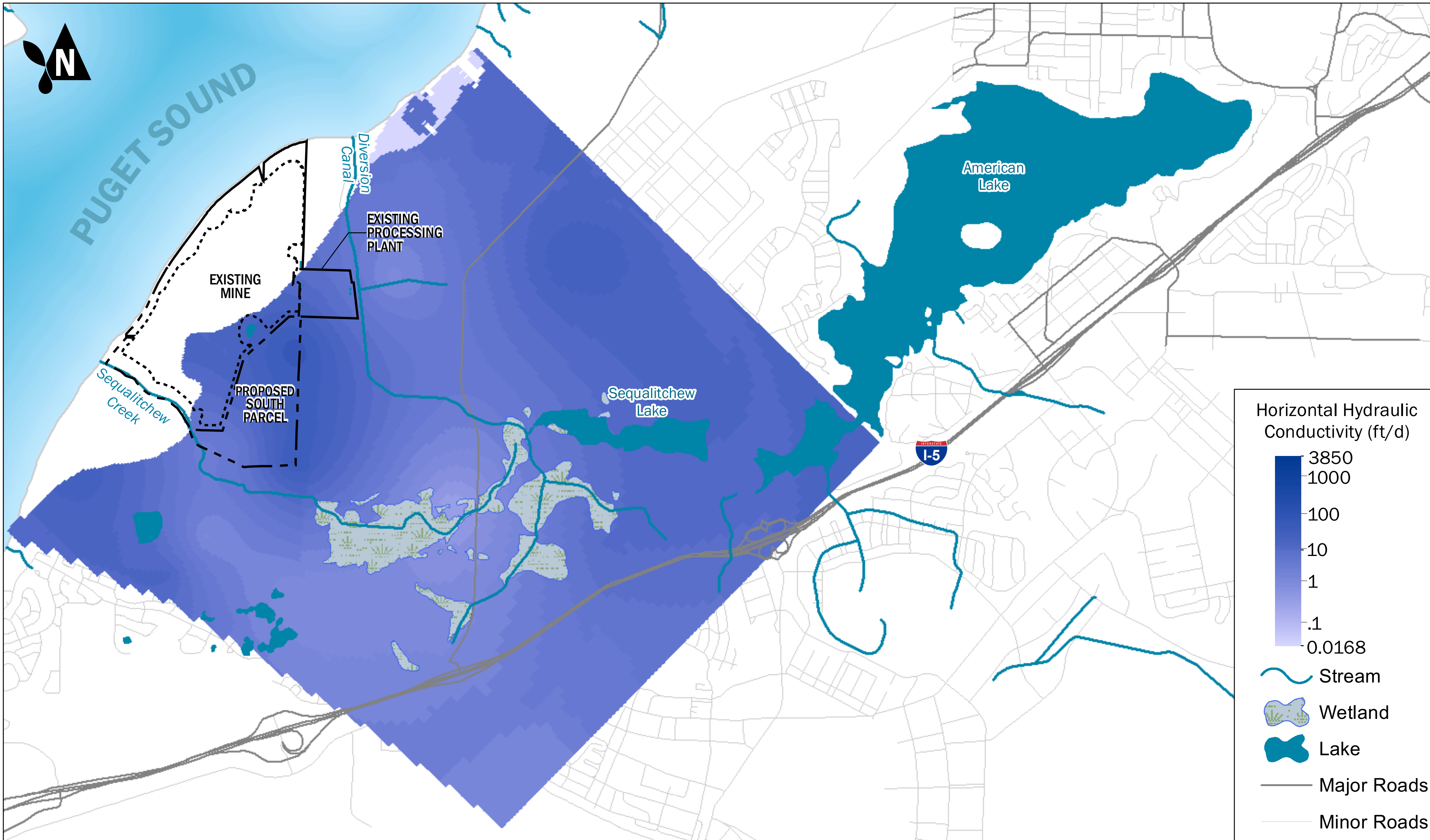

Hydraulic Conductivity by Hydrostratigraphic Unit-Vashon Outwash Deposits

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING

JUN-2017	BY: PSB / HRL	FIGURE NO. 8c
PROJECT NO. 040001-014	REV BY: - - -	

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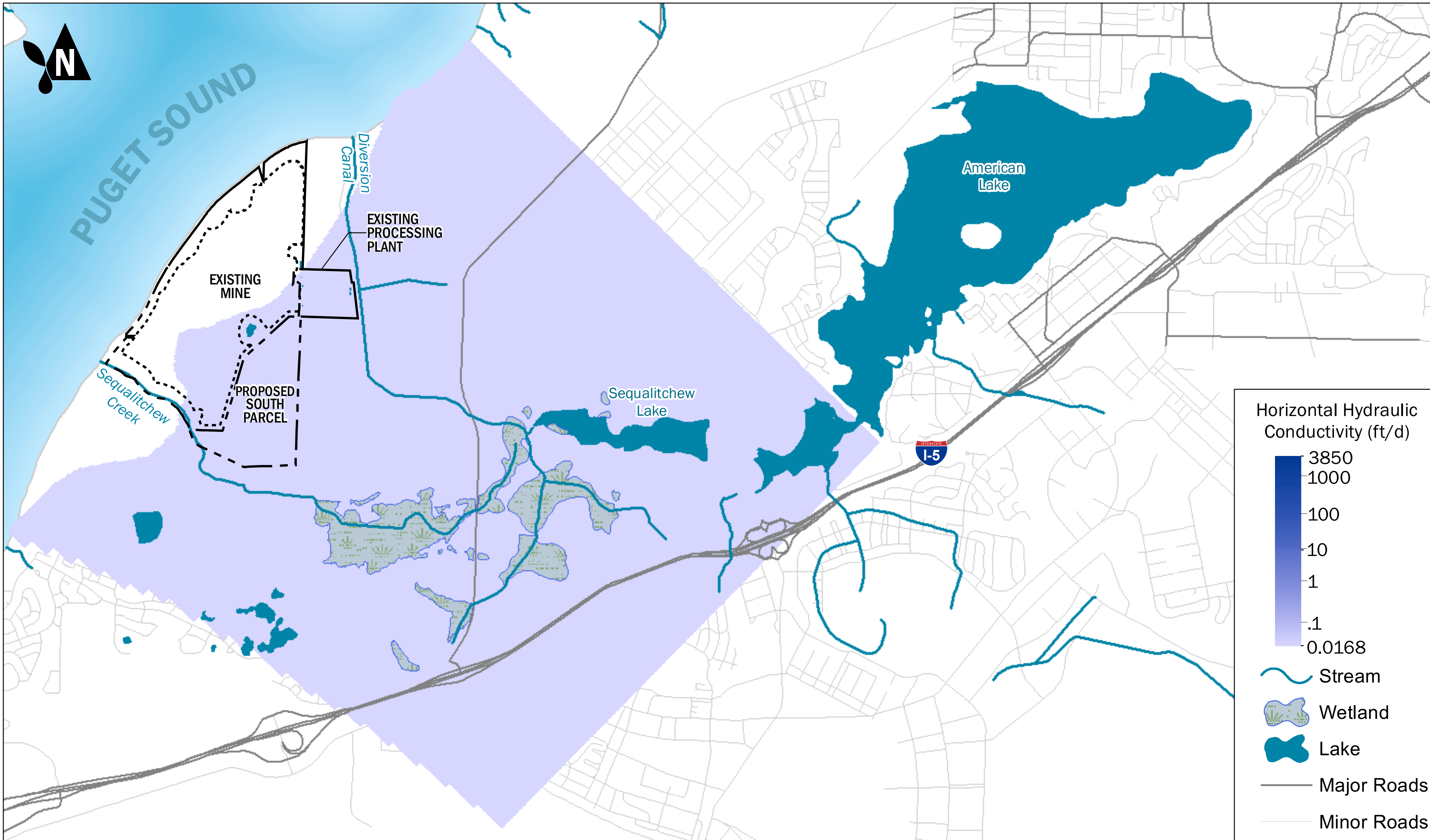

Hydraulic Conductivity by Hydrostratigraphic Unit- Olympia Beds

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO.
	PROJECT NO. 040001-014	REV BY: - - -	8d

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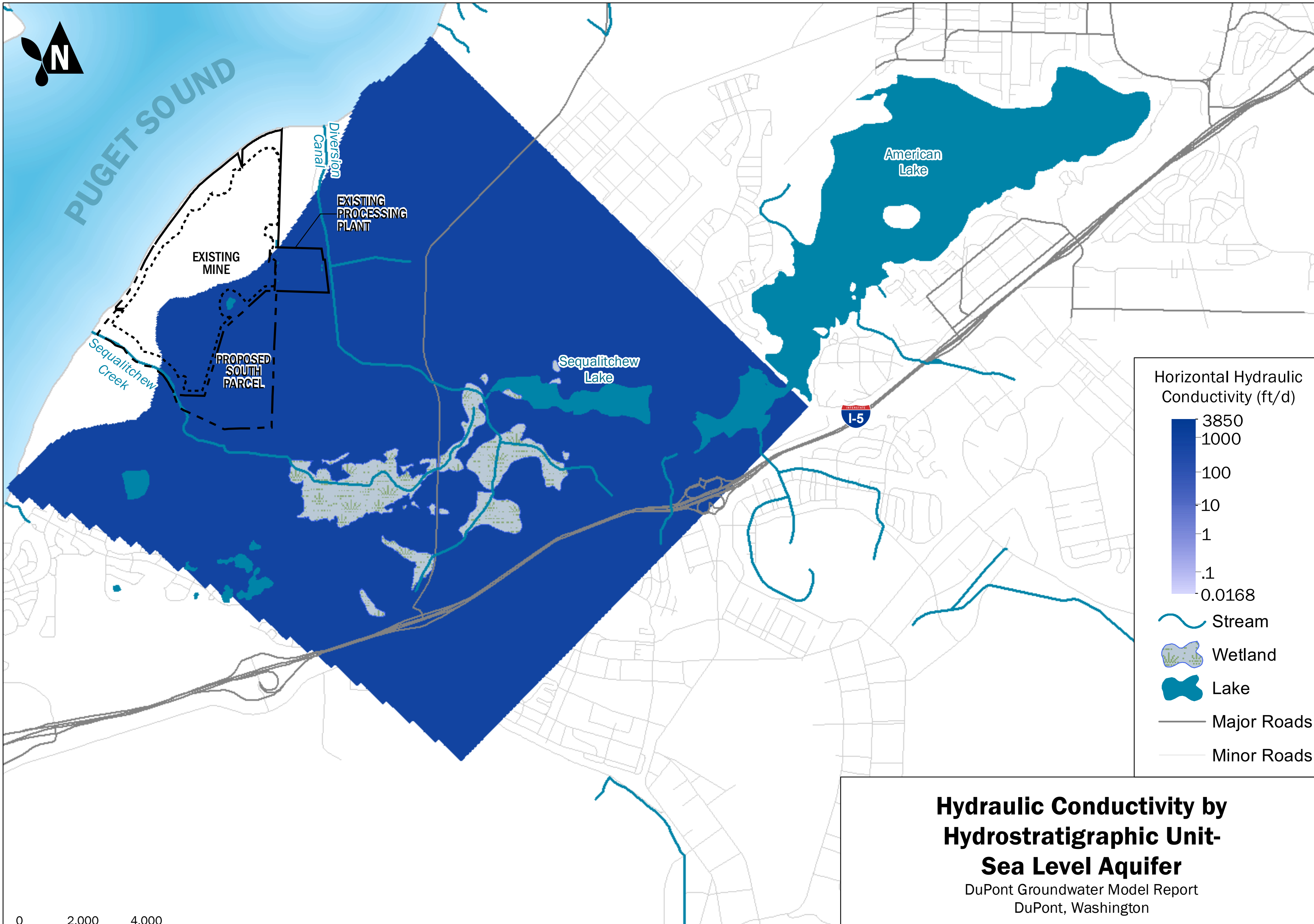


Hydraulic Conductivity by Hydrostratigraphic Unit- Sea Level Aquifer

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO. **8e**
	PROJECT NO. 040001-014	REV BY: - - -	

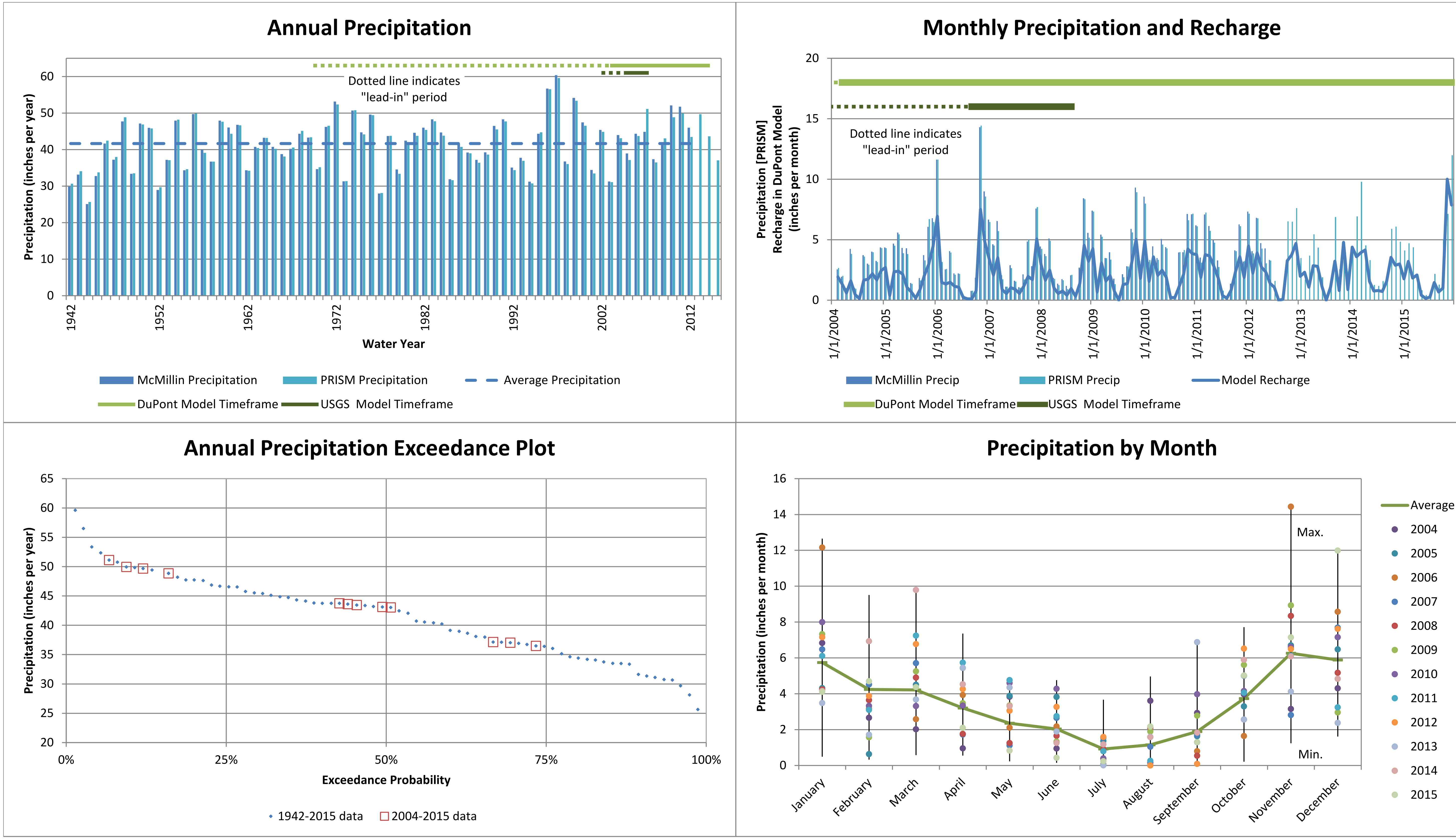
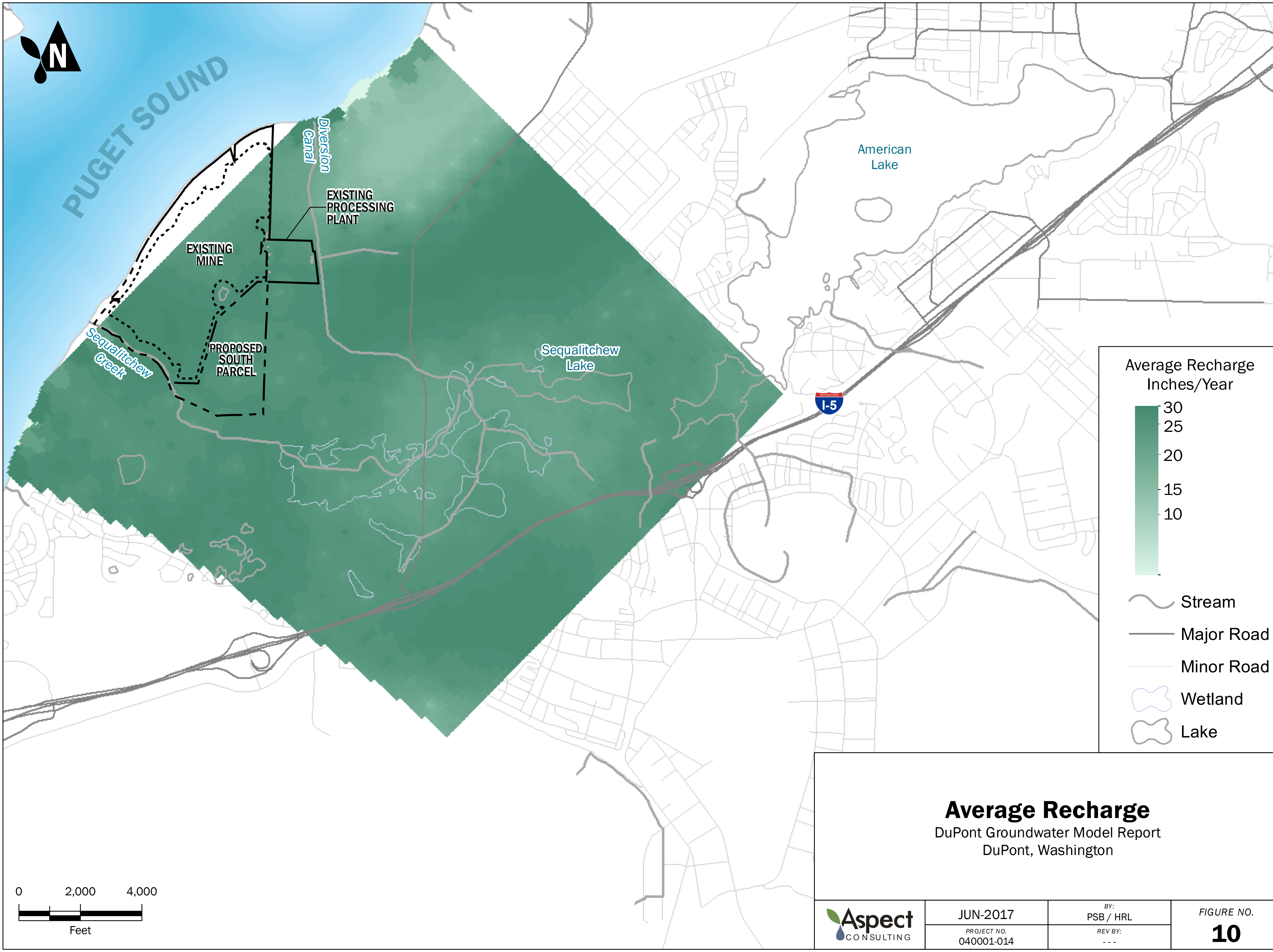


Figure 9
Model Timeframe and Historical Precipitation
Dupont Groundwater Model Report

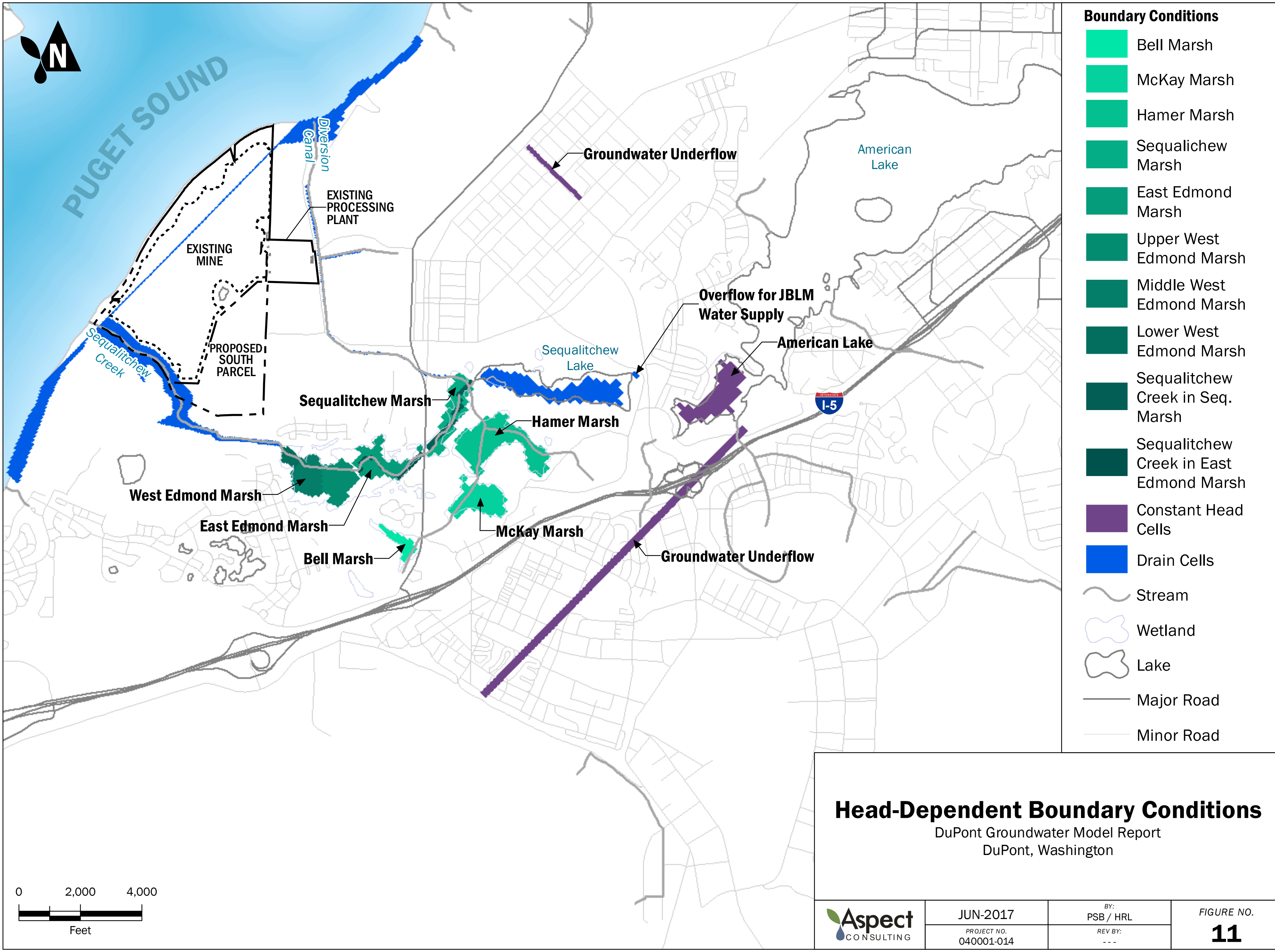


Average Recharge

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO. **10**
	PROJECT NO. 040001-014	REV BY: - - -	

GIS Path: T:\projects_8\DuPont\DuPontSouthParcel_040001\Delivered\GW Model Report\10-AverageRecharge.mxd || Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet || Date Saved: 6/29/2017 || User: pwittman || Print Date: 6/29/2017

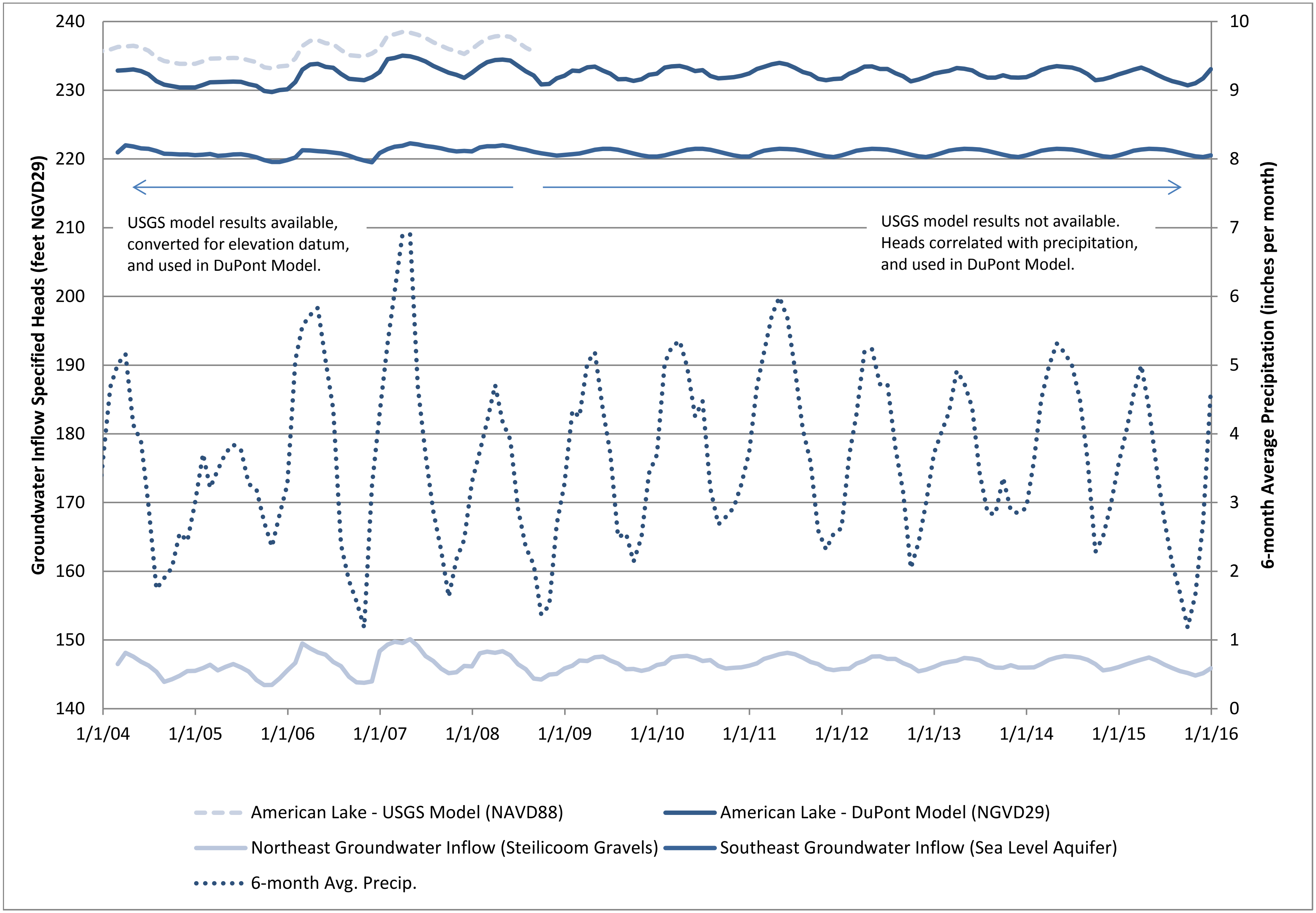


Head-Dependent Boundary Conditions

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING

JUN-2017	BY: PSB / HRL	FIGURE NO.
PROJECT NO. 040001-014	REV BY: - - -	11



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June 2017
S:\CalPortland\DuPont\South Parcel\Groundwater Modeling\DRAFT_20170327\StatusUpdate_20170320

Figure 12
Groundwater Inflow Heads over Time
DuPont Groundwater Model Report

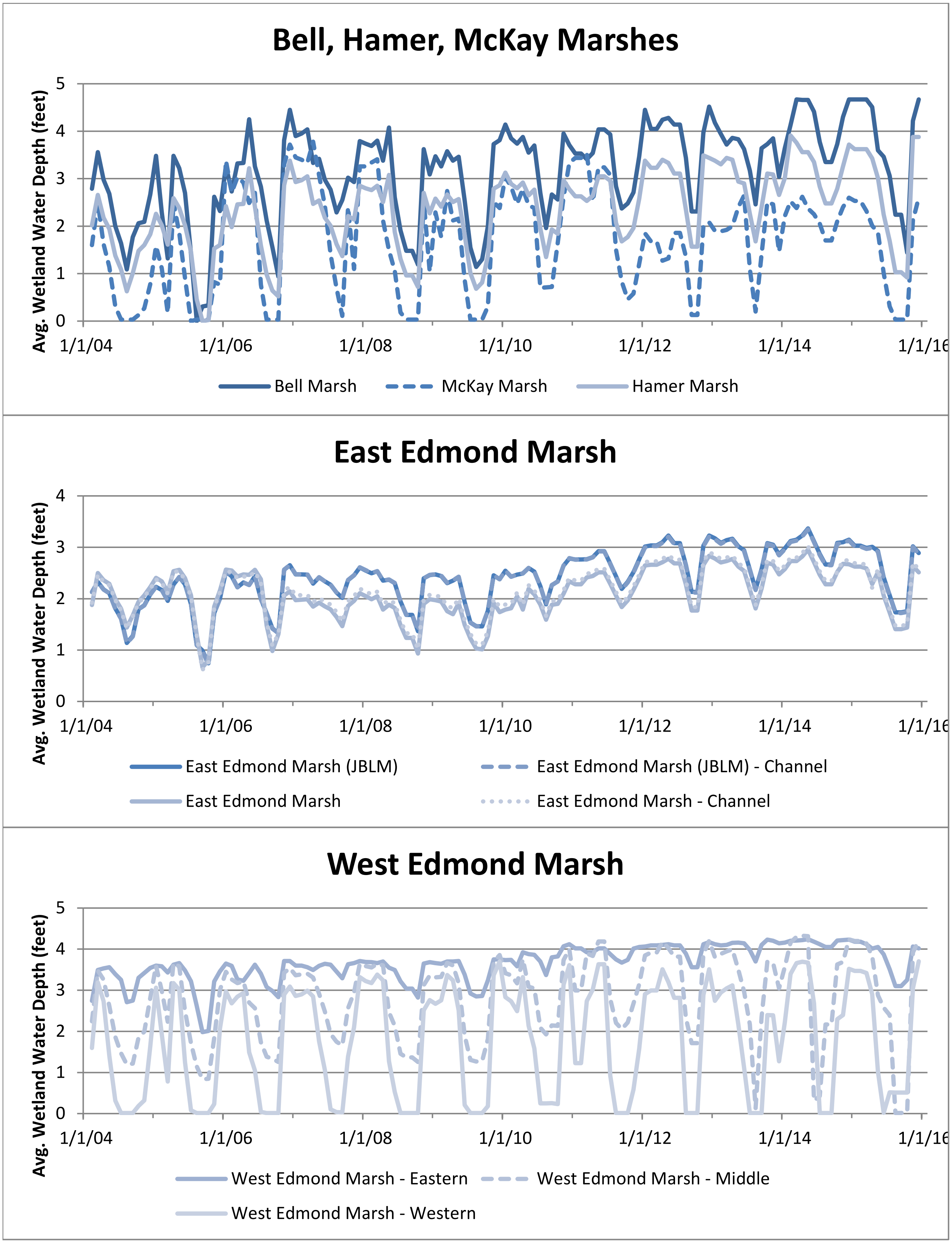
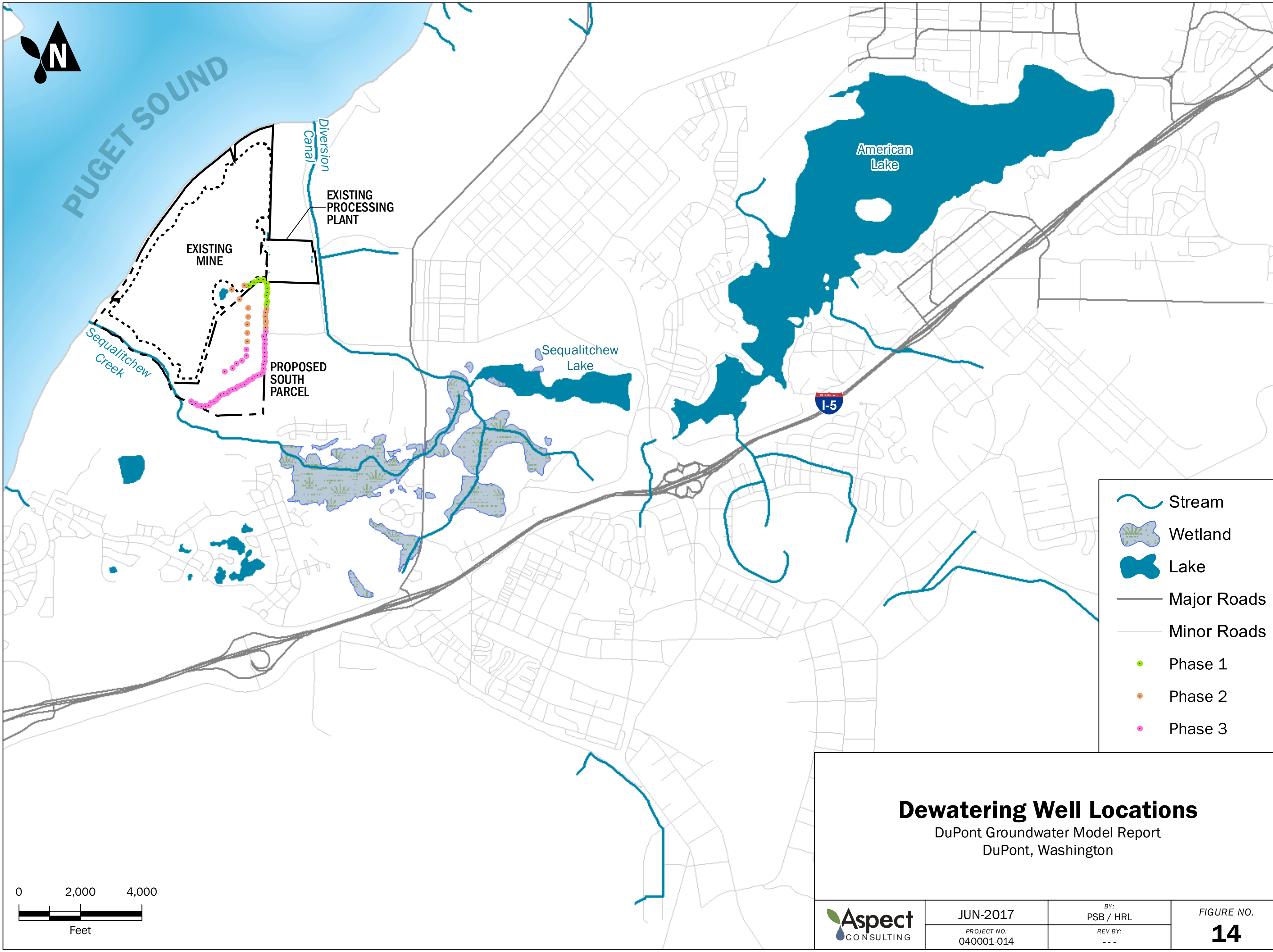


Figure 13

Wetland Water Depths Over Time

DuPont Groundwater Model Report

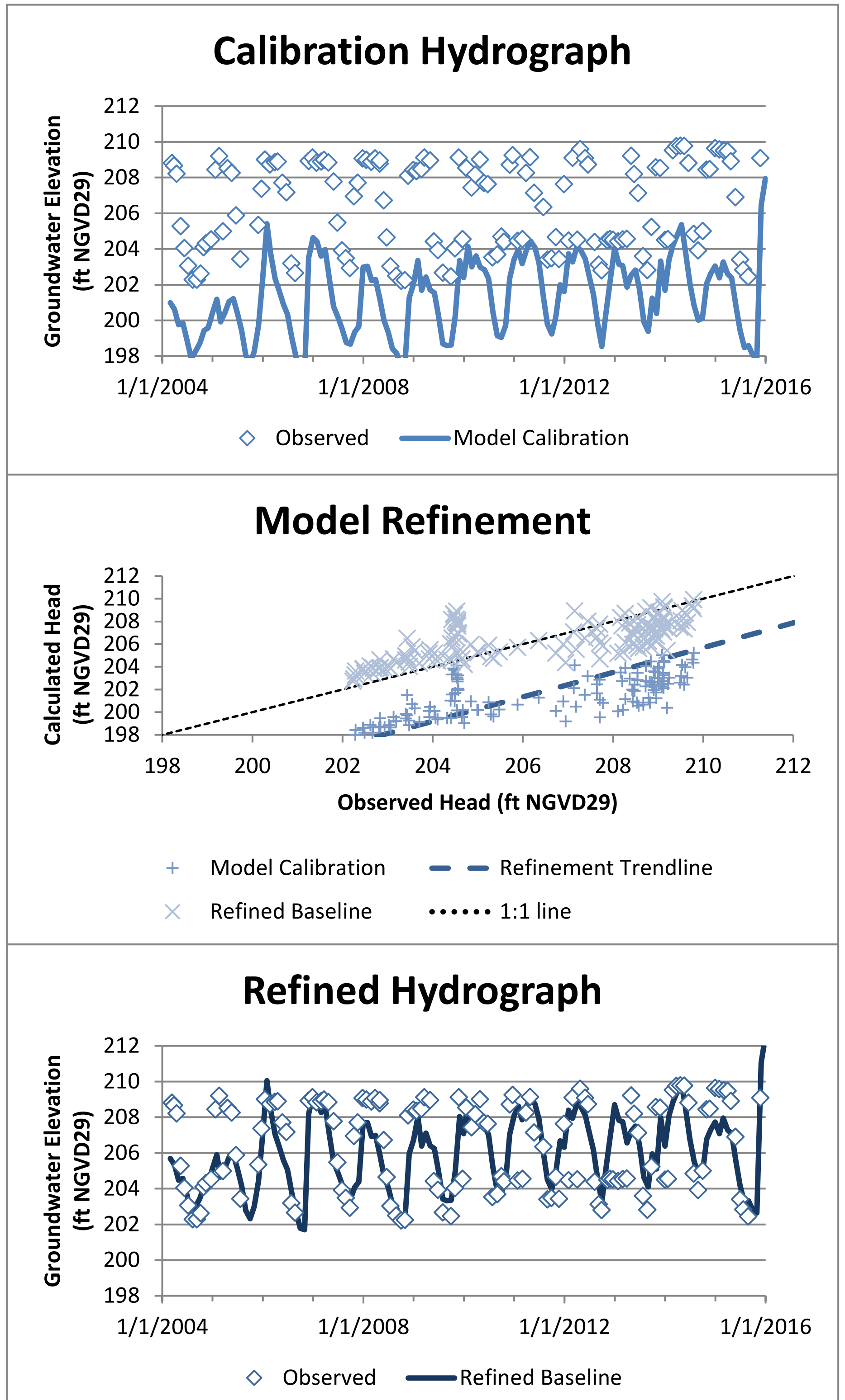


Dewatering Well Locations

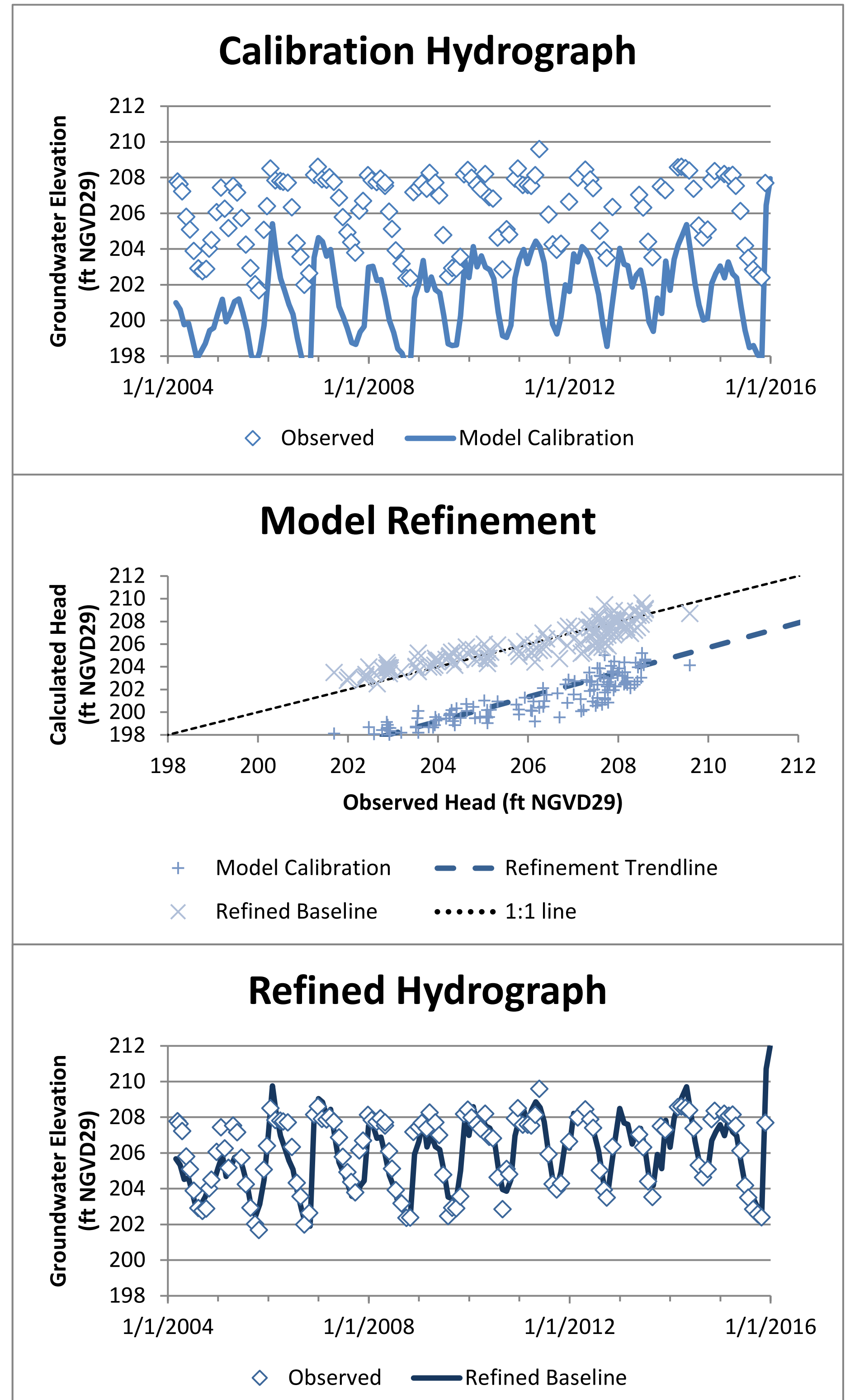
DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO. 14
	PROJECT NO. 040001-014	REV BY: - - -	

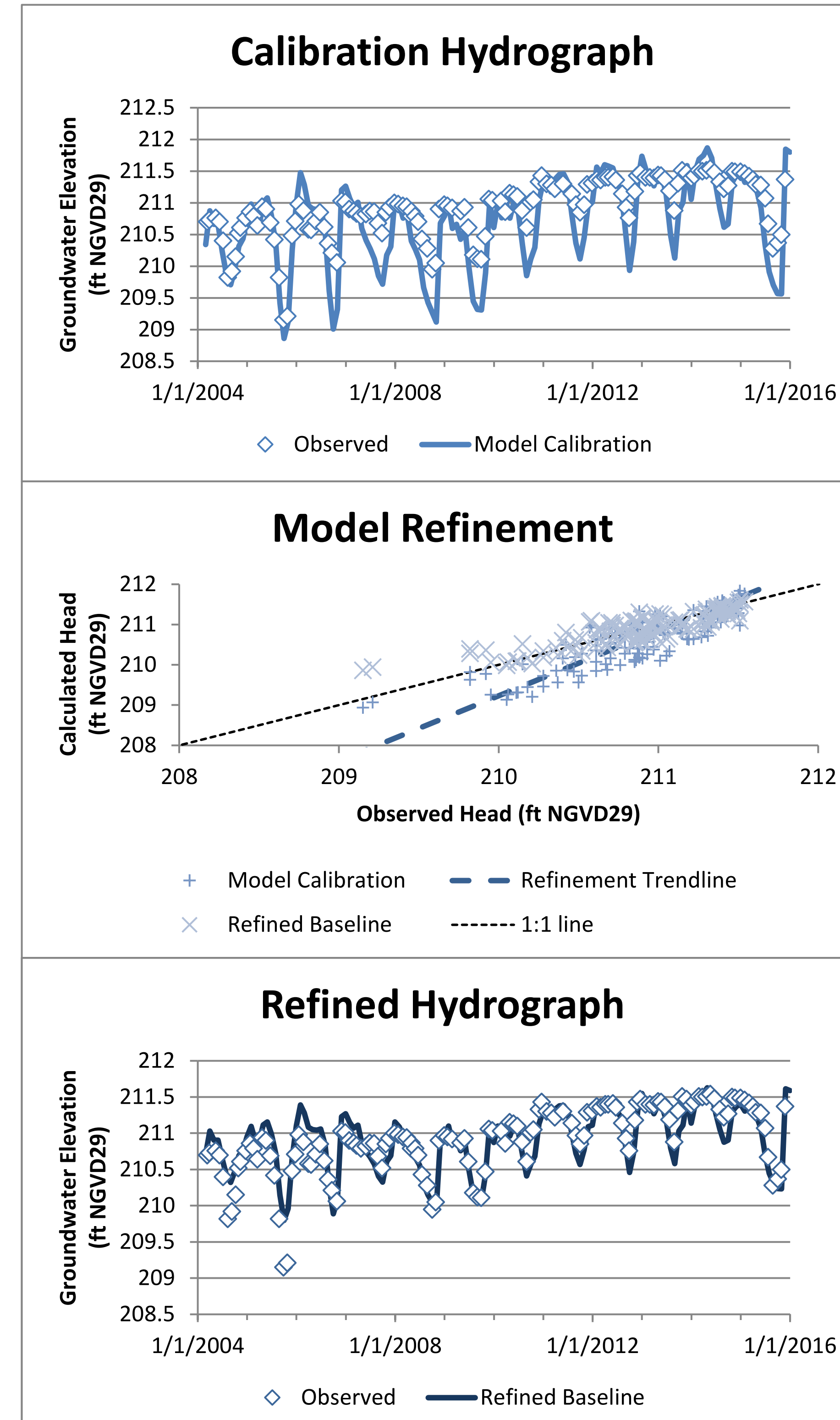
MW-EM-1S



MW-EM-1D



MW-EM-2S



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June 2017
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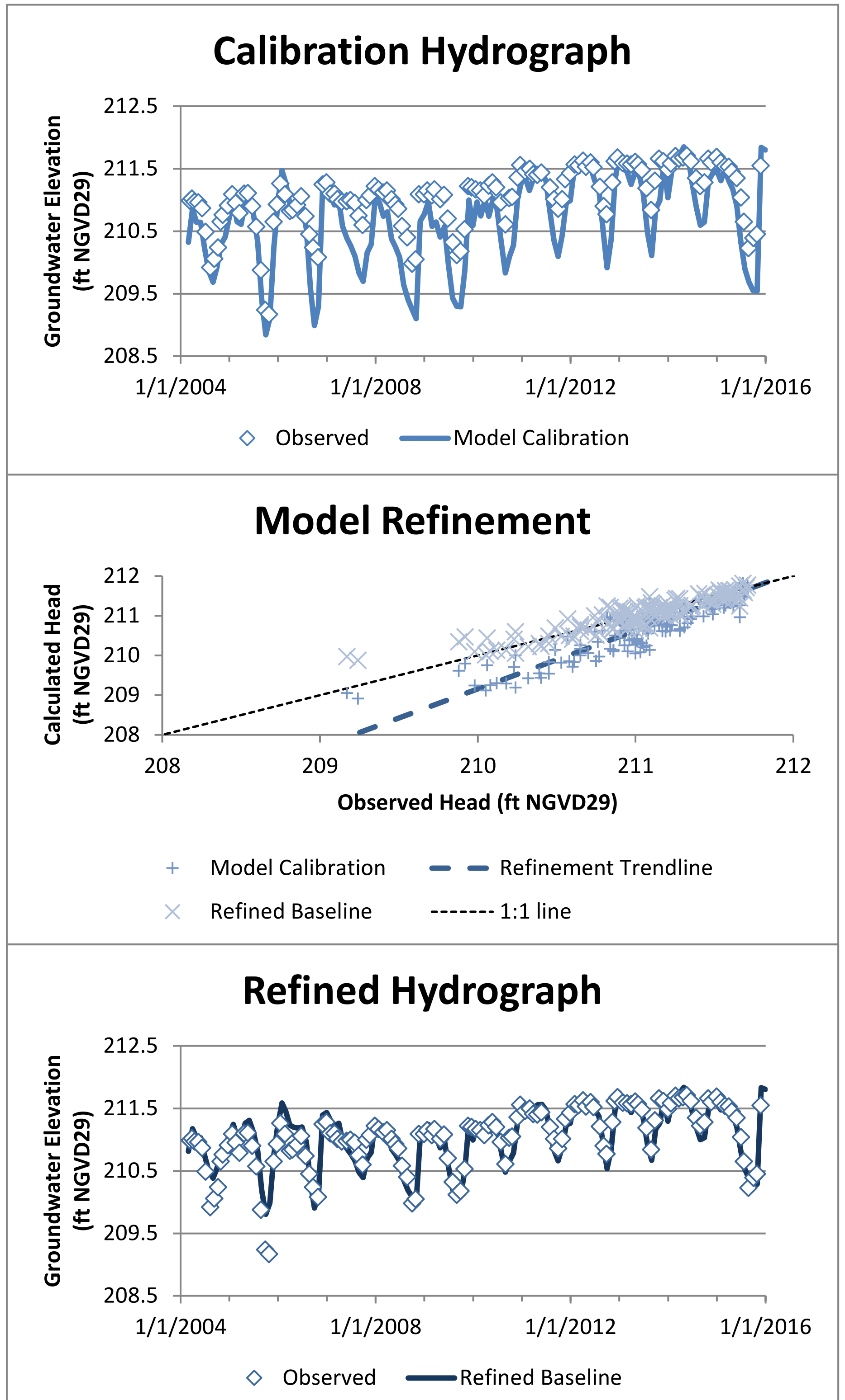
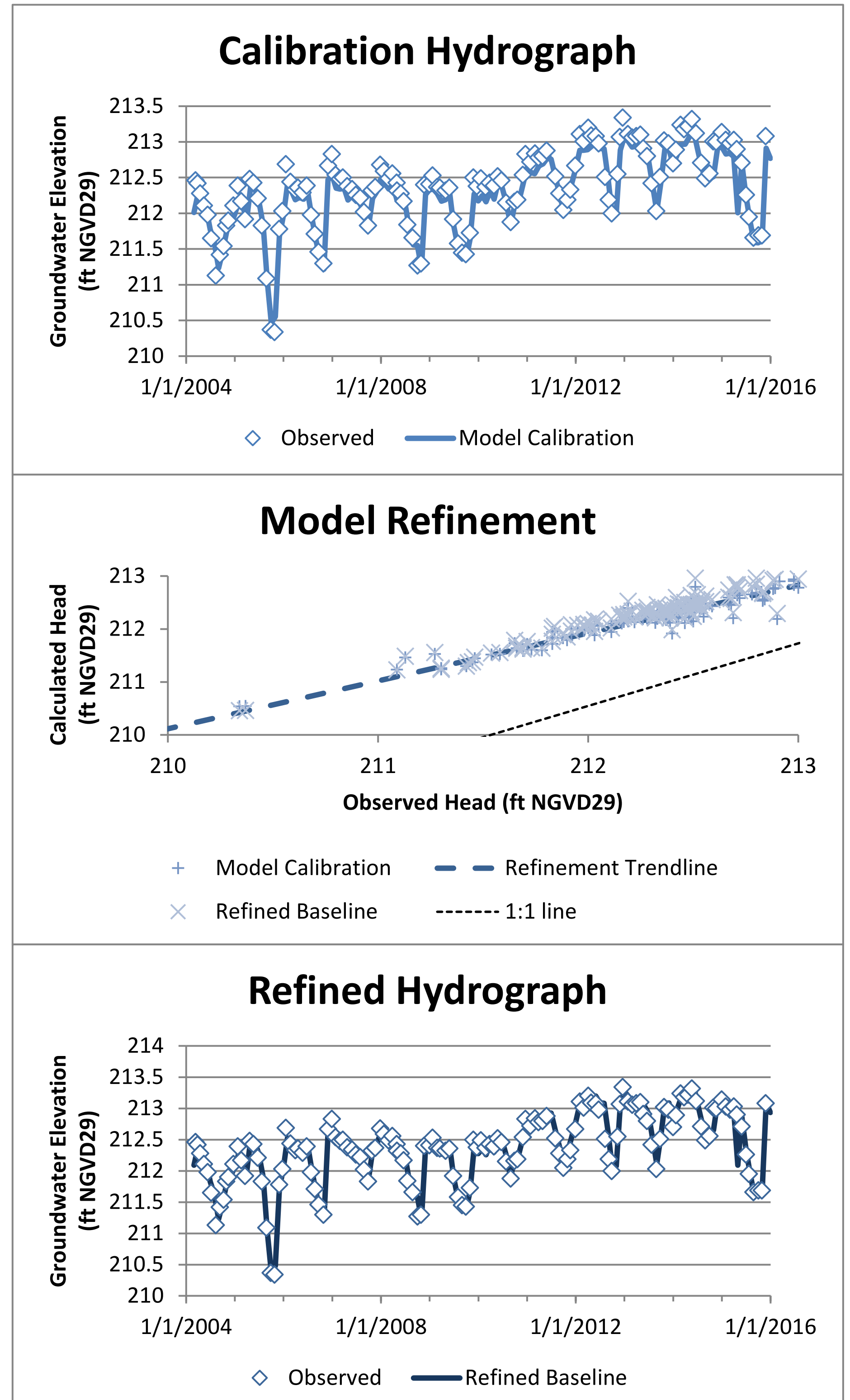
Figure 15
Calibration and Refined Hydrographs
Dupont Groundwater Model Report

MW-EM-2D



MW-EM-3



MW-SRC-2

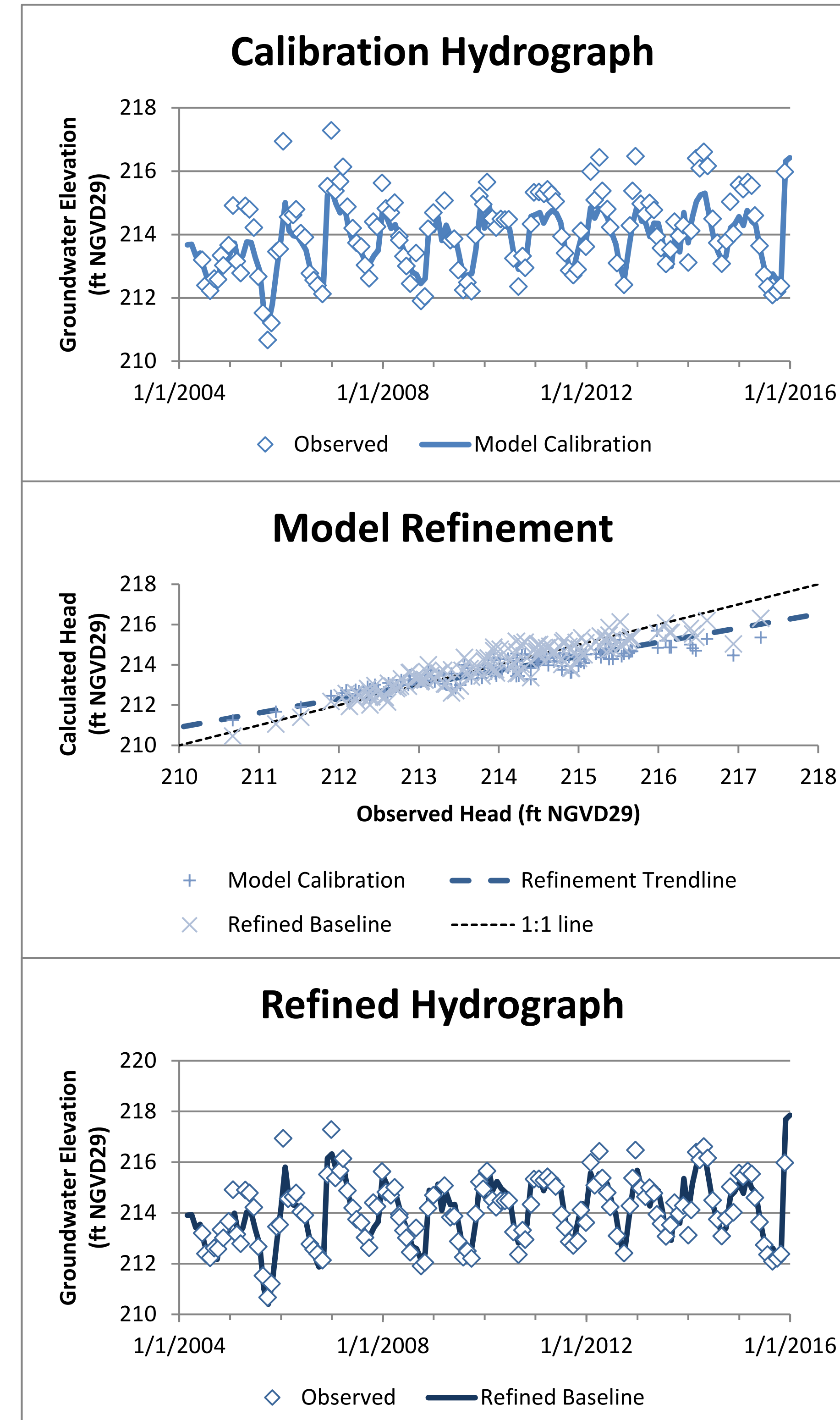


Figure 15
Calibration and Refined Hydrographs

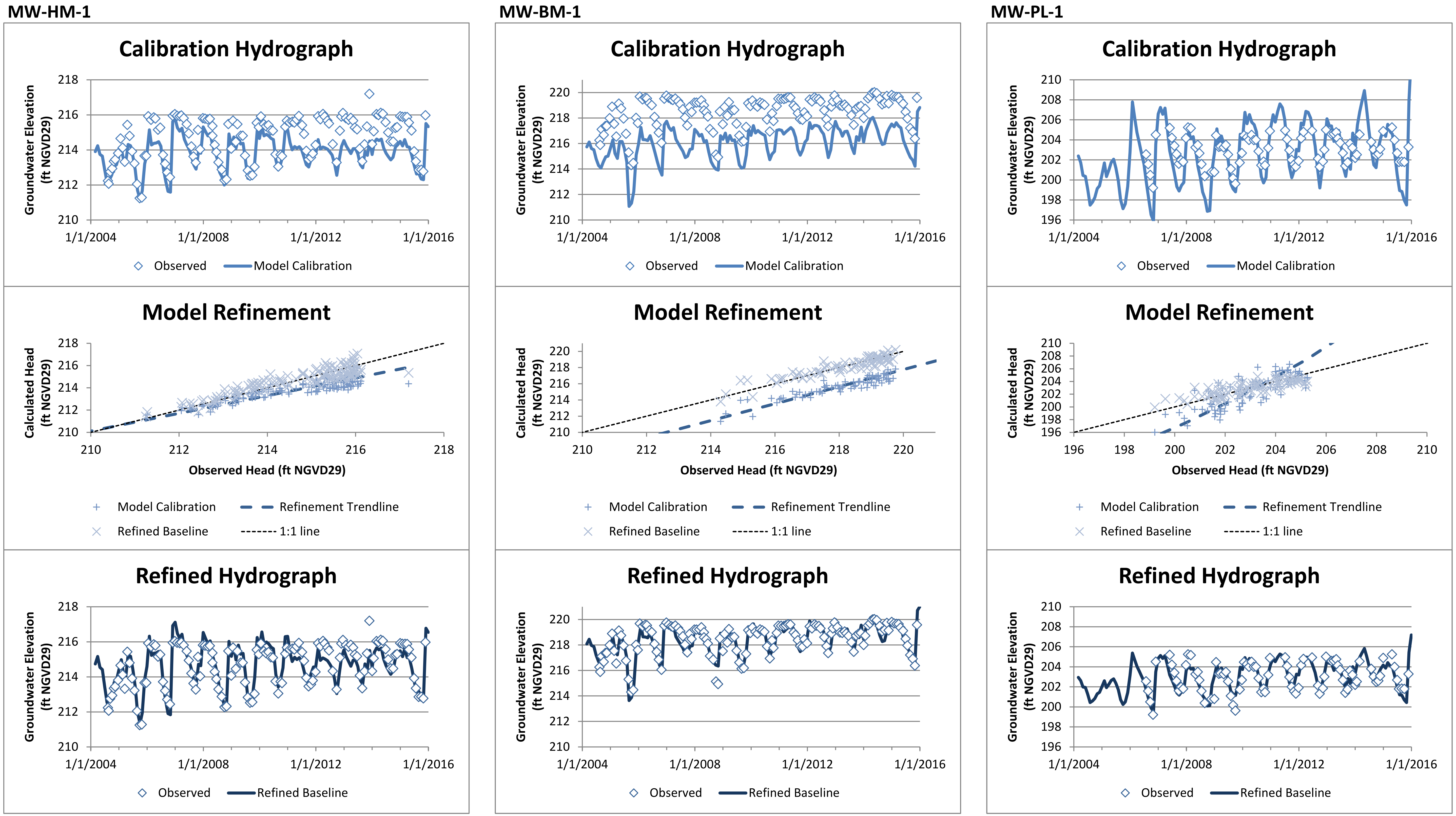


Figure 15
Calibration and Refined Hydrographs
Dupont Groundwater Model Report

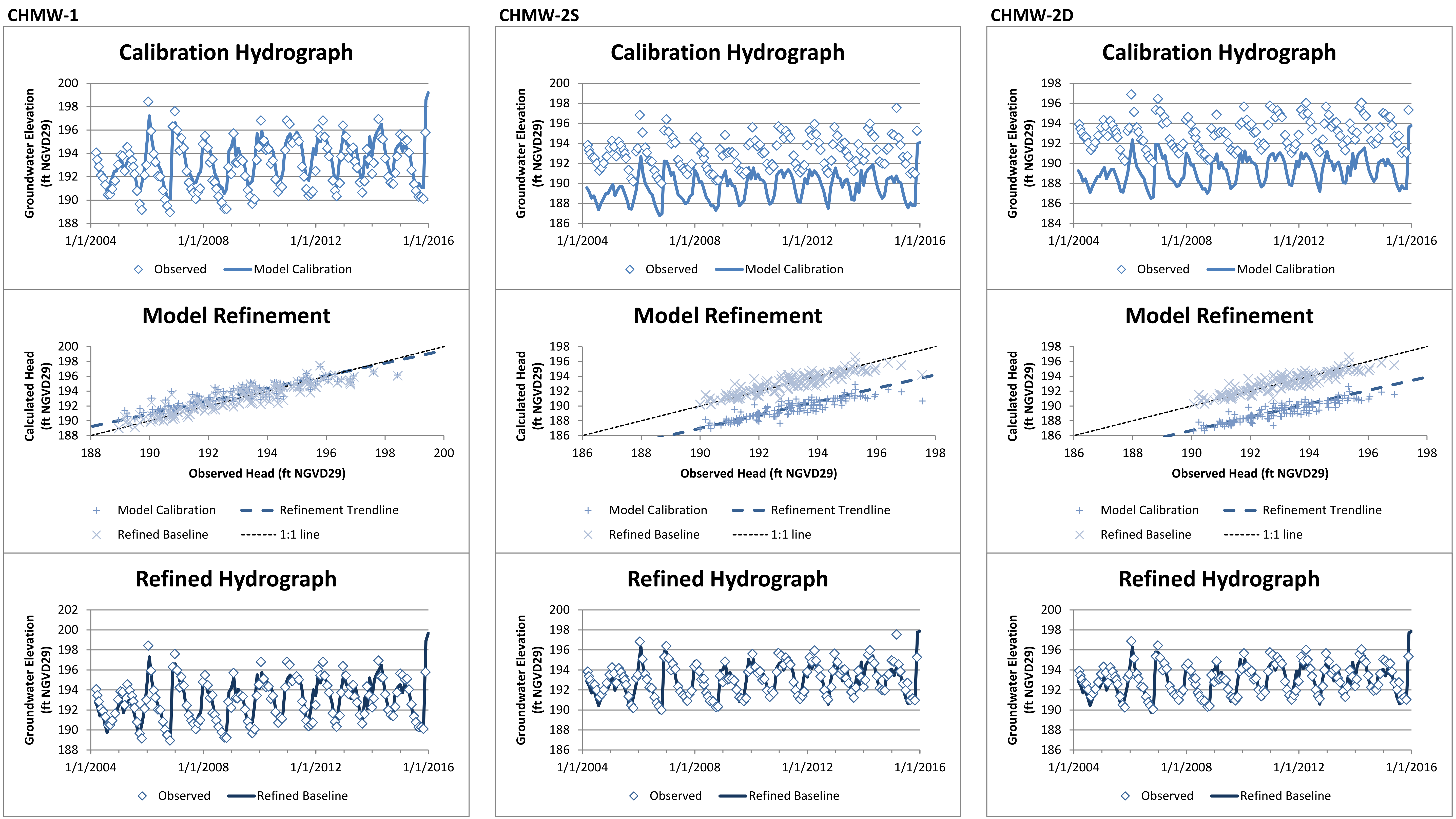


Figure 15
Calibration and Refined Hydrographs
Dupont Groundwater Model Report

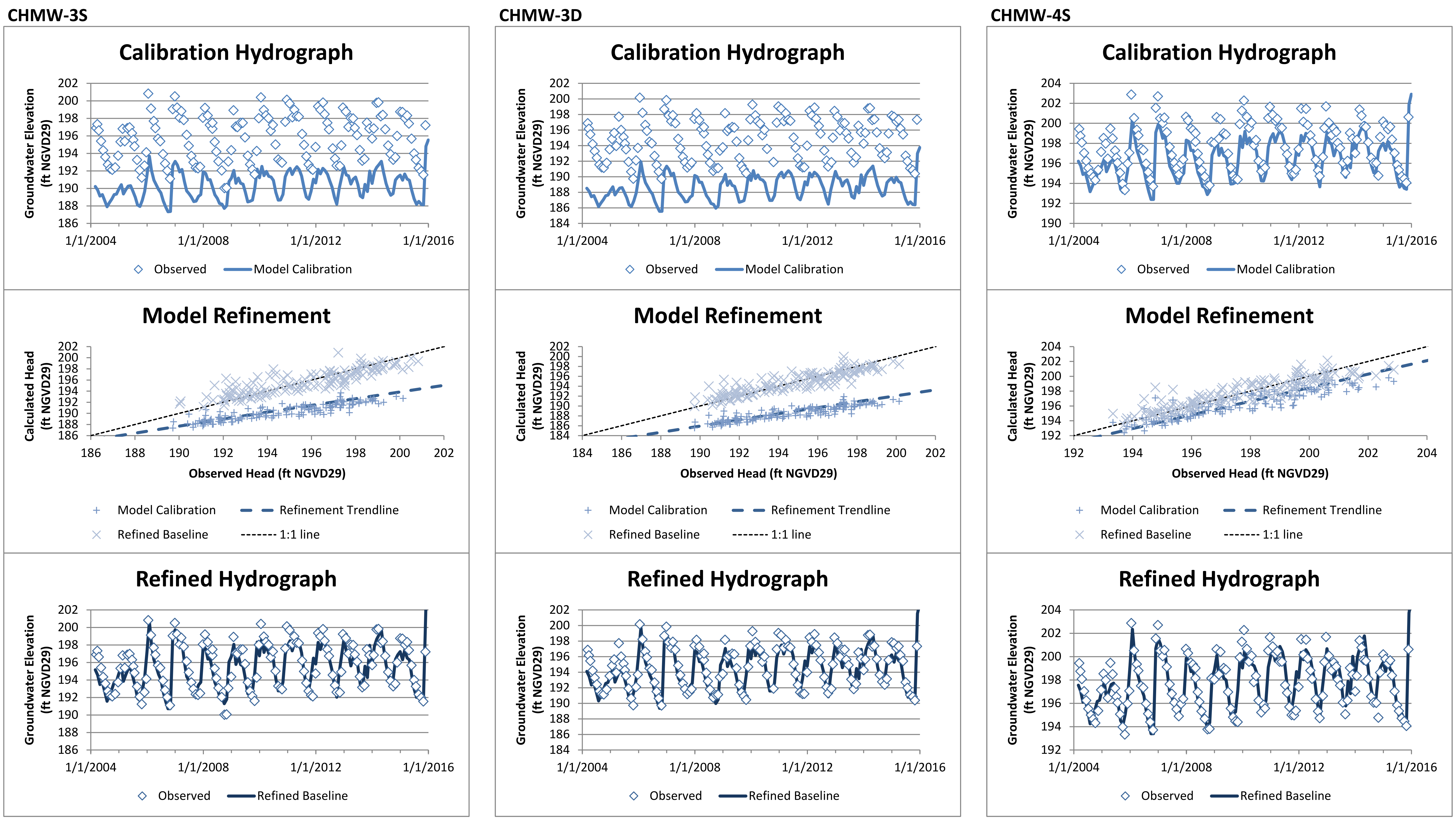


Figure 15
Calibration and Refined Hydrographs
Dupont Groundwater Model Report

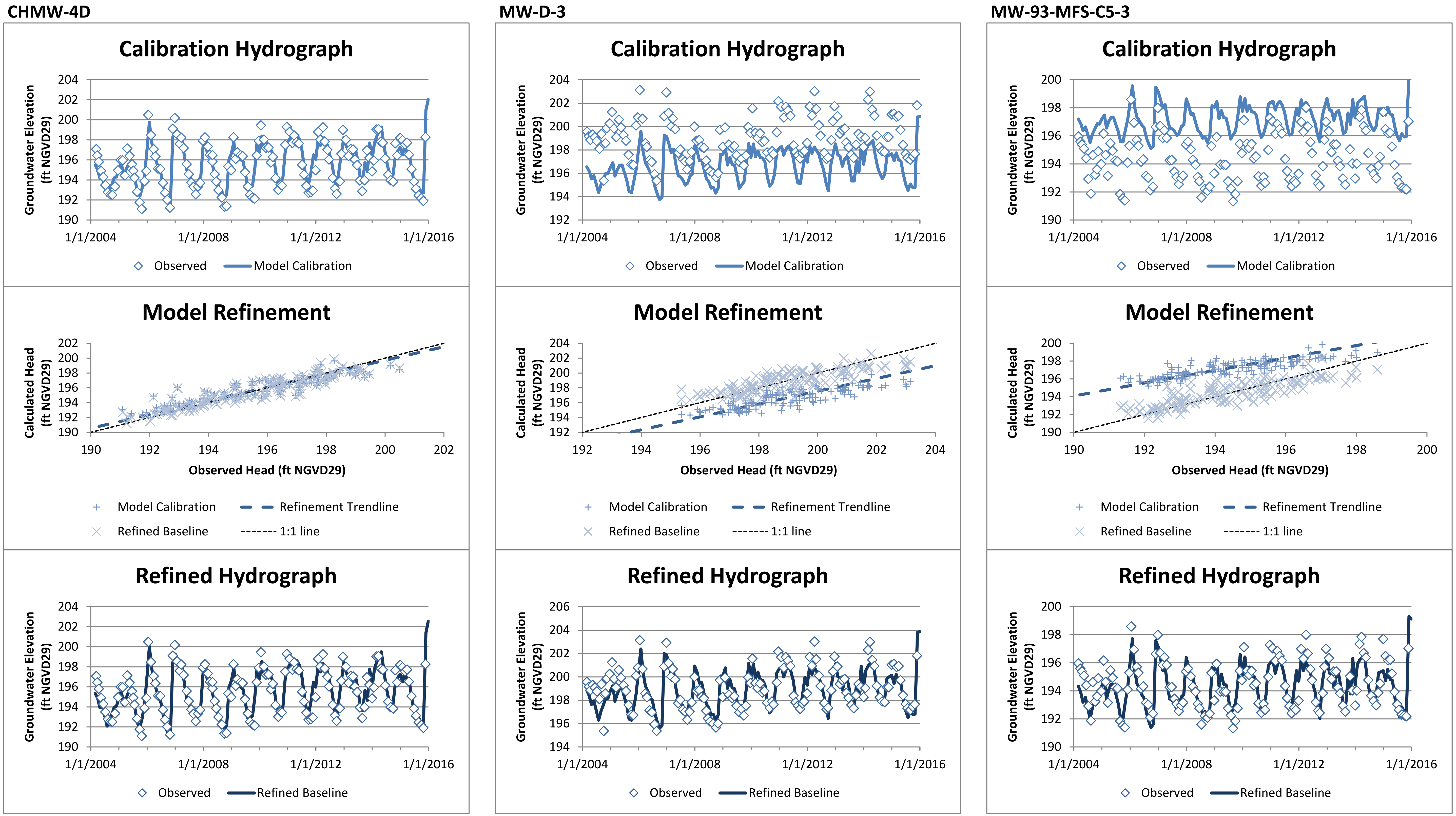


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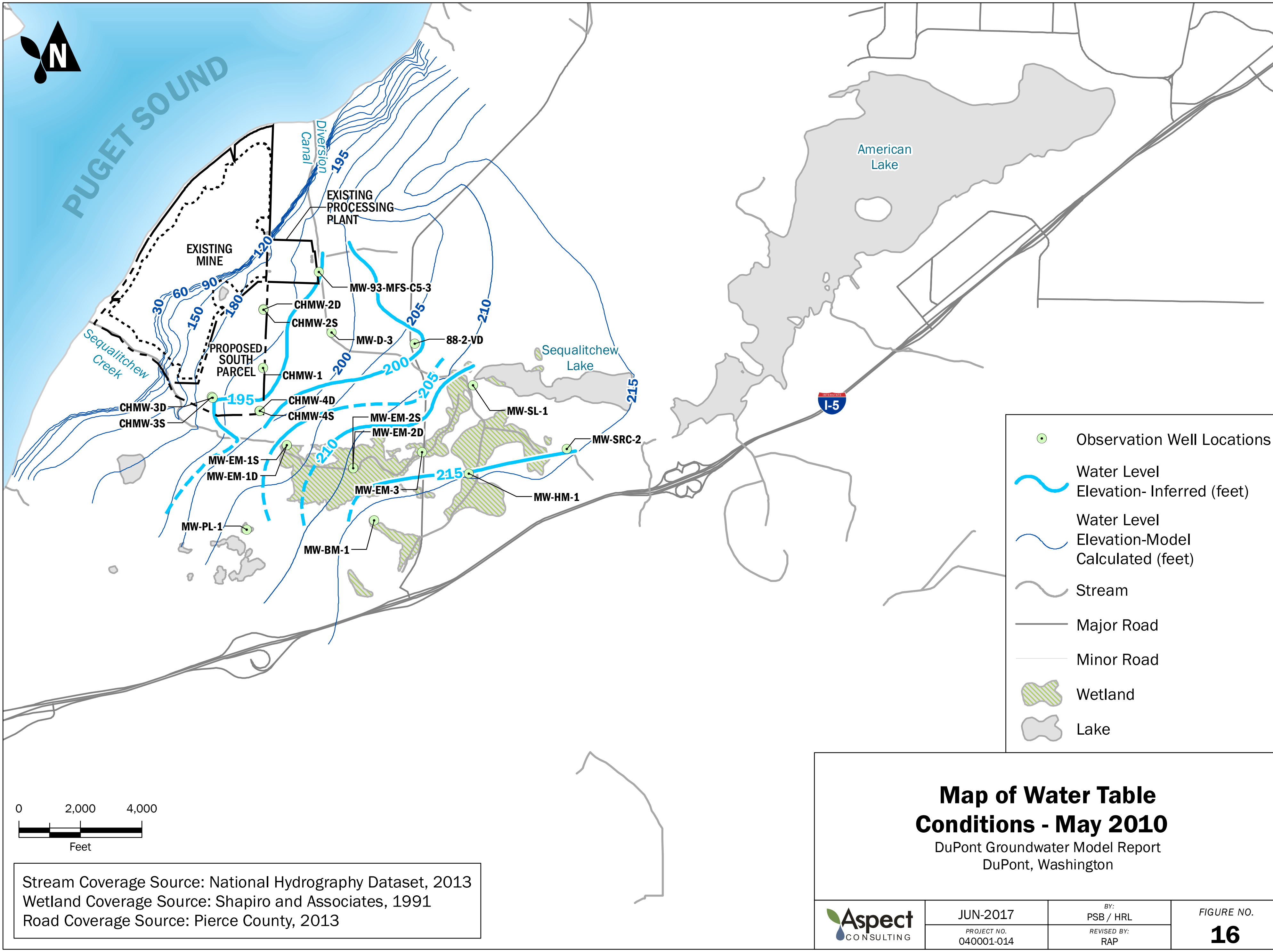
Figure 15
Calibration and Refined Hydrographs
Dupont Groundwater Model Report



Stream Coverage Source: National Hydrography Dataset, 2013
Wetland Coverage Source: Shapiro and Associates, 1991
Road Coverage Source: Pierce County, 2013

Map of Water Table Conditions - May 2010

DuPont Groundwater Model Report
DuPont, Washington

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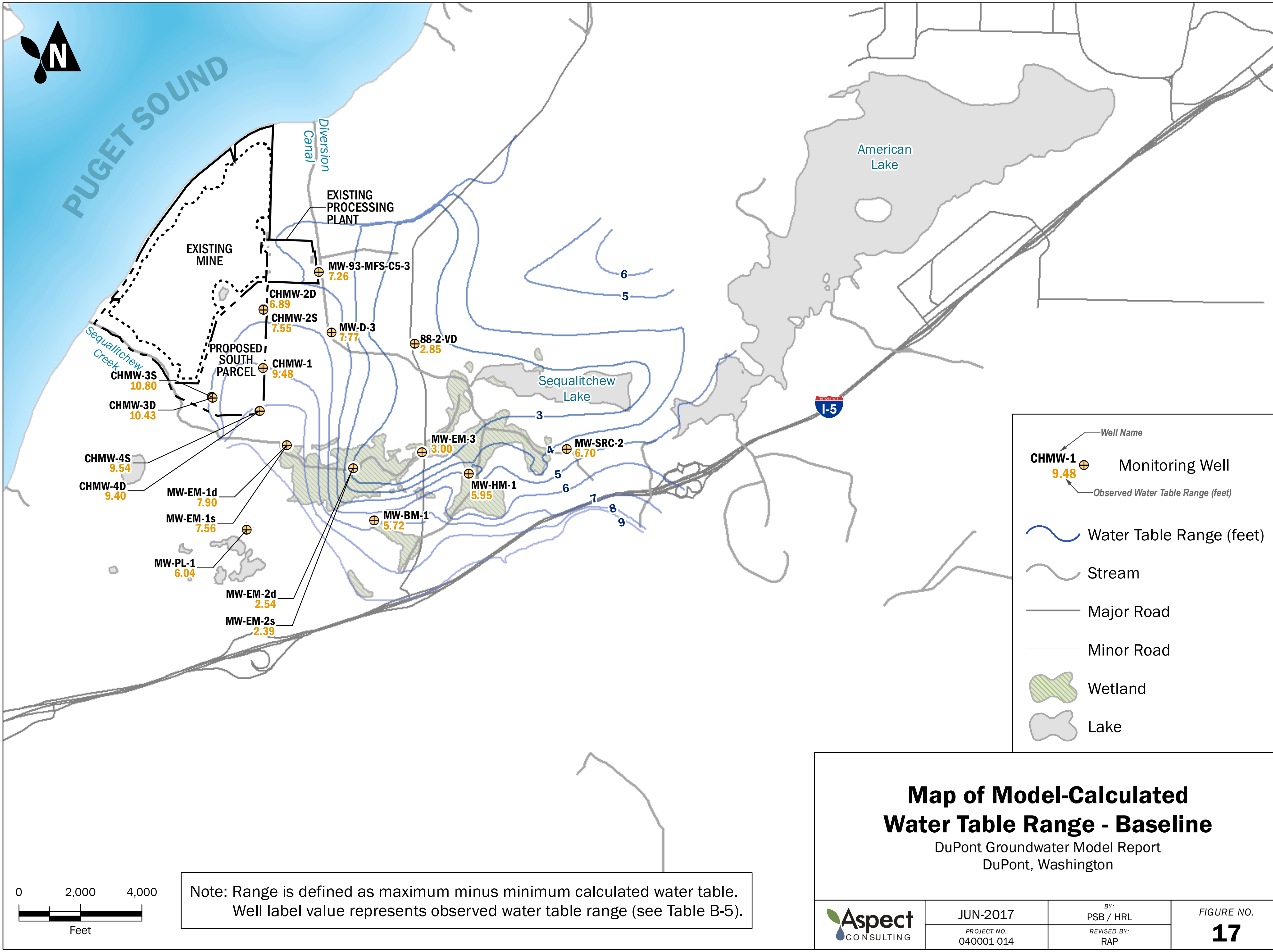
JUN-2017	BY: PSB / HRL	FIGURE NO. 16
PROJECT NO. 040001-014	REVISED BY: RAP	



Note: Range is defined as maximum minus minimum calculated water table. Well label value represents observed water table range (see Table B-5).

Map of Model-Calculated Water Table Range - Baseline

DuPont Groundwater Model Report
DuPont, Washington

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	PROJECT NO. 040001-014	REVISED BY: RAP	

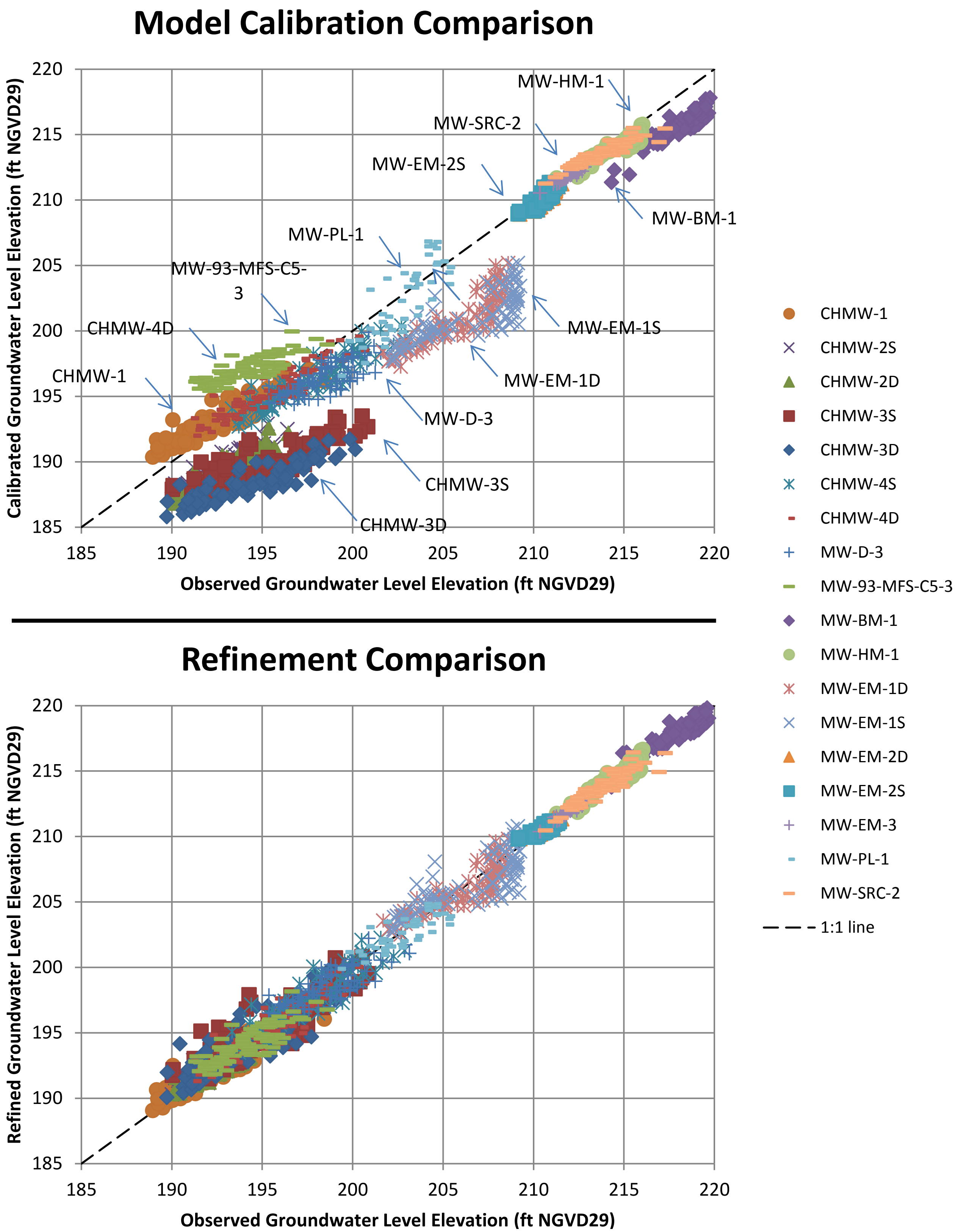
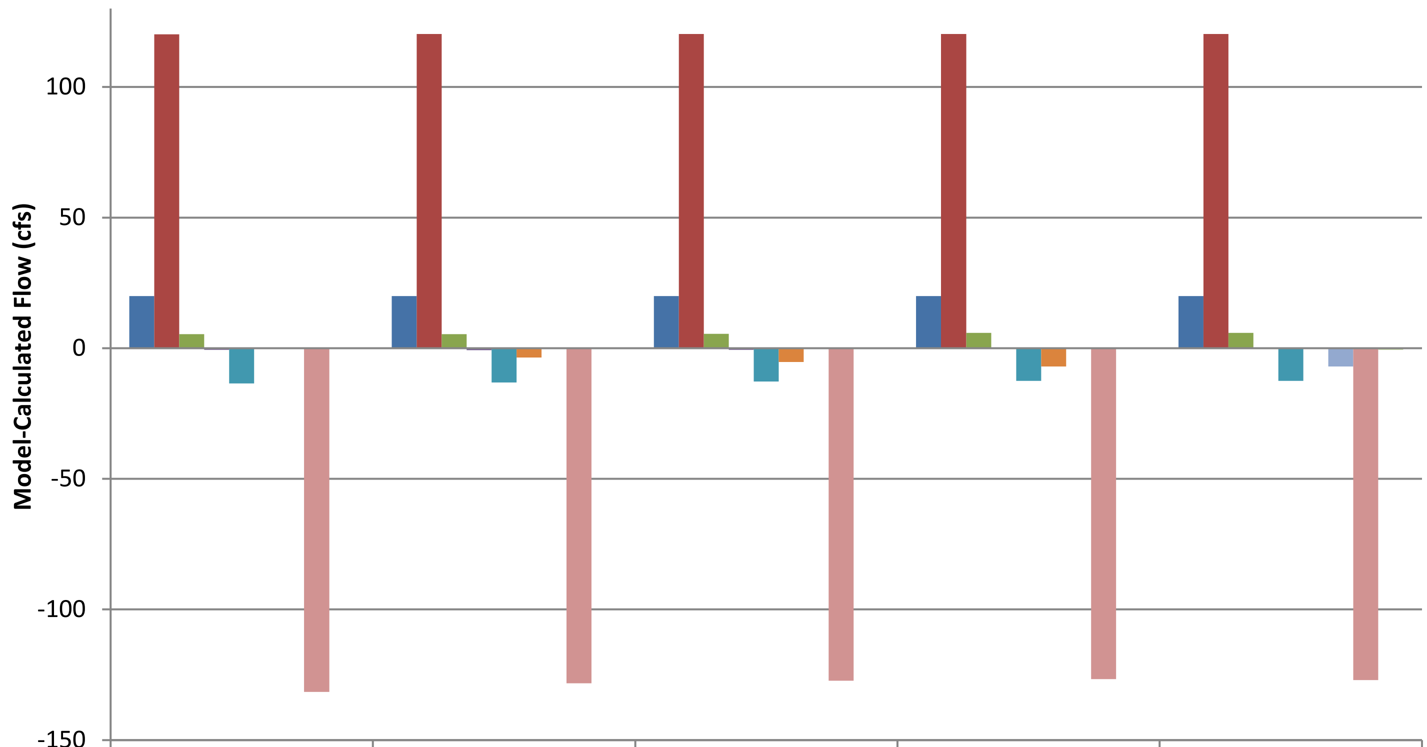


Figure 18

Observed vs. Calculated Groundwater Levels

Dupont Groundwater Model Report



	Baseline	Step 1	Step 2	Step 3	Step 4
Recharge	20.0	20.0	20.0	20.0	20.0
Groundwater Inflow	120.1	120.2	120.3	120.3	120.3
Wetland Infiltration	5.3	5.4	5.5	5.9	5.8
Discharge - Seq Ck	-0.6	-0.7	-0.6	-0.1	-0.1
Discharge - Other Surface Water	-13.5	-13.1	-12.8	-12.5	-12.6
Discharge - Well	0.0	-3.6	-5.2	-6.9	0.0
Discharge - Mine	0.0	0.0	0.0	0.0	-6.9
Groundwater Outflow	-131.5	-128.2	-127.2	-126.7	-127.1
Change in Storage	-0.2	-0.1	0.0	-0.1	-0.6

Figure 19
Average Groundwater Balance Comparison - Overall

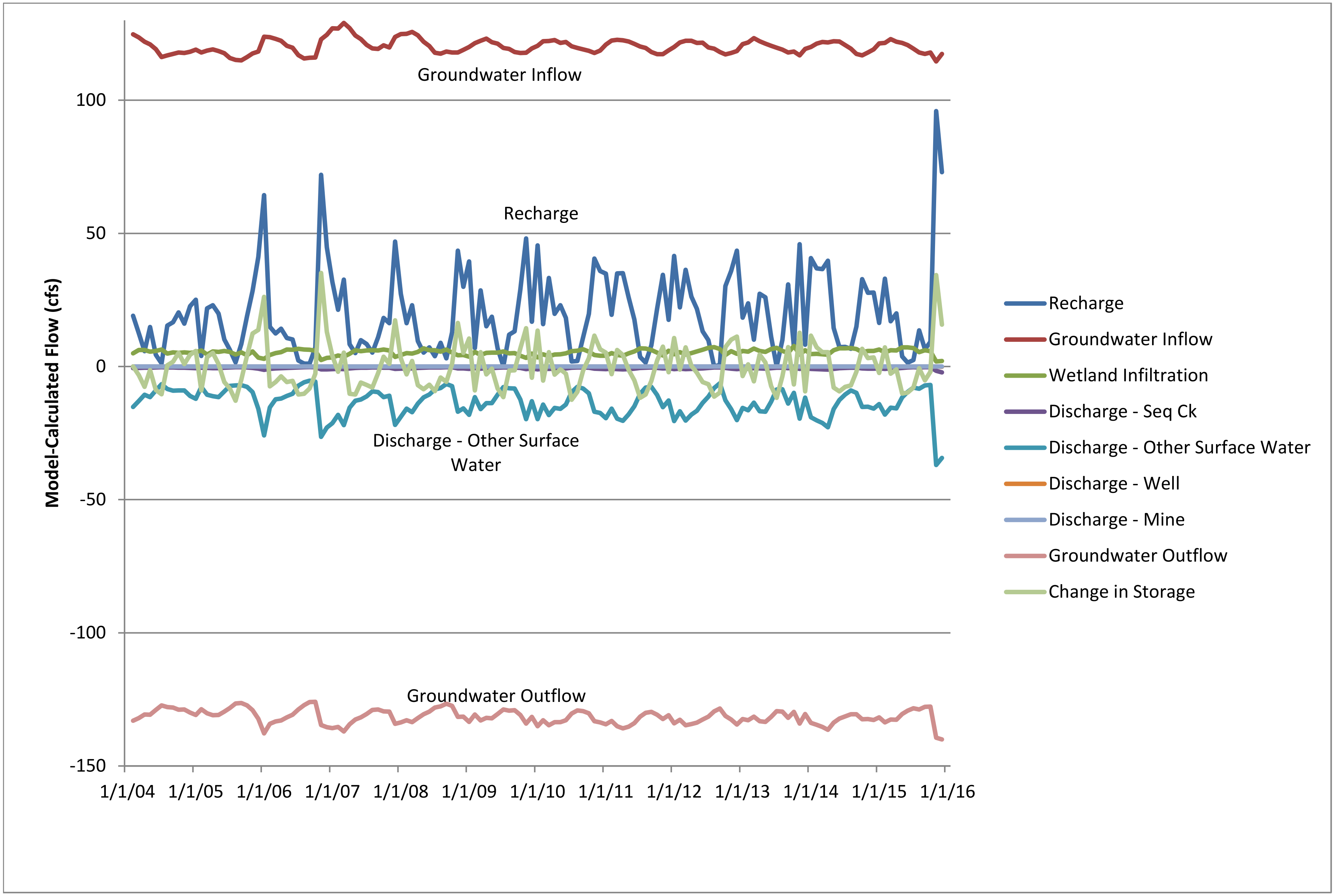


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Figure 20
Baseline Groundwater Balance Over Time - Overall
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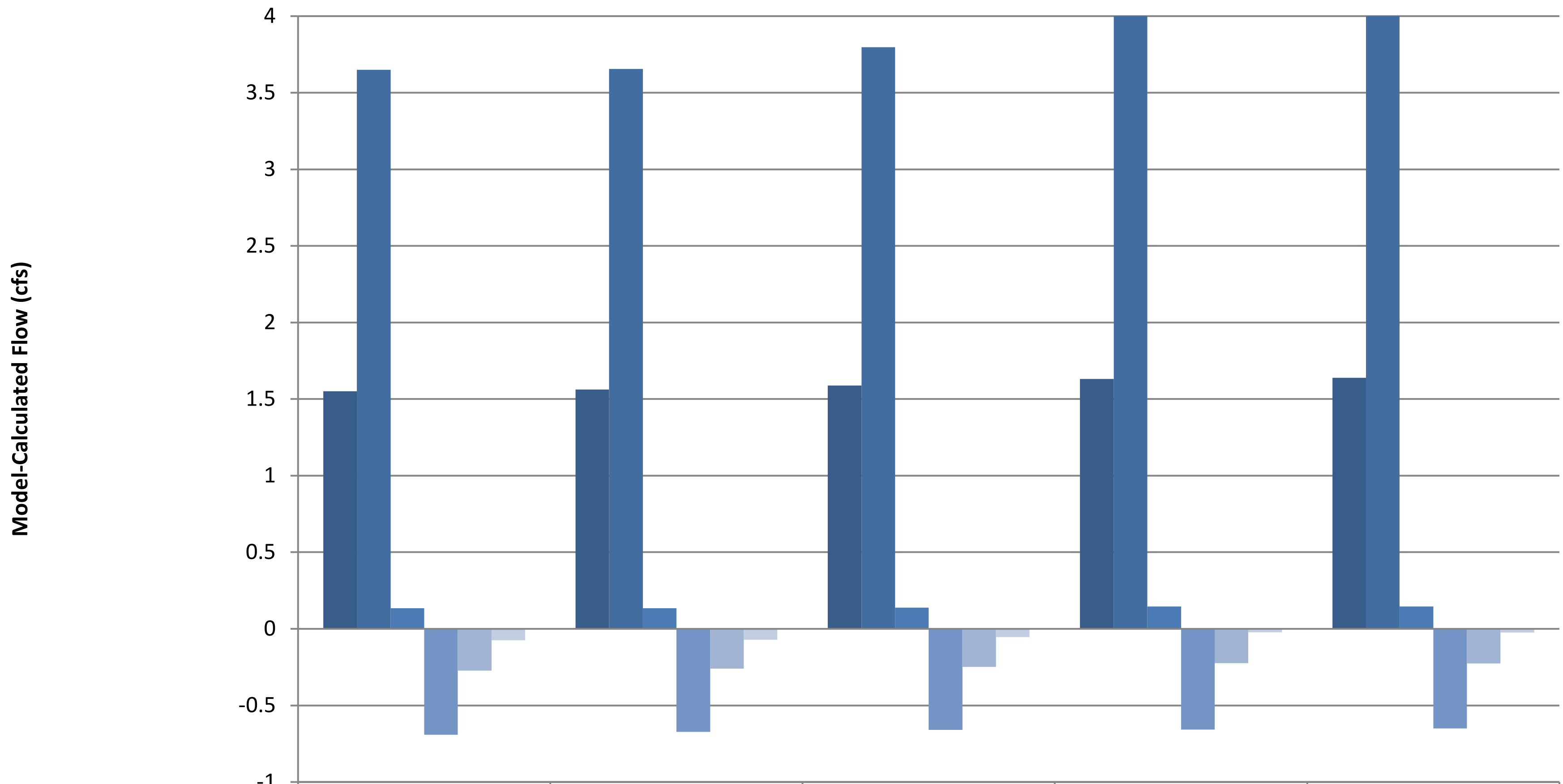


	Baseline	Step 1	Step 2	Step 3	Step 4
Infiltration from BHM	1.6	1.6	1.6	1.6	1.6
Infiltration from East EM	3.6	3.7	3.8	4.1	4.0
Infiltration from West EM	0.1	0.1	0.1	0.1	0.1
Discharge to BHM	-0.7	-0.7	-0.7	-0.7	-0.6
Discharge to East EM	-0.3	-0.3	-0.2	-0.2	-0.2
Discharge to West EM	-0.1	-0.1	-0.1	0.0	0.0

Figure 21
Average Groundwater Balance Comparison - Wetlands

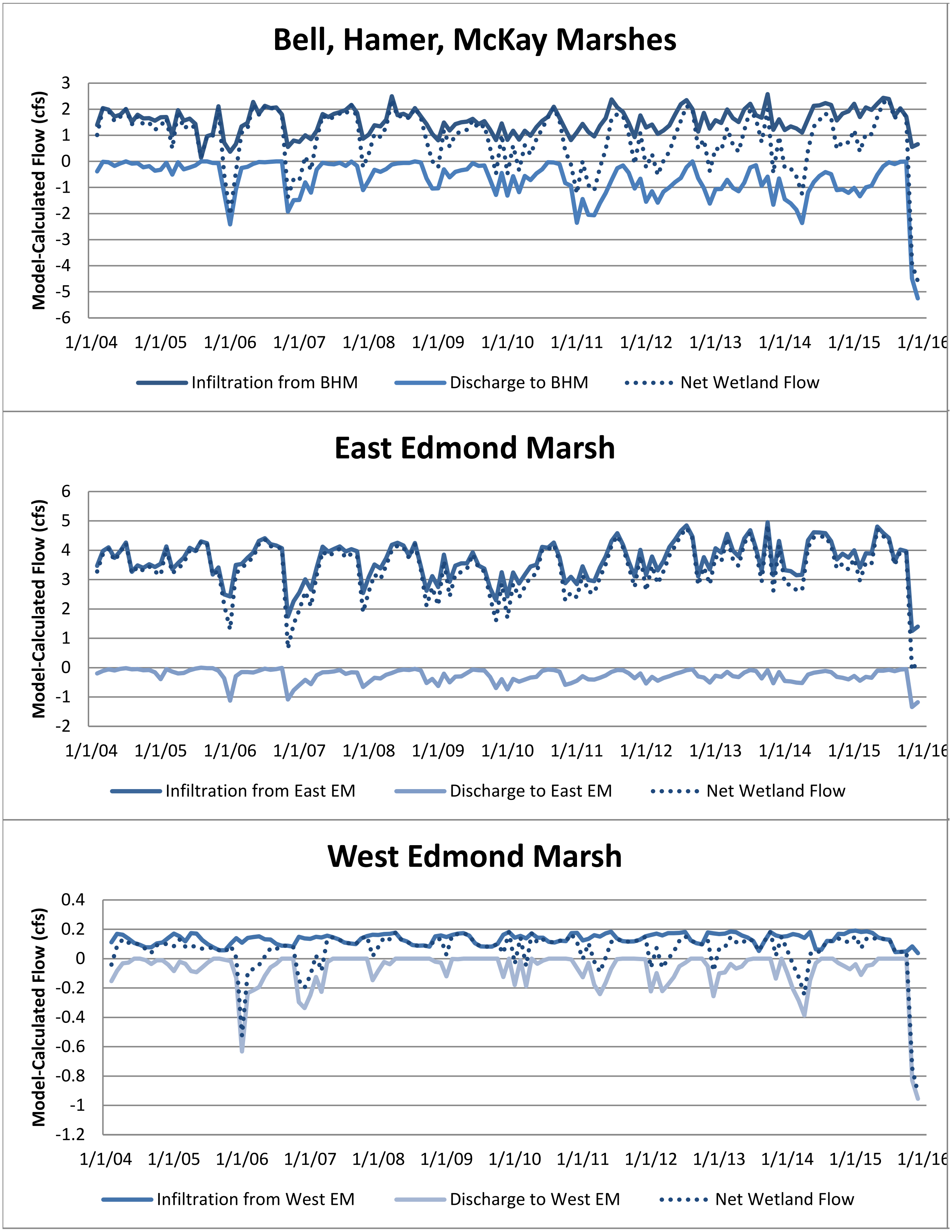


Figure 22

Baseline Groundwater Balance Over Time - Wetlands

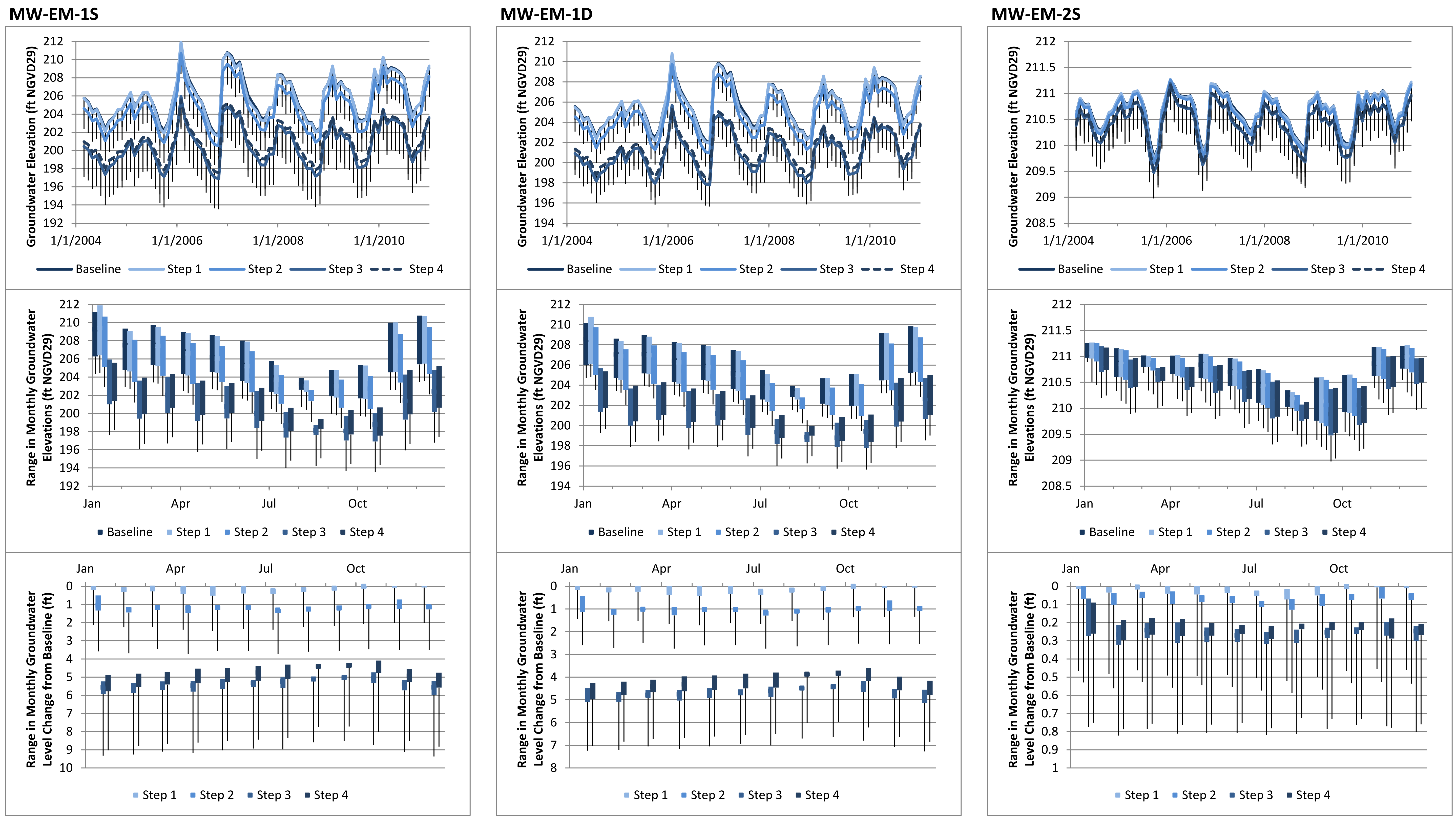
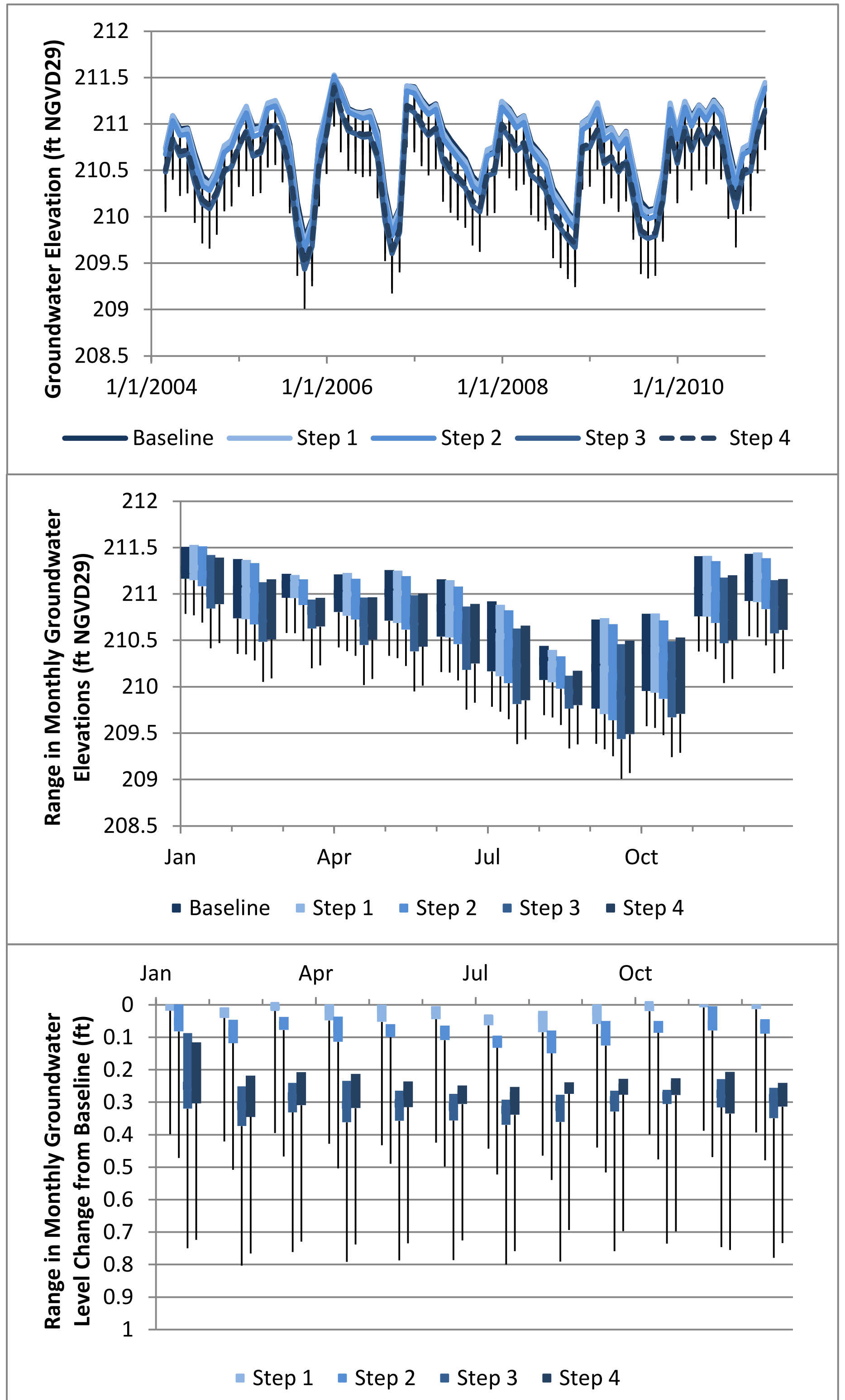
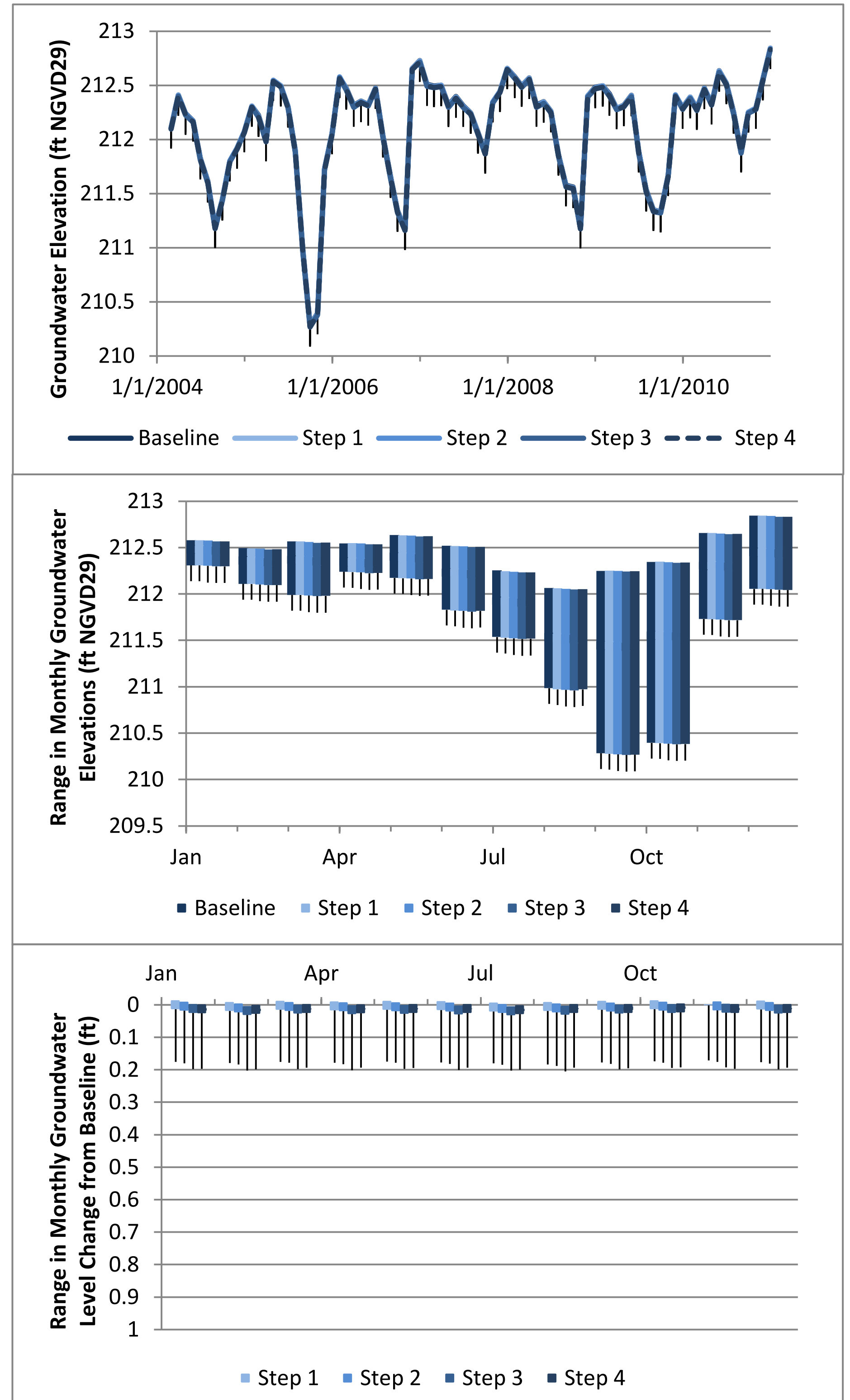


Figure 23
Predicted Changes and Ranges in Groundwater Levels

MW-EM-2D



MW-EM-3



MW-SRC-2

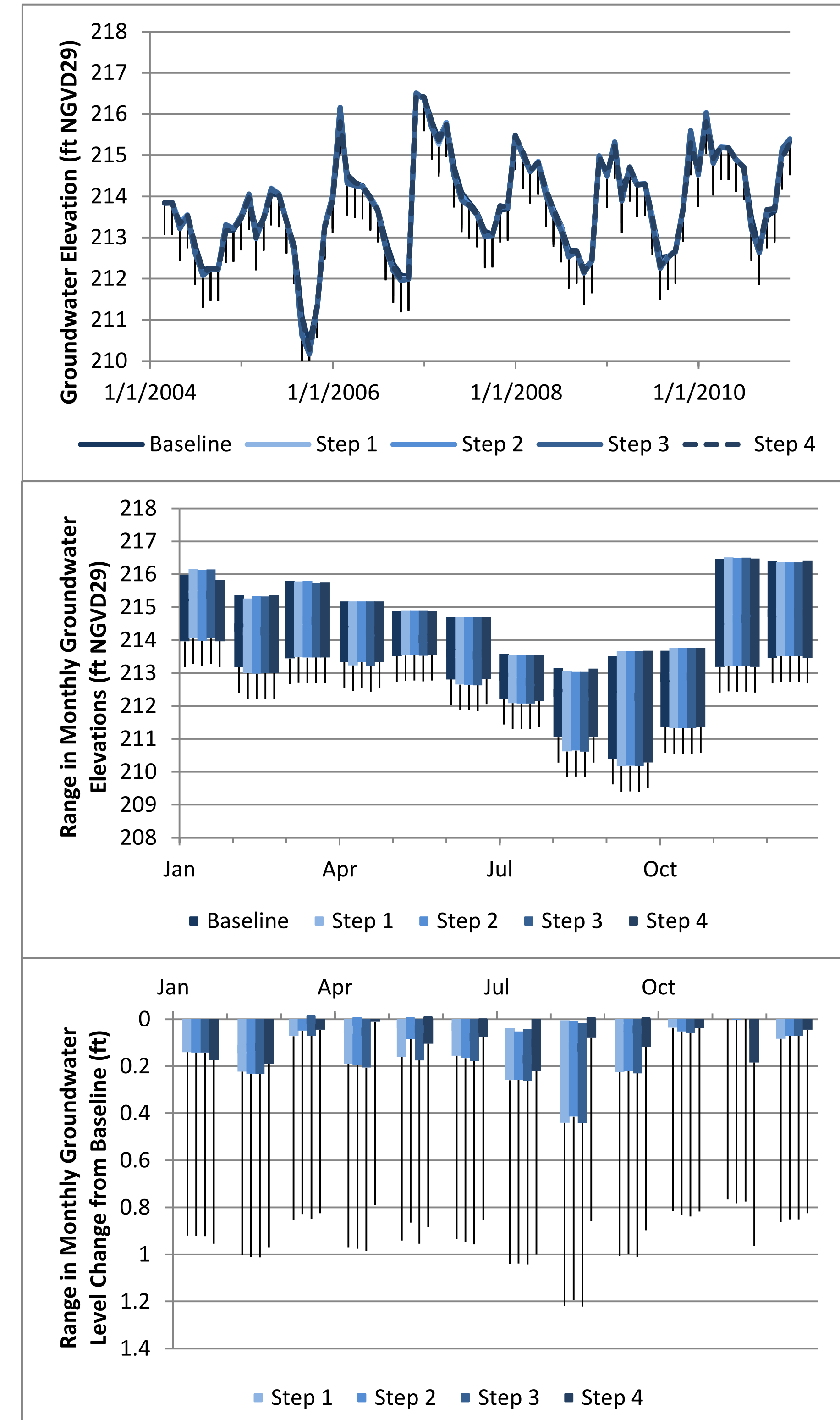


Figure 23

Predicted Changes and Ranges in Groundwater Levels

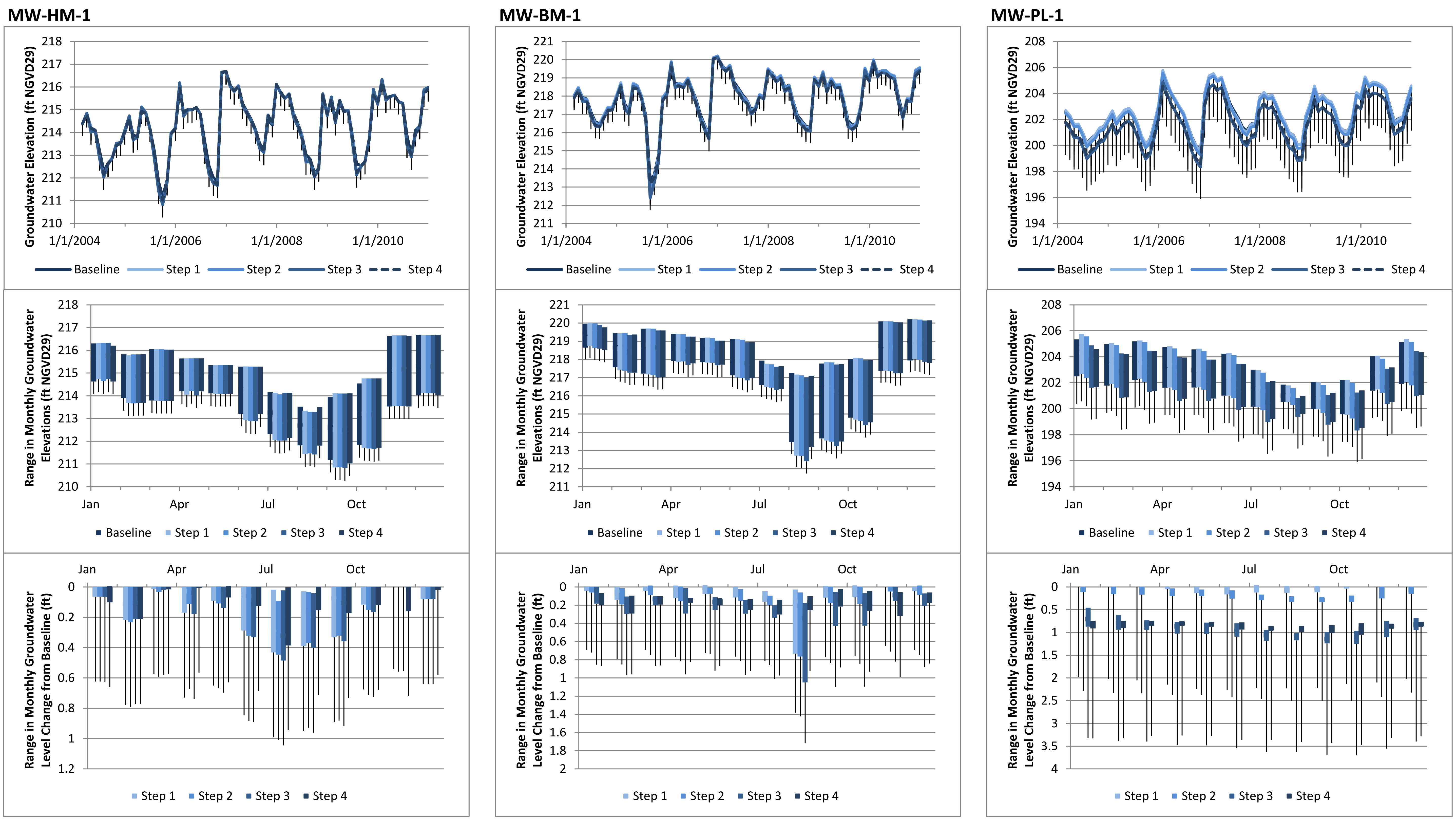


Figure 23

Predicted Changes and Ranges in Groundwater Levels

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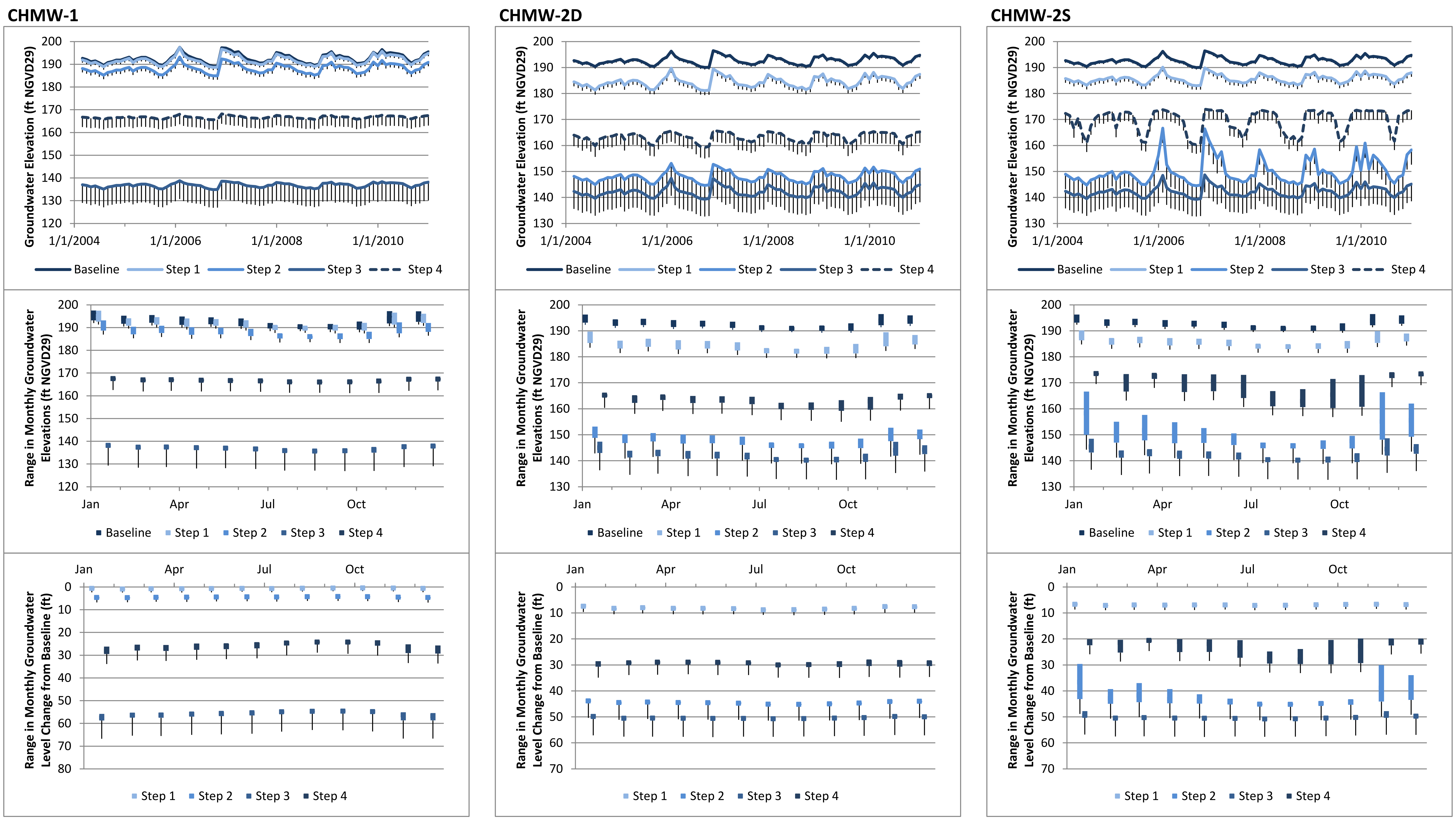

Figure 23

Predicted Changes and Ranges in Groundwater Levels

Dupont Groundwater Model Report

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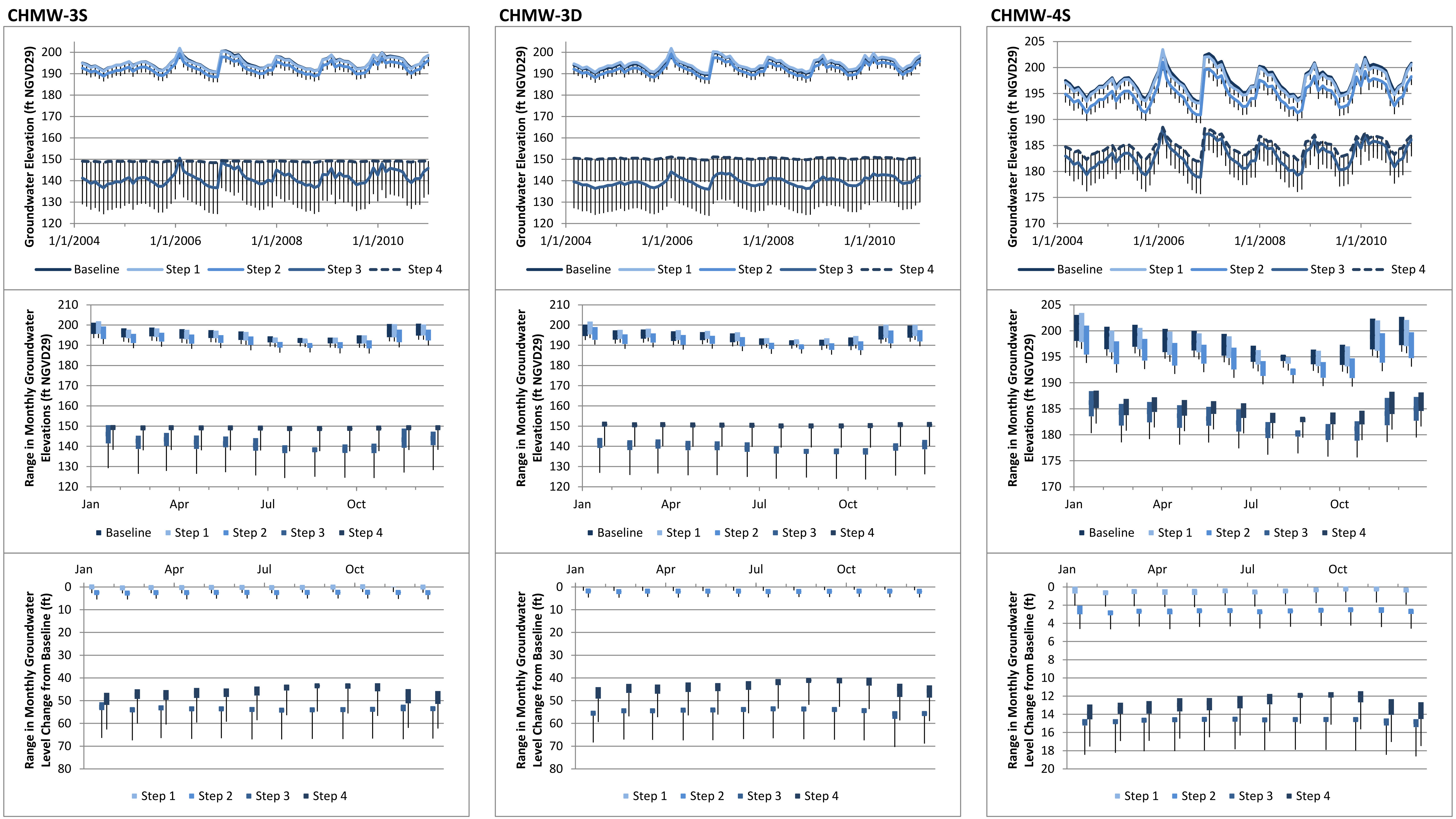

Figure 23

Predicted Changes and Ranges in Groundwater Levels

Dupont Groundwater Model Report

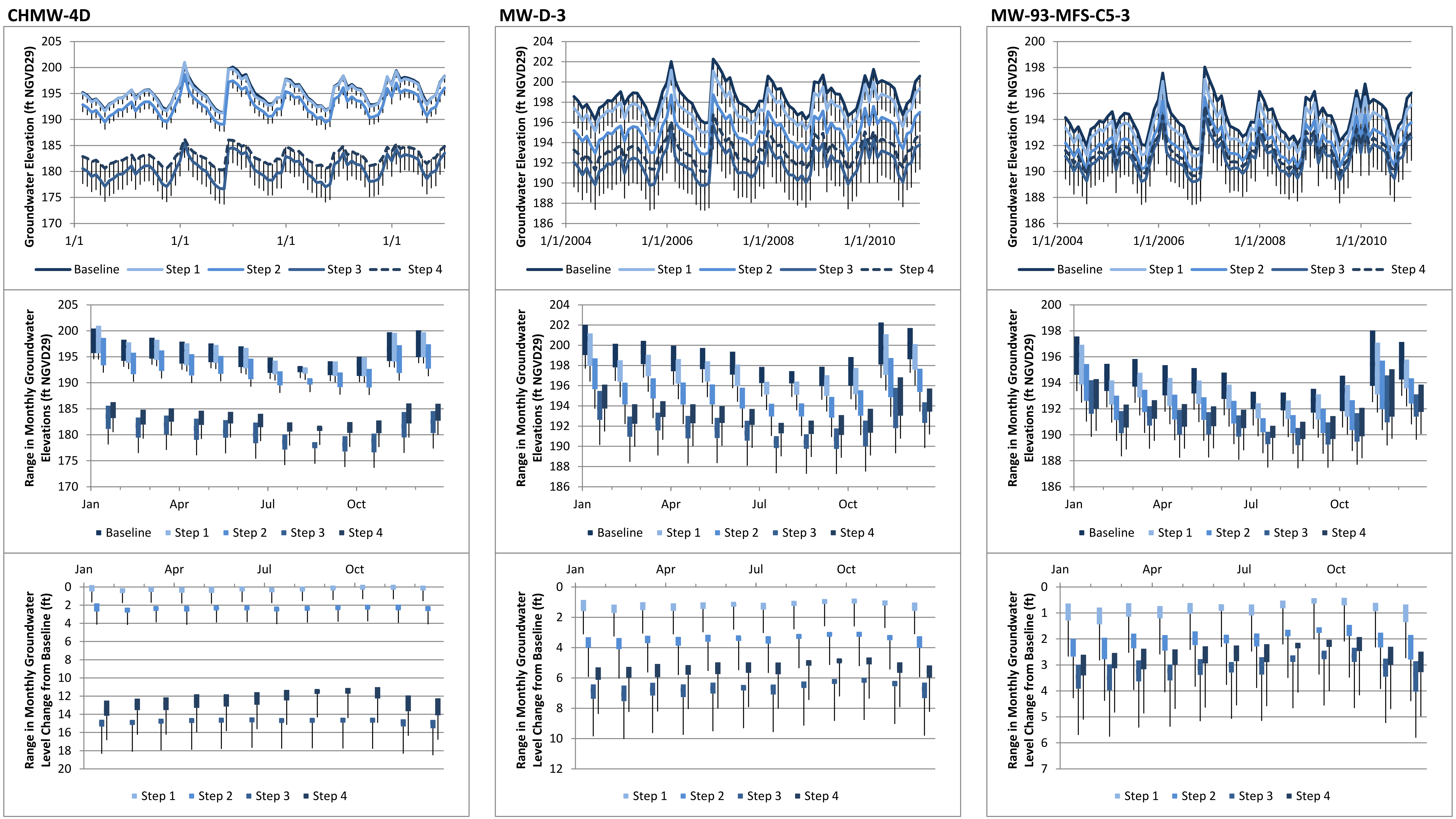

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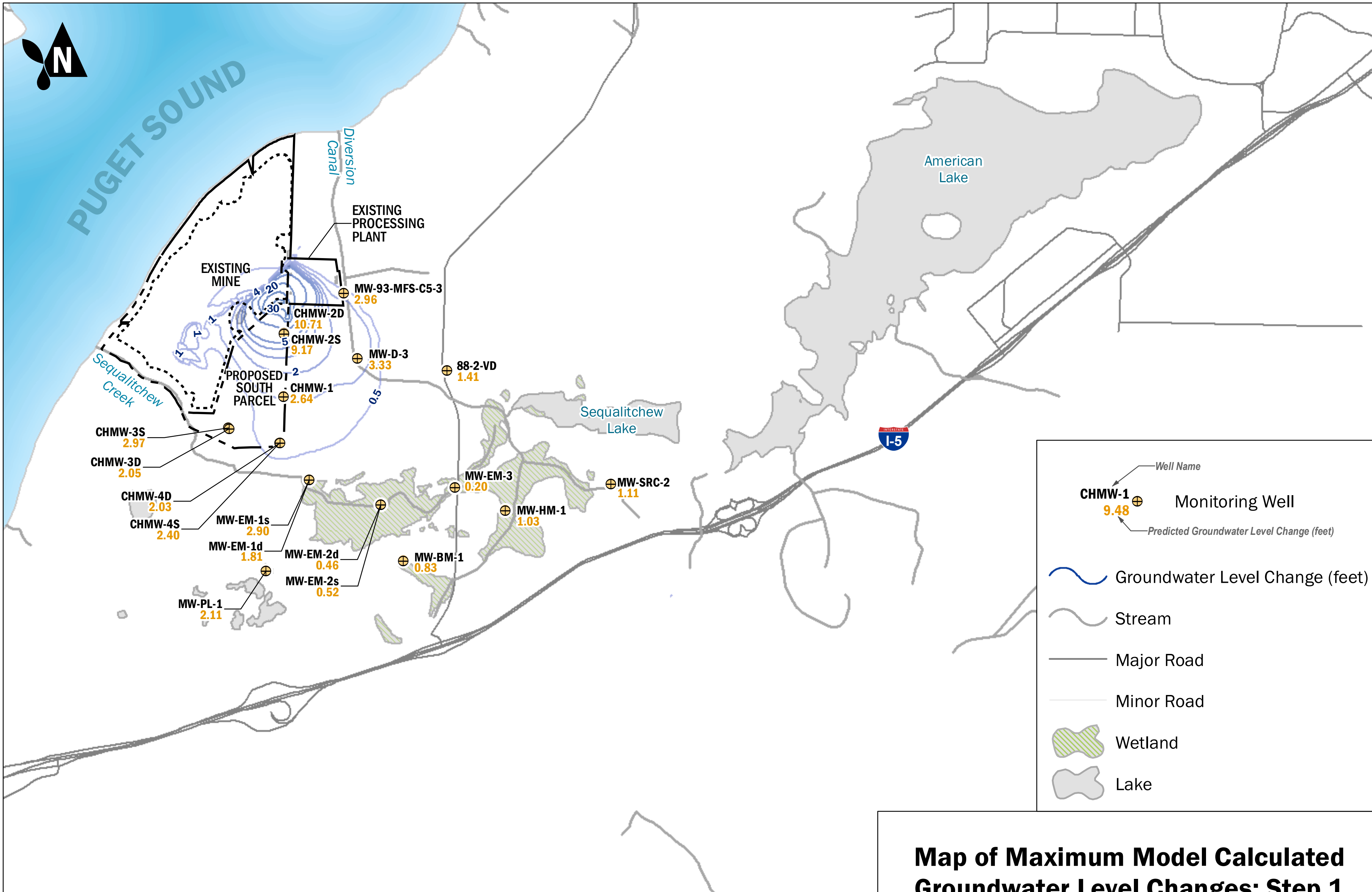
Figure 23
Predicted Changes and Ranges in Groundwater Levels
Dupont Groundwater Model Report

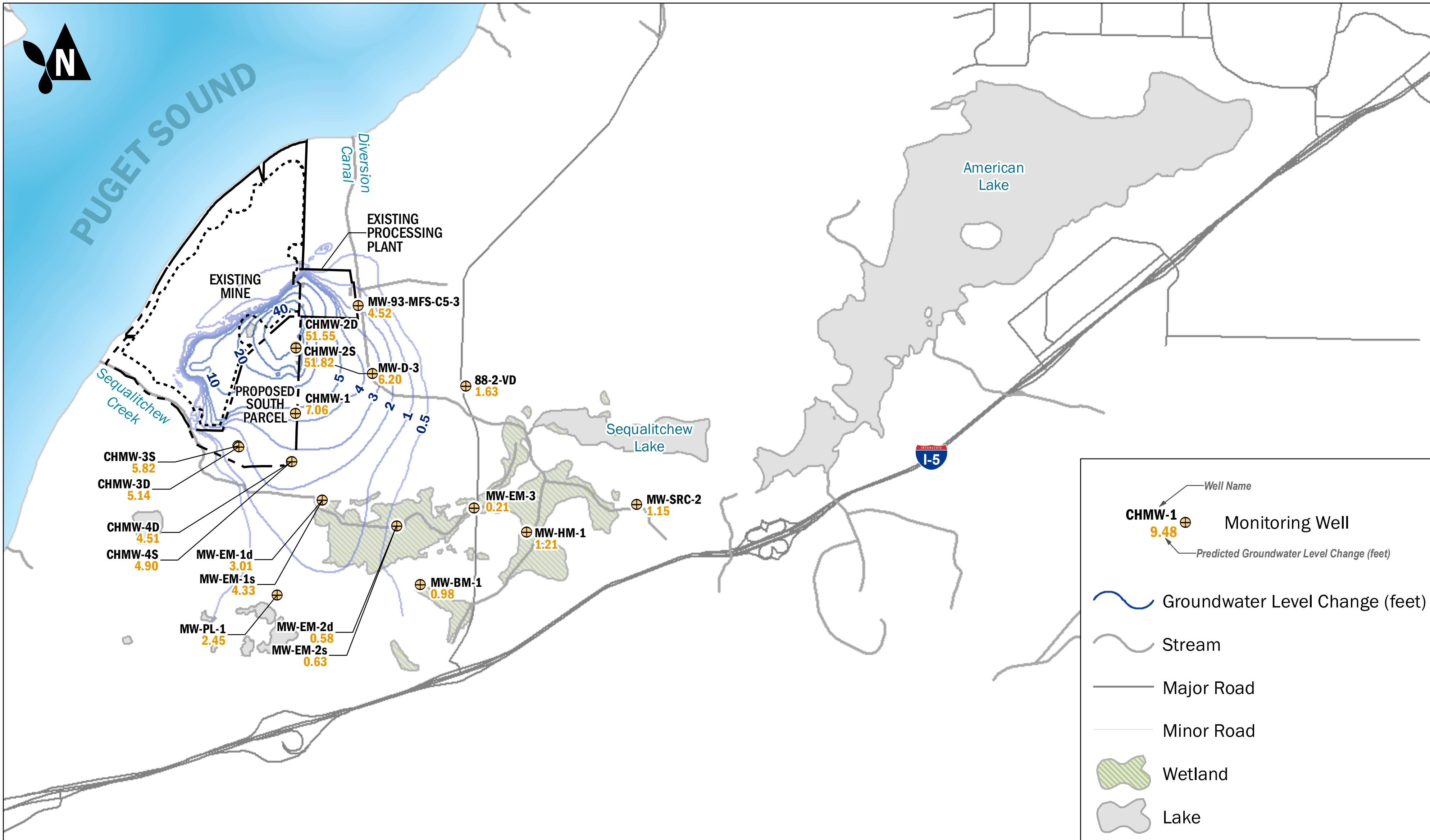


Note: Contours intervals include 0.5, 1-foot contours between 1 and 5 and 10 foot contours between 10-40.
Well label value represents predicted maximum change in water table based on refined model results (see Table B-6).

Map of Maximum Model Calculated Groundwater Level Changes: Step 1

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO.
	PROJECT NO. 040001-014	REVISED BY: RAP	24a



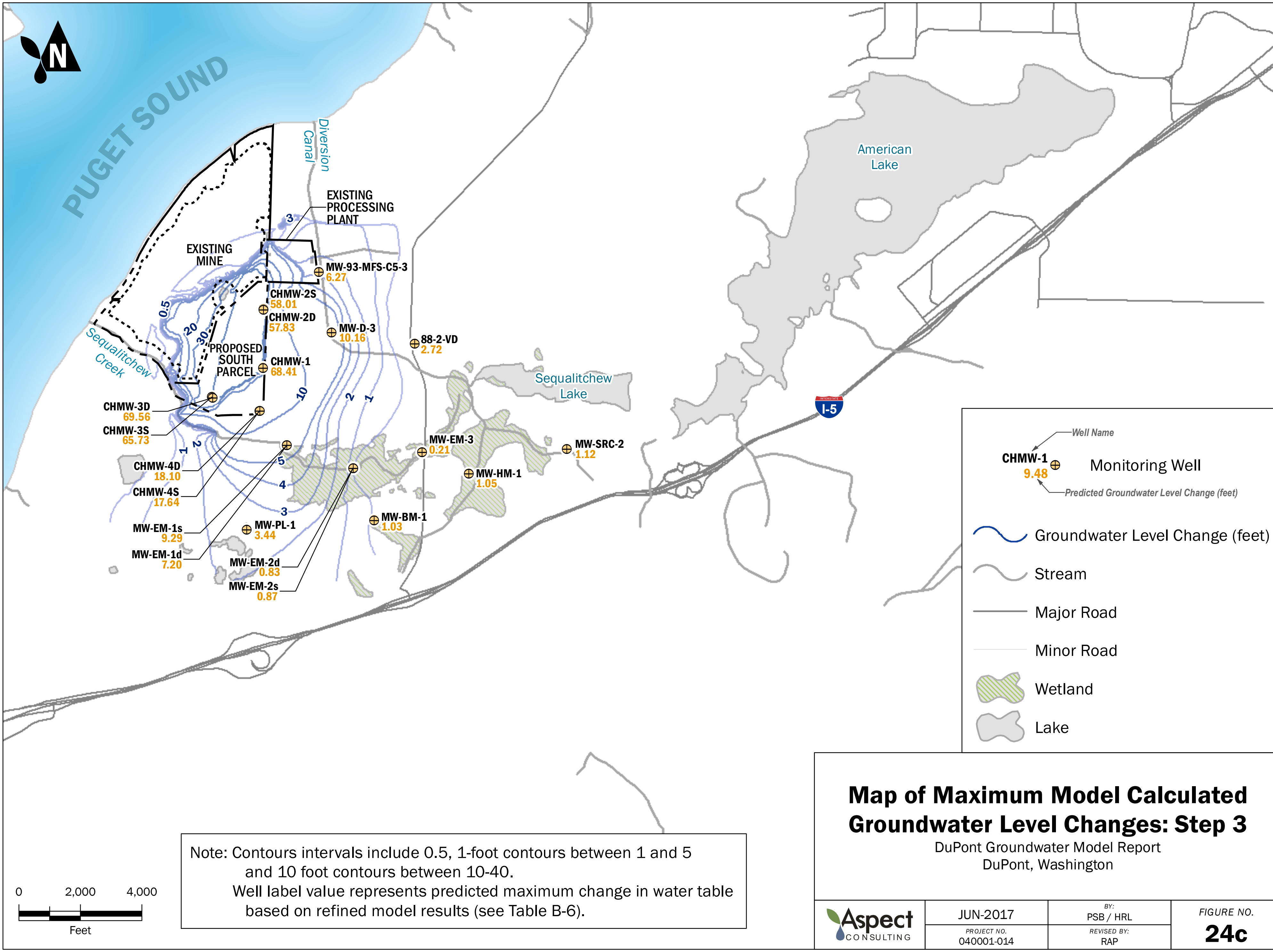
Note: Contours intervals include 0.5, 1-foot contours between 1 and 5 and 10 foot contours between 10-40.
Well label value represents predicted maximum change in water table based on refined model results (see Table B-6).

0 2,000 4,000
Feet

Map of Maximum Model Calculated Groundwater Level Changes: Step 2

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO.
	PROJECT NO. 040001-014	REVISED BY: RAP	24b



Note: Contours intervals include 0.5, 1-foot contours between 1 and 5 and 10 foot contours between 10-40.
Well label value represents predicted maximum change in water table based on refined model results (see Table B-6).

Map of Maximum Model Calculated Groundwater Level Changes: Step 3

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO.
	PROJECT NO. 040001-014	REVISED BY: RAP	24c

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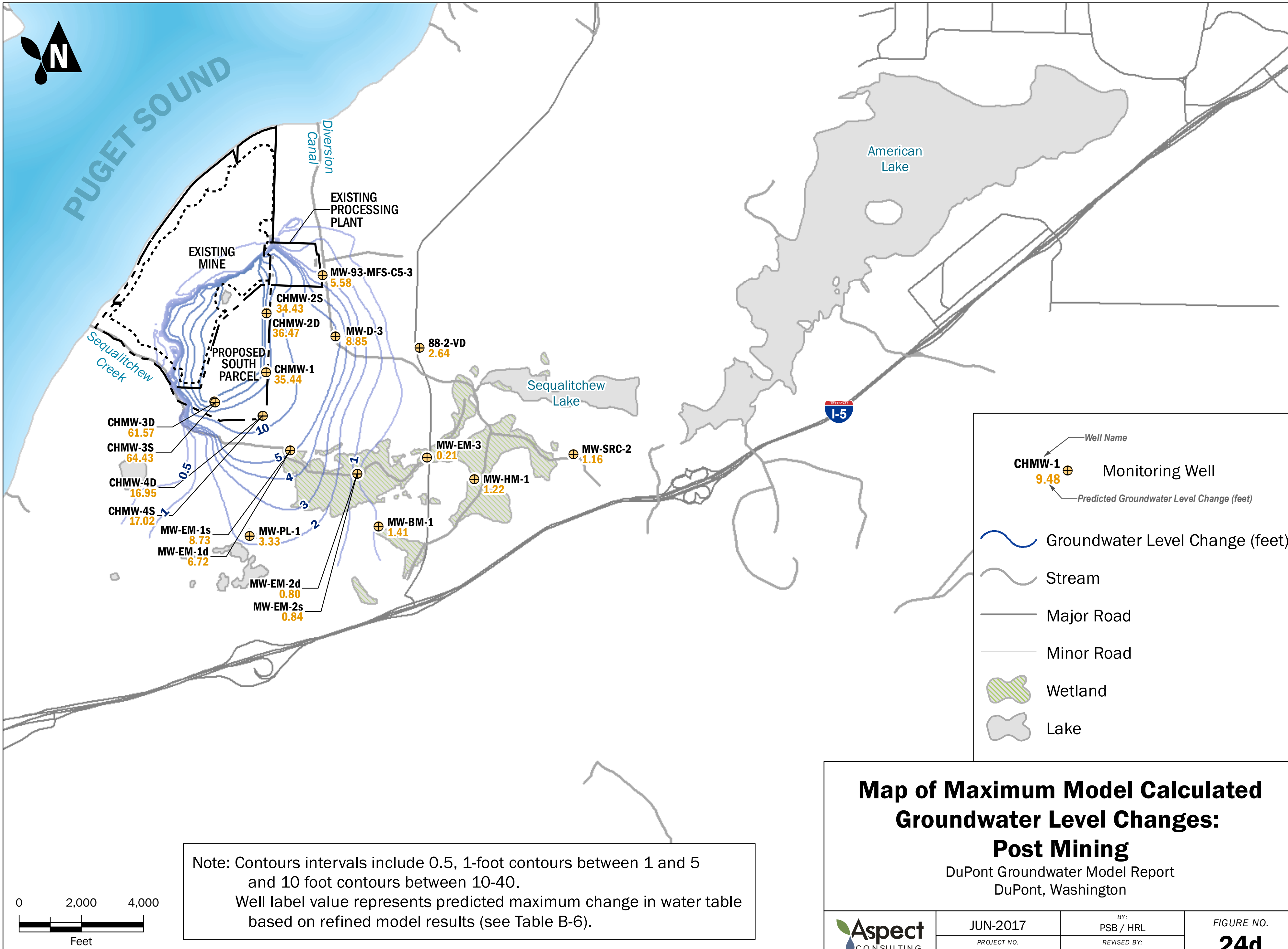

Note: Contours intervals include 0.5, 1-foot contours between 1 and 5 and 10 foot contours between 10-40.
Well label value represents predicted maximum change in water table based on refined model results (see Table B-6).

Map of Maximum Model Calculated Groundwater Level Changes: Post Mining

DuPont Groundwater Model Report
DuPont, Washington

Aspect CONSULTING	JUN-2017	BY: PSB / HRL	FIGURE NO. 24d
	PROJECT NO. 040001-014	REVISED BY: RAP	

GIS Path: T:\projects_8\DuPont\DuPontSouthParcel_040001\Delivered\GW Model Report\24d-WaterLvlChange.mxd || Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet || Date Saved: 6/29/2017 || User: pwittman || Print Date: 6/29/2017