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Project Memorandum

To:	**Pebble Limited Partnership**	**Doc. No.:**	**1872003.0239**
Attention:	**James Fueg, Stephen Hodgson**	**cc:**	
From:	**Craig Thompson, Dawn Paszkowski**	**Date:**	**June 20, 2019**
Subject:	**Pebble Project: Comparison of Numerical Groundwater Flow Models**		
Project No.:	**1872003**		

1.0 INTRODUCTION

1.1. Purpose

The Draft Environmental Impact Statement (DEIS) for the Pebble Project (the Project) was released for public comment by the United States Army Corps of Engineers (USACE) on February 20, 2019. Potential Project impacts to the groundwater hydrology described within the DEIS were based on the results of assessments conducted using a numerical groundwater flow model (PLP, 2011; Piteau, 2018) developed by Piteau Associates (Piteau). This model is referred to as the “Piteau model”.

Pebble Limited Partnership (PLP) retained BGC Engineering USA Inc. (BGC) to develop an updated groundwater flow model for the Project. Details of the model development, calibration, and predictive results are summarized in BGC (2019). This model is referred to as the “BGC model”. This memorandum provides a summary of the similarities and differences between the Piteau and BGC groundwater flow models, including results of the predictive simulations and sensitivity analyses.

1.2. Project Location and Layout

The Project is located north of Iliamna Lake approximately 200 miles southwest of Anchorage, Alaska, and 60 miles west of Cook Inlet (Drawing 01). The Project area straddles the boundary of the Nushagak River and Kvichak River watersheds, in the upper reaches of the North Fork Koktuli River (NFK), South Fork Koktuli River (SFK) and Upper Talarik Creek (UTC) drainages. The north and south forks of Koktuli River are in the Nushagak River watershed, while UTC is in the Kvichak River watershed. Both the Nushagak River and Kvichak River drain into Bristol Bay southwest of the Project.

The Project is located within the Nushagak – Big River Hills, which consists of low, rolling hills separated by wide, shallow valleys with sinuous drainage channels (Detterman and Reed, 1973). Glacial and fluvial sediments of varying thickness cover most low-lying areas, whereas ridges and hills typically exhibit exposed bedrock or have thin veneers of surficial material (Hamilton and Klieforth, 2010). The region is located within a zone of sporadic permafrost (Ferrians, 1965); however, no permafrost has been identified within the Project area (PLP, 2018). South of the

Project, the Nushagak – Bristol Bay Lowlands consist of relatively flat-lying topography with abundant wetlands and ponds along the north shore of Iliamna Lake (Detterman and Reed, 1973).

The Project is proposed to be developed over a 20-year mine life, with a mine area footprint as shown in Drawing 02. Details of the Project description can be found in PLP (2018). An open pit will be developed through a conventional drill, blast, truck, and shovel operation. The open pit will be developed in stages, with each stage expanding the area and depth of the previous stage. At completion, final open pit dimensions will be approximately 6,800 ft in length and 5,600 ft in width. A pit lake will form after mine closure.

Waste rock will be segregated by the potential to generate acid, with Potentially Acid-Generating (PAG) and Metal-Leaching (ML) waste rock stored in the Pyritic Tailings Storage Facility (TSF) until mine closure, when it will be placed in the open pit. Non-PAG (NPAG) and non-ML waste rock will be stockpiled and may be used as construction material. Overburden removed during mining will be segregated based on suitability for construction and use as a growth medium and stockpiled across the mine site at locations that minimize the potential for erosion. Further construction material will be sourced from quarries located in the vicinity of the Bulk TSF. The separate TSFs that will be constructed for bulk and pyritic tailings storage will be located primarily in the NFK watershed. Seepage collection systems will be installed to manage adverse downstream water quality impacts.

Water Management Ponds (WMPs) will be used to store water collected within the Project footprint. The Main WMP will be fully lined and used to store surplus water for milling and for managing water from other impoundment and seepage structures. Water collected from pit dewatering wells and the open pit will be pumped to the lined Open Pit WMP for use in the mill and storage prior to treatment and discharge.

2.0 DESCRIPTION OF MODELS

The groundwater flow models developed by Piteau and BGC both used numerical codes based on MODFLOW. MODFLOW is an industry standard 3-Dimensional (3-D) finite-difference groundwater flow code developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988; Harbaugh et al., 2000; Harbaugh, 2005) to simulate transient groundwater flow in a continuous porous medium under a range of hydrogeological boundaries and stresses.

The following subsections provide descriptions of the Piteau and BGC models, including details regarding the simulation code used, model domain and discretization, material properties, and boundary conditions. Table 2-1 summarizes the information pertaining to the structure of the models and baseline boundary conditions. Table 2-2 and Table 2-3 provide comparisons of boundary conditions used to represent proposed mine facilities at the end of mining and during the post-closure period, respectively.

2.1. Piteau Model

The Piteau model was initially developed using MODFLOW-SURFACT (HGL, 1996), a proprietary version of MODFLOW that provides advanced flow and solver options for MODFLOW.

Subsequent to publication of the Environmental Baseline Document (EBD; PLP, 2011), the simulation code was changed to MODFLOW-NWT (Niswonger et al., 2011). MODFLOW-NWT has similar functionality to MODFLOW-SURFACT but was developed and made publicly available by the U.S. Geological Survey.

The Piteau model domain encompassed the entirety of the NFK, SFK, and UTC watersheds and extended to natural hydrologic boundaries at drainage and watershed divides, with the exception of the western and southwestern margins of the model, where the model domain was truncated along arbitrary linear boundaries (Figure 2-1). Outside of the active model domain, model cells were specified to be inactive. Vertically, the model extended from the land surface to elevations ranging from -2,800 ft to -5,500 ft, with the elevation of the model base varying in a manner similar to surface topography. A sub-model, referred to as the “Piteau pit model” was also developed for the general area of the proposed open pit (Figure 2-1).

The model was discretized using a rectangular grid with uniform 1,000 ft square cells. Vertically, the model was discretized based on hydrogeologic units, including unconsolidated sediments (Layers 1 to 3), weathered bedrock (Layer 4), and bedrock (Layers 5 to model base). The number of layers varied between model versions, ranging from 5 (PLP, 2011) to 10 (PLP, 2019). Material properties, including hydraulic conductivity, specific storage and specific yield were assigned using almost 300 zones (i.e., groups of cells with the same properties) refined through model calibration.

MODFLOW boundary packages used to simulate baseline hydrologic features (Figure 2-2) included the Recharge Package (groundwater recharge), River Package (river and creeks, lakes and ponds), Drain Package (seepage at land surface), and Constant Heads (hydrologic features located along the model perimeter). In later versions of the model (e.g., Piteau, 2018), the Streamflow-Routing Package was used to simulate portions of NFK, SFK, and UTC. Proposed mine features such as the open pit and Bulk TSF were simulated using the Drain Package (excavations) or River Package (ponds; Figure 2-3), and the proposed pit lake was simulated using Constant Heads (Figure 2-4).

2.2. BGC Model

The BGC model was developed using MODFLOW-USG (Panday et al., 2013), a newer version of MODFLOW based on MODFLOW-NWT that incorporates a generalized control-volume finite-difference approach that allows use of non-orthogonal unstructured grid types.

The domain for the BGC model was similar in extent to the Piteau model (Figure 2-1); however, the BGC model domain was truncated at hydrologic boundaries in its western and northeastern margins relative to the Piteau model to reduce the overall size of the model and associated simulation times. Vertically, the model extended from the land surface to a uniform elevation of -5,500 ft.

The model was discretized using a Voronoi grid with cell dimensions ranging from less than 300 ft in the vicinity of the Project to a maximum of 3,000 ft along the model perimeter. Vertically, the model was discretized based on hydrogeologic units similar to the Piteau model, including unconsolidated sediments (Layers 1 to 3), weathered bedrock (Layer 4), and competent bedrock (Layers 5 to 12). Material distributions within layers (e.g., varying unconsolidated sediment types) were assigned based on available site investigation data and surficial geology mapping.

MODFLOW boundary packages used to simulate baseline hydrologic features (Figure 2-2) included the Recharge Package (groundwater recharge), Evapotranspiration Package (groundwater evapotranspiration), Streamflow-Routing Package (NFK, SFK, Koktuli River, and UTC), General Head Boundary Package (other rivers and creeks, lakes and ponds), Drain Package (seepage at land surface), and Specified Gradient Boundary Package (groundwater outflow at the model perimeter). Proposed mine features such as the open pit and Bulk TSF pond were simulated using the Drain Package (excavations) or General Head Boundary Package (ponds and pit lake; Figure 2-3 and Figure 2-4).

Tailings and dam materials comprising the Bulk TSF were simulated using three additional layers added to the top of the model to allow prediction of the total seepage rate, including basin seepage and seepage through the embankments and foundations (Figure 2-5).

3.0 MODEL CALIBRATION

3.1. Piteau Model

The Piteau model was initially calibrated to transient groundwater levels from December 2004 to December 2007 (USACE, 2019) using monthly stress periods (i.e., length of time with constant boundary conditions). The calibration period was subsequently extended to encompass January 2004 through March 2008 (PLP, 2019). Along with groundwater levels, several additional calibration targets (e.g., vertical hydraulic gradients; winter stream flow) were used to assess the model performance; however, quantitative statistics were only documented for groundwater levels. All calibration simulations were conducted using transient monthly simulations. Separate calibration simulations were also conducted using the sub-model developed for the general area of the proposed open pit, which incorporated a modified distribution of hydrogeologic parameters. In addition, local-scale models were developed and calibrated to drawdown measured at five short-term (i.e., several hours to one-day) airlift pumping test locations.

A comparison of simulated and observed groundwater levels for the most recent calibration of the Piteau model (PLP, 2019) for January 2004 through March 2008 along with available calibration statistics is provided in Figure 3-1 (PLP, 2019). Separate calibration statistics were computed for the Piteau pit model; however, they were based on a sub-set of the available data (PLP, 2019) and thus were not included here.

3.2. BGC Model

The BGC model was calibrated to groundwater levels and stream flows in four stages. In the first stage (stage 1), steady-state simulations were used to calibrate the model to long-term average annual groundwater levels and stream flows, and qualitatively assess simulated vertical groundwater flow directions at nested monitoring well locations. During stage 1, the model was calibrated by adjusting hydraulic conductivity, annual groundwater recharge, and annual surface runoff to improve the match between observed and simulated values. In the second and third stages, transient monthly simulations were used to calibrate the model to seasonal differences in groundwater levels and stream flows. Simulations were conducted for both long-term average monthly conditions (stage 2) and monthly conditions for the years 2004 to 2012 (stage 3). In these stages, the model was calibrated by adjusting storage properties, and the distributions of monthly groundwater recharge and surface runoff. In the fourth stage, transient simulations were used to calibrate the model to a 48-hour pumping test conducted in the area of the deposit at GH12-334S in 2013 by locally adjusting hydraulic conductivity and storage properties. A local-scale model was developed for this stage to assist in the calibration process.

A comparison of simulated and observed groundwater levels for the BGC model, restricted to January 2004 through March 2008, along with available calibration statistics is provided in Figure 3-1. The results indicate that observed groundwater levels were similarly well represented by both models. Computed Normalized Root Mean Square Error (NRMSE) of 1% and 1.8% for the Piteau model and BGC model, respectively, are well within recommended guidelines (e.g., NRMSE<10%; NBLM, 2006; BCMOE, 2012). Based on data presented in Figure 3-1, calibration of the BGC model included a larger set of calibration targets relative to the Piteau model (e.g., calibration targets above 1,600 ft were not included in the Piteau dataset).

4.0 MODEL PREDICTIONS

4.1. End-of-Mining Operations

The Piteau and BGC models were both used to predict the effects on the groundwater flow regime of proposed mine development based on the 2018 Project Description (PLP, 2018). However, different open pits were simulated within the respective analyses. The Piteau model simulated a deeper open pit relative to the BGC model, with base of pit elevations of -850 ft and -500 ft, respectively.

4.1.1. Piteau Model

End-of-mining conditions for the proposed Project were simulated using steady-state conditions. Predictions for the Bulk TSF were assessed using the regional-scale Piteau model, while predictions for the open pit were derived from the Piteau pit model.

Groundwater extraction at the open pit was predicted to range from 2,200 US gpm to 2,400 US gpm (4.9 cfs to 5.3 cfs; Piteau, 2018). Drawdown due to the open pit was predicted to primarily be restricted to SFK watershed, although the cone of depression did extend under the Pyritic TSF and into the upper tributaries of UTC watershed (Figure 4-1; USACE, 2019).

Seepage from the Bulk TSF (i.e., basin seepage excluding seepage through the embankments and embankment foundations) was predicted to be 90 US gpm (0.2 cfs; Piteau, 2018). The Bulk

TSF was predicted to result in extensive groundwater mounding that extended into NFK and SFK watersheds, as well as towards the open pit (Figure 4-1).

4.1.2. BGC Model

End-of-mining conditions for the proposed Project were also simulated by the BGC model using steady-state conditions. Groundwater extraction at the open pit was predicted to be 980 US gpm (2.2 cfs), which is approximately 60% less than that predicted by the Piteau model. Differences in predicted open pit groundwater extraction are due to a combination of factors, including the following:

- Shallower pit simulated in the BGC model resulting in a smaller hydraulic gradient directing groundwater flow towards the open pit,
- Finer grid discretization incorporated into the BGC model that allowed an improved representation of the open pit geometry, and
- Overprediction of groundwater levels (i.e., groundwater levels above ground surface) in some areas of the Piteau model resulting in an exaggerated hydraulic gradient directing groundwater flow towards the open pit.

Predicted drawdown due to the open pit was generally similar in extent to the Piteau model (Figure 4-1); however, drawdown was predicted to be more extensive under the Pyritic TSF where groundwater recharge was reduced due to the overlying lined facility. The BGC model also predicted drawdown in the footprints of Quarry B and Quarry C; these features were not included within the Piteau model simulations.

The total seepage rate from the Bulk TSF, including seepage through the embankments, embankment foundations, and into the underlying basin was predicted to be 630 US gpm (1.4 cfs). Basin seepage (i.e., the component of total seepage simulated by the Piteau model) was predicted to comprise 66% of the total seepage rate (415 US gpm; 0.9 cfs). In addition, groundwater mounding was predicted to be appreciably reduced in comparison to the Piteau model (Figure 4-1). Differences in the predicted basin seepage rate from the Bulk TSF are due to a combination of factors, including the simulation approach for the facility, higher tailings hydraulic conductivity in the BGC model (i.e., $3x10^{-6}$ ft/s) relative to the Piteau model ($1x10^{-7}$ ft/s), and overprediction of groundwater levels in some areas of the Piteau model (i.e., groundwater levels above ground surface).

4.2. Post-Closure

4.2.1. Piteau Model

Post-closure conditions for the proposed Project were simulated using steady-state conditions. Predictions for the pit lake were derived from the Piteau pit model, which excluded consideration of the reclaimed Bulk TSF, along with the rest of the reclaimed facilities within the mine footprint.

Groundwater discharge to the pit lake was predicted to be 1,300 US gpm (2.9 cfs; Piteau, 2018). Seepage from the pit lake was predicted to be 0 US gpm. Drawdown was predicted to be reduced relative to end of mining conditions, with the cone of depression predicted to be primarily restricted to the SFK watershed and the upper tributaries of UTC watershed (Figure 4-2).

4.2.2. BGC Model

Post-closure conditions for the proposed Project were also simulated by the BGC model using steady-state conditions. However, in contrast to the Piteau model the influences of the Bulk TSF, Bulk TSF Seepage Collection Pond (SCPs), and Quarries B and C were included in the analysis. The remaining mine facilities were assumed to be reclaimed to baseline conditions.

Groundwater discharge to the pit lake was predicted to be 800 US gpm (1.8 cfs), or about 40% less than the discharge predicted by the Piteau pit model. Consistent with the Piteau pit model, seepage from the pit lake was predicted to be 0 US gpm. Consistent with the end-of-mining results (Section 4.1.2), differences in predicted groundwater discharge to the pit lake are due to a combination of factors, including the shallower pit that was simulated in the BGC model, finer grid discretization incorporated into the BGC model, and overprediction of groundwater levels (i.e., groundwater levels above ground surface) in some areas of the Piteau pit model.

The predicted extents of the cones of depression were similar for both models (Figure 4-2).

5.0 SENSITIVITY ANALYSIS

5.1. Piteau Model

Sensitivity analyses were conducted by Piteau using a null space Monte-Carlo analysis that included 96 realizations (i.e., 96 simulations with different input parameters; Piteau, 2018). For each realization, hydraulic conductivity values were slightly adjusted within specified bounds to ensure that calibration objectives were met (USACE, 2019). Steady-state simulations were conducted for end-of-mining conditions with the Piteau pit model to evaluate potential ranges in groundwater discharge to the open pit and the extent of drawdown. Sensitivity simulations were conducted for post-closure conditions; however, predicted ranges in groundwater discharge to the pit lake were not reported. Sensitivity simulations were not conducted using the regional-scale model; therefore, the potential range of impacts due to the Bulk TSF, along with the rest of the facilities within the mine footprint, were not assessed.

Results of the analysis indicated a narrow range in predicted groundwater extraction at the open pit (i.e., 2,200 US gpm to 2,400 US gpm or 4.9 cfs to 5.3 cfs) and drawdown (Piteau, 2018).

5.2. BGC Model

Twenty-one sensitivity simulations were conducted using the BGC model. The sensitivity analysis included assessment of the influence of comparatively large changes in hydraulic conductivity (i.e., factors of 10 to 100), in addition to the influence of changes in groundwater recharge and overburden thickness (BGC, 2019). For consistency with the Piteau analysis, discussion of results is limited to predictions related to the open pit at the end of mining. More extensive discussion of the sensitivity analysis results is presented in BGC (2019).

The BGC model sensitivity analysis considered a wider range in hydraulic properties, and correspondingly the sensitivity simulations with the BGC model result in a greater range in predicted pit inflows relative to the range predicted by Piteau. Results of the BGC sensitivity analysis indicate that groundwater extraction at the open pit could range from 600 US gpm to 3,000 US gpm (1.3 cfs to 6.7 cfs), compared with the 2,200 US gpm to 2,400 US gpm (4.9 cfs to 5.3 cfs) predicted by Piteau.

6.0 SUMMARY

This memorandum summarizes the similarities and differences between the groundwater flow models developed by Piteau and BGC, including results of the predictive simulations and sensitivity analyses. A synthesis of this information is provided below.

Model Framework: Groundwater flow models developed by Piteau and BGC were both developed using a MODFLOW-based numerical code. Both models encompassed the entirety of the NFK, SFK, and UTC watersheds; however, the BGC model domain was truncated at hydrologic boundaries in its western and northeastern margins relative to the Piteau model domain. The Piteau model incorporated a rectangular grid with uniform 1,000 ft square cells; whereas the BGC model utilized a Voronoi grid with cell dimensions ranging from less than 300 ft in the vicinity of the Project to 3,000 ft along the model perimeter (i.e., the BGC model incorporated finer grid discretization in the Project area).

Model Calibration: The Piteau and BGC groundwater flow models were both calibrated to transient monthly conditions, with similar calibration statistics computed for groundwater levels. However, the Piteau calibration period was limited to January 2004 through March 2008, whereas the BGC model calibration period included the years 2004 to 2012. In addition, the BGC model included a larger set of calibration targets relative to the Piteau model.

End-of-Mining Predictions: Steady-state simulations were used by both the Piteau and BGC models to predict potential Project impacts at the end of mining. The Piteau model predicted an open pit groundwater extraction rate of 2,200 US gpm to 2,400 US gpm (4.9 cfs to 5.3 cfs) relative to the rate predicted by the BGC model of 980 US gpm (2.2 cfs). Predicted drawdown due to the open pit was generally similar between models; however, the BGC model predicted more extensive drawdown under the Pyritic TSF, and in the footprints of Quarries B and C which were not included in the Piteau simulations. Seepage from the Bulk TSF was predicted to be 90 US gpm (0.2 cfs) for the Piteau model relative to 630 US gpm (1.4 cfs) for the BGC model. However, due to differences in model approach, predicted seepage from the Piteau model was restricted to basin seepage; whereas, predicted seepage from the BGC model included seepage through the embankments and embankment foundations in addition to basin seepage. In addition, the extent of groundwater mounding was predicted to be appreciably less for the BGC model.

Post-Closure Predictions: Both the Piteau and BGC models used steady-state simulations to predict impacts from the proposed Project during the post-closure period. Piteau used a sub-model restricted in area to the general vicinity of the proposed open pit, with predicted impacts limited to the influence of the pit lake. In contrast, the BGC model evaluated potential mine impacts at post-closure from the pit lake along with the Bulk TSF, Bulk TSF SCPs, and Quarries B and C. Predicted groundwater discharge to the pit lake for the Piteau and BGC models was 1,300 US gpm (2.9 cfs) and 800 US gpm (1.8 cfs), respectively. Both models predicted seepage from the pit lake of 0 US gpm.

Sensitivity Analysis: Piteau evaluated the sensitivity of groundwater extraction rates at the proposed open pit using a null space Monte Carlo analysis with 96 realizations. Open pit groundwater extraction was predicted to vary over a narrow range; however, the hydraulic conductivity of several hydrogeologic units were not varied appreciably. Results of a more extensive sensitivity analysis conducted using the BGC model indicates that the range in potential groundwater extraction rates at the open pit may be appreciably larger than estimated with the Piteau model. Piteau's sensitivity analysis was limited to the open pit, therefore a comparison of the range of predictions for other mine facilities could not be completed.

Differences in predictions between the Piteau and BGC models are due to a combination of factors, including differences in the representation of mine facilities (e.g., different open pits were simulated, different approach used to simulate the Bulk TSF), finer grid discretization incorporated into the BGC model, and overprediction of groundwater levels (i.e., groundwater levels above ground surface) in some areas of the Piteau model and Piteau pit model. Nevertheless, groundwater flow rates (e.g., open pit groundwater extraction rate) predicted by the Piteau model fall within the bounds of the sensitivity analysis conducted by BGC (2019), with similar project impacts (e.g., drawdown) predicted by both models.

7.0 CLOSURE

BGC Engineering USA Inc. (BGC) prepared this document for the account of Pebble Limited Partnership (PLP) for the purpose of submitting to the United States Army Corps of Engineers (USACE) for USACE's review as part of a permit application. The material in it reflects the judgement of BGC staff in light of the information available to BGC at the time of document preparation. Any use which any party other than PLP or USACE makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

As a mutual protection to our client, the public, and ourselves, this document, including the drawings herein, was prepared and is submitted to our client for a specific project in connection with the USACE permit review process. BGC acknowledges that PLP, USACE and/or AECOM have the right to publish the information contained in this document in its current form as part of the USACE permit review process as contemplated.

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Yours sincerely,

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Attachment(s): Tables
Figures
Drawings

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TABLES

Table 2-1. Summary of Piteau and BGC numerical groundwater flow models.

Model Component	Piteau Model	Piteau Pit Model	BGC Model
Numerical Code	MODFLOW-SURFACT and MODFLOW-NWT	MODFLOW-NWT	MODFLOW-USG
Grid type	Rectangular	Rectangular	Voronoi
Model top elevation	Topography	Topography	Topography
Model bottom elevation	-2,800 ft to -5,500 ft	-2,800 ft to -5,100 ft	-5,500 ft
Horizontal discretization	1,000 ft	1,000 ft	<300 ft to 3,000 ft
Layer Assignments[1]	-Layers 1 to 3: Unconsolidated sediments and weathered bedrock -Layers 4: Weathered bedrock -Layers 5 to model base: Bedrock	-Layers 1 to 3: Unconsolidated sediments and weathered bedrock -Layers 4: Weathered bedrock -Layers 5 to model base: Bedrock	-Layers 1 to 3: Unconsolidated sediments and weathered bedrock -Layer 4: Weathered bedrock -Layers 5 to 12: Bedrock
Vertical discretization	-Layers 1 to 3: 15 ft to 1,080 ft cumulative -Layer 4: Constant (50 ft) -Layer 5 to base: Constant thickness layers (100 ft to 2,000 ft thick) that increase in thickness with depth	-Layers 1 to 3: 15 ft to 760 ft cumulative -Layer 4: Constant (50 ft) -Layer 5 to base: Constant thickness layers (100 ft to 2,000 ft thick) that increase in thickness with depth	-Layers 1 to 3: Variable based on unconsolidated sediment thickness (9 ft to 380 ft cumulative) -Layer 4: Constant (50 ft) -Layers 5 to 12: Variable based on difference between base Layer 4 and base model
Horizontal Hydraulic Conductivity	-Layers 1 to 3: $8x10^{-2}$ ft/s to $2x10^{-8}$ ft/s -Layer 4: $1x10^{-5}$ ft/s to $4x10^{-8}$ ft/s -Layer 5 to base: $3x10^{-2}$ ft/s to $8x10^{-10}$ ft/s	-Layers 1 to 3: $8x10^{-2}$ ft/s to $2x10^{-8}$ ft/s -Layer 4: $1x10^{-5}$ ft/s to $3x10^{-8}$ ft/s -Layer 5 to base: $1x10^{-5}$ ft/s to $8x10^{-10}$ ft/s	-Layers 1 to 3: $2x10^{-3}$ ft/s to $1x10^{-7}$ ft/s -Layer 4: $3x10^{-6}$ ft/s -Layers 5 to 12: $3x10^{-8}$ ft/s
Anisotropy (horizontal:vertical)	-Layers 1 to 3: 5,000:1 to 1:100 -Layer 4: 10:1 to 1:250 -Layer 5 to base: 10:1 to 1:1,000	-Layers 1 to 3: 5,000:1 to 1:5,700 -Layer 4: 5:1 to 1:250 -Layer 5 to base: 30:1 to 1:1,000	-Layers 1 to 3: 10:1 to 1:1 -Layer 4: 1:1 -Layers 5 to 12: 1:1
Specific Storage	-Layers 1 to 3: $3x10^{-2}$ ft^{-1} to $1x10^{-6}$ ft^{-1} -Layer 4: $1x10^{-4}$ ft^{-1} to $1x10^{-6}$ ft^{-1} -Layer 5 to base: $1x10^{-4}$ ft^{-1} to $1x10^{-6}$ ft^{-1}	-Layers 1 to 3: $2x10^{-1}$ ft^{-1} to $4x10^{-7}$ ft^{-1} -Layer 4: $6x10^{-4}$ ft^{-1} to $2x10^{-7}$ ft^{-1} -Layer 5 to base: $3x10^{-4}$ ft^{-1} to $1x10^{-7}$ ft^{-1}	-Layers 1 to 3: $3x10^{-4}$ ft^{-1} to $3x10^{-7}$ ft^{-1} -Layer 4: $3x10^{-7}$ ft^{-1} -Layers 5 to 12: $3x10^{-8}$ ft^{-1}
Specific Yield	-Layers 1 to 3: 0.1 to 0.0001 -Layer 4: 0.01 -Layer 5 to base: 0.01	-Layers 1 to 3: 0.1 to $9x10^{-5}$ -Layer 4: 0.01 -Layer 5 to base: 0.01	-Layers 1 to 3: 0.15 to 0.01 -Layer 4: 0.01 -Layers 5 to 12: 0.001
Baseline Boundary Conditions[2]	-Groundwater Recharge: RCH -Groundwater Evapotranspiration: Not Simulated -Surface Seepage: DRN -Rivers and Creeks: RIV and SFR (portions of Koktuli and Upper Talarik watersheds) -Lakes and Ponds: RIV -Subsurface Outflow: Constant Head	-Groundwater Recharge: RCH -Groundwater Evapotranspiration: Not Simulated -Surface Seepage: DRN -Rivers and Creeks: RIV -Lakes and Ponds: RIV -Subsurface Outflow: Constant Head	-Groundwater Recharge: RCH -Groundwater Evapotranspiration: EVT -Surface Seepage: DRN -Rivers and Creeks: SFR (Koktuli and Talarik watersheds) and GHB (other watersheds) -Lakes and Ponds: GHB -Subsurface Outflow: SGB

Notes:

1. Number of model layers in the Piteau model varied between model versions and ranged from 5 to 10.
2. RCH = recharge; EVT = evapotranspiration; DRN = drain; SFR = streamflow-routing; GHB = general head boundary; SGB = specified gradient boundary; RIV = river.

Table 2-2. Summary of boundary conditions used to represent proposed mine facilities at the end of mining within the Piteau and BGC groundwater flow models.

Facility	Piteau Model	Piteau Pit Model	BGC Model
Open Pit	Simulated using the DRN package with water level set to the base of mining.	Simulated using the DRN package with water level set to the base of mining.	Simulated using the DRN package with water level set to the base of mining.
Open Pit WMP[2]	Simulated using the RIV package with a water level of 1,010 ft.	Simulated using the RIV package with a water level of 1,010 ft.	Assumed seepage of 0.1 L/s simulated using the RCH package.
Bulk TSF	Simulated using the RIV package across facility's entire extent with water level set to 1,690 ft.	Not simulated.	Simulated using 3 additional model layers with the pond represented using the GHB package specified across the planned operating footprint with water level set to 1,690 ft.
Bulk TSF SCPs	North pond simulated using the RIV package with water level of 1,135 ft. South and east ponds not explicitly simulated; however, drainages within footprint of south pond unchanged from baseline conditions.	Not simulated.	North and South ponds simulated using the GHB package with respective water levels of 1,130 ft and 1,350 ft. East pond simulated using the DRN package with a water level of 1,765 ft.
Main WMP[1]	Simulated using the RIV package with water level set to 1,195 ft.	Simulated using the RIV package with water level set to 1,195 ft.	Within the footprint of the lined pond, leakage rate of 1 L/s was simulated using the recharge package. Within the remainder of the lined pond, groundwater recharge specified to be 0 in/yr. Within the embankments, groundwater recharge specified to be 7 in/yr.
Main WMP SCPs	Not explicitly simulated; however, drainages within the pond footprints unchanged from baseline conditions.	Not explicitly simulated; however, drainages within the pond footprints unchanged from baseline conditions.	Simulated using the DRN package with water level set to ground surface.
Pyritic TSF[1]	Simulated using the RIV package with water level set to 1,545 ft.	Simulated using the RIV package with water level set to 1,545 ft.	Within the footprint of the lined pond, leakage rate of 1 L/s was simulated using the recharge package. Within the remainder of the lined pond, groundwater recharge specified to be 0 in/yr. Within the embankments, groundwater recharge specified to be 7 in/yr.
Pyritic TSF SCPs	Not explicitly simulated; however, drainages within the pond footprints unchanged from baseline conditions.	Not explicitly simulated; however, drainages within the pond footprints unchanged from baseline conditions.	Simulated using the DRN package with water level set to ground surface.
Quarries	Not simulated.	Not simulated.	Quarry B and Quarry C simulated using the DRN package. Quarry A not simulated.
Stockpiles	Not simulated.	Not simulated.	Simulated with groundwater recharge specified to be 7 in/yr using the RCH package.

Notes:

1. Seepage rate applied in BGC model for lined facility based on Piteau (2018).
2. Seepage rate in the BGC model from the lined facility assumed based on comparison of facility's area relative to the Main WMP and Pyritic TSF.
3. RCH = recharge; DRN = drain; GHB = general head boundary; RIV = river.

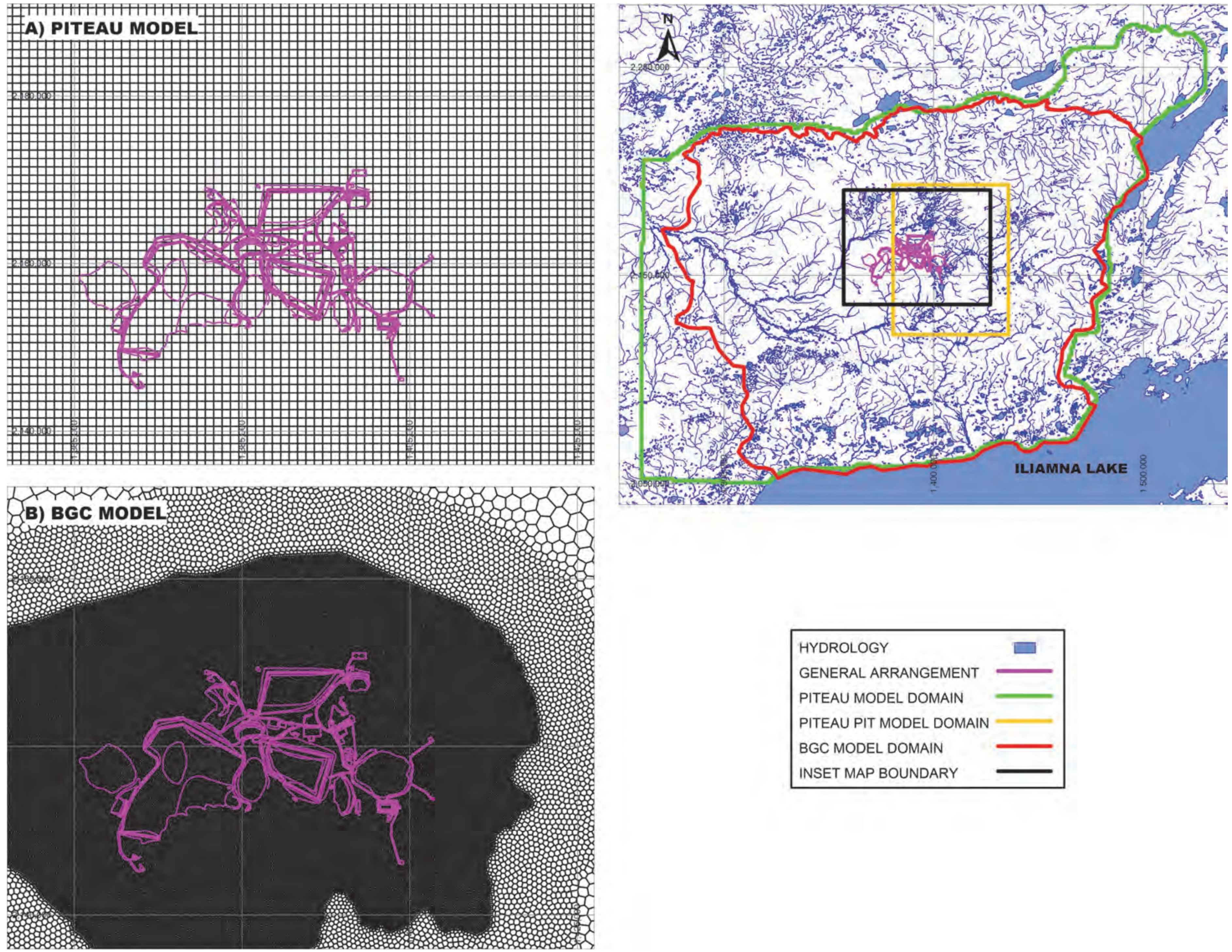
Table 2-3. Summary of boundary conditions used to represent proposed mine facilities at post-closure within the Piteau and BGC groundwater flow models.

Facility	Piteau Model[1]	Piteau Pit Model	BGC Model
Pit Lake	Not simulated.	Simulated using constant head boundaries with water level set to 900 ft.	Simulated using the GHB package with water level set to 900 ft. Seepage at open pit walls simulated using the DRN package with water level set to the base of mining.
Open Pit WMP	Not simulated.	Reclaimed to baseline conditions.	Reclaimed to baseline conditions.
Bulk TSF	Not simulated.	Not simulated.	Simulated using 3 additional model layers with groundwater recharge specified to be 3 in/yr.
Bulk TSF SCPs	Not simulated.	Not simulated.	North and South ponds simulated using the GHB package with respective water levels of 1,130 ft and 1,350 ft. East pond simulated using the DRN package with a water level of 1,765 ft.
Main WMP	Not simulated.	Not simulated.	Reclaimed to baseline conditions.
Main WMP SCPs	Not simulated.	Not simulated.	Reclaimed to baseline conditions.
Pyritic TSF	Not simulated.	Not simulated.	Reclaimed to baseline conditions.
Pyritic TSF SCPs	Not simulated.	Not simulated.	Reclaimed to baseline conditions.
Quarries	Not simulated.	Not simulated.	Quarry B and Quarry C simulated using the DRN package. Quarry A not simulated.
Stockpiles	Not simulated.	Not simulated.	Reclaimed to baseline conditions.

Notes:

1. Post-closure conditions were not simulated using the Piteau model.
2. DRN = drain; GHB = general head boundary.

FIGURES



NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH BGC'S MEMO ENTITLED "PEBBLE PROJECT: COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS" AND DATED 06-20-2019.
4. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE: AS SHOWN	DATE: 06-20-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS	
PREPARED BY: CT	CHECKED BY: CAM			FIGURE TITLE: MODEL DOMAIN AND GRID	
APPROVED BY: RT				PROJECT NO: 1872-003	FIGURE NO: 2-1

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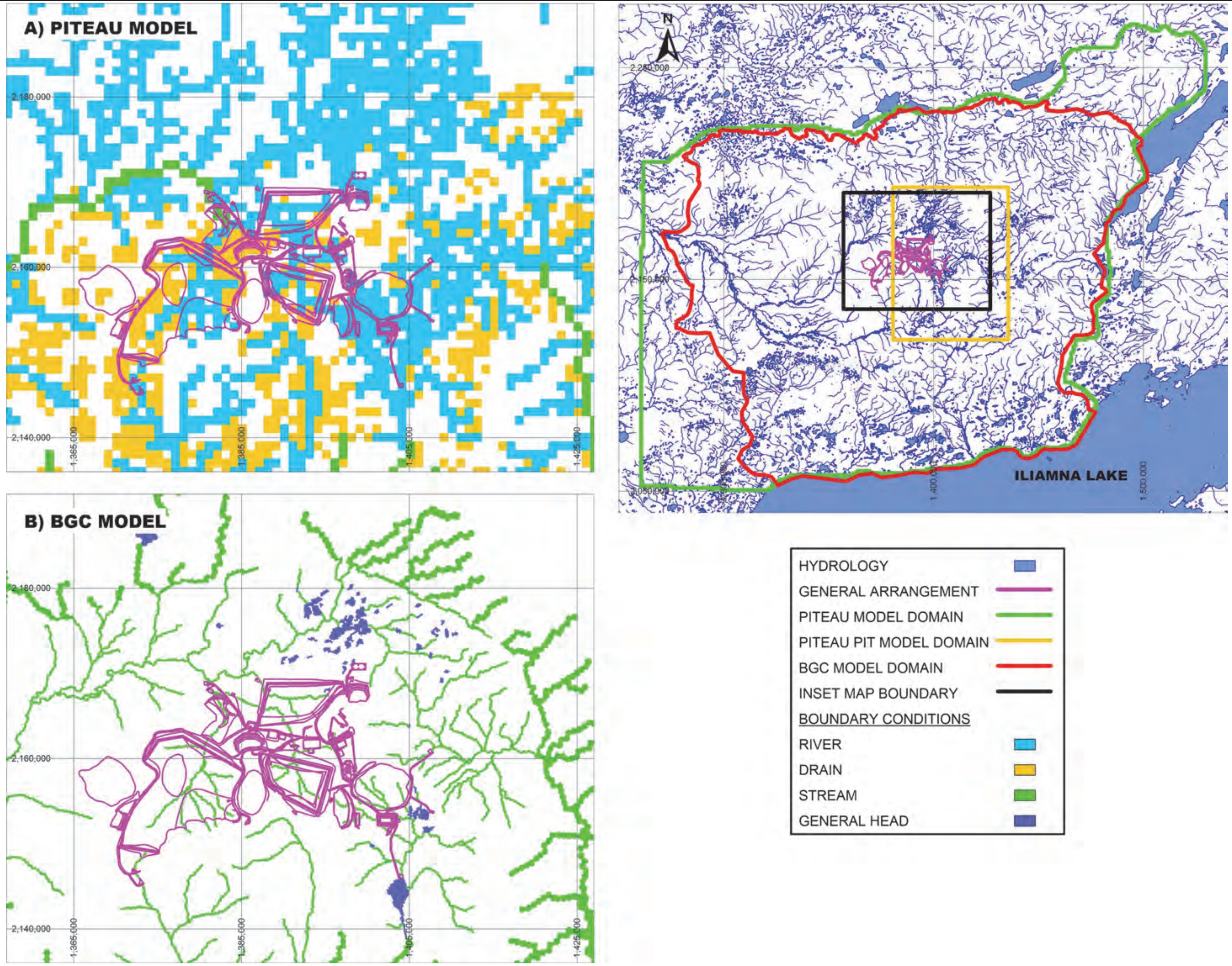

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. IN THE BGC MODEL, DRAIN BOUNDARIES WERE SPECIFIED IN ALL MODEL CELLS WITHOUT STREAM OR GENERAL HEAD BOUNDARIES. LOCATION OF SPECIFIED GRADIENT BOUNDARIES NOT SHOWN.
4. DISTRIBUTION OF GROUNDWATER RECHARGE NOT SHOWN.
5. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH BGC'S MEMO ENTITLED "PEBBLE PROJECT: COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS" AND DATED 06-20-2019.
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SCALE: AS SHOWN	DATE: 06-20-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS
PREPARED BY: CT	CHECKED BY: CAM			FIGURE TITLE: MODEL BASELINE BOUNDARY CONDITIONS
APPROVED BY: RT				PROJECT NO: 1872-003 / FIGURE NO: 2-2

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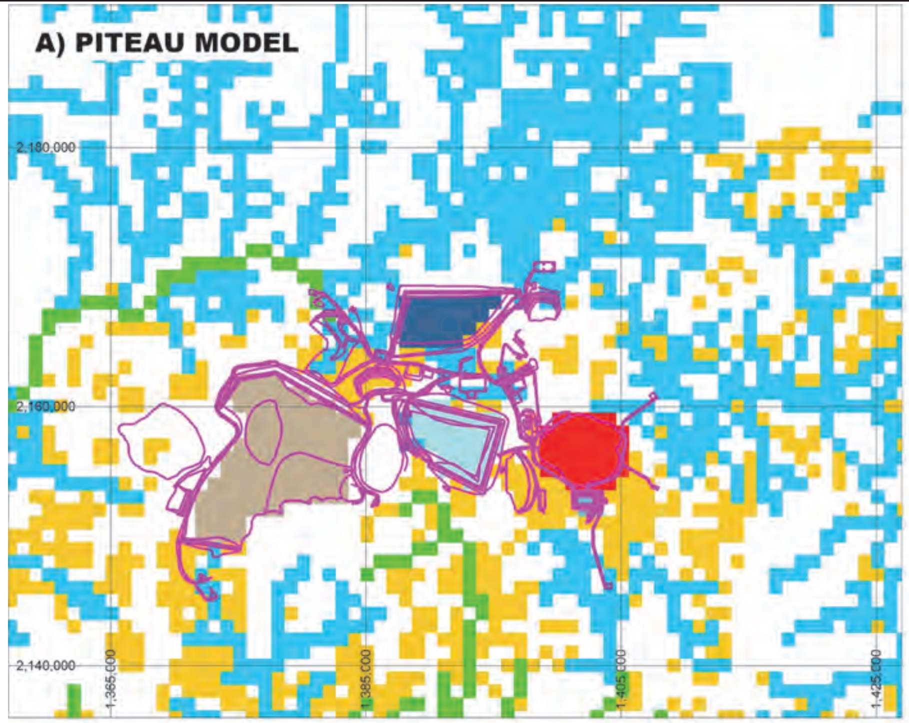

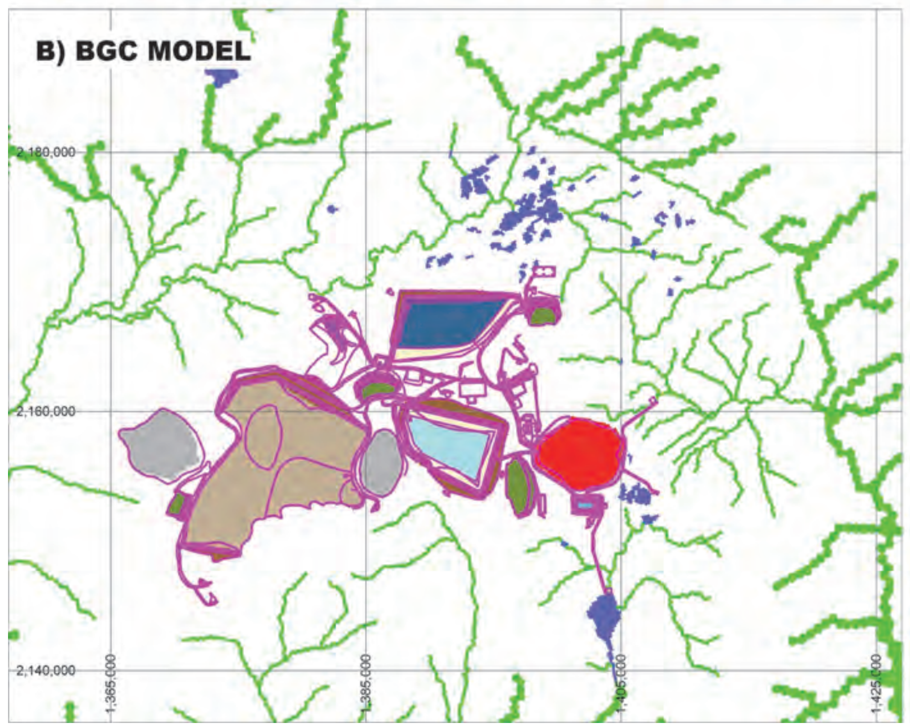

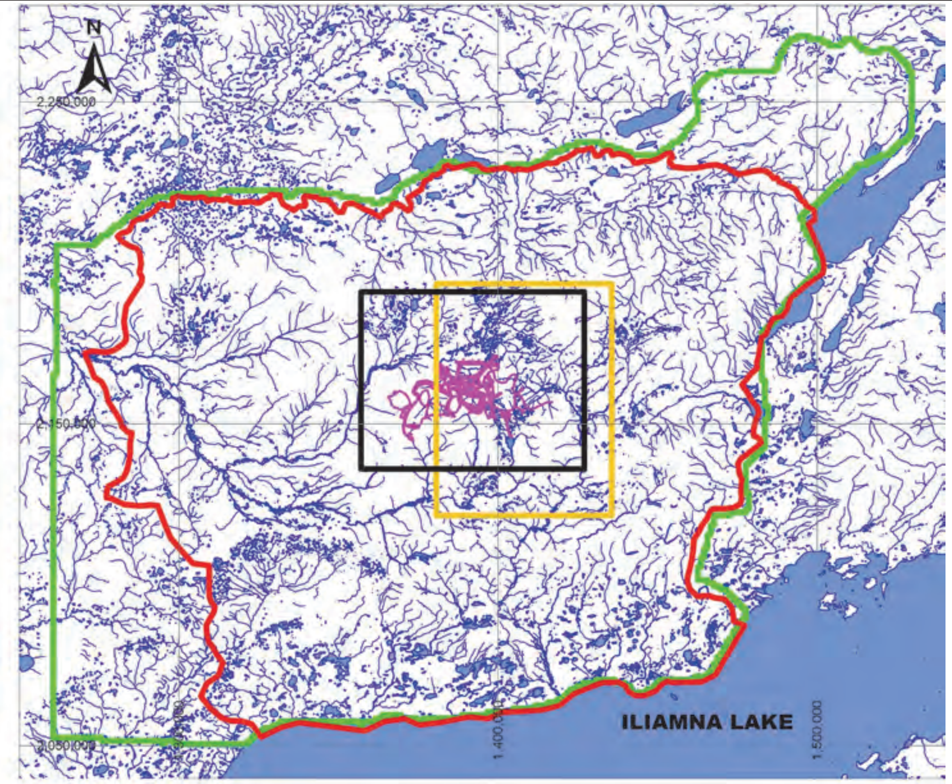

HYDROLOGY	MINE BOUNDARY CONDITIONS
GENERAL ARRANGEMENT	OPEN PIT
PITEAU MODEL DOMAIN	BULK TSF POND
PITEAU PIT MODEL DOMAIN	PYRITIC TSF
BGC MODEL DOMAIN	MAIN WMP
INSET MAP BOUNDARY	OPEN PIT WMP
BOUNDARY CONDITIONS	SEEPAGE COLLECTION PONDS
RIVER	LINER
DRAIN	EMBANKMENTS
STREAM	QUARRIES
GENERAL HEAD	STOCKPILES

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. IN THE BGC MODEL, DRAIN BOUNDARIES WERE SPECIFIED IN ALL MODEL CELLS WITHOUT STREAM OR GENERAL HEAD BOUNDARIES. LOCATION OF SPECIFIED GRADIENT BOUNDARIES NOT SHOWN.
4. DISTRIBUTION OF GROUNDWATER RECHARGE NOT SHOWN.
5. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH BGC'S MEMO ENTITLED "PEBBLE PROJECT: COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS" AND DATED 06-20-2019.
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SCALE: AS SHOWN	DATE: 06-20-2019	REPORT TITLE: PEBBLE PROJECT COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS
PREPARED BY: CT	CHECKED BY: CAM	FIGURE TITLE: MODEL MINING OPERATIONS BOUNDARY CONDITIONS
APPROVED BY: RT		PROJECT NO: 1872-003 / FIGURE NO: 2-3

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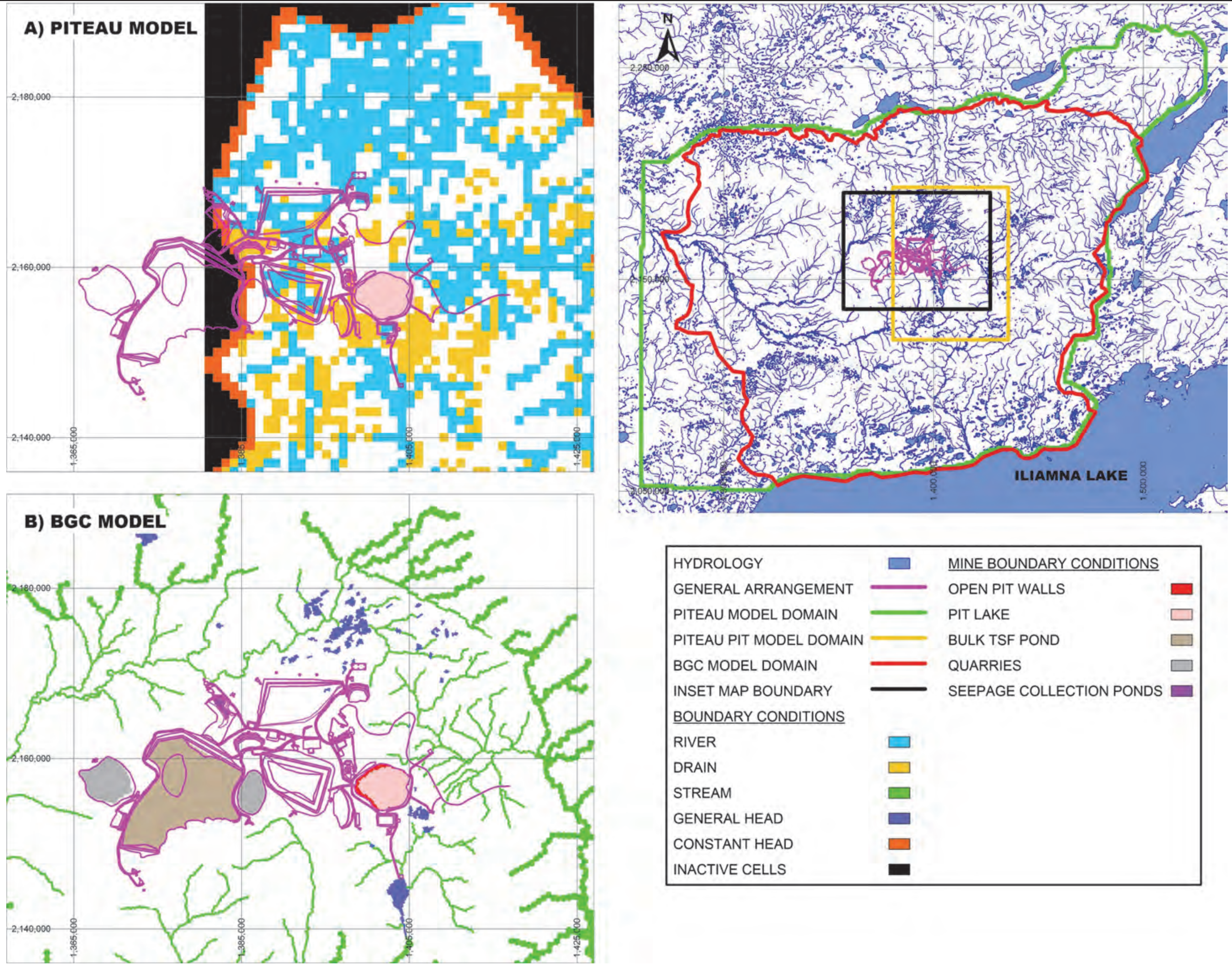

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. PITEAU POST-CLOSURE SIMULATIONS WERE LIMITED TO THE SUB-MODEL FOR THE GENERAL AREA OF THE PROPOSED OPEN PIT.
4. IN THE BGC MODEL, DRAIN BOUNDARIES WERE SPECIFIED IN ALL MODEL CELLS WITHOUT STREAM OR GENERAL HEAD BOUNDARIES. LOCATION OF SPECIFIED GRADIENT BOUNDARIES NOT SHOWN.
5. DISTRIBUTION OF GROUNDWATER RECHARGE NOT SHOWN.
6. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH BGC'S MEMO ENTITLED "PEBBLE PROJECT: COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS" AND DATED 06-20-2019.
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SCALE: AS SHOWN	DATE: 06-20-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS	
PREPARED BY: CT	CHECKED BY: CAM			FIGURE TITLE: MODEL POST-CLOSURE BOUNDARY CONDITIONS	
APPROVED BY: RT				PROJECT NO: 1872-003	FIGURE NO: 2-4

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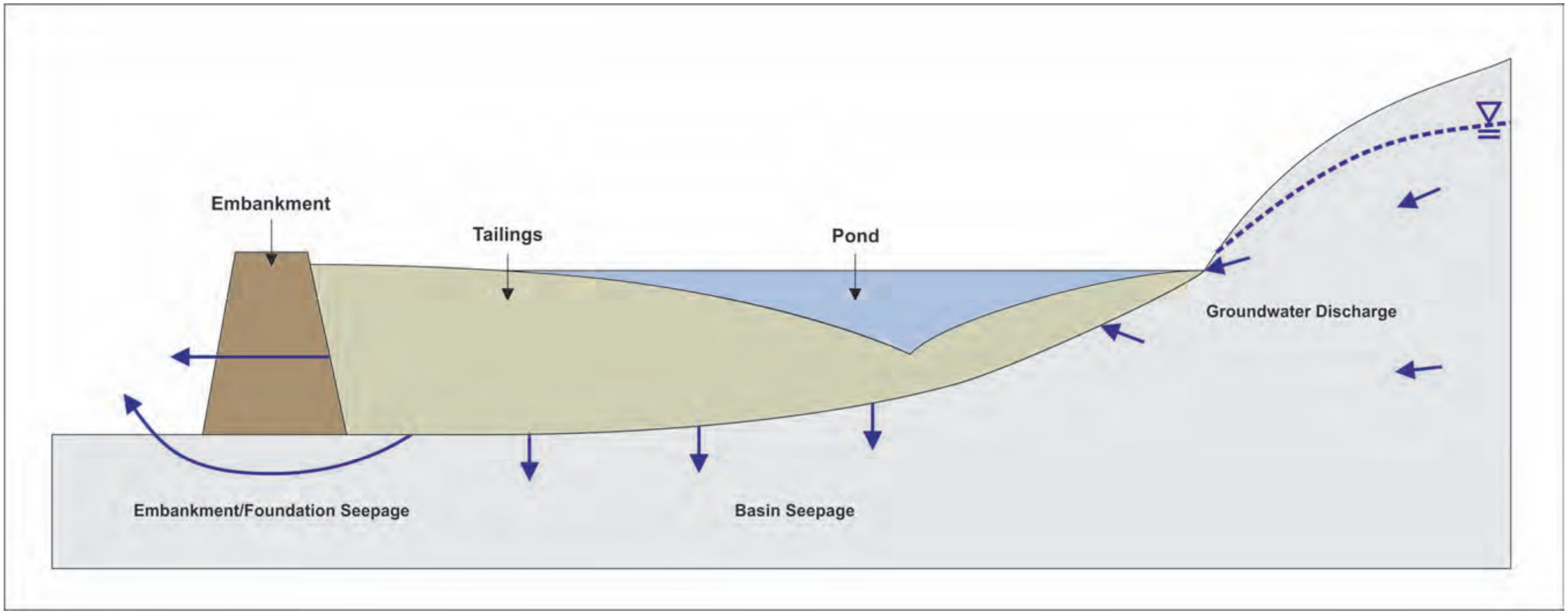

NOTES:
1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH BGC'S MEMO ENTITLED "PEBBLE PROJECT: COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS" AND DATED 06-20-2019.
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SCALE: AS SHOWN	DATE: 06-20-2019	THE pebble PARTNERSHIP	REPORT TITLE: PEBBLE PROJECT COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS
PREPARED BY: CT	CHECKED BY: CAM	BGC	FIGURE TITLE: BULK TSF CONCEPTUAL SEEPAGE DIAGRAM
APPROVED BY: RT			PROJECT NO: 1872-003 / FIGURE NO: 2-5

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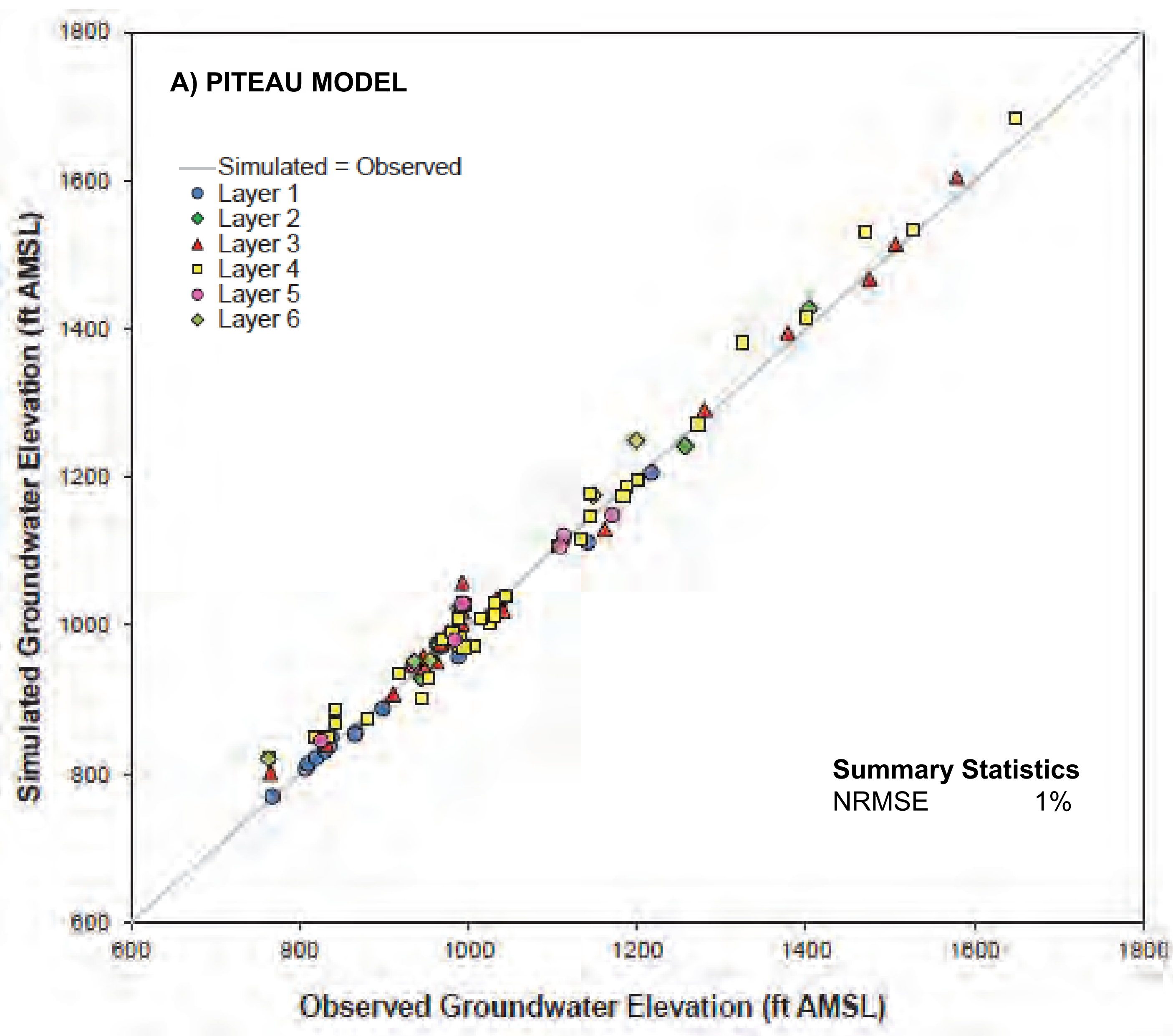

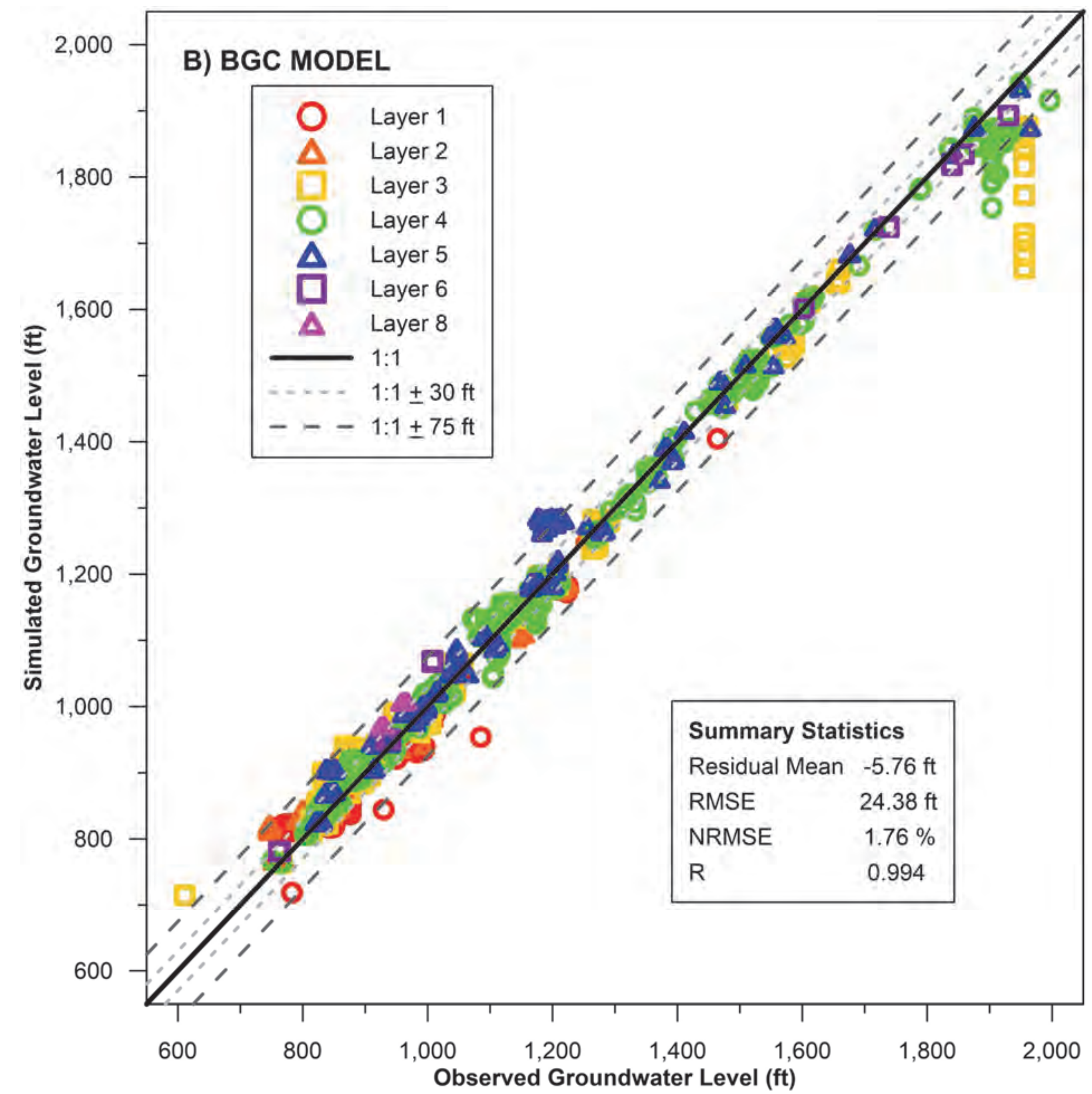

NOTES:
1. PITEAU MODEL DIAGRAM MODIFIED FROM PLP (2019).
2. BGC CALIBRATION STATISTICS COMPUTED FOR JANUARY 2004 THROUGH MARCH 2008.
3. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH BGC'S MEMO ENTITLED "PEBBLE PROJECT: COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS" AND DATED 06-20-2019.
4. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE: AS SHOWN	DATE: 06-20-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS
PREPARED BY: CT	CHECKED BY: CAM			FIGURE TITLE: MODEL CALIBRATION
APPROVED BY: RT				PROJECT NO: 1872-003 / FIGURE NO: 3-1

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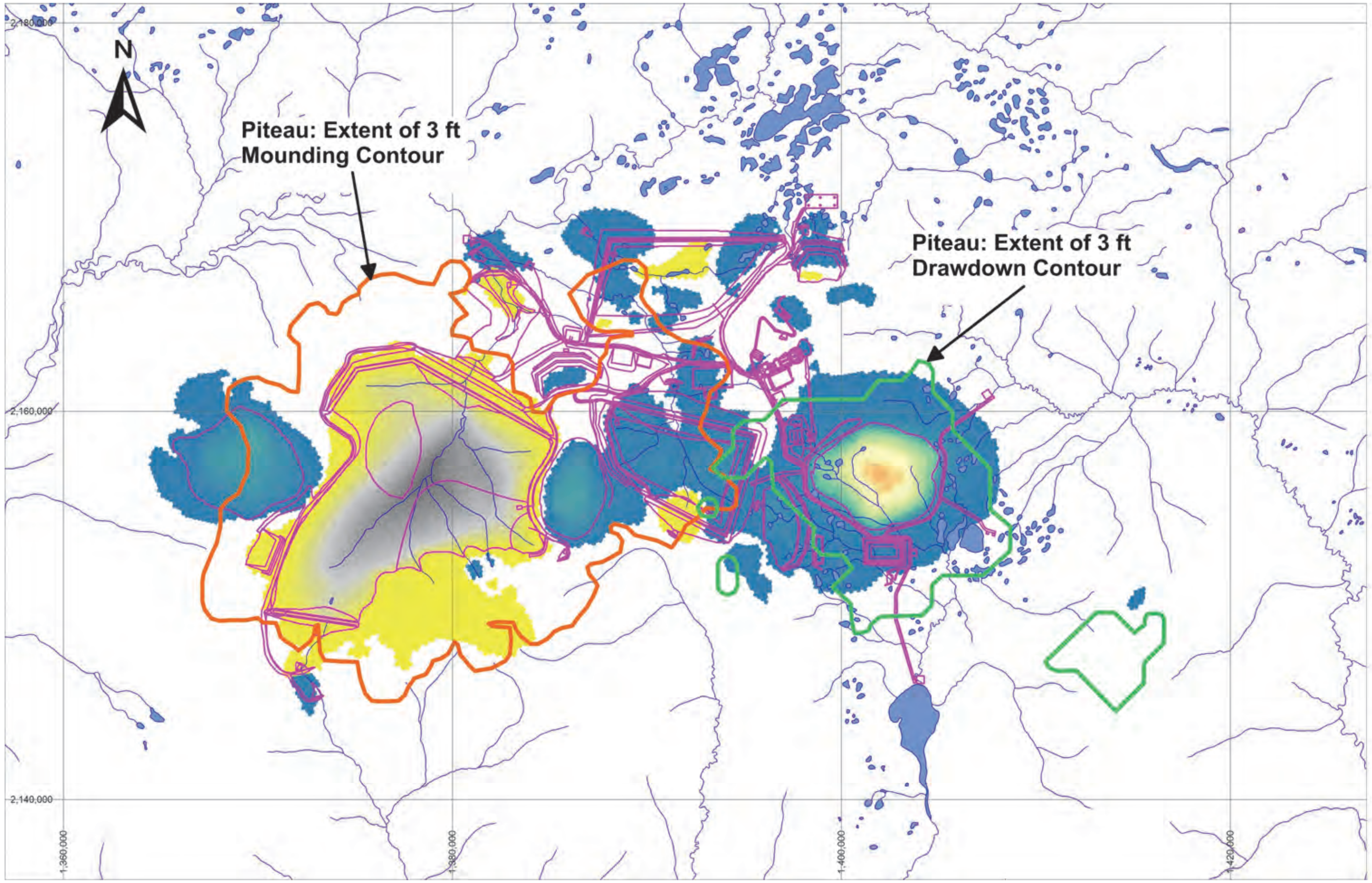

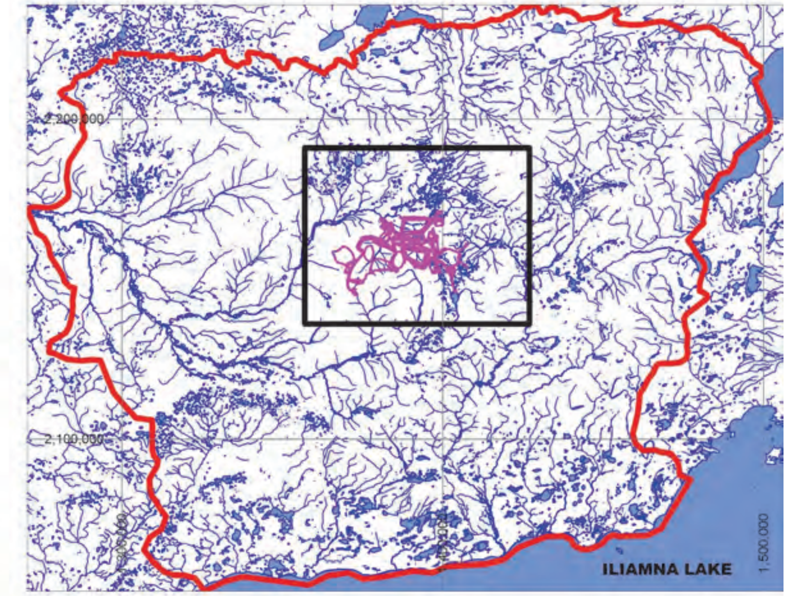

HYDROLOGY	
GENERAL ARRANGEMENT	
BGC MODEL DOMAIN	
PITEAU DRAWDOWN	
PITEAU MOUNDING	
INSET MAP BOUNDARY	

BGC DRAWDOWN

High: 1,650 ft

Low: 3 ft

BGC MOUNDING

High: 400 ft

Low: 3 ft

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. PITEAU DRAWDOWN ESTIMATED FROM "END OF MINING" CONTOUR IN FIGURE 3 OF PITEAU (2018).
4. PITEAU MOUNDING ESTIMATED FROM "3 ft MOUNDING CONTOUR" IN FIGURE 4.17-5 OF "USACE (2019).
5. BGC MODEL DRAWDOWN AND MOUNDING SHOWN FOR MODEL LAYER 5 (i.e., TOP OF COMPETENT BEDROCK).
6. OPEN PIT SIMULATED USING END OF MINING WHITTLE PIT PROVIDED BY PLP IN EMAIL DATED MARCH 8, 2019 (FILE: Expanded Pit (May 25 2018.dxf)).
7. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH BGC'S MEMO ENTITLED "PEBBLE PROJECT: COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS" AND DATED 06-20-2019.
8. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE: AS SHOWN	DATE: 06-20-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS
PREPARED BY: CT	CHECKED BY: CAM			FIGURE TITLE: END OF MINING DRAWDOWN AND MOUNDING
APPROVED BY: RT				PROJECT NO: 1872-003 / FIGURE NO: 4-1

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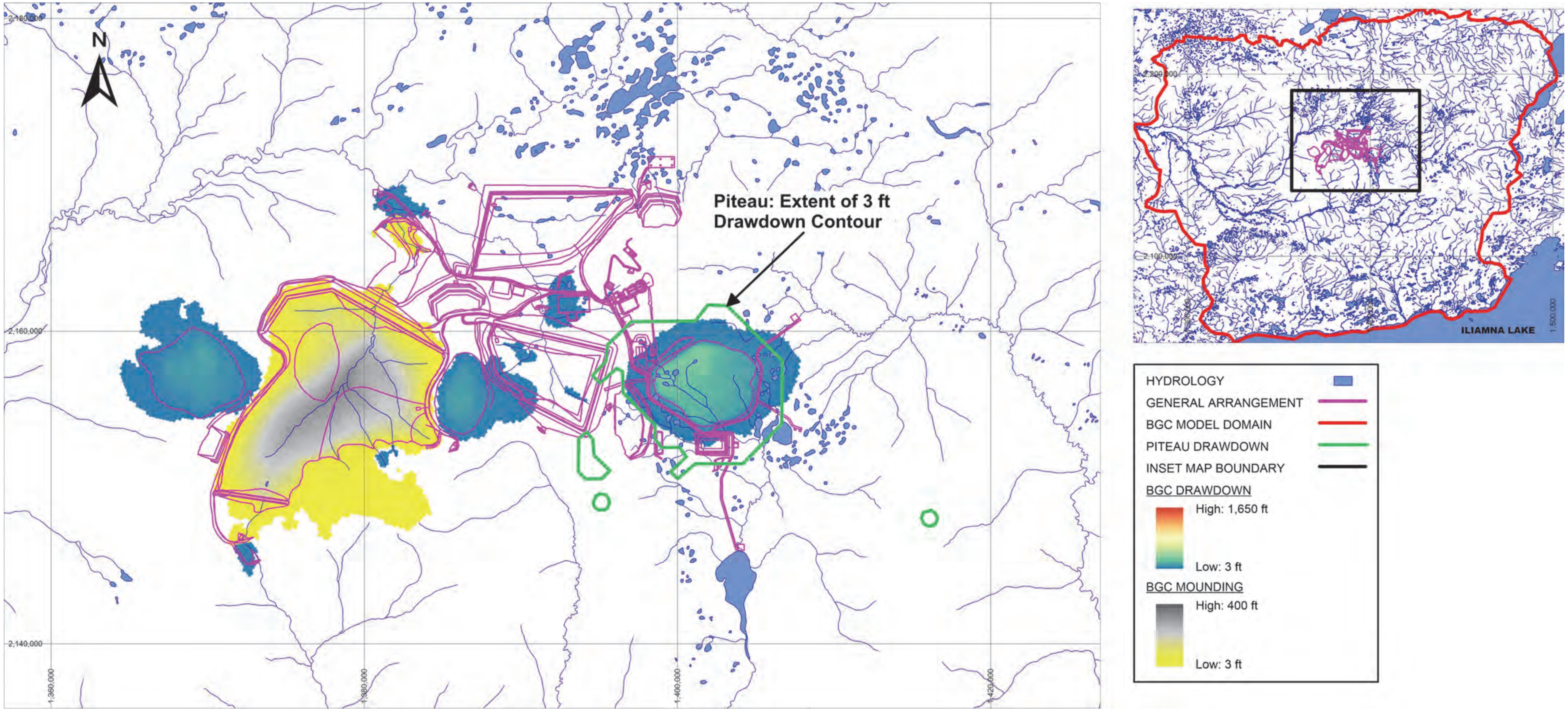

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. PITEAU DRAWDOWN ESTIMATED FROM "50th PERCENTILE" CONTOUR IN FIGURE 8 OF PITEAU (2018).
4. BGC MODEL DRAWDOWN AND MOUNDING SHOWN FOR MODEL LAYER 5 (i.e., TOP OF COMPETENT BEDROCK).
5. OPEN PIT SIMULATED USING END OF MINING WHITTLE PIT PROVIDED BY PLP IN EMAIL DATED MARCH 8, 2019 (FILE: Expanded Pit (May 25 2018.dxf)).
6. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH BGC'S MEMO ENTITLED "PEBBLE PROJECT: COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS" AND DATED 06-20-2019.
7. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE: AS SHOWN	DATE: 06-20-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS	
PREPARED BY: CT	CHECKED BY: CAM			FIGURE TITLE: POST-CLOSURE DRAWDOWN AND MOUNDING	
APPROVED BY: RT				PROJECT NO: 1872-003	FIGURE NO: 4-2

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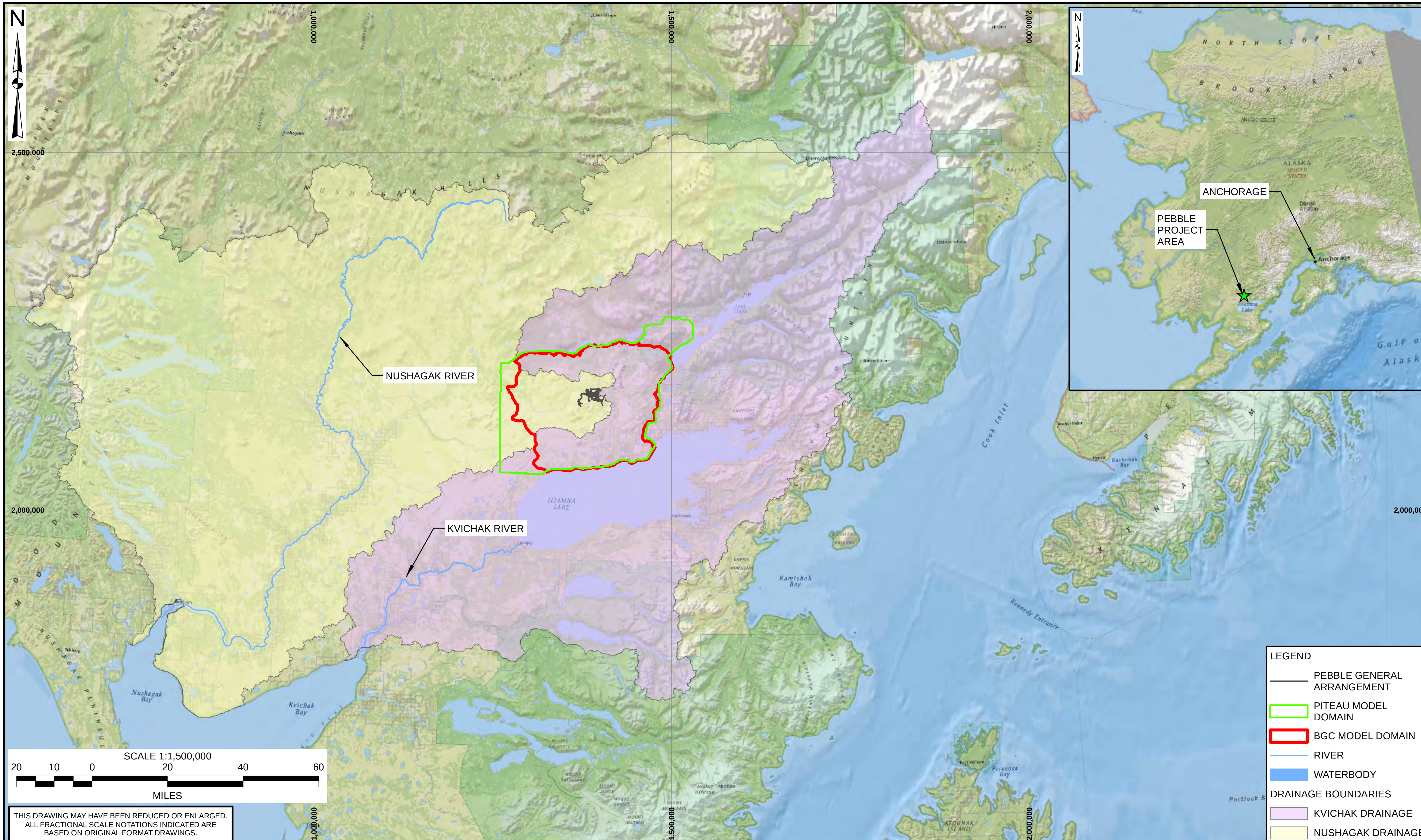
DRAWINGS



NOTES:
1. ALL DIMENSIONS ARE IN FEET UNLESS OTHERWISE SPECIFIED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S MEMO TITLED "PEBBLE PROJECT: COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS", AND DATED JUNE 20, 2019.
3. RIVER DATA PROVIDED BY THE ALASKA DEPARTMENT OF NATURAL RESOURCES.
4. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
5. PROJECTION IS NAD 1983 STATE PLAN ALASKA 5 FIPS 5005 FEET. VERTICAL DATUM IS NAVD88.
6. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:1,500,000
DATE:	JUN 2019
DRAWN:	JVC, JVT
CHECKED:	CT
APPROVED:	RT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THE pebble PARTNERSHIP

PROJECT: PEBBLE PROJECT COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS

TITLE: SITE LOCATION

PROJECT No.:	DWG No:
1872-003	01

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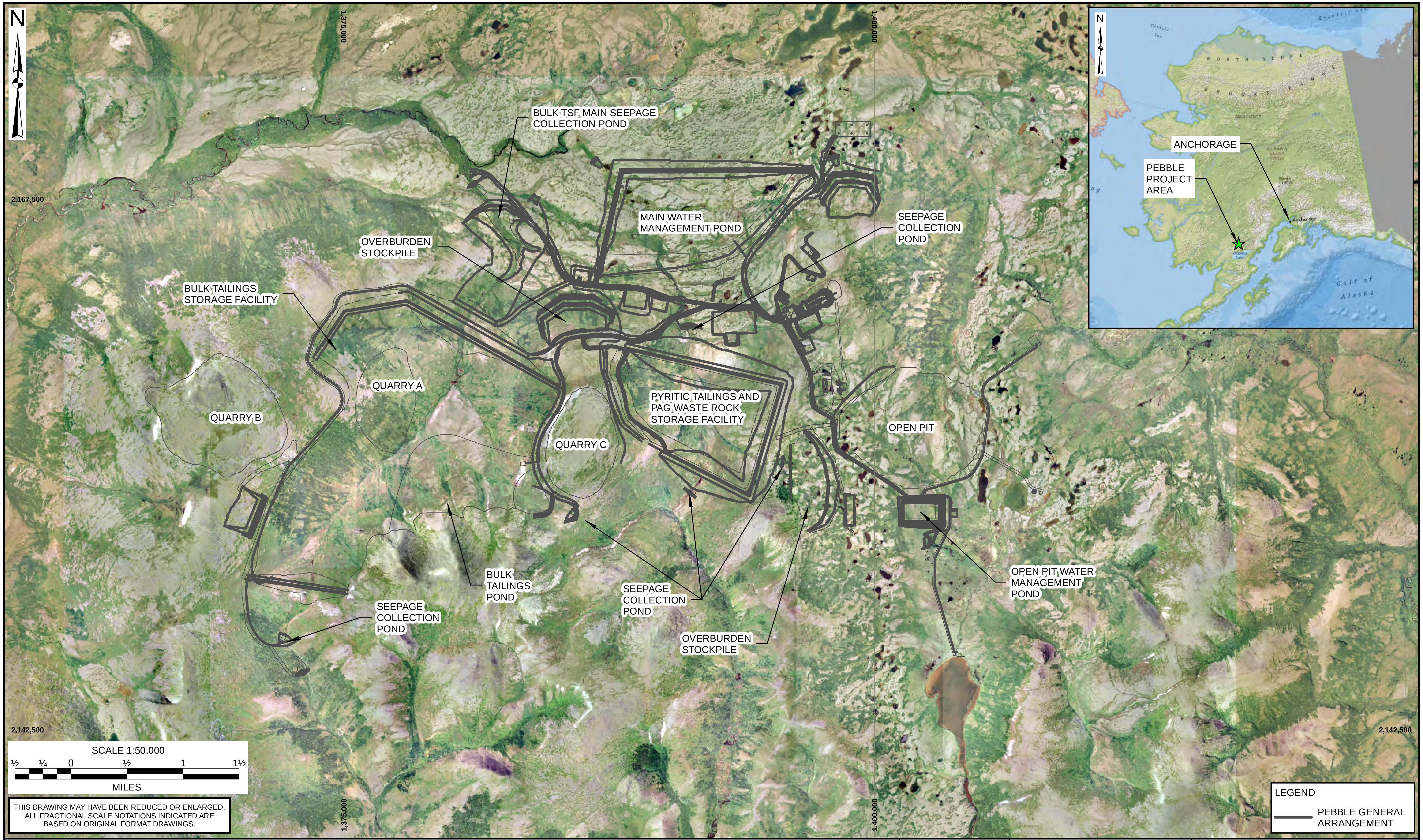

NOTES:
1. ALL DIMENSIONS ARE IN FEET UNLESS OTHERWISE SPECIFIED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S MEMO TITLED "PEBBLE PROJECT: COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS", AND DATED JUNE 20, 2019.
3. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
4. PROJECTION IS NAD 1983 STATEPLANE ALASKA 5 FIPS 5005 FEET. VERTICAL DATUM IS NAVD88.
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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THE pebble PARTNERSHIP

PROJECT: PEBBLE PROJECT COMPARISON OF NUMERICAL GROUNDWATER FLOW MODELS

TITLE: SITE LAYOUT

PROJECT No.: 1872-003

DWG No: 02

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RFI 109d
Pebble Project EIS

Request for Information

Title/Subject:	**Groundwater model validation and sensitivity analysis**
Requestor:	**AECOM**
Date Transmitted:	**3/1/2019**
Recipient:	**Pebble Limited Partnership (PLP)**
Response Requested by:	**3/15/2019**
Rationale:	RFIs 109, 109a, 109b, and 109c requested several items (#1a through #4g) regarding the groundwater model as follow-up to a 12/11/18 technical call and PDEIS EPA/State comments. This RFI lists the outstanding requested items from these RFIs in order to track them to completion. The requested information is necessary to help inform the impact analysis for the Preliminary Final EIS.
Describe the Information Requested and Level of Detail:	• From RFI 109 #1d: Table 4.3 (pumping test results) and Figure 5.27 (streamflow scatter plots) – The response to RFI 109 (received 1/11/19) indicated that these would be provided under a separate cover. In addition, the response indicated that the information provided to date represent a model that is in the process of being updated and is not fully calibrated. Please provide an estimate of when the model update and full calibration are expected to be complete and a calibration report would be available. • From RFI 109 #1e and from RFI 109b: Validation analysis – Response to RFI 109 (received 1/11/19) indicated that this would be provided under a separate cover. RFI 109b provided an additional recommendation that PLP review additional data (post-2007 hydrologic data) prior to conducting validation analysis; response to RFI 109b (received on 1/10/19) indicated that historical streamflow and piezometric levels (2005-2013) are currently being reviewed. • From RFI 109 #4d: Sensitivity Analysis. Response to RFI 109 (received 1/11/2019) indicates that a description of the Monte Carlo analysis will be provided under separate cover and that the sensitivity analysis of tailings and open pit will also be provided under separate cover. The description of the Monte Carlo analysis was received in the RFI 109b response (received 1/10/19). The sensitivity analysis is still outstanding. In addition, RFI 109c provided clarification that hydraulic conductivity values for bedrock below the weathered zone be included in the sensitivity analysis.

Recipient Response Form

Date Received from USACE:	Click here to enter text.
Response from Recipient (Describe Information Requested to the Level of Detail Requested; Provide Attachments as Needed):	Please see the new Numerical Groundwater Flow Model Report provided by PLP under a separate cover for the responses to RFI 109d.
List Number and Type of Response Attachments:	Click here to enter text.
Date Returned to USACE:	6/3/2019

AECOM Intake Form

Date Response was Received:	6/3/2019
Received by:	AECOM
Describe any Follow-up Related to this RFI:	None at this time

BGC ENGINEERING USA INC.
AN APPLIED EARTH SCIENCES COMPANY

PEBBLE LIMITED PARTNERSHIP

PEBBLE PROJECT

NUMERICAL GROUNDWATER FLOW MODEL

FINAL

PROJECT NO.:	1872002	DATE:	May 24, 2019
DOCUMENT NO.:	1872002.0238		

BGC ENGINEERING USA INC.
AN APPLIED EARTH SCIENCES COMPANY
701 12th Street – Suite 211
Golden, CO USA 80401
Telephone (720) 598-5982

May 24, 2019
Project No.: 1872002

James Fueg, Vice President - Permitting
Pebble Limited Partnership
3201 C Street, Suite 505
Anchorage, AK 99503

Dear James,

Re: Pebble Project Numerical Groundwater Flow Model – Final Report

Please find attached a copy of the above referenced final report dated May 24, 2019. Attached to this cover letter is a table listing requests for information (RFIs) submitted to Pebble Limited Partnership (PLP) as part of the Environmental Impact Statement review process that were related to groundwater modeling (i.e., RFIs 019 and 109) previously done for the project by Piteau Associates. The table points to sections in this report that address the RFI, if applicable.

Should you have any questions, please do not hesitate to contact Ms. Dawn Paszkowski at 613-291-7806 or Mr. Trevor Crozier at 604-684-5900 ext. 41178. Thank you for involving us in this world class project.

Yours sincerely,

BGC ENGINEERING USA INC.
per:

DPaszkowski

Dawn Paszkowski, M.Sc., P.Geo.
Hydrogeologist

Table 0. Pebble Project Request for Information (RFI) 019 and 109 summary and BGC Numerical Groundwater Flow Model Report comments and relevant sections (if applicable)

RFI ID	RFI #	RFI	BGC Comment	BGC Numerical Groundwater Flow Model Report Section
019	#1	Provide a Water Management Plan with water balance estimates (for both surface water and groundwater) during operations and closure.	BGC groundwater modeling work considers both the Operations and Closure Water Management Plans prepared by KP in response to RFI 019 #1 (KP, 2018b and 2018c).	N/A
	#2	Provide estimates of streamflow reductions in North and South Fork Koktuli rivers and Upper Talarik Creek, resulting from Mine Site water impoundments and pit dewatering, during both operations and closure.	BGC estimates of stream flow reductions at end of operations and in post-closure are summarized in the modeling report.	Section 7.6.5 (End-of-Mining Operations Analysis - Impacts to Rivers and Creeks) Section 8.4.5 (Post-Closure Analysis - Impacts to Rivers and Creeks)
	#3	Provide locations and pumping rates for all proposed groundwater withdrawal wells (e.g., open pit dewatering, mill water supply, camp water supply, etc.) during all phases of mining.	RFI response provided by KP and dated July 6, 2018 (KP, 2018e). BGC report provides updated estimate of open pit groundwater extraction.	Section 7.6.1 (End-of-Mining Operations Analysis - Open Pit Groundwater Extraction)
	#4	Provide a Groundwater Modelling Report showing groundwater flow conditions during operations and closure. The groundwater modelling should consider a range of scenarios that evaluate variability in hydrogeological properties, model boundary conditions, climate, and the influence of geological structures for all phases of mining.	BGC modeling report documents model development, calibration, results of end of operations and post-closure predictive simulations, and sensitivity analysis.	All report sections.
019c	#1	To better understand conditions during operations, please develop the groundwater model for Realization #36, #5, and #10 for dry, average, and wet years, respectively, as described in the Operations Water Management Plan (Section 4.3.1, Annual Average Balance) (Knight Piesold, July 6, 2018).	The sensitivity analysis completed by BGC and documented in the modeling report includes both wet and dry scenarios (i.e., scenarios with increased and decreased groundwater recharge).	Section 9.0 (Sensitivity Analysis) Table 9-2 (Summary of Sensitivity Simulations)
	#2	Table 1 - Pond - Bulk TSF South SCP: There appears to be an error on the table. Please confirm the grout curtain is at the South Embankment, not the South Seepage Collection Pond.	Comment is specific to Piteau (2018) reporting.	N/A
	#3	Table 1 - Pond - Pyritic TSF South SCP: The table has a blank space under "Grout Curtain." According to response to RFI 006, there is no grout curtain planned at this facility. Please confirm.	Comment is specific to Piteau (2018) reporting.	N/A
	#4	Table 1 Note 1 - Provide a cross-section showing the assumed water table versus the projected actual water table being higher under most of the tailings and lower near the embankment - to depict the gradient toward the Bulk TSF Main Embankment.	Comment is specific to Piteau (2018) modeling and/or reporting. BGC report includes figures showing Bulk TSF conceptual seepage, simulated hydrogeologic units along the Bulk TSF, and simulated water table at end of mining operations and in the post-closure period.	Figure 7-1 (Bulk TSF Conceptual Seepage Diagram) Figure 7-2 (Assigned Hydrogeologic Units along Bulk TSF Cross-Section D) Figure 7-4 (Simulated End-of-Mining Water Table for the Scenario without Pumping Wells) Figure 8-2 (Simulated Water Table: Post-Closure)
	#5	Table 1 Note 2 - Confirm the hydraulic conductivity of $1x10^{-5}$ cm/s used for the grout curtain, because grout curtains are typically designed to have significantly lower hydraulic conductivities of at least $1x10^{-6}$ cm/s or $1x10^{-7}$ cm/s.	Comment is specific to Piteau (2018) reporting. BGC simulated seepage control measures (e.g., upstream liner, low permeability core, grout curtain) using a hydraulic conductivity of $1x10^{-7}$ ft/s.	Section 7.3 (End-of-Mining Operations Analysis - Hydrogeologic Units) Figure 7-1 (Bulk TSF Conceptual Seepage Diagram) Figure 7-2 (Assigned Hydrogeologic Units along Bulk TSF Cross-Section D) Figure 7-3 (Boundary Conditions: End-of-Mining)
	#6	Table 1 Note 3 - Regarding lined facilities and a priori assumed leakage rate: Proper design, as well as adherence to the design and prescribed construction methods, will control the effectiveness of lined facilities. - Describe the liner installation methods and QA/QC procedures. - Will there be a leak detection test(s) prior to filling the facility? - What is the source of the a priori leakage rate and why is it expressed in L/s and not cm/s?	BGC adopted design assumptions (including liner seepage rate of 1 L/s) provided by KP in KP (2019a).	Section 7.4 (End-of-Mining Operations Analysis - Boundary Conditions) Section 7.4.1 (Groundwater Recharge)
	#7	Table 1 Note 4 - Regarding groundwater conditions under the Pyritic TSF and Main Water Management Pond: We understand the conservative approach in excluding the effect of foundation drains - and the resulting "worst-case" scenario if the liner completely failed - thus reflecting maximum potential leakage discharge. However, please provide the results of a more realistic scenario including the beneficial effects of a functioning foundation drains system.	BGC numerical modeling considered both scenarios with and without pumping wells to manage seepage. Simulating the drainage system was beyond the scope of the site wide groundwater flow model.	Section 7.6 (End-of-Mining Operations Analysis - Results) Section 7.6.4 (Particle Tracking - Scenarios with and without Pumping Wells) Figure 7-10 (Particle Tracking Results: Scenario without Pumping Wells End-of-Mining) Figure 7-11 (Particle Tracking Results: Scenario with Pumping Wells End-of-Mining) Figure 7-8 (Particle Tracking Results: Mitigated Scenario End-of-Mining)
	#8	Sec 3 Paragraph 4 - Describe in more detail "100 scenarios" used for the pit area and basic assumptions for model parameters representing hydraulic conductivity, groundwater storage, and boundary conditions. Describe in more detail: "range of uncertainty in the capture zone."	Comment is specific to Piteau (2018) reporting. BGC completed a conventional deterministic sensitivity analysis that considered 21 scenarios and is documented in the modeling report.	Section 9.0 (Sensitivity Analysis)
	#9	Sec 4.1 Figure 1 - Explain why the groundwater outflow southward into the SFK watershed toward the South Embankment SCP is larger (0.4 cfs) then northward (0.3 cfs). This seems confusing because the Bulk TSF is designed for maximum seepage to the north and a grout curtain is included in the South Embankment to reduce seepage.	Comment is specific to Piteau (2018) modeling. Results of BGC simulations suggest that seepage through the Bulk TSF Main (North) Embankment will be greater than seepage through the South Embankment.	Section 7.6.2 (End-of-Mining Operations Analysis - Results - Bulk TSF Seepage) Figure 7-1 (Bulk TSF Conceptual Seepage Diagram)
	#10	Clarify whether the simulated groundwater inflow rates from the overlying tailings of 0.14 cfs (20% of 0.7 cfs = 0.14 cfs) is intended to be the same as with the "leakage from tailings into groundwater" rate of 0.2 cfs shown on Figure 1, and if this discrepancy is a result of rounding.	Comment is specific to Piteau (2018) reporting.	N/A

Table 0. Pebble Project Request for Information (RFI) 019 and 109 summary and BGC Numerical Groundwater Flow Model Report comments and relevant sections (if applicable)

RFI ID	RFI #	RFI	BGC Comment	BGC Numerical Groundwater Flow Model Report Section
019c	#11	Explain why the seepage rates for the Bulk TSF Main Embankment are 1 to 2 orders of magnitude lower than the estimate in RFI 006 (ranging from 3 to 20 cfs). The seepage rate of 0.14 and/or 0.2 cfs (see comment above) is one or two orders of magnitude less than seepage rates provided in part of the response to RFI 006 - Seepage Analysis on June 15, 2018 as follows: "The estimated seepage rates from the Bulk TSF range from 3 to 14 cfs during operations when the pond is at a normal operating size. This range of predicted seepage rates represents the bounds of a sensitivity analysis that accounts for a variety of tailings characteristics, such as permeability and the length of the coarse-grained tailings unit located immediately upstream of the embankment. The seepage rate could increase up to 20 cfs if the pond extends to within 500 feet from the Main Embankment."	BGC report documents predicted seepage from the Bulk TSF, and includes comparison with seepage estimates generated by others.	Section 7.6.2 (End-of-Mining Operations Analysis - Results - Bulk TSF Seepage) Figure 7-1 (Bulk TSF Conceptual Seepage Diagram)
	#12	Describe design, monitoring, and contingency measures that may be required to prevent contact water from potentially seeping through the northwest ridge of the Bulk TSF, beneath the two topographic saddles. The narrative notes the groundwater model does not indicate seepage, but Piteau Associates recognizes the potential for seepage in this area.	BGC model does not predict seepage from the Bulk TSF through the northwest ridge.	Section 7.6 (End-of-Mining Operations Analysis - Results) Section 7.6.2 (Bulk TSF Seepage) Section 7.6.4 (Particle Tracking - Scenarios with and without Pumping Wells) Figure 7-10 (Particle Tracking Results: Scenario without Pumping Wells End-of-Mining) Figure 7-11 (Particle Tracking Results: Scenario with Pumping Wells End-of-Mining) Figure 8-5 (Particle Tracking Results: Post-Closure)
	#13	Explain and quantify the statement: "…the groundwater velocities along these deep flow paths would be very low…"	Comment is specific to Piteau (2018) reporting.	N/A
	#14	Explain how the post-closure seepage rate will be similar to the end of mining seepage rate when there will be more water in the Bulk TSF during mining then during post-closure.	Comment is specific to Piteau modeling. Results of BGC predictive simulations suggest reduced post-closure seepage from the Bulk TSF relative to end-of-mining.	Section 7.6.2 (End-of-Mining Operations Analysis - Results - Bulk TSF Seepage) Section 8.4.2 (Post-Closure Analysis - Results - Bulk TSF Seepage)
	#15	Please quantify to the degree possible for the following statement: "This reduction in the upper watershed is a small proportion of total groundwater discharge in the full UTC watershed."	Comment is specific to Piteau (2018) reporting.	N/A
	N/A	The simulated groundwater inflow rate was ranked for each scenario and ranged from 2200 to 2400 gpm for the 5th and 95th percentiles, respectively. However, the Operations Water Management Plan (top of page 34) states an assumption to the water balance model is groundwater inflow to the Open Pit is 2700 gpm "as provided by Piteau Associates." Please clarify the discrepancy. In addition provide the hydrogeologic parameters (e.g., hydraulic conductivity, storativity) and boundary condition values (e.g., recharge, conductance) that resulted in the range of outcomes presented on Figure 7.	Comment is specific to Piteau (2018) reporting. BGC modeling report documents predicted pit inflows for scenarios with and without pumping wells, and for the range of sensitivity scenarios considered.	Section 7.0 (End-of-Mining Operations Analysis) Section 7.6.1 (Results - Open Pit Groundwater Extraction) Section 9.0 (Sensitivity Analysis) Section 9.4 (End-of-Mining Operations)
	#16	Leakage that may have reached groundwater will continue to migrate and flow toward NFK beyond the time of decommissioning of the Pyritic TSF and Main Water Management Pond. How long is it expected to take to decommission these facilities to the point where no leakage is occurring? How long would it be necessary for pumpback/monitoring wells to remain in place and water quality monitoring to continue after decommissioning?	BGC report documents particle tracking completed to assess potential seepage pathways and travel times from major mine facilities including the Pyritic TSF and Main WMP.	Section 7.6.4 (End-of-Mining Operations Analysis - Results - Particle Tracking) Section 8.4.4 (Post-Closure Analysis - Results - Particle Tracking)
	#17	What is meant by "intermediate" post-closure capture zone? How many years after end of mining is "intermediate post-closure"?	Comment is specific to Piteau (2018) reporting.	N/A
	#18	How long will it take for the pit lake to attain the maximum control elevation of 900 feet?	BGC completed steady state simulations only for the post-closure period, and therefore did not generate an estimate of time required for the pit lake to attain maximum control elevation.	Section 8.1 (Post-Closure Analysis - Overview)
	#19	Text states: "These deeper flowpaths will be reduced considerably because the post-closure pit-lake elevation will be much higher than the pit bottom." Question: Is there potential for flow reversal along the flowpaths?	Results of post-closure predictive simulations are documented in the modeling report. BGC modeling suggests that the post-closure managed pit lake will act as a groundwater 'sink'.	Section 8.4.1 (Post-Closure Analysis - Results - Pit Lake Groundwater)
	#20	Figure 2. Why does the figure depict northward flow from influence of leakage from the Main Water Management Pond at end of mining? Will groundwater be recharged enough by leakage that it would flow north?	Results of end-of-mining predictive simulations are documented in the modeling report, including figures showing groundwater flow paths originating in the Main WMP for scenarios with and without pumping wells.	Section 7.6.3 (End-of-Mining Groundwater Flow System) Section 7.6.4 (Particle Tracking - Scenarios with and without Pumping Wells) Figure 7-10 (Particle Tracking Results: Scenario without Pumping Wells End-of-Mining) Figure 7-11 (Particle Tracking Results: Scenario with Pumping Wells End-of-Mining)
	#21	Where will the groundwater level/quality monitoring locations be at post-closure and at what depth(s) will they be screened?	RFI response provided separately in KP (2018a) and beyond the scope of the BGC modeling work presented here.	N/A
	#22	What would be the layout and configuration of the underdrain system beneath the Main Water Management Pond?	Comment is specific to design work completed by others; details of drainage systems (e.g., ditches, underdrains) were not available for consideration and representation in the BGC numerical model.	Section 7.0 (End-of-Mining Operations Analysis) Section 7.4.7 (Boundary Conditions - Groundwater Outflow)

Table 0. Pebble Project Request for Information (RFI) 019 and 109 summary and BGC Numerical Groundwater Flow Model Report comments and relevant sections (if applicable)

RFI ID	RFI #	RFI	BGC Comment	BGC Numerical Groundwater Flow Model Report Section
019c	#23	How does PLP propose to monitor for potential leakage to the west, southwest, and northeast areas outside the Main Water Management Pond?	Presentation of a groundwater monitoring plan is beyond the scope of the BGC groundwater flow modeling report.	N/A
	#24	Does the groundwater model include water that will be initially entrained in the Bulk TSF, but will seep out over time? (Ref: Operations Water Management Plan, Section 4.3.1, Paragraph 3).	The groundwater model was run using steady-state conditions, and therefore is representative of long-term seepage conditions. Water entrained in the tailings following initially saturated deposition was not included in the simulations.	Section 7.0 (End-of-Mining Operations Analysis) Section 7.4 (Boundary Conditions)
019d	#1	As the pit lake rises, presumably there would be temporary localized flow of contact water into surrounding bedrock. Please provide an estimate of how far this would extend beyond the pit walls, and how long it would take before groundwater rebounds to the point where all flow is toward the pit.	BGC completed steady state simulations only for the post-closure period, and therefore did not generate an estimate of time required for the pit lake to fill or for localized flow to resaturate the bedrock immediately surrounding the pit. A response was provided by PLP on September 25, 2018, indicating a pit lake fill time of approximately 20 years (PLP, 2018).	N/A
109	#1a	Provide additional explanation of the evolution of the model between the EBD and the Piteau (2018) and Knight Piesold (KP) (2018a) reports, i.e., how the model changed from the original 5 layers described in the EBD to 10 layers with "zones" shown in KP (2018a: Figures 1-7). Provide an explanation of what the layers and zones represent, including updated versions of EBD Appendix 8.1J Figures 4.3 (model layers), 4.7-4.9 (layer thicknesses), and 4.10-4.12 (model cross-sections).	The BGC numerical model includes 12 layers; the modeling report includes figures showing distribution of model layers, layer thicknesses, and model cross-sections.	Section 5.0 (Groundwater Flow Model Development) Section 5.3 (Model Domain) Figure 5-1 (Model Grid) Figures 5-2 to 5-4 (Assigned hydrogeologic units along surficial geology cross-sections) Figure 5-5 to 5-7 (Assigned hydrogeologic units along bedrock cross-sections)
	#1b	Has the grid size or temporal discretization changed since the EBD (App. 8.1J, Section 4.1)?	BGC report documents grid size and temporal discretization for all model simulations completed.	Section 5.0 (Groundwater Flow Model Development) Section 5.3 (Model Domain) Section 5.4 (Temporal Discretization)
	#1c	Have the boundary conditions changed since the EBD (Appendix 8.1J, Section 4.2), e.g., RIVER, DRAIN (seeps), and recharge parts of the model?	BGC report documents boundary conditions used for all model simulations.	Section 5.0 (Groundwater Flow Model Development) Section 5.6 (Boundary Conditions) Section 7.4 (End-of-Mining Operations Analysis - Boundary Conditions) Section 8.2 (Post-Closure Analysis - Boundary Conditions)
	#1d	Provide updated calibration information for the current model. For example, this could include updated versions of Appendix 8.1J Table 4.3 (pump test results with updated model layers), Table 5.2 (updated RMSE results), Figure 5.9a-b (head scatter plots), Figure 5.47 (streamflow scatter plots), and updated observed vs. simulated plots that are representative of the main catchment areas (e.g., updated Figures 5.12-5.17).	Calibration of the BGC model is fully documented in modeling report. The model calibration report section provides documentation of the calibration to the 2013 pumping test completed at GH12-334S, and figures showing NRMSE results, head scatter plots, and streamflow scatter plots.	Section 6.0 (Groundwater Flow Model Calibration)
	#1e	The groundwater model in the EBD describes calibrations using simulated vs. observed GW levels from 2004-2007, but is not validated with more recent data. Conduct a validation analysis for the model by comparing modelled and observed piezometer levels for data collected post-2007 (outside the original calibration period).	BGC transient calibration covered the period 2004 through 2012.	Section 6.0 (Groundwater Flow Model Calibration) Section 6.2.3 (Calibration Results - Stage 3: 2004 to 2012 Conditions)
	#2	Action item withdrawn. For #2, RFI 082 provides the technical basis for the approach used for estimating groundwater drawdown-wetlands effects.	N/A	N/A
	#3	Action item withdrawn. For #3, upon further review, the 40-yr estimate appears to conservatively capture the complete life of the main WMP before reclamation is complete (20 yrs operation + 20 yrs closure) (Piteau 2018; KP 2018b).	N/A	N/A
	#4a	Provide a hydraulic conductivity (K) vs. depth graph (such as that in EBD and SEBD Figure 8.1-11c [Schlumberger 2011, 2015], showing geometric means of K values in overburden, shallow bedrock, and deep bedrock.	The BGC report includes a compilation of hydraulic conductivity data plotted vs. depth and categorized by test type and geologic material (e.g., unconsolidated sediments, bedrock type).	Section 4.2.2 (Hydraulic Conductivity) Figure 4-1 (Hydraulic Conductivity Data Summary) Appendix A (Hydraulic Conductivity Estimates with Depth)
	#4b	Clarify whether the KP (2018a) and Piteau Associated (2018) models are derived from the original EBD MODFLOW model or whether they were developed independently. Also confirm whether the model used in Piteau Associates (2018) is the same as that used in KP (2018a).	The BGC numerical groundwater flow model was developed independently of the models presented in KP (2018a) and Piteau (2018).	N/A
	#4c	Confirm whether the 5th to 95th percentile maps in Piteau Associates (2018) represent the 5th to 95th percentile ranges in K, S etc., or the 5th to 95th percentile drawdown as the multiple parameters are varied.	Comment is specific to Piteau model and sensitivity analysis.	N/A
	#4d	Perform a sensitivity analysis (e.g., based on EPA [2009], Anderson et al. [2015], and ASTM [2016] guidance as appropriate) to provide an understanding of how the model parameters affect model output. Piteau Associates (2018) and KP (2018) provide the range of data and results for hydraulic conductivity, storage, river conductance, and recharge. Provide additional analysis of how varying parameters of porosity and boundary conditions affect the results of the model, and a discussion of the sensitivity results reaching a conclusion as to which model parameter(s) have the greatest influence on the model results and cone of depression size.	BGC completed a conventional sensitivity analysis considering 21 scenarios. The sensitivity analysis included assessment of hydraulic conductivity, boundary conductance, and recharge, among other scenarios.	Section 9.0 (Sensitivity Analysis) Table 9-2 (Summary of Sensitivity Simulations)
109a	#4e	Provide groundwater contour maps of the mine site predicted by the model for the end of operations and post-closure. Provide separate maps of shallow and deep groundwater zones for each phase, if necessary to explain the difference in flow between the immediate area around the pit and deeper flow paths along outlying ridges (Piteau Associates 2018).	Figures showing simulated groundwater contours at end of operations and in post-closure are included in BGC report. Simulated drawdown and mounding are presented for both shallow (i.e., water table) and deep zones (i.e., top of competent bedrock).	Section 7.6.3 (End-of-Mining Groundwater Flow System) Section 8.4.3 (Post-Closure Groundwater Flow System) Figure 7-4 to 7-9 (Simulated Water Table, Drawdown, and Mounding: End-of-Mining) Figure 8-2 to 8-4 (Simulated Water Table, Drawdown, and Mounding: Post-Closure)

Table 0. Pebble Project Request for Information (RFI) 019 and 109 summary and BGC Numerical Groundwater Flow Model Report comments and relevant sections (if applicable)

RFI ID	RFI #	RFI	BGC Comment	BGC Numerical Groundwater Flow Model Report Section
109b	#1e	Prior to conducting the validation analysis requested in RFI 109 #1e, review post-2007 hydrologic data sets to determine whether any of the data represent new hydrologic conditions (e.g., 2013 was unusually wet on the Kenai Peninsula, for example) compared to the 2004-2007 period that was used for the initial model calibration. If such data or conditions do not exist, the validation process would not be needed, because it would be unnecessarily duplicative of the original calibration process.	BGC transient calibration covered period 2004 through 2012.	Section 6.0 (Groundwater Flow Model Calibration) Section 6.2.3 (Calibration Results - Stage 3: 2004 to 2012 Conditions)
	#4d	The request in RFI 109 #4d for sensitivity analysis addresses reviewers' concerns over model uncertainty and reliability. A brief expenses discussion of the purposes, methods, and interpretations of the Monte Carlo simulations that were performed would also be helpful. Reviewers may not be familiar with this technology as at least a partial replacement for sensitivity analyses in addressing model uncertainty.	BGC completed a conventional sensitivity analysis considering 21 scenarios.	Section 9.0 (Sensitivity Analysis)
	#4e	In addition to maps requested in RFI 109a #4e, provide contour maps that show the simulated maximum drawdown associated with the open pit at the end of operations and in post closure	BGC report includes contour maps that show simulated drawdown associated with the open pit at the end of mining and in post-closure.	Section 7.6.3 (End-of-Mining Groundwater Flow System) Section 8.4.1. (Pit Lake Groundwater) Section 8.4.3 (Post-Closure Groundwater Flow System) Figure 7-4 to 7-9 (Simulated water table, drawdown, and mounding: End of mining) Figure 8-2 to 8-4 (Simulated water table, drawdown, and mounding: Post-closure)
	#4f	Does the groundwater model predict a zone of influence around the bulk TSF, either from mounding or lowering of the water table? If so, provide an expanded zone of influence map similar to that shown in Piteau Associates (2018) Figure 5, which includes the bulk TSF area. Describe the nature of the influence, whether the bulk TSF and main SCP would cause mounding or lowering of the water table in this area, and how it is expected to change after the end of operations by providing a time plot showing the expected changes.	The BGC report documents the predicted zone of influence around the Bulk TSF at end of mining and in the post-closure period.	Section 7.6 (End-of-Mining Operations Analysis - Results) Section 8.4 (Post-Closure Analysis - Results) Figure 7-4, 7-7 (Simulated end-of-mining water tables) Figure 7-5, 7-6, 7-8, 7-9 (Simulated drawdown and mounding end of mining) Figure 8-2 (Simulated water table: Post-closure) Figures 8-3 and 8-4 (Simulated drawdown and mounding post-closure)
109c	#4d	This item in RFI 109 requested sensitivity analysis for important model parameters. The value of Kx and Kz assigned to bedrock below the weathered zone should be included in the sensitivity analysis.	The Kx and Kz of competent bedrock (i.e., below the weathered bedrock zone) have been varied as part of the sensitivity analysis completed.	Section 9.0 (Sensitivity Analysis) Section 9.2 (Sensitivity Scenarios) Table 9-2 (Summary of Sensitivity Simulations)
	#4g	Knight Piesold's (2018) "Response to RFI 019c" describes layers 7-10 of the groundwater model as having a 50th percentile Kx value of approximately 0.0001 ft/day. This is one to two orders of magnitude lower than measured values of K shown in Figure 8.1-11a of SEBD Chapter 8 (Schlumberger 2015) at all depths, and two to three orders of magnitude lower than values determined from well WB-1 below a depth of 1,500 ft (Figure 8.1-11c of the SEBD). Considering that using values of K that are too low would have the effect of showing a smaller capture zone around the mine pit than would otherwise be simulated, please provide justification of why such low values were used.	BGC numerical model calibrated K values are within the range of observed data at the site.	Section 4.2 (Hydrogeologic Data) Section 6.0 (Groundwater Model Calibration) Table 6-1 (Calibrated Hydrogeologic Parameters) Appendix A (Hydraulic Conductivity Estimates with Depth)
109d	#1d	From RFI 109 #1d: Table 4.3 (pumping test results) and Figure 5.27 (streamflow scatter plots) – The response to RFI 109 (received 1/11/19) indicated that these would be provided under a separate cover. In addition, the response indicated that the information provided to date represent a model that is in the process of being updated and is not fully calibrated. Please provide an estimate of when the model update and full calibration are expected to be complete and a calibration report would be available.	Comment is specific to Piteau groundwater model and reporting. The numerical groundwater flow model developed by BGC is fully documented in the BGC modeling report, including model calibration, results of predictive simulations, and sensitivity analysis.	All report sections.
	#1e	From RFI 109 #1e and from RFI 109b: Validation analysis – Response to RFI 109 (received 1/11/19) indicated that this would be provided under a separate cover. RFI 109b provided an additional recommendation that PLP review additional data (post-2007 hydrologic data) prior to conducting validation analysis; response to RFI 109b (received on 1/10/19) indicated that historical streamflow and piezometric levels (2005-2013) are currently being reviewed.	Refer to response to RFI 109 #1e; BGC transient calibration covered the period 2004 through 2012.	Section 6.0 (Groundwater Flow Model Calibration) Section 6.2.3 (Calibration Results - Stage 3: 2004 to 2012 Conditions)
	#4d	From RFI 109 #4d: Sensitivity Analysis. Response to RFI 109 (received 1/11/2019) indicates that a description of the Monte Carlo analysis will be provided under separate cover and that the sensitivity analysis of tailings and open pit will also be provided under separate cover. The description of the Monte Carlo analysis was received in the RFI 109b response (received 1/10/19). The sensitivity analysis is still outstanding. In addition, RFI 109c provided clarification that hydraulic conductivity values for bedrock below the weathered zone be included in the sensitivity analysis.	Refer to response to RFI 109 #4d; the BGC numerical modeling report provides full documentation of the sensitivity analysis completed. The Kx and Kz of competent bedrock (i.e., below the weathered bedrock zone) have been varied as part of the sensitivity analysis completed.	Section 9.0 (Sensitivity Analysis) Section 9.2 (Sensitivity Scenarios) Table 9-2 (Summary of Sensitivity Simulations)

Notes:
1. Table does not include RFI 019a (questions and clarification requests related to the KP Operations Water Management Plan, KP (2018b)) and RFI 019b (questions related to streamflow reductions, address by KP in the RFI 19b response, KP (2018f)).
2. N/A indicates not applicable.
3. References listed in BGC comment column above:

Knight Piésold Ltd. (KP), 2018a. RFI 19c Response. Letter to PLP, October 3, 2018.
Knight Piésold Ltd. (KP), 2018b. Pebble Project, Pebble Mine Site Operations Water Management Plan. Report prepared for Pebble Limited Partnership, July 6, 2018, VA101-176/57-4.
Knight Piésold Ltd. (KP), 2018c. Pebble Project, Pebble Mine Site – Closure Water Management Plan. Report prepared for Pebble Limited Partnership, Sept. 21, 2018, VA101-176/57-5.
Knight Piésold Ltd. (KP), 2018e. Pebble Project, RFI 19 Part 3: Groundwater Withdrawal Wells. Letter prepared for Pebble Limited Partnership, July 6, 2018, VA101-00176/57-A.01.
Knight Piésold Ltd. (KP), 2018f. PRFI 19b Response. Letter prepared for Pebble Limited Partnership, September 28, 2018.
Knight Piésold Ltd. (KP), 2019a. VA19-00399 prepared for Pebble Limited Partnership March 14, 2019.
Pebble Limited Partnership (PLP), 2018. Request for Information (RFI) 019d recipient response form. Submitted by PLP to USACE and AECOM September 25, 2018.
Piteau Associates (Piteau), 2018. Pebble Project, Groundwater Conditions at End of Mining and Post-Closure. Report prepared for Pebble Limited Partnership, July 2018, Project 3832-R01.

EXECUTIVE SUMMARY

Pebble Limited Partnership (PLP) is presently in the permitting process for the Pebble Project (the Project), located approximately 200 miles southwest of Anchorage, Alaska. A three-dimensional (3-D) numerical hydrogeologic flow model (Groundwater Flow Model) was developed for the Project to support the permitting process and preparation of the Environmental Impact Statement (EIS). This report describes the development and calibration of the Groundwater Flow Model for the Project. The report also documents the use of the Groundwater Flow Model to predict effects of mine-related changes to the groundwater flow regime at the end of mining operations and following post-closure.

Approximately a decade of baseline information and hydrogeologic testing data for the Pebble site were relied upon in the development of the Groundwater Flow Model for the Project. The calibrated Groundwater Flow Model provides a good representation of baseline conditions, and is appropriate for use in predictive simulations to evaluate the effects of mine infrastructure on the groundwater system during operations and after mine closure.

HYDROGEOLOGIC SETTING

The hydrostratigraphy of the Project area is conceptualized to include three main units: unconsolidated sediments, weathered bedrock, and competent bedrock. The unconsolidated sediments, deposited during multiple episodes of glaciation, have variable hydrogeologic properties ranging from highly permeable sands and gravels to very low permeability clays. The weathered bedrock unit, which outcrops along ridges and hilltops, tends to be more permeable than the underlying competent bedrock. No permafrost has been identified in the Project area.

Groundwater recharge enters the hydrogeologic system from precipitation, snowmelt, and seepage from lakes and drainages; recharge occurs over about 7 months of the year (i.e., April or May through October). Groundwater leaves the hydrogeologic system at zones of discharge (i.e., rivers, creeks, seeps, wetlands and other low-lying areas) year-round, and seasonally via evapotranspiration. As a result, groundwater elevations are typically observed to be lowest during the spring prior to snowmelt, and highest immediately following freshet and/or autumn rains.

Based on groundwater level observations, the water table is interpreted to mimic surface topography in a subdued fashion. It is located near or at ground surface in low-lying areas, but at greater depths near ridges and ridge tops. Flowing artesian conditions, where groundwater levels are above land surface, are observed in some low-lying discharge areas.

Stream flows in the Project area exhibit characteristic seasonality, with high flows in spring resulting from snowmelt, low flows in early to mid-summer resulting from dry conditions and depleting snow packs, another high-flow period in later summer and early autumn resulting from frequent rainstorms, and the lowest flows in winter when near-surface freezing occurs and most precipitation falls as snow. Groundwater-surface water interactions within the Project area are complex due to the highly heterogeneous nature of the surficial geology and variable topography.

MODEL DEVELOPMENT AND CALIBRATION

Model development followed three main steps: 1) specify the questions or set of issues the model is intended to address and develop a conceptual hydrogeologic model, 2) develop the model framework (i.e., the mathematical model), and 3) develop and calibrate parameters for the model. Following development and calibration, the model was used to generate predictive simulations for the Project.

The Groundwater Flow Model was developed using MODFLOW-USG, an industry standard 3-D finite-difference flow model developed by the U.S. Geological Survey that incorporates a generalized control-volume finite-difference approach allowing the use of non-orthogonal unstructured grid types. The Groundwater Flow Model for baseline conditions was used to simulate groundwater flow within the study area, surface water flow within a simplified channel network, and groundwater-surface water interactions.

The Groundwater Flow Model was calibrated in four stages using groundwater elevations measured at 551 locations distributed across the Project area, streamflow observations from 26 gaging stations in the North Fork Koktuli River (NFK), South Fork Koktuli River (SFK), and Upper Talarik Creek (UTC) watersheds, and drawdown observations from a pumping test conducted in the Pebble deposit area. The model calibration considered annual average conditions, average monthly conditions, monthly conditions from 2004 to 2012, and the 48-hour pumping test conducted in the deposit area.

The overall model calibration is summarized as follows:

- Simulated groundwater levels show good agreement to measured groundwater levels, including observed seasonal fluctuations and vertical groundwater flow directions.
- Simulated stream flows also show good agreement with available observations, including seasonal fluctuations.
- Calibrated hydraulic conductivity (K) and storage parameters are within observed ranges.
- The simulated water table mimics topography, with groundwater flow from topographically higher locations towards streams and drainages.
- Inflows to the groundwater system are predicted to consist of predominantly groundwater recharge and seepage from surface water bodies and drainages; outflows from the groundwater system are predicted to consist predominantly of discharge to surface water bodies and drainages.

END-OF-MINING OPERATIONS ANALYSIS

The objectives of the predictive mining operations simulations were to quantify the rate of groundwater extraction at the proposed open pit, estimate seepage rates from the proposed Bulk Tailings Storage Facility (TSF), assess changes in groundwater discharge or baseflow to tributaries of NFK, SFK, and UTC watersheds, and predict changes in groundwater elevation (i.e., drawdown and mounding). The baseflow estimates presented herein represent a component of the surface water flows presented in the Project Water Balance Model (WMB) referred to as the Watershed Module, and are distinct from the 'groundwater' estimates generated by the Watershed Module. Simulations were conducted for a scenario without groundwater extraction wells and for a scenario that included conceptual pit dewatering and seepage collection well layouts.

The results of the end-of-mining operations analysis are summarized as follows:

- Groundwater extraction at the open pit is predicted to be approximately 980 US gpm (2.2 cfs) for the scenario without pumping wells. For the pumping well scenario, the total groundwater extraction rate is predicted to increase to 1,350 US gpm (3.0 cfs), with 500 US gpm (1.1 cfs) reporting to the open pit and 850 US gpm (1.9 cfs) extracted at the pit dewatering wells.
- The total seepage rate (i.e., including seepage through the embankments and foundations) from the Bulk TSF is predicted to be approximately 630 US gpm (1.4 cfs). Basin seepage is predicted to comprise 66% (415 US gpm; 0.9 cfs) of the total seepage rate, with 30% (190 US gpm; 0.4 cfs) and 4% (25 US gpm; 0.06 cfs) occurring through the Main Embankment and South Embankment, respectively.
- The minimum predicted water table elevation and maximum predicted drawdown at the end of mining occur at the low point of the open pit, with respective values of approximately -500 ft and 1,615 ft. Drawdown due to open pit dewatering is predicted to be primarily restricted to the SFK watershed; however, the cone of depression is predicted to extend under the upper tributaries of the UTC watershed. Groundwater mounding of up to 400 ft is predicted within the footprint of the Bulk TSF.
- Particle tracking simulations indicate that seepage from the Bulk TSF is predicted to report to the valley bottoms immediately downstream of the Main and South Embankments. Some seepage from the Pyritic TSF, Main Water Management Pond (WMP), and Open Pit WMP is predicted to flow past proposed Seepage Collection Ponds (SCPs) in the scenario without pumping wells. However, results of the scenario with pumping wells indicate that seepage collection wells could be used to aid in management of seepage from these facilities.
- Predicted reductions in stream baseflow for the scenario without pumping wells relative to baseline conditions, excluding discharge of treated water, range from approximately 17 cfs (14%) above NK100A1 gaging station in the NFK watershed, to 5 cfs (7%) above SK100B1 gaging station in SFK watershed, to 0.1 cfs (0.7%) above UT100D in UTC watershed. For the pumping well scenario, baseflow reduction in NFK and UTC watersheds is predicted to increase to 18 cfs (14%) and 0.2 cfs (1.3%), respectively, while negligible difference is predicted for SFK watershed.

POST-CLOSURE ANALYSIS

The objectives of the post-closure simulations were to estimate groundwater flow rates to and from the open pit lake, estimate seepage rates from the reclaimed Bulk TSF, assess changes in baseflow to tributaries of NFK, SFK, and UTC watersheds, and predict changes in groundwater elevation (i.e., drawdown and mounding).

The results of the post-closure analysis are summarized as follows:

- Groundwater discharge to the pit lake is predicted to be approximately 800 US gpm (1.8 cfs). Seepage from the pit lake to the groundwater system is predicted to be 0 US gpm (0 cfs; i.e., the pit lake, managed at an elevation of 900 ft, will act as a groundwater sink).
- The total seepage rate from the Bulk TSF is predicted to be reduced from the end-of-mining operations model to approximately 420 US gpm (0.9 cfs). Basin seepage is predicted to comprise 69% (285 US gpm; 0.6 cfs) of the total seepage rate, with 27% (115 US gpm; 0.3 cfs) and 4% (20 US gpm; 0.04 cfs) occurring through the Main Embankment and South Embankment, respectively. Total predicted groundwater discharge downstream of the Bulk TSF is greater than the total predicted seepage rate from the facility, indicating that the discharge will include both TSF seepage and groundwater derived from outside of the footprint of the facility.
- The elevation of the water table in the footprint of the pit lake, managed at an elevation of 900 ft, is drawn down a maximum of approximately 400 ft relative to baseline conditions. Drawdown due to the pit lake is predicted to be primarily restricted to the SFK watershed; however, the cone of depression is predicted to extend under the upper tributaries of the UTC watershed. Groundwater mounding of up to 345 ft is predicted within the footprint of the Bulk TSF.
- Particle tracking simulations indicate that seepage from the Bulk TSF is predicted to report to the valley bottoms immediately downstream of Main and South Embankments.
- Predicted reductions in baseflow (excluding discharge of treated water) relative to baseline conditions range from approximately 14 cfs (11%) above NK100A1 gaging station in NFK watershed, to 4 cfs (6%) above SK100B1 gaging station in SFK watershed, to 0.1 cfs (0.4%) above UT100D in UTC watershed. It is likely that this analysis overpredicts baseflow reduction in the post-closure period, particularly in the NFK watershed, as a number of drainages represented in the baseline simulation are not re-established in the post-closure simulation. This will be addressed at a future stage of Project design and permitting.

SENSITIVITY ANALYSIS

A sensitivity analysis was performed to quantify the uncertainty in the calibrated base case model caused by uncertainty in the estimated parameter values. The calibrated values for K, groundwater recharge, and boundary conditions were systematically changed within reasonable ranges to evaluate the effect on the model outputs. The model inputs for the sensitivity scenarios were selected based on calibration statistics and measured data ranges. Steady-state sensitivity simulations were performed for baseline conditions, end-of-mining conditions for the scenario without pumping wells, and post-closure conditions.

The sensitivity analysis, which included 21 unique scenarios (i.e., S1 through S21) is summarized as follows:

- Groundwater extraction at the open pit at the end of mining is predicted to range from 600 US gpm (1.3 cfs; S8) to 3,000 US gpm (6.7 cfs; S7) relative to the base case rate of 980 US gpm (2.2 cfs).
- Groundwater discharge to the pit lake post-closure is predicted to range from 560 US gpm (1.2 cfs; S10) to 1,800 US gpm (4.0 cfs; S7) relative to the base case rate of 800 US gpm (1.8 cfs). In all scenarios, no seepage from the pit lake to the groundwater system is predicted (i.e., the pit lake, managed at an elevation of 900 ft, will act as a groundwater sink).
- At the end of mining operations, seepage from the Bulk TSF is predicted to range from 320 US gpm (0.7 cfs; S18) to 5,300 US gpm (12 cfs; S20) relative to the base case rate of 630 US gpm (1.4 cfs). At post-closure, seepage from the Bulk TSF is predicted to range from 200 US gpm (0.4 cfs; S21) to 930 US gpm (2.1 cfs; S17) relative to the base case rate of 420 US gpm (0.9 cfs).
- At the end of mining operations, reductions in baseflow (excluding discharge of treated water) in NFK watershed above NK100A1 are predicted to range from 12% (S2) to 20% (S1) relative to the base case reduction of 14%. At post-closure, reductions in baseflow in NFK watershed are predicted to range from 9% (S2) to 19% (S1) relative to the base case reduction of 14%.
- At the end of mining operations, reductions in baseflow (excluding discharge of treated water) in SFK watershed above SK100B1 are predicted to range from 5% (S2) to 14% (S1) relative to the base case reduction of 7%. At post-closure, reductions in baseflow in SFK watershed are predicted to range from 4% (S2) to 13% (S1) relative to the base case reduction of 6%.
- At the end of mining operations, reductions in baseflow (excluding discharge of treated water) in UTC watershed above UT100D are predicted to range from 0% (S2) to 6% (S15) relative to the base case reduction of 0.7%. At post-closure, reductions in baseflow in UTC watershed are predicted to range from 0% (S2) to 3% (S15) relative to the base case reduction of 0.7%.

Based on the results of the sensitivity analysis, simulated scenarios with increased or decreased K in the unconsolidated sediments and bedrock (S1 to S8) were identified as Type III scenarios. A Type III scenarios is one that results in a significant effect on model predictions but also results in a significant effect on model calibration. Simulation results for these scenarios generally result in a poorer fit to baseline conditions; however, future hydrogeologic testing should be designed to reduce the uncertainty in K within the unconsolidated sediments and bedrock in the Project area. Sensitivity scenarios classified as Type IV (i.e., scenarios where model calibration is relatively unaffected, but model predictions are significantly altered) include the high K fault scenario (S15), scenarios with increased and decreased tailings K (S17 and S18), the larger Bulk TSF pond and saturated tailings scenarios (S19 and S20), and the scenario with a low K cover placed on the Bulk TSF at post-closure (S21). Possible negative outcomes from these scenarios (e.g., increased groundwater discharge to the open pit, increased Bulk TSF seepage) should be managed through targeted data collection as the Project progresses, and through effective management of the Bulk TSF during mining operations.

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ACRONYMS AND ABBREVIATIONS

Acronyms and abbreviations used in this report:

ATS	Adaptive Time Stepping
BCMOE	British Columbia Ministry of Environment
BGC	BGC Engineering USA Inc.
cfs	Cubic Feet per Second (ft^3/s)
CLN	Connected Linear Network
DRN	Drain package
ESI	Environmental Simulations Inc.
EVT	Evapotranspiration package
˚F	Degrees Fahrenheit
ft	Feet
GHB	General Head Boundary package
Ha	Hectare
HGL	Hydrogeologic Inc.
HSPL	HydroAlgorithmics Pty Ltd.
IPCC	Intergovernmental Panel on Climate Change
K	Hydraulic conductivity
KP	Knight Piésold Ltd.
KRT	Koktuli River Tributary
ML	Metal-Leaching
NBLM	Nevada Bureau of Land Management
NFK	North Fork Koktuli River
NPAG	Non-Potentially Acid-Generating
NRMSE	Normalized Root Mean Square Error
PAG	Potentially Acid-Generating
PLP	Pebble Limited Partnership
R	Correlation Coefficient
RCH	Recharge package
RMSE	Root Mean Square Error

RQD	Rock Quality Designation
SCP	Seepage Collection Pond
SFK	South Fork Koktuli River
SFR	Streamflow-Routing package
SGB	Specified Gradient Boundary package
S_s	Specific storage
S_y	Specific yield
TSF	Tailings Storage Facility
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
US gpm	U.S. gallons per minute
USGS	U.S. Geological Survey
UTC	Upper Talarik Creek
VWP	Vibrating Wire Piezometer
WMP	Water Management Pond
WTP	Water Treatment Plant

LIMITATIONS

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1.0 INTRODUCTION

Pebble Limited Partnership (PLP) is presently in the process of permitting the Pebble Project (the Project) located approximately 200 miles southwest of Anchorage, Alaska (Drawing 01). To support this process and the preparation of the Environmental Impact Statement (EIS), this report describes the development and calibration of the three dimensional (3-D) numerical groundwater flow model (Groundwater Flow Model) for the Project. The Groundwater Flow Model was developed as a tool to characterize groundwater flow rates and directions in the Project study area. This report also documents the use of the Groundwater Flow Model to predict the effects of mine-related groundwater extraction on the groundwater flow regime, and updates results presented in PLP (2011a, 2015).

1.1. General Approach

Model development can be viewed as a process with three main steps: (1) specify the questions or set of issues the model is intended to address and develop a conceptual model, (2) develop the model framework (i.e., the mathematical model) and (3) develop and calibrate parameters for the model and apply the model to generate predictive simulations that focus on the set of issues the model is intended to address (USEPA, 2009; BCMOE, 2012). This general process was followed to meet the modeling objectives outlined in the following section.

1.2. Study Objectives

The objectives of the groundwater modeling study were as follows:

- Develop and calibrate the Groundwater Flow Model for the Project that represents the Conceptual Model for the area of interest.

Use the calibrated Groundwater Flow Model to:

- Estimate the groundwater extraction rate at the proposed open pit at the end of mining
- Estimate the seepage rate from the proposed Bulk Tailings Storage Facility (TSF)
- Evaluate the potential impact of the proposed mine on local surface waters, including North Fork Koktuli River (NFK), South Fork Koktuli River (SFK), and Upper Talarik Creek (UTC)
- Estimate changes to groundwater levels and flow conditions at the end of mining operations and during the post-closure period.

2.0 STUDY LOCATION AND PROJECT LAYOUT

2.1. Study Location

The Project is located north of Iliamna Lake approximately 200 miles southwest of Anchorage, Alaska and 60 miles west of Cook Inlet (Drawing 01). The closest communities are the villages of Iliamna, Newhalen, and Nondalton, each located approximately 17 miles from the Project. The Project is located in the upper reaches of the NFK, SFK and UTC drainages, which ultimately drain into Bristol Bay southwest of the Project.

The Project is located within the Nushagak - Big River Hills, which consists of low, rolling hills separated by wide, shallow valleys with sinuous drainage channels (Detterman and Reed, 1973). Glacial and fluvial sediments of varying thickness cover most low-lying areas, whereas ridges and hills typically exhibit exposed bedrock or have thin veneers of surficial material (Hamilton and Klieforth, 2010). The region is located within a zone of sporadic permafrost (Ferrians, 1965); however, no permafrost has been identified within the Project area (PLP, 2018a). South of the Project, the Nushagak - Bristol Bay Lowlands consists of relatively flat-lying topography with abundant wetlands and ponds along the north shore of Iliamna Lake (Detterman and Reed, 1973). The Project area that has been investigated to support hydrogeologic and geotechnical studies is shown in Drawing 01.

2.2. Project Description

The mineral resource of the Project (Drawing 02) is located in the headwaters of SFK and consists of a copper-gold-molybdenum porphyry deposit (Pebble Deposit; PLP, 2018a). The proposed open pit mine would be developed at an average mining rate of 70 million tons per year, producing approximately 7.4 billion pounds of copper, 398 million pounds of molybdenum, and 12.1 million ounces of gold at a milling rate of up to 66 million tons per year over a 20-year mine life. The Project includes four primary areas: the mine site at the Pebble Deposit location which is the focus of this assessment, the port site at Amakdedori on Cook Inlet, the transportation corridor connecting these two sites, and a natural gas pipeline connecting to existing infrastructure on Kenai Peninsula.

The Pebble Deposit is hosted in intrusive and sedimentary rock that will be mined through a conventional drill, blast, truck, and shovel operation. The open pit will be developed in stages, with each stage expanding the area and depth of the previous stage. At completion, final open pit dimensions will be approximately 6,800 ft in length and 5,600 ft in width. A pit lake will form after mine closure.

Waste rock will be segregated by the potential to generate acid, with Potentially Acid-Generating (PAG) and Metal-Leaching (ML) waste rock stored in the Pyritic Tailings Storage Facility (TSF) until mine closure, when it will be placed in the open pit. Non-PAG (NPAG) and non-ML waste rock will be stockpiled and may be used as construction material. Overburden removed during mining will be segregated based on suitability for construction and use as a growth medium and stockpiled across the mine site at locations that minimize the potential for erosion. Further construction material will be sourced from quarries located in the vicinity of the Bulk TSF (Drawing 02).

Separate TSFs will be constructed for bulk and pyritic tailings storage and will be located primarily in the NFK watershed. The Bulk TSF will be unlined with two embankments and the lined Pyritic TSF will have three embankments. Cumulative TSF capacity will be sufficient to store the total tailings of 1.3 billion tons produced over the 20-year mine life. Seepage collection systems will be installed to manage adverse downstream water quality impacts.

Water Management Ponds (WMPs) will be used to store water collected within the Project footprint. The Main WMP will be fully lined and used to store surplus water for milling or for managing water from other impoundment and seepage structures. Water collected from pit dewatering wells and the open pit will be pumped to the lined Open Pit WMP for storage prior to treatment and discharge.

3.0 CLIMATE AND PHYSIOGRAPHY

3.1. Climate

The Project area is located in a transitional climatic zone with strong maritime influences (PLP, 2011b). Summer temperatures are moderated by the open waters of Iliamna Lake, Bristol Bay, and Cook Inlet. Winter temperatures are more continental because of the presence of ice on Iliamna Lake and Bristol Bay during the coldest months of the year. Winter weather systems typically travel into the region from the Bering Sea to the west, from along the Aleutian Islands chain to the southwest, and from the Gulf of Alaska to the southeast. These weather systems consist of cool to cold air that is saturated with moisture, resulting in frequent clouds, rain, and snow. Less frequent wintertime incursions of frigid, stable arctic air masses bring shorter periods of clear and very cold conditions to the region. Incursions of very warm air masses from the interior of Alaska can cause atmospheric instability in the summer months, which results in the development of cumulus clouds and thunderstorm activity. Throughout the year, precipitation rates are influenced by elevation (i.e., orographic effect) and location (e.g., rain shadow, blowing snow; PLP, 2011a).

Climate data have been collected at stations distributed across the Project area (Drawing 03) since 2005 (PLP, 2011b). Long-term climate data (i.e., 1942 to 2017) are also available from Iliamna Airport (Drawing 03). Knight Piésold Ltd. (KP) generated long-term synthetic climate datasets for Iliamna Airport and Pebble 1 stations based on data from Iliamna Airport station, regional climate records, and stream flow observations (KP, 2018a). Based on this dataset, annual average temperature and precipitation at Pebble 1 station are 30.1 °F and 54.6 in/yr, respectively. Potential evapotranspiration at Pebble 1 was estimated by KP (2018a) using the Thornthwaite equation; actual evapotranspiration was calculated from potential evapotranspiration by KP (2018a) based on an assumed soil moisture storage capacity. From this analysis, annual average potential evapotranspiration and actual evapotranspiration are 16.3 in/yr and 7.9 in/yr, respectively. Average annual sublimation was estimated at 4 in/yr, although KP (2018a) note that there is considerable uncertainty in this estimate. Average monthly and annual climate variables are summarized in Table 3-1.

Global temperatures have risen over the last century, with each of the past three decades being successively warmer than any previously on record (IPCC, 2013). In Alaska, temperatures have risen more than twice as rapidly as the rest of the United States (Chapin et al., 2014), increasing by about 5 ˚F since the 1960s (KP, 2018a). In the Project area, the climate is expected to continue to warm, with projected increases in annual temperature of up to 6 ˚F to 7 ˚F by the end of the century (KP, 2018a). Over the same period, annual precipitation is projected to increase by 15% to 20% (KP, 2018a); however, concurrent increases in evapotranspiration and the length of the growing season may lead to drier overall conditions (Chapin et al., 2014).

3.2. Physiography

The Project area consists of low, rolling hills separated by wide, shallow valleys with sinuous drainage channels (Detterman and Reed, 1973; PLP, 2011c). Topographic elevations range from approximately 46 ft at Iliamna Lake, to 580 ft at the junction of NFK and SFK, to over 3,000 ft in the surrounding mountain peaks. The deposit area, located near the pass between the SFK and UTC, lies at approximately 1,000 ft elevation.

Glacial and fluvial sediments of varying thickness cover valleys and lower hillslopes, whereas hills, ridges and mountains typically exhibit exposed bedrock or have thin veneers of surficial material (PLP, 2011c). The hills, ridges and mountains tend to be moderately sloped with rounded tops. The valley bottoms are relatively flat with topography influenced by glacial history (PLP, 2011c):

- The main stream channels are sinuous, and their floodplains contain wetlands and oxbow lakes.
- Glaciofluvial terraces of outwash sediments occupy parts of the main valleys and take the form of flat to gently sloping benches or terraces situated above the adjacent floodplains.
- Glaciolacustrine deposits occupy the upper parts of the three main valleys and are represented by flat, poorly drained terrain. Frying Pan Lake is a shallow residual waterbody with a maximum depth of approximately 3 ft, located in the glaciolacustrine basin in the upper part of the SFK valley.
- Extensive areas of glacial drift deposits occur along lower hillslopes and near the headwaters of the main stream valleys and are characterized by undulating terrain and numerous kettle lakes.

South of the Project area, the Nushagak - Bristol Bay Lowlands consists of relatively flat-lying topography with abundant wetlands and ponds along the north shore of Iliamna Lake (PLP, 2011c).

3.2.1. Hydrology

The Project area is situated within the Bristol Bay drainage basin, which encompasses 41,900 square miles within southwestern Alaska (PLP, 2011d). The largest rivers draining into Bristol Bay are the Nushagak River and Kvichak River (Drawing 01), whose combined drainage areas comprise 49% of the Bristol Bay drainage basin. The Project area straddles the boundary of the Nushagak River and Kvichak River watersheds, in the upper reaches of the NFK, SFK and UTC drainages (Drawing 03). The north and south forks of the Koktuli River are in the Nushagak River watershed, while UTC is in the Kvichak River watershed.

Stream flows across the Project area are monitored by a network of 29 established stream gages (Drawing 03) distributed along the NFK (6), SFK (8), UTC (12), and Kaskanak Creek (1) drainages, as well as within a tributary to the Koktuli River downstream of the junction of NFK and SFK (KRT, 2). Based on observations collected since 2004, the annual pattern of stream flows is characterized by high flows in spring resulting from snowmelt, low flows in early to mid-summer resulting from dry conditions and depleting snow packs, another high-flow period in later summer and early autumn resulting from frequent rainstorms, and the lowest flows in winter when freezing occurs and most precipitation falls as snow. The low stream flows in winter are considered to be baseflow (i.e., sustained by groundwater discharge to creeks). Representative hydrographs from NFK, SFK, and UTC watersheds are shown in Figure 3-1.

Springs and seeps occur throughout the Project area and have been mapped from low to relatively high elevations, even on steeper slopes (PLP, 2011a; 2015). Numerous small pools also occur throughout the Project area; these have been generally classified as either ephemeral perched-precipitation pools or perennial flow-through pools (PLP, 2011d; Rains, 2011).

3.2.2. Vegetation and Wetlands

The Project area is situated within the low-scrub shrub ecological zone (PLP, 2011e). Vegetation within the area is predominately classified as shrubs (81% by area), with dwarf shrub types being most common. Open water or unvegetated/sparsely vegetated land cover types cover approximately 10% of the area, and herbaceous vegetation types cover approximately 9% of the area. Forested vegetation types are negligible, covering less than 1% of the Project area (PLP, 2011e).

Wetland mapping was completed in parts of the Project area to determine location, type, and extent of wetlands and water bodies. Approximately 33% of the area mapped was determined to be wetlands and open water (i.e., including the small pools discussed in Section 3.2.1), with slope- and riverine-type wetlands most commonly observed (PLP, 2011g).

3.3. Water Balance Models

Two water balance models (WBMs) were developed for the Project within a spreadsheet framework using a monthly timestep. These two models are designed to represent different scales of hydrologic systems. The first WBM, referred to as the Watershed Module, consists of a lumped-parameter model that encompasses the NFK, SFK, and UTC drainages upstream of the NK100A, SK100A, and UT100-APC1 gaging stations (Drawing 03), respectively. The Watershed module, which is documented in PLP (2011a; 2019a), represents surface water flows across the entire Project area and was used to aid in estimation of groundwater recharge rates within this assessment. The second WBM, referred to as the Mine Plan Module, was developed to represent the movement of water within the proposed mine system (e.g., TSF, open pit). The Mine Plan Module is documented in KP (2018b, 2018c).

4.0 HYDROGEOLOGIC SETTING

This section presents the hydrogeologic setting of the Project area, which includes descriptions of the surficial and bedrock geology, groundwater elevation data and interpreted groundwater flow directions, and a summary of hydrogeologic property data that are available. These data and interpretations are collectively used to define the Conceptual Model for the Project, which is summarized at the end of the section.

4.1. Geology

4.1.1. Unconsolidated Sediments

Surficial geology of the Project area and surrounding region is shown on Drawing 04; the surficial geology in the Project area is based on mapping commissioned by PLP and documented in Hamilton (2007, 2011), while regional surficial geology is based on USGS data (Wilson et al., 2012). The distribution of surficial materials is shown in cross-section in the Pebble deposit area (Drawing 05) and along the SFK (Drawings 06 and 07), with section numbers and orientations corresponding to those presented in PLP (2015).

The Project area was strongly impacted by at least four episodes of glaciation in the late-Pleistocene (Detterman and Reid, 1973), resulting in the deposition of glacial drift up to hundreds of feet thick in low-lying parts of the Project area. Glacier-related geomorphic features in the Project area include: end moraines; meltwater deposits with abundant kettle depressions, many of which contain surface water; broad outwash aprons; and pronounced meltwater channels (Hamilton and Klieforth, 2010).

Glaciers from the Lake Clark structural trough entered the site from the north and northeast and glaciers from the Cook Inlet and Iliamna Lake basin area entered the site from the south (Hamilton and Klieforth, 2010). The glaciers blocked all major drainages in the Project area at various times (i.e., the NFK, SFK and UTC), with ice-dammed lakes resulting in the widespread deposition of glaciolacustrine material. During glacial retreat, extensive ice-contact meltwater deposition occurred, resulting in numerous meltwater channels (Hamilton and Klieforth, 2010).

Paleodrainage features are widespread in the Project area (Hamilton and Klieforth, 2010). Most can be interpreted in the context of existing terrain and mapped glacial advance, however some imply the presence of other controls on preglacial and periglacial drainage patterns in the Project area. Most surficial deposits are now covered by organic material and vegetation (Section 3.2.2), but some gravel deposits remain exposed at surface.

4.1.2. Bedrock

The Pebble Deposit is hosted by Mesozoic-aged, volcanic-derived sediments of Kahiltna terrane (PLP, 2013). These sediments were deposited on the landward (i.e., Alaska) side of the Talkeetna volcanic arc as it approached North America. The volcanic arc and associated Peninsular Terrane had docked with the North American continent by the Mid-Cretaceous, though continued to move along regional faults. During the Mid- to Late-Cretaceous, when the transition from compressive docking of the arc to sliding along continental margin occurred, there was widespread magmatic activity within the Kahiltna Terrane (Goldfarb et al., 2013). This resulted in numerous granodiorite intrusions, including the Kaskanak batholith which formed to the west and beneath the Pebble deposit (Drawing 08). The Kaskanak batholith is considered the source of the resource at Pebble and drove the magmatic-hydrothermal system that formed the deposit (Anderson et al., 2013; Lang et al., 2013). In the late-Cretaceous to early-Tertiary, the Pebble area was lifted and eroded, then tilted and dropped by regional tectonic forces (Lang et al., 2013). Ongoing volcanism and erosion in the Tertiary resulted in the filling of dropped-down basins with basalts, andesites, lake sediments, and conglomerates (PLP, 2013).

PLP developed a 3-D geologic model using Vulcan software within the proposed open pit area that classifies the Cretaceous and Tertiary bedrock units. The 3-D geologic model units are shown in cross-section on Drawings 09, 10, and 11. As shown on Drawing 09, the western portion of the Cretaceous-hosted deposit outcrops at surface, while the eastern portion is unconformably overlain by a wedge of late-Cretaceous to early-Tertiary sedimentary and volcanic rock. The simplified Cretaceous units provided by PLP and shown include: Granodiorite Sill, Granodiorite Pluton, Diorite Sill, Mega Breccia, and undifferentiated sediments (i.e., the oldest units which host or were intruded by the deposit). The simplified Tertiary units provided by PLP and shown include: Basalt, Cobble Conglomerate, Wacke, Mudstone-Siltstone, and Pebble Conglomerate. The 3-D geologic model also includes alteration types, and the following major alteration types are shown in section below the Tertiary/Cretaceous boundary: sodic-potassic, illite-pyrite, potassic-silicate, sodic-calcic-potassic, and quartz-sericite-pyrite.

The structure of the Pebble region is broadly defined by northeast trending faults related to translation motion along the Lake Clark Fault, which occurs at the boundary between the Kahiltna and Peninsular Terranes (PLP, 2011f). Numerous faults and shear zones have been identified by surface mapping and analysis of drill core (Drawing 08). In the general deposit location, seven major fault zones (i.e., ZA to ZG) have been identified. Faults ZA through ZF are considered to be brittle faults with displacements ranging from tens to hundreds of feet (Lang et al., 2013; PLP, 2011f).

The ZG1 fault vertically offsets both the deposit mineralization and the Cretaceous-Tertiary unconformity by over 3,000 ft, east side down. ZG1 forms the northwest boundary of the East Graben, a steep and narrow feature located on the northwest side of Koktuli Mountain. The ZH fault forms the southeast boundary of the graben, and both ZG1 and ZH trend northeast subparallel to the regional Lake Clark structural zone (PLP, 2011f). Further from the deposit location faults include the east-trending Koktuli Fault, located in the south-central part of the Project area, and the east-trending Sharp Mountain Fault, which is located to the south of the Koktuli Fault.

A horizon of weathered bedrock typically overlies competent bedrock. Periglacial activity contributed to the weathering of near-surface bedrock in the Project area, and rubble formed by repeated freeze-thaw cycles is commonly observed where bedrock is exposed at surface (Drawing 04). Low Rock Quality Designation (RQD) observations (i.e., observations suggesting low quality of rock based on the density of discontinuities) are common in upper-5 to 30 ft in core logged in GH-series drill holes (PLP, 2011a).

4.2. Hydrogeologic Data

Available hydrogeologic data include testing results from packer tests, slug tests, airlift tests, and a pumping test, along with groundwater level data that have been collected across the Project area from 2004 through 2012. The data were collected and analyzed by others unless otherwise specified; the data are described in PLP (2011a, 2015) and SLR (2013) and are briefly summarized below.

4.2.1. Groundwater Levels and Vertical Gradients

Groundwater level data are available for approximately 550 locations that include monitoring wells, pumping wells, standpipe piezometers, multi-level piezometers (i.e., Westbay installations), and vibrating wire piezometers (VWPs). The network of instrumentation in the Project area is shown on Drawings 12 and 13. Interpreted groundwater elevation contours based on April 2011 water level data from wells completed in unconsolidated sediments and bedrock are provided in Drawing 14 and Drawing 15, respectively. The available data suggest that, in general, the water table mimics the surface topography.

The vertical direction of groundwater flow in the Project area, determined based on vertical hydraulic gradients observed at nested well locations, is shown on Drawing 16. Both downward and upward groundwater flow (i.e., groundwater recharge and discharge) are observed in the Project area. There is a notable cluster of wells indicating downward groundwater flow in the “South Fork flats” area to the south of Frying Pan Lake; this is the area where groundwater flow between the SFK and UTC watersheds has been identified (PLP, 2011a). Many nested wells show vertical gradients that are consistent throughout the period of record, though some have vertical gradients that reverse on a seasonal basis. In places vertical gradient direction changes seasonally; Drawing 16 only shows locations where vertical gradient direction, and therefore groundwater flow direction, is observed to be consistent throughout the year.

4.2.2. Hydraulic Conductivity

Over 1,000 hydraulic response tests have been completed to characterize the hydraulic conductivity (K) of geologic materials at the Project site, including approximately 200 tests conducted in unconsolidated sediments and approximately 850 tests conducted in bedrock. The majority of the K tests were small-scale or “point-scale” tests (i.e., packer and slug tests). In addition to these small-scale tests, “airlift” tests were completed at nine locations (i.e., PW-1, PW-3, PW-4, PW-5, PW-6, PW-7, PW-8, PW-08-9, PW-08-10) and one 48-hour pumping test was completed at pumping well GH12-334S in the deposit area in 2013. To characterize deep bedrock K, cross-hole testing was completed between multi-level piezometer WB-1 and DH8417 in the deposit area in 2008.

Results from the single-well response tests (i.e., slug tests), airlift tests, and pumping tests are shown on Drawing 17, and results from packer tests are shown on Drawing 18. Results from all hydraulic response tests completed in the Project area are plotted by test type and depth in Appendix A.

4.2.2.1. Unconsolidated Sediments

Approximately 200 estimates of K are available to characterize the surficial deposits at the Project site. The majority of the unconsolidated sediment hydraulic response tests (i.e., 129) were completed in material logged as sand and gravel (Figure 4-1); K calculated from these tests ranged from $2x10^{-8}$ ft/s to $4x10^{-2}$ ft/s, with a geometric mean of $8x10^{-5}$ ft/s. The geometric mean for tests completed in material logged as sand was similar (i.e., $7x10^{-5}$ ft/s), while the geometric means for tests completed in materials logged as gravel and silt were slightly higher ($2x10^{-4}$ ft/s and $1x10^{-4}$ ft/s, respectively). Only two response tests were completed in material logged as clay; K calculated from these tests had a geometric mean of $1x10^{-6}$ ft/s (Figure 4-1).

4.2.2.2. Bedrock

Approximately 850 estimates of K are available to characterize bedrock at the Project site. Figure 4-1 shows results of hydraulic response tests completed in material logged as undefined bedrock, andesite/dacite/latite/rhyolite, basalt, breccia/volcaniclastics, conglomerate, diorite/ granodiorite, gabbro, monzonite/monzodiorite, mudstone/siltstone, and sandstone/wacke. An appreciable spread in data is observed for each rock type (i.e., four to eight orders of magnitude), and there are no clear trends in K based on bedrock lithology (Figure 4-1).

The highest mean K was observed in material logged as undefined bedrock; K calculated from these tests ranged from $1x10^{-7}$ ft/s to $9x10^{-4}$ ft/s, with a geometric mean of $2x10^{-5}$ ft/s. The lowest mean K was observed in material logged as mudstone/ siltstone; K calculated from these tests ranged from $6x10^{-10}$ ft/s to $2x10^{-3}$ ft/s, with a geometric mean of $3x10^{-7}$ ft/s (Figure 4-1). Bedrock K is observed to decrease with depth in the datasets for some rock types (e.g., diorite/granodiorite and mudstone/siltstone); however, this trend is not observed for all rock types (e.g., sandstone/wacke; Appendix A). The decrease in K with depth in competent bedrock is considered minor relative to the distinct decrease in K between weathered and competent bedrock.

In addition to packer testing in the Project area to characterize the hydraulic properties of deep bedrock, cross-hole testing was completed between multi-level piezometer WB-1 and DH8417 in 2008 (PLP, 2011a). These data were interpreted by PLP (2011a) to support the presence of a compartmentalized deep bedrock groundwater system.

4.2.3. Storage Properties

Storage properties are important when stresses, which either release water from or add water to the groundwater system (e.g., pumping and dewatering, groundwater recharge and evapotranspiration), are placed on the groundwater system over a period of time. The amount of water that can be removed from or can be added to a material is dependent upon the magnitude of the change in hydraulic head and the material's storage parameters. Specific yield (S_y) describes the storage behavior of a material related to the physical draining or filling of pore space (i.e., unconfined conditions); specific storage (S_s) describes the storage behavior of a material when water is removed from or added to a saturated material by compression or expansion of the porous medium and water (i.e., confined conditions).

4.2.3.1. Unconsolidated Sediments

Based on the airlift tests conducted in PW-08-09, completed in sand and gravel in the Pebble deposit area (Drawing 13), the S_s of the unconsolidated sediments was estimated to have a geometric mean of $3x10^{-6}$ ft^{-1}. Based on airlift tests conducted in PW-3, -4, -6, and -7, located along the SKF drainage south of Frying Pan Lake, the S_s of the unconsolidated sediments was estimated to range from $8x10^{-6}$ to $3x10^{-4}$ ft^{-1}. The S_y calculated for three of the four tests ranged from 0.1 to 0.2. In addition to the short-term, variable-rate airlift tests, a 48-hour, larger-scale pumping test was completed in GH12-334S (Drawing 13) in 2013. The pumping test, which targeted the confined lower-unconsolidated sediments and bedrock contact zone near the proposed open pit, resulted in a geometric mean S_s of $6x10^{-5}$ ft^{-1}. The memorandum presenting analysis of the 2013 pumping test at GH12-334S is included as Appendix B.

4.2.3.2. Bedrock

Based on airlift tests conducted in wells PW-1, PW-5, PW-8, and PW08-10, completed in bedrock in the South Fork flats, Pebble deposit, and NFK areas (Drawings 12 and 13), the S_s of the upper 60 ft of bedrock was estimated to range from $8x10^{-7}$ to $1x10^{-4}$ ft^{-1}. The S_y was calculated for two of the airlift tests and ranged from 0.04 to 0.1.

4.3. Conceptual Hydrogeologic Models

The baseline conceptual hydrogeologic model (i.e., Conceptual Model) for the Project is informed by site investigations, monitoring data, and modeling work completed over approximately a decade. Hydrogeologic conditions in the Project area are discussed in detail in PLP (2011a) and PLP (2015). Drawing on previous work and the details provided in the preceding report sections, the Conceptual Model for the Project, along with additional detail on the conceptual understanding of the mining operations and post-closure periods, is presented below.

4.3.1. Baseline

The hydrostratigraphy of the Project area is conceptualized to include three main hydrogeologic units: unconsolidated sediments, weathered bedrock, and competent bedrock. The unconsolidated sediments have variable hydrogeologic properties, ranging from highly permeable sands and gravels to very low permeability clays. The weathered bedrock unit, which is considered to have a thickness up to 50 ft (e.g., PLP, 2015), tends to be more permeable than the underlying competent bedrock. In general, the K of the bedrock decreases with depth, though this decrease is considered minor relative to the decrease in K between weathered and competent bedrock. The bedrock is cut by a number of faults, however there is no strong evidence to suggest that any particular fault controls groundwater flow. Therefore, fault structures are not defined as separate hydrogeologic features in the Conceptual Model.

Groundwater recharge enters the hydrogeologic system from precipitation, snowmelt, and seepage from lakes and drainages; recharge occurs over about 7 months of the year (i.e., April or May through October). Groundwater recharge rates vary spatially, and are influenced by variability in surficial geology, topographic slope, and position within the groundwater flow system (i.e., recharge vs. discharge location). Groundwater leaves the hydrogeologic system at zones of discharge (i.e., rivers, creeks, seeps, wetlands and other low-lying areas) year-round, and seasonally via evapotranspiration. As a result, groundwater elevations are observed to be lowest during the spring prior to snowmelt, and highest immediately following freshet and/or autumn rains.

Based on groundwater level observations, the water table is interpreted to mimic surface topography in a subdued fashion. It is located near or at ground surface in low-lying areas, but at greater depths near ridges and ridge tops. Flowing artesian conditions, where groundwater levels are above land surface, are observed in some low-lying discharge areas.

Stream flows in the Project area exhibit characteristic seasonality, with high flows in spring resulting from snowmelt, low flows in early to mid-summer resulting from dry conditions and depleting snow packs, another high-flow period in later summer and early autumn resulting from frequent rainstorms, and the lowest flows (i.e., baseflow) in winter when near-surface freezing occurs and most precipitation falls as snow. Groundwater-surface water interactions within the Project area are complex due to the heterogeneous nature of the surficial geology and the variable topography. Results of stream flow surveys completed during low-flow periods suggest that both the NFK and SFK have both gaining and losing reaches (i.e., sections that receive groundwater discharge and sections that recharge groundwater, respectively), while the UTC is primarily gaining (i.e., receives groundwater discharge; PLP, 2011a).

4.3.2. Mining Operations

A conceptual sketch of the Pebble deposit area and three main watersheds is provided in Figure 4-2. Development of the proposed Project will result in changes to the baseline hydrogeologic regime during mining operations, primarily due to dewatering required to enable open pit advance, modified groundwater recharge rates due to changes in land use, and seepage from mine facilities (i.e., the TSFs and WMPs).

4.3.2.1. Open Pit Dewatering

Mining below the water table requires dewatering. The scale and effort of the dewatering required depends on the hydrogeological characteristics of the rock mass and unconsolidated sediments within and surrounding the excavation, and the depth of the excavation below the water table.

The proposed open pit will be mined over 20 years and will increase in footprint area and depth over time. Commonly used depressurization techniques for open pits include vertical perimeter wells, vertical in-pit wells, and horizontal drains drilled into open pit bench faces (Figure 4-3).

Because the dewatering system for the proposed Pebble pit is at an early stage of design, it is anticipated that all three techniques may be used.

Groundwater withdrawals as part of pit dewatering will result in an area of reduced groundwater levels, referred to as a cone of depression, extending outward from the footprint of the open pit and dewatering well network (Figure 4-3). It is anticipated that the cone of depression will be located primarily within the SFK watershed, but will extend under the upper tributaries of the UTC watershed as well. The reduced groundwater levels are expected to lead to a reduction in stream flow in the upper reaches of the SFK and UTC, which will be offset by discharge of water from the WTPs (KP, 2018b).

4.3.2.2. Altered Recharge Rates and Groundwater Seepage

The Bulk TSF (Drawing 02) will be an unlined facility, with a flow-through Main (northern) Embankment designed to minimize accumulation of water in the TSF. Seepage at the South (southern) Embankment will be managed using an upstream liner or low K embankment core, along with a grout curtain (KP, 2018b). It is anticipated that development of the Bulk TSF will result in increased recharge to the underlying materials, with most seepage discharging to the NFK watershed where it will be collected in the Bulk TSF Main Seepage Collection Pond (SCP).

The Pyritic TSF, Main WMP, and Open Pit WMP (Drawing 02) will be fully lined facilities. Therefore, groundwater recharge to the underlying materials will be appreciably decreased within the footprints of these facilities, compared to baseline conditions. Both the Main WMP and Pyritic TSF will have underdrains installed below the liners to direct groundwater drainage below the facilities towards designated collection points (KP, 2018b). It is anticipated that seepage from these facilities will report to proposed SCPs or the open pit (i.e., for the Open Pit WMP) and that any additional seepage would be detected by monitoring and managed appropriately (e.g., seepage interception by wells, trenches, or other methods).

Throughout active mining, runoff and shallow infiltration from rainfall and snowmelt to the open pit will be limited through interception by the slope depressurization and surface water management systems, such that groundwater recharge within the footprint of the open pit will be effectively reduced.

4.3.3. Post-Closure

The post-closure water management plan for the Project is described by KP (2018c). The Main WMP will be fully reclaimed, with discharge of surface water runoff routed to the downstream environment. The Bulk TSF will be reclaimed by re-sloping the facility and covering the tailings beach with low-permeability cover and rockfill materials. The low-permeability cover will limit infiltration into the former tailings beach, and will promote surface runoff that will be directed to a spillway. Reclamation of the Pyritic TSF will include transfer of PAG waste rock and pyritic tailings to the open pit, followed by regrading and reclamation of the facility footprint.

Pit dewatering will cease when mining and placement of waste materials within the open pit is complete (KP, 2018c). After this time, the groundwater system will begin to recover, and the open pit will fill with surface water runoff and groundwater, eventually approaching baseline conditions with a pit lake located in the former open pit (Figure 4-4). The pit lake elevation will be managed to prevent seepage from the pit lake to the groundwater system and to avoid unmanaged flow from the pit lake to surface water. Surplus water will be pumped and treated to maintain a water level below an elevation of 900 ft**.**

Inflows to the open pit during the post-closure period will consist of direct precipitation and surface runoff, groundwater flows, and Bulk TSF seepage collected at the Bulk TSF SCPs. Outflows from the pit lake will include evaporation and water pumped from the lake to a WTP for treatment and discharge to the receiving environment (Figure 4-4). At this stage, groundwater levels will approach baseline conditions; however, the managed lake water level will result in a slight hydraulic gradient directing groundwater flow towards the open pit, making the pit lake a groundwater sink.

5.0 GROUNDWATER FLOW MODEL DEVELOPMENT

5.1. Model Framework

The objective for development of the Groundwater Flow Model is to simulate groundwater flow directions and groundwater flow rates by incorporating controlling features of the Conceptual Model for the site described in Section 4.3. A baseline model was first developed and calibrated to existing conditions. Following calibration, the baseline model was modified to simulate hydrogeologic conditions for the Project area at the end of mining and during the post-closure period.

The Groundwater Flow Model for baseline conditions was used to represent the following components of the hydrologic system:

- Groundwater flow within the study area
- Surface water flow within the study area
- Groundwater/surface water interaction
- Groundwater recharge
- Groundwater evapotranspiration
- Groundwater/surface water flow exiting the study area.

Surface water flow within the study area was simulated using a simplified channel network to incorporate groundwater/surface water interactions and to estimate potential changes to stream baseflow associated with proposed mine development. While appropriate for simulating the interaction of the groundwater system with surface waters, this approach is limited in its ability to represent rapidly changing stream flows (e.g., peak flows following snowmelt or large precipitation events).

The numerical code selected for the Project had to be capable of simulating the hydrological components identified above, together with the aspects of the Conceptual Model identified in Section 4.3. With these considerations, MODFLOW-USG (Panday et al., 2013) was selected as the numerical code. Groundwater Vistas (Version 7; ESI., 2017), a graphical user interface, was used to develop the MODFLOW-USG groundwater flow model for the site. AlgoMesh (Version 1.2.0.37827; HAPL, 2016), a grid/mesh generation software, was used to generate the Voronoi grid for the model domain.

MODFLOW is an industry standard 3-D finite-difference flow model developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988; Harbaugh et al., 2000; Harbaugh, 2005) to simulate transient groundwater flow in a continuous porous medium under a variety of hydrogeological boundaries and stresses. MODFLOW-USG is an unstructured grid version of MODFLOW that incorporates a generalized control-volume finite-difference approach that allows use of non-orthogonal unstructured grid types.

5.2. Overview of Model Development

A previous groundwater model for the Project was developed by Piteau Associates (PLP, 2011a) using MODFLOW-SURFACT (HGL, 2015). The Piteau model domain documented in PLP

(2011a) was similar to the model domain used for this assessment (see Section 5.3), but also extended east to the confluence of the Chulitna River with Lake Clark and west to an arbitrary easting of approximately 1,259,600 ft. The Piteau model was discretized using uniform 1,000 ft rectangular grid cells and 5 layers. The Piteau model was calibrated to baseline conditions from 2004 to 2007 and compared to flow predictions from the Watershed Module (PLP, 2011a). Work completed since 2011 has included incorporation of additional hydrogeologic data and extension of the calibration period to 2008 (PLP, 2019b), as well as evaluation of the groundwater flow regime at the end of mining and post-closure (Piteau, 2018).

The Groundwater Flow Model developed by BGC for the current assessment provides an update to the previous work, incorporating additional data collected since 2008, and has been designed to provide greater resolution within the Project area.

5.3. Model Domain

The Groundwater Flow Model domain encompasses the area shown in Drawing 03, including the entire watersheds of the NFK, SFK, and UTC. The model domain was generally defined along drainages and surface water divides. Exceptions include segments along the western model edge where the Koktuli River, the Stuyahok River, and Kaskanak Creek exit the model domain, and along the northeastern model edge where the Chulitna River exits the model domain.

5.3.1. Horizontal Discretization

The Groundwater Flow Model consists of 80,211 Voronoi cells per layer covering an area of approximately 1,100 square miles (Figure 5-1). Model cells were specified to be approximately 300 ft wide in watersheds within the general vicinity of the mine area. Outside of the mine area, model cells were expanded progressively from 1,000 ft to a maximum of 3,000 ft.

5.3.2. Vertical Discretization

The top of model layer 1 was set to ground surface using a compiled topographic dataset for the Project area provided by PLP and regional topographic contours from the U.S. Geological Survey. Twelve model layers were used to discretize the groundwater flow model domain vertically, for a total of 962,532 model cells. Definition of model layers was guided by requirements for adequate delineation of hydrogeologic units, defined in Section 5.5. Model layers 1 to 3 were used to represent unconsolidated sediments and varied in thickness from 3 ft to approximately 130 ft. Model layer 4 was specified to have a uniform thickness of 50 ft and was used to represent weathered bedrock. The eight remaining model layers were used to represent competent bedrock. The thickness of these model layers was gradually expanded from 80 ft to a maximum thickness of 2,600 ft in layer 12. The base of the model was set to a uniform elevation of -5,500 ft, resulting in the total thickness of the model ranging from approximately 5,500 ft to 8,500 ft.

5.4. Temporal Discretization

The Groundwater Flow Model was used to simulate both steady-state (i.e., no change in groundwater levels or storage over time) and transient (i.e., changing groundwater levels and storage) conditions. Steady-state simulations were used to calibrate the model to long-term average annual groundwater levels and stream flows, and to predict the influence of the Project on groundwater conditions at the end of mining operations and following mine closure. Transient simulations were used to calibrate the model to seasonal differences in groundwater levels and stream flows for average monthly conditions, monthly conditions from 2004 to 2012, and to simulate the 48-hour pumping test at GH12-334S.

For the monthly transient simulations, monthly stress periods (i.e., length of time with constant boundary conditions) were used. In general, each stress period was simulated using one timestep; however, the Adaptive Time Stepping (ATS) scheme was used to allow simulation of multiple timesteps per stress period as required, with the length of the additional timesteps automatically calculated by the numerical model code.

For the pumping test simulation, stress period lengths were approximately 2 days and coincided with observed pumping and recovery periods. For this simulation, each stress period was discretized using approximately 10 to 50 timesteps.

5.5. Hydrogeologic Units

The model domain was broken into three general hydrogeologic units identified in Section 4.3.1, including unconsolidated sediments, weathered bedrock, and competent bedrock. The distribution of hydrogeologic units assigned within each model layer is shown in Appendix C and summarized in the following sections. Cross-sections through the Project area depicting assigned distributions of unconsolidated sediments and bedrock hydrogeologic units are provided in Figure 5-2 to Figure 5-4 and Figure 5-5 to Figure 5-7, respectively.

5.5.1. Unconsolidated Sediments

Within the area investigated to support hydrogeologic and geotechnical studies (Drawing 01), the depth of unconsolidated sediments within the model domain (Figure 5-8) was specified based on available site investigation data and surficial geology mapping (Hamilton, 2007, 2011; Wilson et al., 2009). Outside of this area, assigned unconsolidated sediment depths were specified using surficial geology mapping with the assumption that similar thicknesses of unconsolidated sediments are present across the study area. The influence of specified unconsolidated sediment depth outside of the area of investigation was evaluated using sensitivity simulations (see Section 9.0).

Unconsolidated sediments were assigned to model layers 1 to 3, with a minimum specified thickness of 3 ft. Distributions of unconsolidated sediments and the hydraulic properties assigned to them were based on logged material descriptions and generalized material types from surficial geology mapping (Drawing 04). Within the area with site investigation data, logged textural classes were assigned a thickness-weighted numerical value and interpolated within each model layer using a kriging algorithm. Outside of this area, the material distributions were specified to be constant with depth.

5.5.2. Bedrock

Model cells in bedrock outcrop areas and areas of thin (i.e., <3 ft) unconsolidated sediments within layers 1 to 3 were specified to be weathered bedrock. Within the uniform 50 ft thick model layer 4, all model cells were specified to be weathered bedrock.

The spatial distribution of bedrock hydrogeologic units was specified in model layers 5 to 12 based on regional geologic polygons (Drawing 08). Outside of the Project area, the vertical distribution of bedrock units was assumed to remain constant with depth. Within the Project area, the lateral and vertical distributions of bedrock hydrogeologic units were modified to reflect material distributions within the Project area 3-D geologic model.

Fault structures within the bedrock have not been defined as discrete hydrogeologic features within the Conceptual Model, as available data (Section 4.0) collected to date suggest faults do not have a controlling effect on groundwater flow at the site. Nevertheless, the potential influence of Project area faults that have been identified (Drawing 08) was evaluated using sensitivity simulations (see Section 9.0).

5.6. Boundary Conditions

5.6.1. Atmospheric Fluxes

Precipitation was estimated across the model domain to constrain simulated groundwater evapotranspiration, groundwater recharge, and surface runoff rates within the Groundwater Flow Model. Where possible, precipitation for each model cell (Figure 5-9) was derived from KP (2018a; see Appendix D). Outside the area of coverage provided in KP (2018a), precipitation was estimated by interpolation and extrapolation of mean values from the synthetic climate datasets for Iliamna Airport and Pebble 1 climate stations (KP, 2018a). For each model cell, an external water budget calculation was performed to determine the available water, referred to as the net precipitation:

$$Net\ Precipitation = Precipitation - Actual\ Evapotranspiration - Sublimation$$

Using this equation, actual evapotranspiration and sublimation (see Section 3.1) were removed from the total precipitation in calculations conducted external to the model. The remaining net precipitation was then partitioned into groundwater recharge (see Section 5.6.1.1) and surface runoff (see Section 5.6.2). Groundwater evapotranspiration, equal to the difference between potential and actual evapotranspiration, was also applied within the model (see Section 5.6.1.2).

5.6.1.1. Groundwater Recharge

Groundwater recharge was simulated using the Recharge (RCH) package. The recharge rate (Figure 5-10) was specified based on surficial geology and the Watershed Module and ranged from 2.0 in/yr in clay materials to 31.5 in/yr in sands and gravels. For transient simulations, the monthly distribution of groundwater recharge was based on precipitation patterns, with snowmelt simulated to occur over the months of April through June.

5.6.1.2. Groundwater Evapotranspiration

Groundwater evapotranspiration was simulated using the Evapotranspiration (EVT) package. The groundwater evapotranspiration rate was specified to be uniform across the model domain, and equal to the difference between potential evapotranspiration and actual evapotranspiration (Table 3-1). The evapotranspiration extinction depth (i.e., water table depth below which evapotranspiration is zero) was assumed to range from 2 ft in unconsolidated sediments to 1 ft within weathered bedrock based on predominant vegetation types (PLP, 2011e; 2011g) and typical rooting depths for tundra areas (Canadell et al., 1996). In model cells with simulated lakes and water courses, the groundwater evapotranspiration rate was specified to be zero.

5.6.2. Rivers and Creeks

Within the NFK, SFK, Koktuli River, and UTC watersheds, surface water was routed through rivers and creeks using the Streamflow-Routing (SFR) package (Figure 5-11). Stream bed elevations and stages for each water course were estimated from surface topography and the K of the streambed material was specified to be $3x10^{-4}$ ft/s. Surface runoff (i.e., overland flow and interflow) was assigned to SFR cells based on the remaining precipitation (i.e., after removing evapotranspiration, sublimation, and groundwater recharge) within contributing watershed areas (Figure 5-12).

In the remaining watersheds, rivers and creeks were simulated using the General-Head Boundary (GHB) package (Figure 5-11). Consistent with SFR cells, stream bed elevations and stages for each water course were estimated from surface topography and the K of the streambed material was specified to be $3x10^{-4}$ ft/s.

5.6.3. Lakes and Ponds

Lakes and ponds within the model domain were simulated using the GHB package (Figure 5-11). Lake elevations were estimated from surface topography and the K of the lake bed material was specified to be $3x10^{-7}$ ft/s. Lakes and ponds with areas considerably smaller than the respective grid cell area were not explicitly simulated but were represented by allowing water to pond above the simulated ground surface.

5.6.4. Groundwater Outflow

Groundwater outflow or discharge from the model was simulated at ground surface and from the perimeter of the model using the Drain (DRN) package and Specified Gradient Boundary (SGB) package, respectively. The DRN package was used to simulate surface seeps throughout the model domain, with the discharge elevation set to 1 ft above ground surface. The SGB package was used to simulate groundwater outflow from the model within unconsolidated sediments along the western model edge where the Koktuli River, the Stuyahok River, and Kaskanak Creek exit the model domain, and along the northeastern model edge where the Chulitna River exits the model domain (Figure 5-11). At each location, a horizontal gradient of 0.01 was assumed based on the topographic slope.

5.6.5. Pumping Wells

Groundwater extracted during the simulated pumping test at GH12-334S (see Section 6.0) was simulated using the Well (WEL) and Connected Linear Network (CLN) packages. Simulated pumping rates were specified based on available flow measurements.

5.6.6. No Flow Boundaries

No flow boundaries were assumed to be present in all layers along the model perimeter at surface water divides and below drainages. The base of the model was also assumed to represent a no flow boundary.

6.0 GROUNDWATER FLOW MODEL CALIBRATION

The baseline Groundwater Flow Model was calibrated to groundwater levels and stream flows in four stages. In the first stage, steady-state simulations were used to calibrate the model to long-term average annual groundwater levels and stream flows, and qualitatively assess simulated vertical hydraulic gradients at nested monitoring well locations. In this stage, the model was calibrated by adjusting K, annual groundwater recharge, and annual surface runoff to improve the match between observed and simulated values. In the second and third stages, transient simulations were used to calibrate the model to seasonal differences in groundwater levels and stream flows. Simulations were conducted for both long-term average monthly conditions (stage 2) and for the years 2004 to 2012 (stage 3). In these stages, the model was calibrated by adjusting storage properties, and the distributions of monthly groundwater recharge and surface runoff. In the fourth stage, transient simulations were used to calibrate the model to a 48-hour pumping test conducted at GH12-334S in 2013 (Appendix B) by locally adjusting K and storage properties. A local-scale model was developed for this stage to assist in the calibration process (Appendix E). Modifications to the distribution of K and storage properties within the local-scale model were incorporated into the Groundwater Flow Model such that a consistent set of parameters was used by both models for all calibration scenarios.

The resulting set of calibrated hydrogeologic parameters are listed in Table 6-1. The monthly distribution of average atmospheric fluxes including groundwater recharge are plotted in Figure 6-1.

6.1. Calibration Targets

Groundwater levels were available for 551 locations within the model domain, with the dataset spanning the years 2004 to 2012. For the stage 1 steady-state model calibration, the arithmetic average of available data was used for calibration at each target location. The simulated vertical direction of groundwater flow was also qualitatively assessed at 63 locations (Drawing 16) where the observed direction of groundwater flow is consistent throughout the year. Similarly, for the stage 2 transient calibration, arithmetic average monthly water levels were used for calibration. However, in stage 2 the number of targets was reduced to 72 locations using the constraint that each location must have a minimum of 3 measurements for each month of the year. For the stage 3 transient calibration, all available water level data for each of the 551 locations were used for calibration. For the stage 4 calibration, drawdown measurements from 5 targets were available, including the pumping well and 4 observation wells.

Stream flow observations from 26 gaging stations located within NFK, SFK, and UTC watersheds were used for the first three stages of model calibration. Similar to the groundwater level targets, arithmetic average stream flows were used for the stage 1 steady-state and the stage 2 transient calibration, while all available data were used for stage 3 transient calibration. For the stage 4 calibration, stream flows were not utilized as calibration targets; well pumping rates were used to constrain the solution.

Targets used for calibrating the Groundwater Flow Model for each calibration stage are summarized in Table 6-2.

6.2. Results

6.2.1. Stage 1: Steady-State

Simulated and observed groundwater levels and stream flows for average annual conditions are shown in Figure 6-2. Spatial distributions of groundwater level residuals are also plotted in Appendix F. The normalized root mean square errors (NRMSE) of 2.0% and 6.6% for groundwater levels and stream flows, respectively, are well within recommended guidelines (i.e., NRMSE<10%; NBLM, 2006; BCMOE, 2012). Simulated vertical groundwater flow directions also match the observed direction of vertical groundwater at 75% of the 63 target locations (Figure 6-3), indicating that the average condition of the hydrogeologic system was well-replicated.

6.2.2. Stage 2: Average Monthly Conditions

Simulated and observed groundwater levels and stream flows for average monthly conditions are shown in Figure 6-4. Calibration statistics are similar to the stage 1 calibration, with NRMSE of 2.1% and 6.7% for hydraulic heads and stream flows, respectively.

Time series plots for average monthly conditions are provided at monitoring wells completed in unconsolidated sediments (Figure 6-5) and bedrock (Figure 6-6), and at stream gaging stations (Figure 6-7) for selected target locations. At the groundwater level targets, there is generally an offset between the simulated and observed groundwater level (i.e., 0 ft to 35 ft in plots shown); however, overall trends in the period and amplitude of seasonal groundwater levels are well-captured. At the stream flow targets, simulated seasonal trends in stream flows are similarly well-represented.

6.2.3. Stage 3: 2004 to 2012 Conditions

Simulated and observed groundwater levels and stream flows for 2004 to 2012 conditions are shown in Figure 6-8 and Figure 6-9, respectively; time series plots are provided at monitoring wells completed in unconsolidated sediments (Figure 6-10), bedrock (Figure 6-11), and at stream gaging stations (Figure 6-12) for selected target locations. The NRMSE of 1.8% (groundwater levels) and 7.4% (stream flows) for this stage of calibration are also well within recommended guidelines, indicating that the model provided a good representation of transient changes in groundwater levels and stream flows for the period of record.

Time series plots at groundwater level targets show that the magnitude and timing of seasonal fluctuations are well-captured, consistent with simulated results for average monthly conditions. Seasonal changes in stream flows are also well-represented.

6.2.4. Stage 4: GH12-334S Pumping Test

Simulated and observed drawdown at pumping well GH12-334S and surrounding observation wells are shown in Figure 6-13. At the pumping well, the maximum drawdown was overpredicted by approximately 5.3 ft. At the observation wells, the simulated maximum drawdown ranged from being underpredicted by 2.3 ft at GH11-265S to being overpredicted by 0.8 ft at P-05-36M. The results indicate that the observed timing and magnitude of the response to pumping was well-replicated and is similar in magnitude to predictions from the local-scale model (Appendix E).

6.3. Groundwater Flow System

Simulation results agree with the observation that the water table mimics topography (Figure 6-14), with groundwater flow from topographically higher locations towards streams and drainages. Inflows to the groundwater system in the NFK, SFK, and UTC watersheds are predicted to consist of predominately groundwater recharge (40 to 50%) and seepage from surface water bodies and drainages (30 to 50%; Table 6-3). Within these watersheds, outflows from the groundwater system are predicted to consist predominately of discharge to surface water bodies and drainages (60 to 80%). Within the SFK watershed, where groundwater flow between the SFK and UTC watersheds has been identified, groundwater outflow to adjacent watersheds comprises approximately 40% of the total outflow. On an annual basis, gaining and losing sections of drainages are predicted throughout the NFK, SFK, and UTC watersheds (Figure 6-15), the location of which are governed by topographic slope, depth of unconsolidated deposits, and the distribution of hydraulic conductivity.

6.4. Summary

The overall model calibration and baseline model results are summarized as follows:

- The Groundwater Flow Model was calibrated in four stages, which included average annual conditions, average monthly conditions, 2004 to 2012 conditions, and a 48-hour pumping test conducted at GH12-334S.
- Simulated groundwater levels show good agreement to measured groundwater levels, including observed seasonal fluctuations and vertical groundwater flow directions.
- Simulated stream flows also show good agreement with available observations, including seasonal fluctuations.
- Calibrated hydraulic conductivity and storage parameters are within observed ranges.
- The simulated water table mimics topography, with groundwater flow from topographically higher locations towards streams and drainages. Inflows to the groundwater system in the NFK, SFK, and UTC watersheds are predicted to consist of predominantly groundwater recharge and seepage from surface water bodies and drainages; outflows from the groundwater system are predicted to consist predominantly of discharge to surface water bodies and drainages.

7.0 END-OF-MINING OPERATIONS ANALYSIS

7.1. Overview

The calibrated Groundwater Flow Model was used to predict potential impacts to the hydrogeological system, compared to the baseline scenario, due to development of the Project, including:

- The rate of groundwater extraction at the proposed open pit
- Seepage rates from the proposed Bulk TSF
- Changes in groundwater discharge or baseflow to tributaries of NFK, SFK, and UTC watersheds
- Changes in groundwater elevation (i.e., drawdown and mounding).

Groundwater extracted at the proposed open pit will consist of water reporting directly to the pit as well as water collected from groundwater extraction wells (PLP, 2018a), which will be required to achieve pit slope depressurization needs and aid in maintenance of dry working conditions. Dewatering plans have not yet been developed at this stage of the Project; therefore, a scenario was simulated that did not include pit dewatering wells. However, a conceptual pit dewatering layout was simulated in a pumping well scenario to estimate potential additional Project impacts that may occur (e.g., groundwater extraction rates, drawdown extent). Within the pumping well scenario, conceptual layouts of seepage collection wells were also simulated.

Steady-state simulations were conducted for end-of-mining conditions for the proposed Project (Drawing 02). Two scenarios were simulated:

- A scenario without pumping wells for pit dewatering and seepage collection downstream of proposed mine facilities, and
- A pumping well scenario with pit dewatering wells and seepage collection wells at locations where migration of water from mine facilities was predicted in the base case scenario.

Details of modifications to the steady-state baseline model incorporated for this analysis, including the vertical extent of the model domain, distribution of hydrogeologic units, and boundary conditions are provided in the following sections.

7.2. Model Domain

The model domain was modified to explicitly define the Bulk TSF and allow prediction of the total seepage rate (i.e., embankment and foundation seepage and basin seepage; Figure 7-1) using a single model. Three additional layers (i.e., layers 1A to 3A) were added to the baseline Groundwater Flow Model (Section 5.3). The top of model layer 1A was set to the top of the proposed Bulk TSF based on cross-sections through the Main Embankment and South Embankment (USACE, 2019) and a conceptual tailings surface provided by KP (email attachment, personal communication, March 25, 2019), with resulting layer thickness ranging from 3 ft to approximately 170 ft. Outside of the footprint of the Bulk TSF, all model cells in layers 1A to 3A were assigned a nominal thickness of 1 ft and specified to be inactive.

7.3. Hydrogeologic Units

Materials within the Bulk TSF, including tailings and embankment materials, were assigned in model layers 1A to 3A based on cross-sections through the Main Embankment and South Embankment (USACE, 2019; Figure 7-2). The tailings were conservatively specified to have an isotropic K of $3x10^{-6}$ ft/s (Table 7-1), consistent with coarse tailings properties assumed in previous seepage assessments conducted (KP, personal communication, March 25, 2019). The embankment materials were specified to have a horizontal K of $3x10^{-5}$ ft/s and a vertical K of $3x10^{-6}$ ft/s based on the assumption that the materials would be compacted during construction.

Proposed seepage control measures include a combination of an upstream liner or low K embankment core along with a grout curtain (KP, 2018b). At the Bulk TSF South Embankment and Bulk TSF SCPs, these features were simulated using a line of model cells with isotropic K set at 10^{-7} ft/s (Table 7-1) from the top of the active model to the base of weathered bedrock in model layer 4 (Figures 7-2 and 7-3). The proposed Bulk TSF Main Embankment will be operated as a flow-through dam; therefore, seepage control measures were not simulated within the embankment.

7.4. Boundary Conditions

The distribution of boundary conditions used to simulate proposed mine facilities at the end of mining are shown in Figure 7-3.

7.4.1. Groundwater Recharge

Groundwater recharge was modified from the baseline model within the footprints of proposed mine facilities. Within the open pit where bedrock will be exposed at surface, the recharge rate was reduced to 3.9 in/yr, equivalent to the rate specified for weathered bedrock in bedrock outcrop areas. Similarly, within Quarry B and Quarry C, the recharge rate was reduced to 3.9 in. Within the footprints of the embankments, stockpiles, and Bulk TSF tailings, the recharge rate was specified to be 7 in/yr, approximately equivalent to the rate specified for a sandy silt.

Within the footprint of the lined Main WMP and Pyritic TSF, groundwater recharge was set to a leakage rate of approximately 16 US gpm (0.04 cfs or 1 L/s) distributed across each impoundment based on available seepage estimates (Piteau, 2018), corresponding to a groundwater recharge rate of approximately 0.5 in/yr for the Main WMP and 0.7 in/yr for the Pyritic TSF. Within the footprint of the lined Open Pit WMP, the recharge rate was specified based on an assumed leakage rate of approximately 1.6 US gpm (0.004 cfs; 0.4 in/yr) based on a comparison of the facility's area relative to the Main WMP and Pyritic TSF.

7.4.2. Groundwater Evapotranspiration

Consistent with groundwater recharge, groundwater evapotranspiration was modified from the baseline model within the footprints of proposed mine facilities. Within the open pit, quarries, embankments, stockpiles, and lined ponds, groundwater evapotranspiration was specified to be

0 in/yr. Within the Bulk TSF tailings, the groundwater evapotranspiration rate was unchanged; however, the evapotranspiration extinction depth was reduced to 1 ft.

7.4.3. Open Pit and Quarries

The proposed open pit was simulated using the DRN package. Water levels within the DRN cells were specified at the maximum depth of mining, with a minimum pit bottom elevation of -500 ft and maximum depth of more than 1,650 ft. Quarry B and Quarry C were also simulated using the DRN package, with boundary water levels set to 2,009 ft and 1,831 ft, respectively. Quarry A was not simulated as it lies within the footprint of the Bulk TSF.

7.4.4. Bulk TSF Ponds

The Bulk TSF pond was simulated using the GHB package within the footprint shown in Drawing 02 and Figure 7-3, with the water level set to an elevation of 1,690 ft (Piteau, 2018). The Bulk TSF North SCP and Bulk TSF South SCP were also simulated using the GHB package, with estimated operating water levels of 1,130 ft and 1,350 ft, respectively. The Bulk TSF East SCP, located at higher elevation than the Bulk TSF pond, was simulated using the DRN package with an estimated operating water level of 1,765 ft.

7.4.5. Pumping Wells

Pit dewatering wells and seepage collection wells were included in the pumping well scenario. The wells were simulated using the WEL package with simulated pumping rates ranging from 3 US gpm (0.01 cfs) to 150 US gpm (0.33 cfs). Each well was assumed to extend from ground surface to the base of the weathered bedrock in model layer 4, with depths ranging from approximately 60 ft to 200 ft. The wells were simulated to be screened across their entire extent by specifying elevated values of hydraulic conductivity in model cells intersected by the simulated well screens.

7.4.6. Rivers and Creeks

The SFR cells used to simulate tributaries of NFK and SFK within the proposed mine footprint were removed for the end-of-mining operations analysis. Within these watersheds, it was assumed that runoff and groundwater discharge would be diverted to contact water management facilities consistent with the proposed operations water management plan (KP, 2018b).

7.4.7. Groundwater Outflow

Within the footprints of the Main WMP, Pyritic TSF, Open Pit WMP, stockpiles, and tailings, DRN boundaries used in the baseline model to simulate groundwater outflow were removed to allow groundwater mounding to occur. Groundwater discharging to these facilities will be managed through systems composed of ditches and underdrains (i.e., for lined facilities); however, details of the drainage systems were not available to allow representation within the model.

7.5. Particle Tracking

Mod-PATH3DU (Muffels et al., 2016), a particle tracking code, was used to predict groundwater flow paths and travel times from the Bulk TSF, Pyritic TSF, Main WMP, and Open Pit WMP. Within the Bulk TSF, particles were specified to be released in all model cells within layers 1A to 3A simulated as tailings. Within the Pyritic TSF, Main WMP, and Open Pit WMP, particles were specified to be released in all model cells in layer 1 within the footprint of the lined ponds. Simulated particles were tracked forward in time using the Waterloo Method (Muffels et al., 2016) until they were predicted to either exit the flow system (i.e., at the ground surface or to a surface water body) or until their travel time reached the specified maximum travel time of 100 years. Each particle was started below the predicted water table; therefore, predicted travel times are limited to flow within the saturated groundwater system. The simulated porosity of the Bulk TSF tailings, Bulk TSF embankments, and seepage control are summarized in Table 7-1. In the unconsolidated deposits and bedrock, the simulated porosity was specified to be equivalent to the simulated S_y (Table 6-1).

7.6. Results

Results of the two end-of-mining simulations are summarized below. Where differences between the scenarios with and without pumping wells are predicted, the results for each scenario are described separately.

7.6.1. Open Pit Groundwater Extraction

Groundwater extraction at the open pit for the scenario without pit dewatering wells is predicted to be approximately 980 US gpm (2.2 cfs). For the pumping well scenario, the total groundwater extraction rate is predicted to increase to 1,350 US gpm (3.0 cfs), with 500 US gpm (1.1 cfs) and 850 US gpm (1.9 cfs) extracted at the open pit and pit dewatering wells, respectively.

7.6.2. Bulk TSF Seepage

The total seepage rate from the Bulk TSF to groundwater is predicted to be approximately 630 US gpm (1.4 cfs). Basin seepage (Figure 7-1) is predicted to comprise 66% (415 US gpm; 0.9 cfs) of the total seepage rate, with 30% (190 US gpm; 0.4 cfs) and 4% (25 US gpm; 0.06 cfs) leaving the facility through the Main Embankment and South Embankment, respectively. Groundwater discharge to the Bulk TSF from the surrounding ridges is predicted to be approximately 130 US gpm (0.3 cfs).

These seepage rates are lower than previous estimates for seepage through the Main Embankment, which ranged from approximately 1,350 to 6,280 US gpm (3 to 14 cfs; PLP, 2018b). However, it was noted that the predicted seepage rates were sensitive to the simulated extent of the pond. Consequently, differences in pond location and extent may account for some of the differences between the previous and current model estimates. Nevertheless, the extent of the Bulk TSF pond simulated by the Groundwater Flow Model is consistent with the proposed operational water management plan (KP, 2018b).

Groundwater discharge at the downstream side of the Bulk TSF Main and South Embankments is predicted to be approximately 370 US gpm (0.8 cfs) and 45 US gpm (0.1 cfs), respectively. Groundwater discharge to the Bulk TSF SCPs is predicted to be approximately 480 US gpm (1.1 cfs). Most of the groundwater discharge (395 US gpm; 0.9 cfs) is predicted to report to the Bulk TSF North SCP, with the remaining groundwater discharge (85 US gpm; 0.2 cfs) predicted to report to the Bulk TSF South SCP. The predicted total groundwater discharge downstream of the Bulk TSF (895 US gpm; 2.0 cfs) is greater than the total predicted seepage rate from the Bulk TSF, indicating that the discharge will include both TSF seepage and groundwater derived from outside of the footprint of the facility.

7.6.3. End-of-Mining Groundwater Flow System

Plots of predicted water table elevation, water table drawdown and mounding, and drawdown and mounding at the top of competent bedrock in model layer 5 are provided in Figures 7-4, 7-5, and 7-6, for the scenario without pumping wells, and in Figures 7-7, 7-8, and 7-9 for the pumping well scenario. These figures demonstrate that the elevation of the water table is drawn down appreciably within the footprint of the open pit due to the simulated groundwater extraction. The minimum predicted water table elevation (approximately -500 ft) and maximum predicted drawdown (approximately 1,615 ft) at the end of mining are present at the low point of the open pit. Drawdown due to the open pit is predicted to be primarily restricted to the SFK watershed; however, the cone of depression (i.e., approximated by the predicted 3 ft drawdown contour) is predicted to extend under the upper tributaries of the UTC watershed. Near the open pit, the drawdown extent is predicted to be similar for scenarios with and without pumping wells.

At Quarry B and Quarry C, the water table is predicted to be drawn down to the base of the quarries to elevations of 2,009 ft and 1,831 ft, respectively. Drawdown within both quarries is predicted to reach approximately 150 ft.

At the Bulk TSF, a large groundwater mound is predicted to develop, with increased groundwater levels up to 400 ft. The groundwater mound is predicted to be primarily restricted to the footprint of the Bulk TSF, except for an area located to the southeast of the facility where the mounding is predicted to extend towards several tributaries of the SFK. However, groundwater levels in this region are predicted to remain elevated above the Bulk TSF, with groundwater flow directions oriented from the ridge tops towards the facility.

At the Bulk TSF North SCP and Bulk TSF South SCP, groundwater mounding is predicted within the footprint of the simulated ponds. At the downstream end of these SCPs, groundwater flow is restricted by the simulated grout curtains resulting in drawdown being predicted. At the Bulk TSF East SCP, negligible change in groundwater levels is predicted.

Within the footprint of the Main WMP and Pyritic TSF, zones of both drawdown and groundwater mounding are predicted due to the combination of reduced groundwater recharge and evapotranspiration, and removal of groundwater discharge to drainages and seepage areas. For the pumping well scenario, the predicted drawdown extent is appreciably larger due to the simulated groundwater extraction at the seepage collection wells.

7.6.4. Particle Tracking

7.6.4.1. Scenario Without Pumping Wells

Results of the particle tracking simulations for the scenario without pumping wells are provided in Figure 7-10. The results indicate that seepage from the Bulk TSF is predicted to report to the valley bottom immediately downstream of the Main and South Embankments. Predicted particle travel times range from 0 years (i.e., particle started in a model cell with groundwater discharge) to 100 years.

Particle tracking results for the Pyritic TSF predict that seepage from the facility will report to a former tributary of NFK at or near the location of a proposed SCP, with travel times ranging from less than 1 year to approximately 46 years. Some particles are predicted to discharge downstream of the SCP, indicating that additional mitigation measures, such as pumping wells, may need further consideration at this location as the Project design and understanding of the groundwater flow system advances.

Particles released from the Main WMP are predicted to primarily flow northward towards NFK and surrounding lakes and ponds. The area receiving seepage from the facility is predicted to be relatively widespread, indicating a network of pumping wells may be required to control seepage if leakage is detected. Predicted particle travel times for the facility range from less than 1 year to 41 years.

Particle tracking results for the Open Pit WMP indicate that most seepage from the facility will report to the proposed open pit. However, seepage entering the groundwater system along the eastern margin of the facility is predicted to flow towards SFK, indicating that mitigation measures may need to be implemented in this area if seepage is detected. Predicted particle travel times from the Open Pit WMP range from 0 years to 44 years.

7.6.4.2. Pumping Well Scenario

Results of the particle tracking simulations for the pumping well scenario (i.e., with pit dewatering and seepage collection wells) are provided in Figure 7-11. The results indicate that seepage collection wells could be used to manage seepage from the Main WMP, Pyritic TSF, and Open Pit WMP, as no particles are predicted to travel beyond the simulated wells. The predicted groundwater extraction from the seepage collection wells at the Main WMP, Pyritic TSF, and Open Pit WMP is approximately 1,000 US gpm (2.2 cfs), 100 US gpm (0.2 cfs), and 40 US gpm (0.09 cfs), respectively.

7.6.5. Impacts to Rivers and Creeks

Reduced baseflow to tributaries in NFK, SFK, and UTC watersheds is expected due to the removal of several tributaries and the proposed open pit being adjacent to several drainages. Treated water will be released at one discharge location in each watershed (Drawing 02) to offset the loss of baseflow (KP, 2018d); however, this offset was not included within the estimated baseflow reduction presented here. The baseflow estimates presented herein represent a component of the surface water flows presented in the Watershed Module (PLP, 2011a; 2019a), and are distinct from the 'groundwater' estimates generated by the Watershed Module.

Predicted reductions in baseflow for the scenario without pumping wells relative to baseline conditions range from approximately 17 cfs (14%) above NK100A1 gaging station in NFK watershed, to 5 cfs (7%) above SK100B1 gaging station in SFK watershed, to 0.1 cfs (0.7%) above UT100D in UTC watershed. For the pumping well scenario, baseflow reductions are predicted to increase in the NFK and UTC watersheds to 18 cfs (14%) and 0.2 cfs (1.3%), respectively. Within the SFK watershed, the predicted difference in baseflow between the scenarios with and without pumping wells is negligible.

7.7. Summary

The end-of-mining operations analysis is summarized as follows:

- Groundwater extraction at the open pit is predicted to be approximately 980 US gpm (2.2 cfs) for the scenario without pumping wells. For the pumping well scenario, the total groundwater extraction rate is predicted to increase to 1,350 US gpm (3.0 cfs), with 500 US gpm (1.1 cfs) and 850 US gpm (1.9 cfs) extracted at the open pit and pit dewatering wells, respectively.
- The total seepage rate from the Bulk TSF is predicted to be approximately 630 US gpm (1.4 cfs). Basin seepage is predicted to comprise 66% (415 US gpm; 0.9 cfs) of the total seepage rate, with 30% (190 US gpm; 0.4 cfs) and 4% (25 US gpm; 0.06 cfs) occurring through the Main Embankment and South Embankment, respectively. Total predicted groundwater discharge downstream of the Bulk TSF is greater than the total predicted seepage rate from the facility, indicating that the discharge will be composed of both TSF seepage and groundwater derived from outside of the footprint of the facility.
- The minimum predicted water table elevation and maximum predicted drawdown at the end of mining are present at the low point of the open pit, with respective values of approximately -500 ft and 1,615 ft. Drawdown due to the open pit is predicted to be primarily restricted to the SFK watershed; however, the cone of depression is predicted to extend under the upper tributaries of the UTC watershed. Groundwater mounding of up to 400 ft is predicted within the footprint of the Bulk TSF.
- Particle tracking simulations indicate that seepage from the Bulk TSF is predicted to report to the valley bottom immediately downstream of Main and South Embankments. Seepage from the Pyritic TSF, Main WMP, and Open Pit WMP is predicted to flow past proposed SCPs in the scenario without pumping wells. However, results of the pumping well scenario indicate that seepage collection wells could be used to manage seepage at these locations.
- Predicted reductions in stream baseflow for the scenario without pumping wells relative to baseline conditions, excluding discharge of treated water, range from approximately 17 cfs (14%) above NK100A1 gaging station in NFK watershed, to 5 cfs (7%) above SK100B1

gaging station in SFK watershed, to 0.1 cfs (0.7%) above UT100D in UTC watershed. Relative to the scenario without pumping wells, baseflow reduction (excluding discharge of treated water) for the pumping well scenario in NFK and UTC watersheds is predicted to increase to 18 cfs (14%) and 0.2 cfs (1.3%), respectively, while negligible difference is predicted for the SFK watershed.

8.0 POST-CLOSURE ANALYSIS

8.1. Overview

The calibrated Groundwater Flow Model was used to predict potential impacts to the hydrogeological system, compared to the baseline scenario, following closure of the proposed mine, including:

- Groundwater flow rates to/from the open pit lake
- Seepage rates from the reclaimed Bulk TSF
- Changes in baseflow to tributaries of NFK, SFK, and UTC watersheds
- Changes in groundwater elevation (i.e., drawdown and mounding).

Groundwater levels will recover following cessation of groundwater extraction at the open pit and reclamation of other mine facilities such as the Main WMP and Pyritic TSF, eventually approaching baseline conditions at post-closure. However, the managed lake water level will result in a hydraulic gradient directing groundwater flow towards the open pit, making the pit lake a groundwater sink.

Steady-state simulations were conducted for post-closure conditions for the proposed Project (Drawing 02). Details of modifications to the steady-state end-of-mining operations model incorporated for this analysis are provided in the following sections.

8.2. Boundary Conditions

The distribution of boundary conditions used to simulate proposed mine facilities at the end of mining are shown in Figure 8-1.

8.2.1. Groundwater Recharge

Groundwater recharge was modified from the end-of-mining operations model within the footprints of reclaimed mine facilities. Within the Main WMP, Pyritic TSF, Open Pit WMP, and stockpiles, the groundwater recharge rate was specified to be equal to baseline conditions. Within the footprint of the Bulk TSF tailings area, where a low permeability cover will be placed (KP, 2018c), the groundwater recharge rate was decreased to 3 in/yr.

8.2.2. Groundwater Evapotranspiration

Consistent with groundwater recharge, groundwater evapotranspiration was modified from the end-of-mining operations model within the footprints of reclaimed mine facilities. Within the Main WMP, Pyritic TSF, Open Pit WMP, and stockpiles, the groundwater evapotranspiration rate and evapotranspiration extinction depth were specified to be equal to baseline conditions. Within the Bulk TSF tailings, groundwater evapotranspiration from below the low permeability cover was specified to be 0 in/yr.

8.2.3. Open Pit, Pit Lake, and Quarries

Boundary conditions used to simulate the open pit were modified to account for the development of the pit lake. Within the open pit the pit lake was simulated using the GHB package, with the water level set to the maximum managed level at elevation 900 ft (KP, 2018c). Pit walls situated above the maximum managed level were simulated using the DRN package, consistent with the end-of-mining operations model. Similarly, DRN boundaries used to simulate Quarry B and Quarry C were unchanged from the end-of-mining operations model.

8.2.4. Bulk TSF Ponds

The Bulk TSF pond was removed as a boundary condition as reclamation of the Bulk TSF will include draining of the pond (KP, 2018c). Respective GHB and DRN boundary conditions used to simulate the Bulk TSF North SCP and Bulk TSF South SCP, and Bulk TSF East SCP, were unchanged from the end-of-mining operations model.

8.2.5. Rivers and Creeks

The closure water management plan specifies that following mine closure, drainage pathways will be returned to conditions similar to baseline conditions (KP, 2018c). To simulate this scenario, SFR cells used to simulate tributaries of NFK and SFK within the proposed mine footprint, but outside of the footprint of the Bulk TSF and Bulk TSF SCPs were returned to baseline conditions.

8.2.6. Groundwater Outflow

Within the footprints of the Main WMP, Pyritic TSF, Open Pit WMP, and stockpiles, DRN boundaries were specified to simulate groundwater outflow at surface seeps consistent with the baseline model.

8.3. Particle Tracking

Particle tracking simulations were used to predict groundwater flow paths and travel times from the Bulk TSF. Particles were specified to be released in all model cells within layers 1A to 3A simulated as tailings. Simulated particles were tracked forward in time using the Waterloo Method (Muffels et al., 2016) until they were predicted to either exit the flow system (i.e., at the ground surface or a surface water body) or until their travel time reached the specified maximum travel time of 100 years. Predicted travel times are limited to flow through the underlying groundwater system, with each particle starting below the predicted water table.

8.4. Results

8.4.1. Pit Lake Groundwater

Groundwater discharge to the pit lake, including seepage from the pit walls, is predicted to be approximately 800 US gpm (1.8 cfs). Seepage from the pit lake to the groundwater system is predicted to be 0 US gpm (0 cfs). These results are consistent with maintenance of the pit lake at the maximum managed level of 900 ft, which results in a hydraulic gradient directing groundwater flow towards the open pit making the pit lake a groundwater sink.

8.4.2. Bulk TSF Seepage

The total seepage rate from the Bulk TSF is predicted to decrease from the end-of-mining operations model to approximately 420 US gpm (0.9 cfs). Basin seepage (Figure 7-1) is predicted to comprise 69% (285 US gpm; 0.6 cfs) of the total seepage rate, with 27% (115 US gpm; 0.3 cfs) and 4% (20 US gpm; 0.04 cfs) leaving the facility through the Main Embankment and South Embankment, respectively. Groundwater discharge to the Bulk TSF is predicted to be approximately 275 US gpm (0.6 cfs).

Groundwater discharge at the downstream side of the Bulk TSF Main and South Embankments is predicted to be approximately 275 US gpm (0.6 cfs) and 40 US gpm (0.09 cfs), respectively. Groundwater discharge to the Bulk TSF SCPs is predicted to be approximately 505 US gpm (1.1 cfs). Most of the groundwater discharge (420 US gpm; 0.9 cfs) is predicted to report to the Bulk TSF North SCP, with the remaining groundwater discharge predicted to report to the Bulk TSF South SCP (85 US gpm; 0.2 cfs). The predicted total groundwater discharge downstream of the Bulk TSF of 820 US gpm (1.8 cfs) is greater than the total predicted seepage rate from the Bulk TSF, indicating that the discharge will be comprised of both TSF seepage and groundwater derived from outside of the footprint of the facility.

8.4.3. Post-Closure Groundwater Flow System

Plots of predicted water table elevation, water table drawdown and mounding, and drawdown and mounding at the top of competent bedrock in model layer 5 are provided in Figures 8-2, 8-3, and 8-4, respectively. As seen from these figures, the elevation of the water table in the footprint of the pit lake is drawn down a maximum of approximately 400 ft relative to baseline conditions to the elevation of the pit lake at 900 ft. Drawdown due to the pit lake is predicted to be primarily restricted to the SFK watershed; however, the cone of depression is predicted to extend under the upper tributaries of the UTC watershed.

At Quarry B and Quarry C, the water table is predicted to be drawn down to the base of the quarries to elevations of 2,009 ft and 1,831 ft, respectively. Drawdown within both quarries is predicted to reach approximately 150 ft.

At the Bulk TSF, the large groundwater mound predicted by the end-of-mining operations model is predicted to persist through post-closure, with groundwater levels approximately 345 ft above baseline conditions. The groundwater mound is predicted to be primarily restricted to the footprint of the Bulk TSF, except to the southeast of the facility where the mounding is predicted to extend towards several tributaries of SFK. Consistent with the end-of-mining groundwater flow system, groundwater levels in this region are predicted to remain elevated above the Bulk TSF, with groundwater flow directions oriented from the ridge tops towards the facility.

At the Bulk TSF North SCP and Bulk TSF South SCP, groundwater mounding is predicted within the footprint of the simulated ponds. At the downstream end of these SCPs, groundwater flow is restricted by the simulated grout curtains resulting in drawdown being predicted. At the Bulk TSF East SCP, negligible change in groundwater levels is predicted.

Within the footprint of the Main WMP and Pyritic TSF, groundwater levels are predicted to return to near baseline conditions following reclamation of the facilities.

8.4.4. Particle Tracking

Results of the particle tracking simulations are provided in Figure 8-5. The results indicate that seepage from the Bulk TSF is predicted to report to the valley bottom immediately downstream of Main and South Embankments. Predicted particle travel times range from 0 years (i.e., particle started in a model cell with groundwater discharge) to 100 years.

8.4.5. Impacts to Rivers and Creeks

Reduced baseflow to tributaries in NFK, SFK, and UTC watersheds is expected to continue through the post-closure period due to the removal of several tributaries and the close proximity of the pit lake to several drainages. Treated water will be released at one discharge location in each watershed (Drawing 02) to offset the loss of baseflow (KP, 2018d); however, this offset was not included within the estimated baseflow reduction presented here.

Predicted reductions in baseflow relative to baseline conditions range from approximately 14 cfs (11%) above NK100A1 gaging station in NFK watershed, to 4 cfs (6%) above SK100B1 gaging station in SFK watershed, to 0.1 cfs (0.4%) above UT100D in UTC watershed. Because a number of the drainages represented in the baseline simulation (Figure 5-11) are not re-established in the post-closure simulation (Figure 8-1), it is likely that this analysis overpredicts the reduction in baseflow, particularly in the NFK watershed. As additional detail on surface water diversions and water management in general in the post-closure period becomes available, it is anticipated that the predicted baseflow reduction in the NFK watershed will decrease.

8.5. Summary

The post-closure analysis is summarized as follows:

- Groundwater discharge to the pit lake is predicted to be approximately 800 US gpm (1.8 cfs). Seepage from the pit lake to the groundwater system is predicted to be 0 US gpm (0 cfs; i.e., the pit lake, managed at an elevation of 900 ft, will act as a groundwater sink).
- The total seepage rate from the Bulk TSF is predicted to be reduced from the end-of-mining operations model to approximately 420 US gpm (0.9 cfs). Basin seepage is predicted to comprise 69% (285 US gpm; 0.6 cfs) of the total seepage rate, with 27% (115 US gpm; 0.3 cfs) and 4% (20 US gpm; 0.04 cfs) occurring through the Main Embankment and South Embankment, respectively. Total predicted groundwater discharge downstream of the Bulk TSF is greater than the total predicted seepage rate from the facility, indicating that the discharge will be composed of both TSF seepage and groundwater derived from outside of the footprint of the facility.

- The elevation of the water table in the footprint of the pit lake is drawn down a maximum of approximately 400 ft relative to baseline conditions to the elevation of the pit lake at 900 ft. Drawdown due to the pit lake is predicted to be primarily restricted to the SFK watershed; however, the cone of depression is predicted to extend under the upper tributaries of the UTC watershed. Groundwater mounding of up to 345 ft is predicted within the footprint of the Bulk TSF.
- Particle tracking simulations indicate that seepage from the Bulk TSF is predicted to report to the valley bottom immediately downstream of Main and South Embankments.
- Predicted reductions in baseflow relative to baseline conditions (excluding discharge of treated water) range from approximately 14 cfs (11%) above NK100A1 gaging station in NFK watershed, to 4 cfs (6%) above SK100B1 gaging station in SFK watershed, to 0.1 cfs (0.4%) above UT100D in UTC watershed. It is likely that this analysis overpredicts baseflow reduction in the post-closure period, particularly in the NFK watershed, as a number of drainages represented in the baseline simulation are not re-established in the post-closure simulation. This will be addressed at a future stage of Project design and permitting.

9.0 SENSITIVITY ANALYSIS

The purpose of a sensitivity analysis is to quantify the uncertainty in a calibrated model caused by the potential variability in the estimated parameter values (Anderson and Woessner, 1992). Traditionally a sensitivity analysis systematically changes calibrated values for K, storage parameters, recharge, and boundary conditions within ranges considered to be reasonable given the circumstances to investigate the effect on the model outputs (e.g., predicted groundwater extraction at the open pit, predicted reductions in stream baseflow). In this sensitivity analysis, the model inputs for the runs were selected based on calibration statistics and measured data ranges.

9.1. Characterization Types for Sensitivity Analyses

The sensitivity of the model to the parameter(s) changed are characterized based on the change in calibration statistics relative to the change in the predictive results (Table 9-1). Further explanation of Table 9-1 and the implications of each type of sensitivity are summarized as follows (BCMOE, 2012):

- <u>Type I:</u> The change in the model parameter(s) produces an insignificant impact on both model calibration residuals and predictive model results (relative to modeling objectives). In other words, the parameter is varied within a reasonable range of values, but nothing significant happens as a result.
- <u>Type II:</u> The change in the model parameter(s) produces a significant effect on model calibration, but an insignificant effect on predictive model results (relative to modeling objectives). In other words, varying the parameter within a reasonable range of values affects the model fit to baseline conditions (residuals increase for some part of the parameter range being tested), but the results predicted by the model do not change.
- <u>Type III:</u> There is a significant effect on both model calibration and model prediction results (relative to modeling objectives). In other words, varying parameter within a reasonable range of values affects the model fit to baseline conditions as well as the results predicted by the model.
- <u>Type IV:</u> There is an insignificant effect on model calibration, but a significant effect on predictive model results (relative to modeling objectives). In other words, varying the parameter within a reasonable range of values affects the results predicted by the model, but the model calibration fit to baseline conditions is not affected.

Sensitivity Types I and II are of no concern because the impact on predictions is insignificant. Sensitivity Type III is of concern but can result in a poorer fit to baseline conditions, and therefore the level of confidence that a Type III sensitivity outcome may be realized is reduced. Analysis of outcomes characterized as Sensitivity Type IV is important because varying the model input does not affect model calibration to observed conditions, but significantly alters model predictions.

Steady-state sensitivity simulations were performed for baseline conditions, end-of-mining conditions for the scenario without pumping wells, and post-closure conditions. Model calibration statistics and results of predictive scenarios are compared in the following sections. Each sensitivity type is discussed, and both Type III and Type IV sensitivity results are highlighted.

9.2. Sensitivity Scenarios

A total of 21 sensitivity scenarios (Table 9-2) were considered as part of this analysis for comparison to the calibrated base case results. Sixteen of these scenarios were simulated for baseline conditions. The five remaining scenarios pertained specifically to either end-of-mining conditions or post-closure conditions or both, and thus were not simulated for baseline conditions.

For each sensitivity scenario, one to two model parameters were modified to investigate the impact on simulation results. No attempt was made to calibrate the sensitivity scenarios (i.e., sensitivity simulations do not represent alternative conceptualizations of the site).

For sensitivity scenarios S13 and S14, the depth of unconsolidated sediments was modified outside of the area of site investigations. Within the Project area, where the depth of unconsolidated sediments was estimated based on site investigation data, the simulated depth was unchanged from the base case. The simulated depth of unconsolidated sediments is depicted in Figure G-17 of Appendix G.

Simulated faults in sensitivity scenarios S15 and S16 were limited to faults identified within the Project's 3-D geologic model (Drawing 08) for the deposit area. K data are not available to characterize the faults; therefore, conservatively high and low values of 10^{-5} ft/s and 10^{-10} ft/s, respectively, were assigned to all faults in these scenarios. Faults were simulated in the model by adjusting model cell K along fault traces for a width of at least three adjacent cells in each bedrock layer. Vertically, cells assigned fault properties were made to overlap at least one cell face from one layer to the next in the direction of dip. Faults included in the two fault sensitivity runs are depicted in Figure G-18 of Appendix G.

For sensitivity scenario S19, the Bulk TSF pond was increased to approximately 920 ha and the pond water level was raised to 1,700 ft. For sensitivity scenario S20, GHB boundaries were assigned to all tailings within the Bulk TSF, with water levels ranging from 1,690 ft to 1,720 ft based on the top of tailings surface. The simulated Bulk TSF pond for these scenarios relative to the base case scenario is shown in Figure G-19 of Appendix G.

9.3. Calibration Comparison

Steady-state groundwater level and stream flow calibration statistics for each sensitivity scenario are summarized in Table 9-3. Scatter plots for each sensitivity scenario are provided in Appendix G. The NRMSE for groundwater levels for the sensitivity simulations ranged from approximately 1.9% (S6, S8, and S9) to 7.0% (S7) relative to the NRMSE of the base case scenario of 2.0%. The NRMSE for stream flows for the sensitivity simulations ranged from approximately 5.3% (S14) to 24.0% (S1) relative to the NRMSE of the base case scenario of 6.6%. The results indicate that simulated groundwater levels and stream flows are insensitive to:

- Increasing and decreasing the streambed K (S11 and S12)
- Inclusion of faults as either high or low K features (S15 and S16).

Simulated groundwater levels are sensitive to:

- Decreasing the K of the unconsolidated deposits (S2). In this scenario, many observed groundwater levels are overpredicted relative to the base case scenario, with deteriorated calibration statistics.
- Increasing the K of the weathered and competent bedrock (S3, S5, and S6). In each of these scenarios, groundwater level calibration statistics deteriorate as many observed values are underpredicted.
- Decreasing the K of the weathered and competent bedrock (S4, S6, and S8). In each of these scenarios, the NRMSE is improved relative to the base case scenario; however, many groundwater levels are overpredicted resulting in a larger residual means (i.e., deteriorated).
- Increasing the groundwater recharge (S9). In this scenario, the NRMSE is improved relative to the base case scenario; however, many groundwater levels are overpredicted resulting in a larger residual mean (i.e., deteriorated).

Simulated stream flows are sensitive to:

- The thickness of unconsolidated sediments outside of the Project area (S13 and S14). The NRMSE is improved for S14 and worsened for S13. However, the simulated thickness outside of the Project area is not expected to impact predictions within the Project area; therefore, the sediment thickness simulated within the base case scenario was not modified based on this result.

Simulated groundwater levels and stream flows are sensitive to:

- Increasing the K of the unconsolidated sediments (S1). In this scenario, many groundwater levels are underpredicted, while stream flows are both overpredicted and underpredicted. Calibration statistics for both groundwater levels and stream flows are deteriorated relative to the base case scenario.

9.4. End-of-Mining Operations

Predicted groundwater extraction at the open pit, seepage from the Bulk TSF, and baseflow reductions for the NFK, SFK, and UTC watersheds (excluding discharge of treated water) for each sensitivity scenario for the case without pumping wells are summarized in Table 9-4. Results of the sensitivity simulations indicate that:

- Groundwater extraction at the open pit is predicted to range from 600 US gpm (1.3 cfs; S8) to 3,000 US gpm (6.7 cfs; S7) relative to the base case rate of 980 US gpm (2.2 cfs).
- Seepage from the Bulk TSF is predicted to range from 320 US gpm (0.7 cfs; S18) to 5,300 US gpm (12 cfs; S20) relative to the base case rate of 630 US gpm (1.4 cfs).

- Reductions in baseflow in the NFK watershed above gage NK100A1 are predicted to range from 12% (S2) to 20% (S1) relative to the base case reduction of 14%.
- Reductions in baseflow in the SFK watershed above gage SK100B1 are predicted to range from 5% (S2) to 14% (S1) relative to the base case reduction of 7%.
- Reductions in baseflow in the UTC watershed above gage UT100D are predicted to range from 0% (S2) to 6% (S15) relative to the base case reduction of 0.7%.

Results of the sensitivity simulations indicate that predicted groundwater extraction rates at the open pit are sensitive to:

- Simulated K of the unconsolidated sediments and bedrock (S1 to S8), with increased groundwater extraction for higher K scenarios and decreased groundwater extraction for lower K scenarios.
- Inclusion of faults as high K features (S15). Groundwater extraction is predicted to increase by a factor of more than 2.5 for this scenario.
- Simulated groundwater recharge (S9 and S10) with increased groundwater extraction for the higher groundwater recharge scenario and decreased groundwater extraction for the lower groundwater recharge scenario.

Results of the sensitivity simulations indicate that predicted seepage rates from the Bulk TSF are sensitive to:

- Simulated K of the unconsolidated sediments (S1 and S2), with increased seepage for the higher K scenario and decreased seepage for the lower K scenario.
- Simulated higher bedrock K (S3, S5, and S7). The Bulk TSF seepage is predicted to increase by a factor of approximately 1.6 to 3 for these scenarios.
- Simulated K of the tailings (S17 and S18), with increased seepage for the higher K scenario and decreased seepage for the lower K scenario.
- Simulated extent of the Bulk TSF pond and saturated tailings (S19 and S20). The Bulk TSF seepage is predicted to increase by a factor of approximately 1.2 to 8.5 in these scenarios.

Results of the sensitivity simulations indicate that predicted baseflow reduction in all watersheds is sensitive to:

- Simulated K of the unconsolidated sediments (S1 and S2), with increased baseflow reduction for the higher K scenario and decreased baseflow reduction for lower K scenario.

Results of the sensitivity simulations indicate that predicted baseflow reduction in UTC watershed is also sensitive to:

- Simulated higher bedrock K (S3, S5, and S7). The UTC watershed baseflow reduction is predicted to increase by a factor of approximately 2 to 7 for these scenarios.

- Inclusion of faults as high K features (S15). Baseflow reduction in UTC watershed is predicted to increase by a factor of more than 8 for this scenario.

9.5. Post-Closure

Predicted groundwater discharge to the pit lake, seepage from the Bulk TSF, and baseflow reductions in the NFK, SFK, and UTC watersheds (excluding discharge of treated water) for each sensitivity scenario are summarized in Table 9-5. Results of the sensitivity simulations indicate that:

- Groundwater discharge to the pit lake is predicted to range from 560 US gpm (1.2 cfs; S10) to 1,800 US gpm (4.0 cfs; S7) relative to the base case rate of 800 US gpm (1.8 cfs). In all scenarios, seepage from the pit lake to the groundwater system is predicted to be 0 US gpm (0 cfs).
- Seepage from the Bulk TSF is predicted to range from 200 US gpm (0.4 cfs; S21) to 930 US gpm (2.1 cfs; S17) relative to the base case rate of 420 US gpm (0.9 cfs).
- Reductions in baseflow in the NFK watershed above NK100A1 are predicted to range from 9% (S2) to 19% (S1) relative to the base case reduction of 14%.
- Reductions in baseflow in the SFK watershed above SK100B1 are predicted to range from 4% (S2) to 13% (S1) relative to the base case reduction of 6%.
- Reductions in baseflow in the UTC watershed above UT100D are predicted to range from 0% (S2) to 3% (S15) relative to the base case reduction of 0.7%.

Results of the sensitivity simulations indicate that predicted groundwater discharge rates to the pit lake are sensitive to:

- Simulated K of the unconsolidated sediments and bedrock (S1 to S8), with increased groundwater discharge for higher K scenarios and decreased groundwater discharge for lower K scenarios.
- Inclusion of faults as high K features (S15). Groundwater discharge is predicted to increase by a factor of approximately 1.1 for this scenario.
- Simulated groundwater recharge (S9 and S10) with increased groundwater discharge for the higher groundwater recharge scenario and decreased groundwater discharge for the lower groundwater recharge scenario.

Results of the sensitivity simulations indicate that predicted seepage rates from the Bulk TSF are sensitive to:

- Simulated K of the unconsolidated sediments (S1 and S2), with increased seepage for the higher K scenario and decreased seepage for lower K scenario.
- Simulated K of the tailings (S17 and S18), with increased seepage for the higher K scenario and decreased seepage for the lower K scenario.

- Simulated low K cover placed on the Bulk TSF (S21). The Bulk TSF seepage is predicted to decrease by a factor of approximately 2 in this scenario.

Results of the sensitivity simulations indicate that predicted baseflow reduction in all watersheds is sensitive to:

- Simulated K of the unconsolidated sediments (S1 and S2), with increased baseflow reduction for the higher K scenario and decreased baseflow reduction for lower K scenario.

Results of the sensitivity simulations indicate that predicted baseflow reduction in UTC watershed is also sensitive to:

- Simulated higher bedrock K (S3, S5, and S7). The reduction in baseflow is predicted to increase by a factor of approximately 3 to 5 for these scenarios.
- Inclusion of faults as high K features (S15). Baseflow reduction in UTC watershed is predicted to increase by a factor of approximately 3 for this scenario.

9.6. Classification of Sensitivity Scenarios

Based on the results of the sensitivity simulations, each scenario was classified as a Type I to Type IV sensitivity type (Table 9-6) using the criteria in Table 9-1 and discussed in Section 9.1. As noted above, sensitivity Type III scenarios are of concern as they result in a significant effect on model predictions but can be readily identified as they also result in a significant effect on model calibration. Sensitivity scenarios falling into this category include those with increased and decreased simulated K of the unconsolidated sediments and bedrock (S1 to S8). Scenario S1 can be rejected as a plausible representation of the hydrogeologic system due to the large NRMSE for stream flows. Calibration statistics for both groundwater levels and stream flows for scenarios S2 to S8 are within recommended guidelines (i.e., NRMSE<10%; NBLM, 2006; BCMOE, 2012), suggesting that these scenarios could be plausible; however, simulation results indicate that these scenarios result in an overall poorer fit to baseline conditions. Nevertheless, future hydrogeologic testing should be designed such that uncertainty in K within the unconsolidated sediments and bedrock in the Project area is reduced through additional measurements.

Identification of sensitivity Type IV scenarios is important because varying the model input does not affect model calibration to observed conditions, but significantly alters model predictions. Sensitivity scenarios falling into this category include the high K fault scenario (S15), scenarios with higher and lower tailings K (S17 and S18), the larger Bulk TSF pond and saturated tailings scenarios (S19 and S20), and the scenario with a low K cover placed on the Bulk TSF at post-closure (S21). Of these scenarios, the high K fault and higher K tailings scenarios are of greatest concern due to the possible negative outcomes of increased groundwater discharge to the open pit (S15) and increased Bulk TSF seepage (S17); however, the uncertainty associated with these concerns can be managed through targeted data collection as the Project progresses. The potential negative outcome of increased seepage from the Bulk TSF in scenarios S19 and S20 is of less concern as it can be mitigated through effective management of the volume of water stored within the facility. Lower predicted seepage rates from the Bulk TSF for scenarios S18 and S21 is considered a positive outcome from the perspective of potential Project impacts, but these scenarios may pose a concern from an operational perspective.

9.7. Summary

The outcome of the sensitivity analysis is summarized as follows:

- Groundwater extraction at the open pit is predicted to range from 600 US gpm (1.3 CFS; S8) to 3,000 US gpm (6.7 cfs; S7) relative to the base case rate of 980 US gpm (2.2 cfs).
- Groundwater discharge to the pit lake is predicted to range from 560 US gpm (1.2 cfs; S10) to 1,800 US gpm (4.0 cfs; S7) relative to the base case rate of 800 US gpm (1.8 cfs). In all scenarios, seepage from the pit lake to the groundwater system is predicted to be 0 US gpm (0 cfs).
- At the end of mining operations, seepage from the Bulk TSF is predicted to range from 320 US gpm (0.7 cfs; S18) to 5,300 US gpm (12 cfs; S20) relative to the base case rate of 630 US gpm (1.4 cfs). At post-closure, seepage from the Bulk TSF is predicted to range from 200 US gpm (0.4 cfs; S21) to 930 US gpm (2.1 cfs; S17) relative to the base case rate of 420 US gpm (0.9 cfs).
- At the end of mining operations, reductions in baseflow (excluding discharge of treated water) in NFK watershed above NK100A1 are predicted to range from 12% (S2) to 20% (S1) relative to the base case reduction of 14%. At post-closure, reductions in baseflow (excluding discharge of treated water) in NFK watershed are predicted to range from 9% (S2) to 19% (S1) relative to the base case reduction of 14%.
- At the end of mining operations, reductions in baseflow (excluding discharge of treated water) in SFK watershed above SK100B1 are predicted to range from 5% (S2) to 14% (S1) relative to the base case reduction of 7%. At post-closure, reductions in baseflow (excluding discharge of treated water) in SFK watershed are predicted to range from 4% (S2) to 13% (S1) relative to the base case reduction of 6%.
- At the end of mining operations, reductions in baseflow (excluding discharge of treated water) in UTC watershed above UT100D are predicted to range from 0% (S2) to 6% (S15) relative to the base case reduction of 0.7%. At post-closure, reductions in baseflow (excluding discharge of treated water) in UTC watershed are predicted to range from 0% (S2) to 3% (S15) relative to the base case reduction of 0.7%.
- Sensitivity scenarios classified as Type IV sensitivity types include the high K fault scenario (S15), scenarios with higher and lower tailings K (S17 and S18), the larger Bulk TSF pond and saturated tailings scenarios (S19 and S20), and the scenario with a low K cover placed on the Bulk TSF at post-closure (S21).

10.0 SUMMARY AND CONCLUSIONS

A 3-D groundwater flow model was developed for the Pebble Project area using MODFLOW-USG. The model was calibrated to baseline conditions in 4 stages, including steady-state average annual conditions, transient average monthly conditions, transient monthly 2004 to 2012 conditions, and to a 48-hour pumping test conducted at GH12-334S. The model was calibrated to groundwater levels and streams flows in stages 1 to 3, and to drawdown measurements in stage 4.

Simulated groundwater levels for baseline conditions show good agreement to measured groundwater levels, including observed seasonal fluctuations and vertical groundwater flow directions. Simulated stream flows also show good agreement with available observations, including seasonal fluctuations.

Following model calibration, the Groundwater Flow Model was used to simulate steady-state conditions at the end of mining operations and at post-closure.

The end-of-mining operations analysis is summarized as follows:

- Groundwater extraction at the open pit for the scenario without pumping wells is predicted to be approximately 980 US gpm (2.2 cfs). For the pumping well scenario, the total groundwater extraction rate is predicted to be increased to 1,350 US gpm (3.0 cfs), with 500 US gpm (1.1 cfs) and 850 US gpm (1.9 cfs) extracted at the open pit and pit dewatering wells, respectively. Drawdown due to the open pit is predicted to be primarily restricted to the SFK watershed; however, the cone of depression is predicted to extend under the upper tributaries of the UTC watershed.
- The total seepage rate from the Bulk TSF is predicted to be approximately 630 US gpm (1.4 cfs). Basin seepage is predicted to comprise 66% (415 US gpm; 0.9 cfs) of the total seepage rate, with 30% (190 US gpm; 0.4 cfs) and 4% (25 US gpm; 0.06 cfs) occurring through the Main Embankment and South Embankment, respectively. Total predicted groundwater discharge downstream of the Bulk TSF is greater than the total predicted seepage rate from the facility, indicating that the discharge will be comprised of both TSF seepage and groundwater derived from outside of the footprint of the facility. Groundwater mounding of up to 400 ft is predicted within the footprint of the Bulk TSF.
- Particle tracking simulations indicate that seepage from the Bulk TSF is predicted to report to the valley bottom immediately downstream of the Main and South Embankments. Some seepage from the Pyritic TSF, Main WMP, and Open Pit WMP is predicted to flow past proposed SCPs in the scenario without pumping wells. However, results of the pumping well scenario indicate that seepage collection wells could be used to manage seepage from these locations.
- Predicted reductions in stream baseflow for the scenario without pumping wells relative to baseline conditions, excluding discharge of treated water, range from approximately 17 cfs (14%) above NK100A1 gaging station in NFK watershed, to 5 cfs (7%) above SK100B1

gaging station in SFK watershed, to 0.1 cfs (0.7%) above UT100D in UTC watershed. Relative to the scenario without pumping wells, baseflow reduction (excluding discharge of treated water) for the pumping well scenario in NFK and UTC watersheds is predicted to increase to 18 cfs (14%) and 0.2 cfs (1.3%), respectively, while negligible difference is predicted for SFK watershed.

The post-closure analysis is summarized as follows:

- Groundwater discharge to the pit lake is predicted to be approximately 800 US gpm (1.8 cfs). Seepage from the pit lake to the groundwater system is predicted to be 0 US gpm (0 cfs; i.e., the pit lake, managed at an elevation of 900 ft, will act as a groundwater sink). Drawdown due to the pit lake is predicted to be primarily restricted to the SFK watershed; however, the cone of depression is predicted to extend under the upper tributaries of the UTC watershed.
- The total seepage rate from the Bulk TSF is predicted to be reduced from the end-of-mining operations model to approximately 420 US gpm (0.9 cfs). Basin seepage is predicted to comprise 69% (285 US gpm; 0.6 cfs) of the total seepage rate, with 27% (115 US gpm; 0.3 cfs) and 4% (20 US gpm; 0.04 cfs) occurring through the Main Embankment and South Embankment, respectively. Total predicted groundwater discharge downstream of the Bulk TSF is greater than the total predicted seepage rate from the facility, indicating that the discharge will be comprised of both TSF seepage and groundwater derived from outside of the footprint of the facility. Groundwater mounding of up to 345 ft is predicted within the footprint of the Bulk TSF.
- Particle tracking simulations indicate that seepage from the Bulk TSF is predicted to report to the valley bottom immediately downstream of Main and South Embankments.
- Predicted reductions in baseflow relative to baseline conditions (excluding discharge of treated water) range from approximately 14 cfs (11%) above NK100A1 gaging station in NFK watershed, to 4 cfs (6%) above SK100B1 gaging station in SFK watershed, to 0.1 cfs (0.4%) above UT100D in UTC watershed.

A sensitivity analysis was conducted to quantify the uncertainty in model predictions related to uncertainty in estimated model parameter values using a total of 21 sensitivity scenarios. Results of the sensitivity analysis are summarized as follows

- Groundwater extraction at the open pit is predicted to range from 600 US gpm (1.3 cfs; S8) to 3,000 US gpm (6.7 cfs; S7) relative to the base case rate of 980 US gpm (2.2 cfs).
- Groundwater discharge to the pit lake is predicted to range from 560 US gpm (1.2 cfs; S10) to 1,800 US gpm (4.0 cfs; S7) relative to the base case rate of 800 US gpm (1.8 cfs). In all scenarios, seepage from the pit lake to the groundwater system is predicted to be 0 US gpm (0 cfs).
- At the end of mining operations, seepage from the Bulk TSF is predicted to range from 320 US gpm (0.7 cfs; S18) to 5,300 US gpm (12 cfs; S20) relative to the base case rate

of 630 US gpm (1.4 cfs). At post-closure, seepage from the Bulk TSF is predicted to range from 200 US gpm (0.4 cfs; S21) to 930 US gpm (2.1 cfs; S17) relative to the base case rate of 420 US gpm (0.9 cfs).

- At the end of mining operations, reductions in baseflow (excluding discharge of treated water) in NFK watershed above NK100A1 are predicted to range from 12% (S2) to 20% (S1) relative to the base case reduction of 14%. At post-closure, reductions in baseflow (excluding discharge of treated water) in NFK watershed are predicted to range from 9% (S2) to 19% (S1) relative to the base case reduction of 14%.
- At the end of mining operations, reductions in baseflow (excluding discharge of treated water) in SFK watershed above SK100B1 are predicted to range from 5% (S2) to 14% (S1) relative to the base case reduction of 7%. At post-closure, reductions in baseflow (excluding discharge of treated water) in SFK watershed are predicted to range from 4% (S2) to 13% (S1) relative to the base case reduction of 6%.
- At the end of mining operations, reductions in baseflow (excluding discharge of treated water) in UTC watershed above UT100D are predicted to range from 0% (S2) to 6% (S15) relative to the base case reduction of 0.7%. At post-closure, reductions in baseflow (excluding discharge of treated water) in UTC watershed are predicted to range from 0% (S2) to 3% (S15) relative to the base case reduction of 0.7%.
- Sensitivity scenarios classified as Type IV sensitivity types include the high K fault scenario (S15), scenarios with higher and lower tailings K (S17 and S18), the larger Bulk TSF pond and saturated tailings scenarios (S19 and S20), and the scenario with a lined Bulk TSF at post-closure (S21).

Almost a decade of baseline information and hydrogeologic testing data were relied upon in developing the Groundwater Flow Model for the Project. The Groundwater Flow Model is considered a good representation of baseline conditions, and appropriate for use in predictive simulations to evaluate the impacts of mine development.

11.0 CLOSURE

We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

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TABLES

Table 3-1. Average temperature, precipitation, and evapotranspiration for Pebble 1 station.

Period	Temperature (°F)	Precipitation (in)	Potential Evapotranspiration (in)	Actual Evapotranspiration (in)
January	11.4	4.3	0	0.0
February	13.6	3.7	0	0.0
March	16.6	3.9	0	0.0
April	27.3	1.7	0.1	0.0
May	38.3	2.0	2	1.0
June	46.5	2.7	3.8	1.8
July	50.8	4.3	4.5	2.1
August	49.9	7.7	3.7	1.8
September	43.0	7.0	2.1	1.1
October	30.6	4.9	0.2	0.1
November	19.8	6.9	0	0.0
December	12.6	5.6	0	0.0
Annual	**30.1**	**54.6**	**16.3**	**7.9**

Note:

1. Modified from KP (2018a).

Table 6-1. Calibrated hydrogeologic parameters.

Material	Description	Hydraulic Conductivity (fts^{-1})		Specific Storage (ft^{-1})	Specific Yield (-)
		Horizontal	Vertical		
Unconsolidated sediments	Sand and gravel	$2x10^{-3}$	$2x10^{-4}$	$3x10^{-6}$	0.15
	Silty sand and gravel	$2x10^{-4}$	$2x10^{-5}$	$5x10^{-6}$	0.13
	Clayey/silty sand and gravel	$9x10^{-5}$	$9x10^{-6}$	$7x10^{-6}$	0.12
	Clayey sand and gravel	$4x10^{-5}$	$4x10^{-6}$	$1x10^{-5}$	0.10
	Sandy/gravelly silt	$2x10^{-5}$	$2x10^{-6}$	$1x10^{-5}$	0.08
	Clayey/sandy silt	$9x10^{-6}$	$9x10^{-7}$	$2x10^{-5}$	0.06
	Silt	$4x10^{-6}$	$4x10^{-7}$	$3x10^{-5}$	0.05
	Clayey silt/silty clay	$7x10^{-7}$	$7x10^{-8}$	$1x10^{-4}$	0.03
	Clay	$1x10^{-7}$	$1x10^{-8}$	$3x10^{-4}$	0.01
Bedrock	Weathered	$3x10^{-6}$	$3x10^{-6}$	$3x10^{-7}$	0.01
	Competent	$3x10^{-8}$	$3x10^{-8}$	$3x10^{-8}$	0.001

Notes:
1. Unconsolidated sediments simulated in model layers 1 to 3.
2. Weathered bedrock simulated in model layers 1 to 4.
3. Competent bedrock simulated in model layers 5 to 12. Model cells were zonated based on geology; however, all competent bedrock was assigned the same K and storage parameters.

Table 6-2. Summary of calibration stages.

Component	Calibration Stage	Number of Targets	Number of Observations	Range of Observations	
				Minimum	Maximum
Groundwater Level	1	551	551	610 ft	1,980 ft
	2	70	840	745 ft	1,680 ft
	3	551	19,648	610 ft	2,010 ft
Stream Flow	1	26	26	5 cfs	320 cfs
	2	26	312	0 cfs	665 cfs
	3	26	2,609	0 cfs	1,050 cfs
Drawdown	4	5	1,327	0 ft	46 ft

Table 6-3. Simulated average annual groundwater budget for NFK, SFK, and UTC watersheds.

Component	NFK (Mft^3/d)		SFK (Mft^3/d)		UTC (Mft^3/d)	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Groundwater Recharge	12.4	0.0	13.0	0.0	15.6	0.0
Groundwater Evapotranspiration	0.0	0.6	0.0	0.4	0.0	0.7
Rivers and Creeks	14.5	23.5	11.7	16.3	9.5	24.7
Lakes and Ponds	1.1	0.8	0.6	0.7	0.1	0.5
Adjacent Watersheds	2.7	5.8	2.2	10.1	5.1	4.4
Total	30.7	30.7	27.5	27.5	30.3	30.3

Note:

1. Groundwater inflow = flow into the groundwater system (e.g., seepage from surface water bodies; groundwater recharge). Groundwater outflow = flow from the groundwater system (e.g., discharge to surface water bodies; groundwater evapotranspiration).

Table 7-1. Simulated hydrogeologic parameters of mining materials.

Material	Description	Hydraulic Conductivity (fts^{-1})		Porosity (-)
		Horizontal	Vertical	
Mining Materials	Bulk TSF tailings	$3x10^{-6}$	$3x10^{-6}$	0.05
	Bulk TSF embankments	$3x10^{-5}$	$3x10^{-6}$	0.05
	Seepage control	$1x10^{-7}$	$1x10^{-7}$	0.01

Notes:

1. Bulk TSF tailings and embankments simulated in model layers 1A to 3A.
2. Seepage control simulated in model layers 1 to 4.
3. Porosity defined for particle tracking simulations.

Table 9-1. Classification of sensitivity types.

Change of Predicted Parameter		CHANGE IN CALIBRATION	
	(effect)	Insignificant	Significant
CHANGE IN PREDICTION RESULTS	Insignificant	Type I	Type II
	Significant	Type IV	Type III

Note:

1. Modified from Brown (1996) and BCMOE (2012).

Table 9-2. Summary of sensitivity simulations.

Scenario	Description
S0	Base case
S1	Unconsolidated sediments K increased by factor of 10
S2	Unconsolidated sediments K decreased by factor of 10
S3	Weathered bedrock K increased by factor of 10
S4	Weathered bedrock K decreased by factor of 10
S5	Competent bedrock K increased by factor of 10
S6	Competent bedrock K decreased by factor of 10
S7	Bedrock K increased by factor of 10
S8	Bedrock K decreased by factor of 10
S9	Groundwater recharge increased by 50% with corresponding decrease in surface runoff
S10	Groundwater recharge decreased by 50% with corresponding increase in surface runoff
S11	SFR streambed K increased by factor of 10
S12	SFR streambed K decreased by factor of 10
S13	Unconsolidated sediments thickness increased by 25% outside area of site investigations
S14	Unconsolidated sediments thickness decreased by 25% outside area of site investigations
S15	Faults were simulated as high K features
S16	Faults were simulated as low K features
S17	Bulk TSF tailings K increased by factor of 10
S18	Bulk TSF tailings K decreased by factor of 100
S19	Bulk TSF pond increased to 920 ha with water level at 1,700 ft
S20	Bulk TSF tailings saturated with water level ranging from 1,690 ft to 1,720 ft
S21	Low K cover placed on reclaimed Bulk TSF; groundwater recharge set to 0

Notes:

1. Scenarios S17 and S18 simulated only for end-of-mining operations and post-closure scenarios.
2. Scenarios S19 and S20 simulated only for end-of-mining operations scenarios.
3. Scenario S21 simulated only for post-closure scenarios.

Table 9-3. Calibration statistics for baseline sensitivity simulations.

Scenario	Description	Groundwater Levels			Stream Flows			Effect on Calibration Statistics
		Residual Mean (ft)	NRMSE (%)	R (-)	Residual Mean (cfs)	NRMSE (%)	R (-)	
S0	Base Case	-2.62	1.89	0.995	-0.45	6.56	0.979	-
S1	Unconsolidated sediments K x 10	7.61	2.08	0.995	-4.69	24.03	0.799	Significant (worse)
S2	Unconsolidated sediments K x 0.1	-12.47	2.24	0.995	-0.32	6.54	0.980	Significant (worse)
S3	Weathered bedrock K x 10	6.14	2.28	0.995	-1.55	6.54	0.979	Significant (worse)
S4	Weathered bedrock K x 0.1	-5.82	1.84	0.995	0.97	6.67	0.979	Significant (inconclusive)
S5	Competent bedrock K x 10	24.49	6.69	0.969	-0.14	6.54	0.979	Significant (worse)
S6	Competent bedrock K x 0.1	-3.83	1.73	0.996	-0.30	6.57	0.979	Significant (inconclusive)
S7	Bedrock K x 10	30.22	6.93	0.969	-0.73	6.55	0.979	Significant (worse)
S8	Bedrock K x 0.1	-6.84	1.74	0.996	-3.59	7.04	0.975	Significant (inconclusive)
S9	Recharge x 1.5	-5.12	1.76	0.996	0.68	6.66	0.979	Significant (inconclusive)
S10	Recharge x 0.5	3.61	2.69	0.992	-1.69	6.49	0.979	Significant (worse)
S11	SFR streambed K x 10	-2.62	1.89	0.995	-0.48	6.55	0.979	Insignificant
S12	SFR streambed K x 0.1	-2.66	1.89	0.995	-0.21	6.63	0.979	Insignificant
S13	Unconsolidated sediments thickness x 1.25	-2.51	1.89	0.995	1.76	8.26	0.966	Significant (worse)
S14	Unconsolidated sediments thickness x 0.75	-2.73	1.89	0.995	-2.44	5.33	0.987	Significant (improved)
S15	High K faults	-1.99	1.89	0.995	-0.58	6.55	0.979	Insignificant
S16	Low K faults	-2.64	1.88	0.995	-0.45	6.56	0.979	Insignificant

Table 9-4. Sensitivity simulation results for end-of-mining conditions.

Scenario	Description	Open Pit Groundwater Extraction (US gpm)	Bulk TSF Seepage (US gpm)	Baseflow Reduction (%)			Effect on Predictive Results
				NFK	SFK	UTC	
S0	Base Case	980	630	14	7	0.7	-
S1	Unconsolidated sediments K x 10	1,300	1,700	20	14	3.5	Significant
S2	Unconsolidated sediments K x 0.1	740	500	12	5	0.0	Significant
S3	Weathered bedrock K x 10	1,300	1,000	15	7	1.5	Significant
S4	Weathered bedrock K x 0.1	820	590	13	7	0.5	Significant
S5	Competent bedrock K x 10	2,900	1,200	13	7	4.3	Significant
S6	Competent bedrock K x 0.1	700	610	14	7	0.4	Significant
S7	Bedrock K x 10	3,000	1,700	14	7	4.8	Significant
S8	Bedrock K x 0.1	600	570	13	7	0.4	Significant
S9	Recharge x 1.5	1,100	750	14	7	0.8	Significant
S10	Recharge x 0.5	680	540	13	7	0.6	Significant
S11	SFR streambed K x 10	980	630	13	7	0.7	Insignificant
S12	SFR streambed K x 0.1	980	630	15	7	0.7	Insignificant
S13	Unconsolidated sediments thickness x 1.25	980	630	13	7	0.7	Insignificant
S14	Unconsolidated sediments thickness x 0.75	980	630	14	7	0.7	Insignificant
S15	High K faults	2,600	630	14	7	5.8	Significant
S16	Low K faults	960	630	14	7	0.7	Insignificant
S17	Bulk TSF tailings K increased by factor of 10	980	1,800	14	7	0.7	Significant
S18	Bulk TSF tailings K decreased by factor of 100	980	320	14	7	0.7	Significant
S19	Bulk TSF pond increase to 920 ha with water level at 1,700 ft	980	780	14	7	0.7	Significant
S20	Bulk TSF tailings saturated with water level ranging from 1,690 ft to 1,720 ft	980	5,300	14	7	0.7	Significant

Notes:
1. All simulation results for the scenario without pumping wells.
2. NFK, SFK, and UTC baseflow reduction reported above gaging stations NK100A1, SK100B1, and UT100D, respectively.

Table 9-5. Sensitivity simulation results for post-closure conditions.

Scenario	Description	Pit Lake Groundwater Discharge (US gpm)	Bulk TSF Seepage (US gpm)	Baseflow Reduction (%)			Effect on Predictive Results
				NFK	SFK	UTC	
S0	Base Case	800	420	11	6	0.4	-
S1	Unconsolidated sediments K x 10	1,300	470	19	13	3.2	Significant
S2	Unconsolidated sediments K x 0.1	590	340	9	4	0.0	Significant
S3	Weathered bedrock K x 10	1,300	430	12	6	1.1	Significant
S4	Weathered bedrock K x 0.1	710	410	10	6	0.2	Insignificant
S5	Competent bedrock K x 10	1,400	400	10	6	1.4	Significant
S6	Competent bedrock K x 0.1	730	420	11	6	0.3	Insignificant
S7	Bedrock K x 10	1,800	390	11	6	2.0	Significant
S8	Bedrock K x 0.1	640	410	10	6	0.4	Significant
S9	Recharge x 1.5	990	500	11	6	0.5	Significant
S10	Recharge x 0.5	560	290	10	6	0.3	Significant
S11	SFR streambed K x 10	800	420	11	6	0.4	Insignificant
S12	SFR streambed K x 0.1	800	420	12	6	0.4	Insignificant
S13	Unconsolidated sediments thickness x 1.25	800	420	10	6	0.4	Insignificant
S14	Unconsolidated sediments thickness x 0.75	800	420	11	6	0.4	Insignificant
S15	High K faults	880	420	11	5	1.1	Insignificant
S16	Low K faults	790	420	11	6	0.4	Insignificant
S17	Bulk TSF tailings K increased by factor of 10	800	930	11	6	0.4	Significant
S18	Bulk TSF tailings K decreased by factor of 100	800	250	11	6	0.4	Significant
S21	Low K cover placed on reclaimed Bulk TSF; groundwater recharge set to 0	800	200	11	6	0.4	Significant

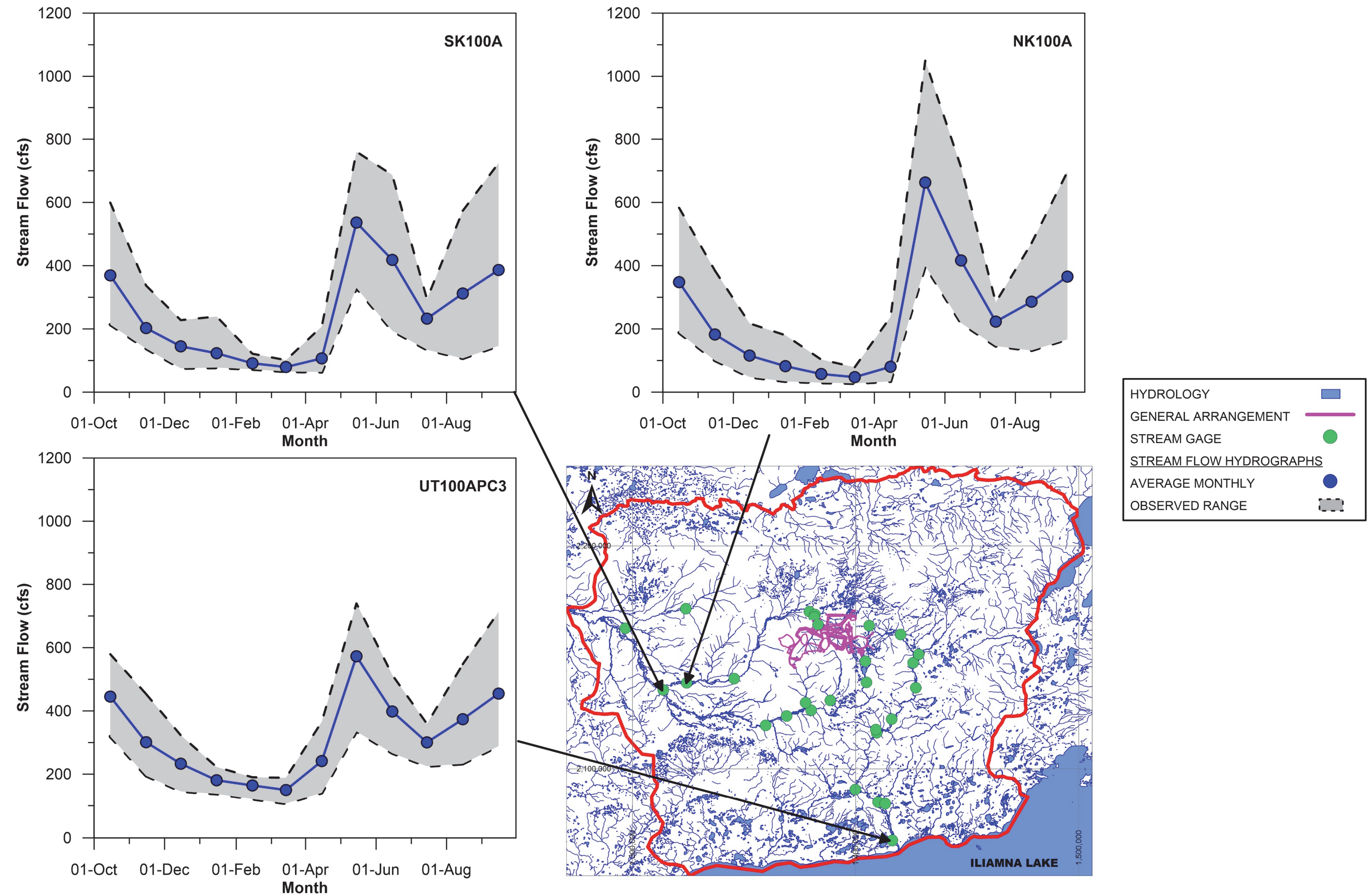
Note:
1. NFK, SFK, and UTC baseflow reduction reported above gaging stations NK100A1, SK100B1, and UT100D, respectively.

Table 9-6. Classification of sensitivity scenarios.

Scenario	Description	Effect on Calibration Statistics	Effect on Predictive Results		Sensitivity Type (I to IV)
			End-of-Mining	Post-Closure	
S1	Unconsolidated sediments K x 10	Significant (worse)	Significant	Significant	Type III
S2	Unconsolidated sediments K x 0.1	Significant (worse)	Significant	Significant	Type III
S3	Weathered bedrock K x 10	Significant (worse)	Significant	Significant	Type III
S4	Weathered bedrock K x 0.1	Significant (inconclusive)	Significant	Insignificant	Type III
S5	Competent bedrock K x 10	Significant (worse)	Significant	Significant	Type III
S6	Competent bedrock K x 0.1	Significant (inconclusive)	Significant	Insignificant	Type III
S7	Bedrock K x 10	Significant (worse)	Significant	Significant	Type III
S8	Bedrock K x 0.1	Significant (inconclusive)	Significant	Significant	Type III
S9	Recharge x 1.5	Significant (inconclusive)	Significant	Significant	Type III
S10	Recharge x 0.5	Significant (worse)	Significant	Significant	Type III
S11	SFR streambed K x 10	Insignificant	Insignificant	Insignificant	Type I
S12	SFR streambed K x 0.1	Insignificant	Insignificant	Insignificant	Type I
S13	Unconsolidated sediments thickness x 1.25	Significant (worse)	Insignificant	Insignificant	Type II
S14	Unconsolidated sediments thickness x 0.75	Significant (improved)	Insignificant	Insignificant	Type II
S15	High K faults	Insignificant	Significant	Insignificant	Type IV
S16	Low K faults	Insignificant	Insignificant	Insignificant	Type I
S17	Bulk TSF tailings K increased by factor of 10	-	Significant	Significant	Type IV
S18	Bulk TSF tailings K decreased by factor of 100	-	Significant	Significant	Type IV
S19	Bulk TSF pond increase to 920 ha with water level at 1,700 ft	-	Significant	-	Type IV
S20	Bulk TSF tailings saturated with water level ranging from 1,690 ft to 1,720 ft	-	Significant	-	Type IV
S21	Low K cover placed on reclaimed Bulk TSF; groundwater recharge set to 0	-	-	Significant	Type IV

Notes:
1. All end-of-mining simulation results for the scenario without pumping wells.
2. NFK, SFK, and UTC baseflow reduction reported above gaging stations NK100A1, SK100B1, and UT100D, respectively.
3. Sensitivity type defined in Section 9.1 and Table 9-1.

FIGURES



NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. STREAM FLOW DATA FROM KP (2018a).
4. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
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SCALE: AS SHOWN	DATE: 05-24-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: REPRESENTATIVE MONTHLY HYDROGRAPHS FOR NFK, SFK, AND UTC WATERSHEDS
APPROVED BY: RT				PROJECT NO: 1872-002 / FIGURE NO: 3-1

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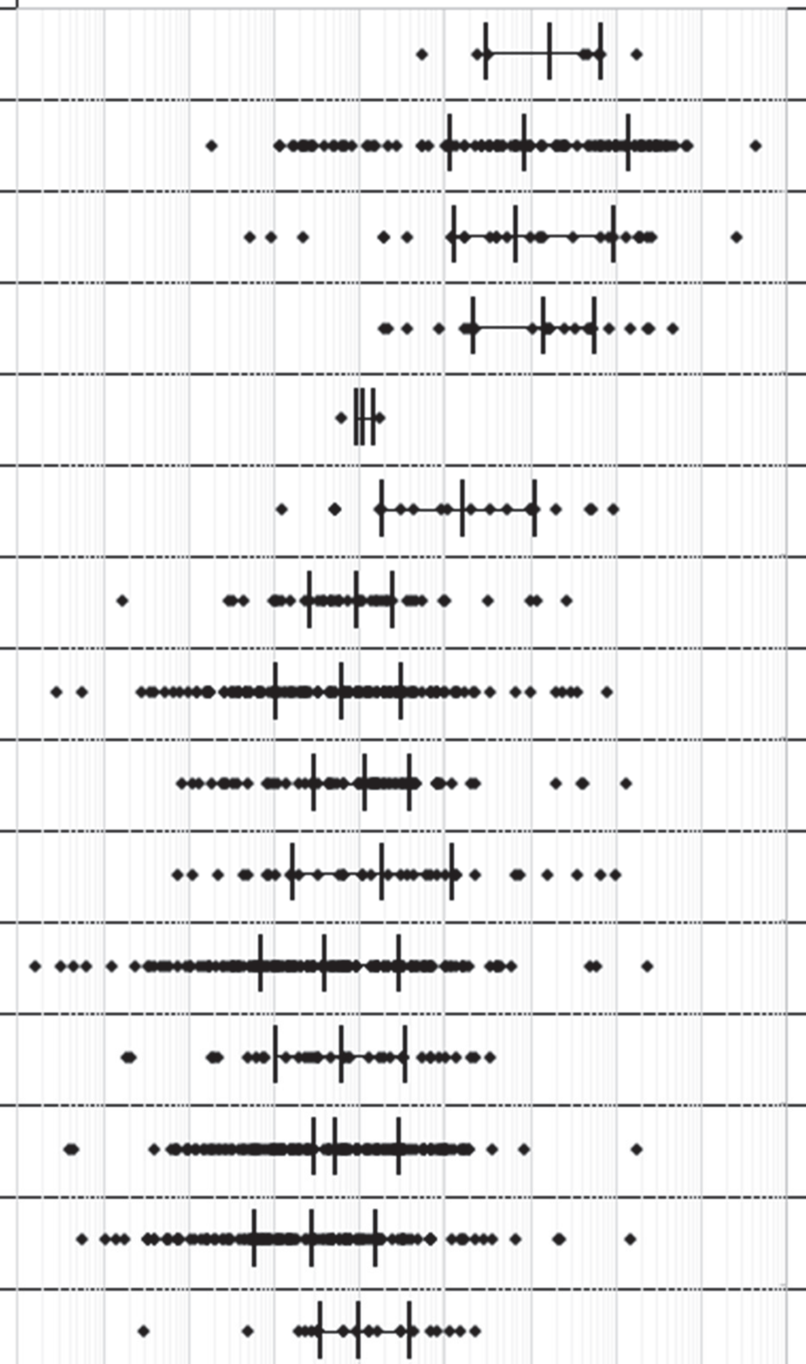

HSU	Geologic Unit	Hydraulic Conductivity Data (ft/s) 1.E-10 1.E-09 1.E-08 1.E-07 1.E-06 1.E-05 1.E-04 1.E-03 1.E-02 1.E-01	Test Count	Min K (ft/s)	Quartile Q1	Geometric Mean K (ft/s)	Quartile Q3	Max K (ft/s)
Unconsolidated Sediments	Gravel		8	5E-06	3E-05	2E-04	6E-04	2E-03
	Sand and Gravel		129	2E-08	1E-05	8E-05	1E-03	4E-02
	Sand		29	5E-08	1E-05	7E-05	9E-04	3E-02
	Silt		23	2E-06	2E-05	1E-04	5E-04	5E-03
	Clay		2	6E-07	9E-07	1E-06	1E-06	2E-06
Bedrock	Bedrock (Undefined)		21	1E-07	2E-06	2E-05	1E-04	9E-04
	Andesite/Dacite/ Latite/Rhyolite		42	2E-09	3E-07	9E-07	2E-06	3E-04
	Basalt		157	3E-10	1E-07	6E-07	3E-06	8E-04
	Breccia/ Volcaniclastics		70	8E-09	3E-07	1E-06	4E-06	1E-03
	Conglomerate		35	7E-09	2E-07	2E-06	1E-05	1E-03
	Diorite/ Granodiorite		162	2E-10	7E-08	4E-07	3E-06	2E-03
	Gabbro		37	2E-09	1E-07	6E-07	3E-06	3E-05
	Monzonite/ Monzodiorite		158	4E-10	3E-07	5E-07	3E-06	2E-03
	Mudstone/ Siltstone		136	6E-10	5E-08	3E-07	1E-06	2E-03
	Sandstone/ Wacke		23	3E-09	3E-07	9E-07	4E-06	2E-05

NOTES:
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PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: HYDRAULIC CONDUCTIVITY DATA SUMMARY
APPROVED BY: RT				PROJECT NO: 1872-002 / FIGURE NO: 4-1

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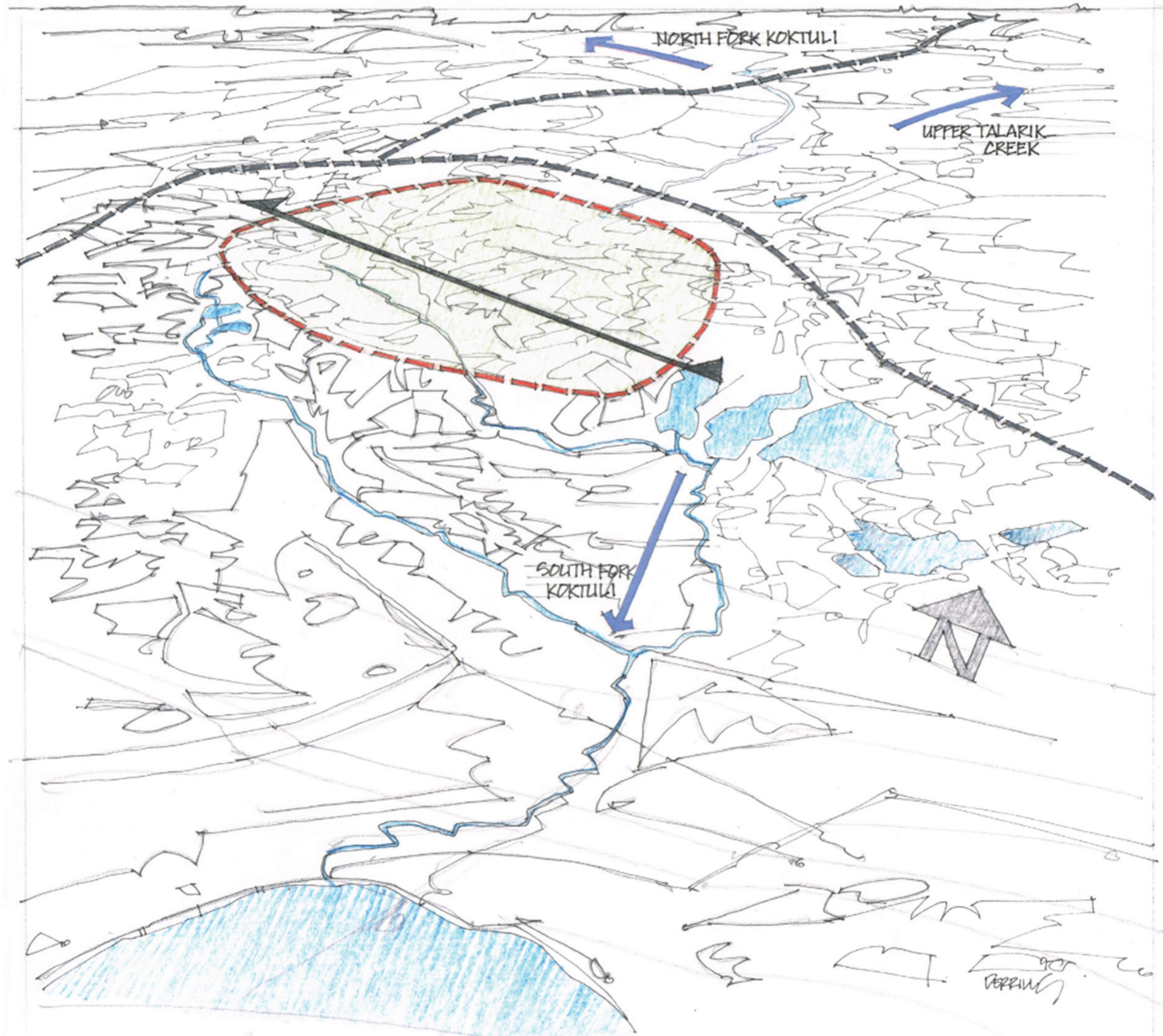

LEGEND

- WATERSHED DIVIDES
- DIRECTION OF SURFACE WATER FLOW
- PROPOSED PIT OUTLINE
- CROSS SECTION ALIGNMENT (SEE NOTE 1)

NOTES:
1. CROSS-SECTION ALIGNMENT REFERS TO CONCEPTUAL HYDROGEOLOGIC MODEL FIGURES 4-3 AND 4-4.
2. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
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PREPARED BY: CT	CHECKED BY: TWC
APPROVED BY: RT	

REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL	
FIGURE TITLE: CONCEPTUAL HYDROGEOLOGIC MODEL: BASELINE CONDITIONS IN DEPOSIT AREA	
PROJECT NO: 1872-002	FIGURE NO: 4-2

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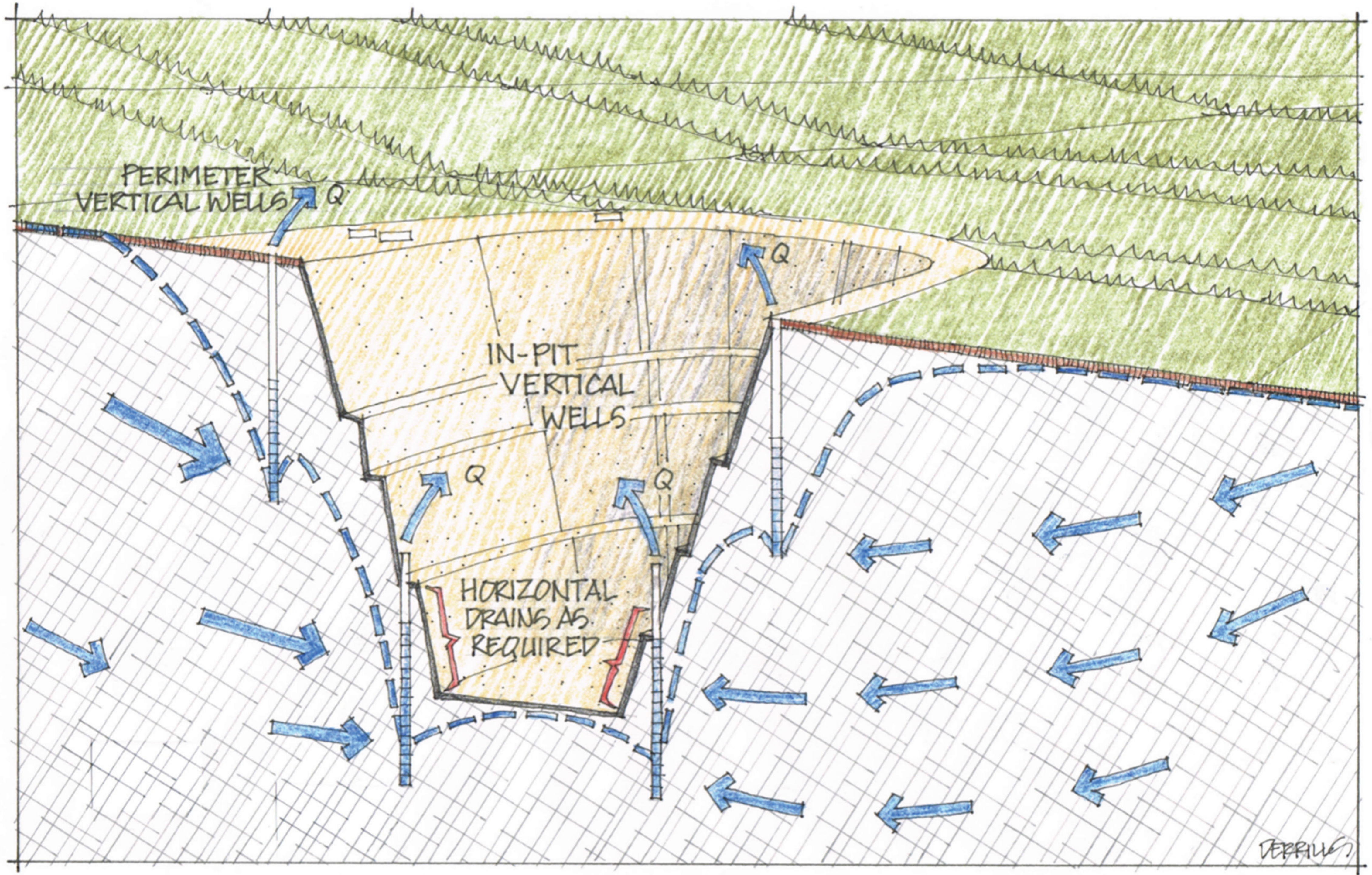

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PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: CONCEPTUAL HYDROGEOLOGIC MODEL: END-OF-MINING AT THE OPEN PIT
APPROVED BY: RT				PROJECT NO: 1872-002 / FIGURE NO: 4-3

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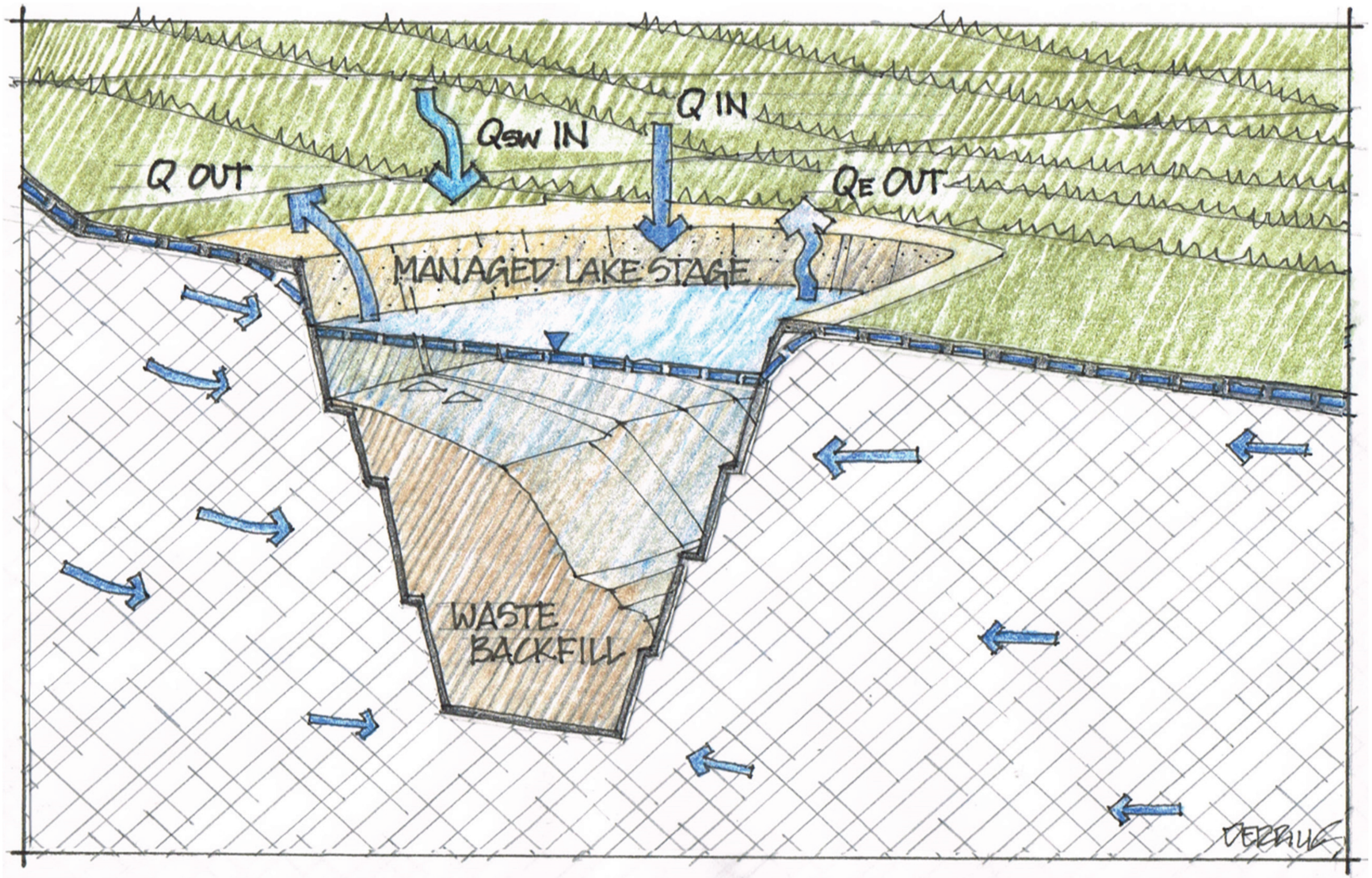

NOTES:

1. Q_{IN} INCLUDES DIRECT PRECIPITATION AND INFLOWS FROM SEEPAGE COLLECTION FACILITIES. $Q_{SW\ IN}$ INDICATES SURFACE WATER RUNOFF.
2. Q_{OUT} INCLUDES WATER PUMPED TO TREATMENT FOR DISCHARGE TO THE RECEIVING ENVIRONMENT. $Q_{E\ OUT}$ INDICATES EVAPORATION.
3. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
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PREPARED BY: CT	CHECKED BY: TWC	FIGURE TITLE: CONCEPTUAL HYDROGEOLOGIC MODEL: POST-CLOSURE AT THE OPEN PIT
APPROVED BY: RT		PROJECT NO: 1872-002 / FIGURE NO: 4-4

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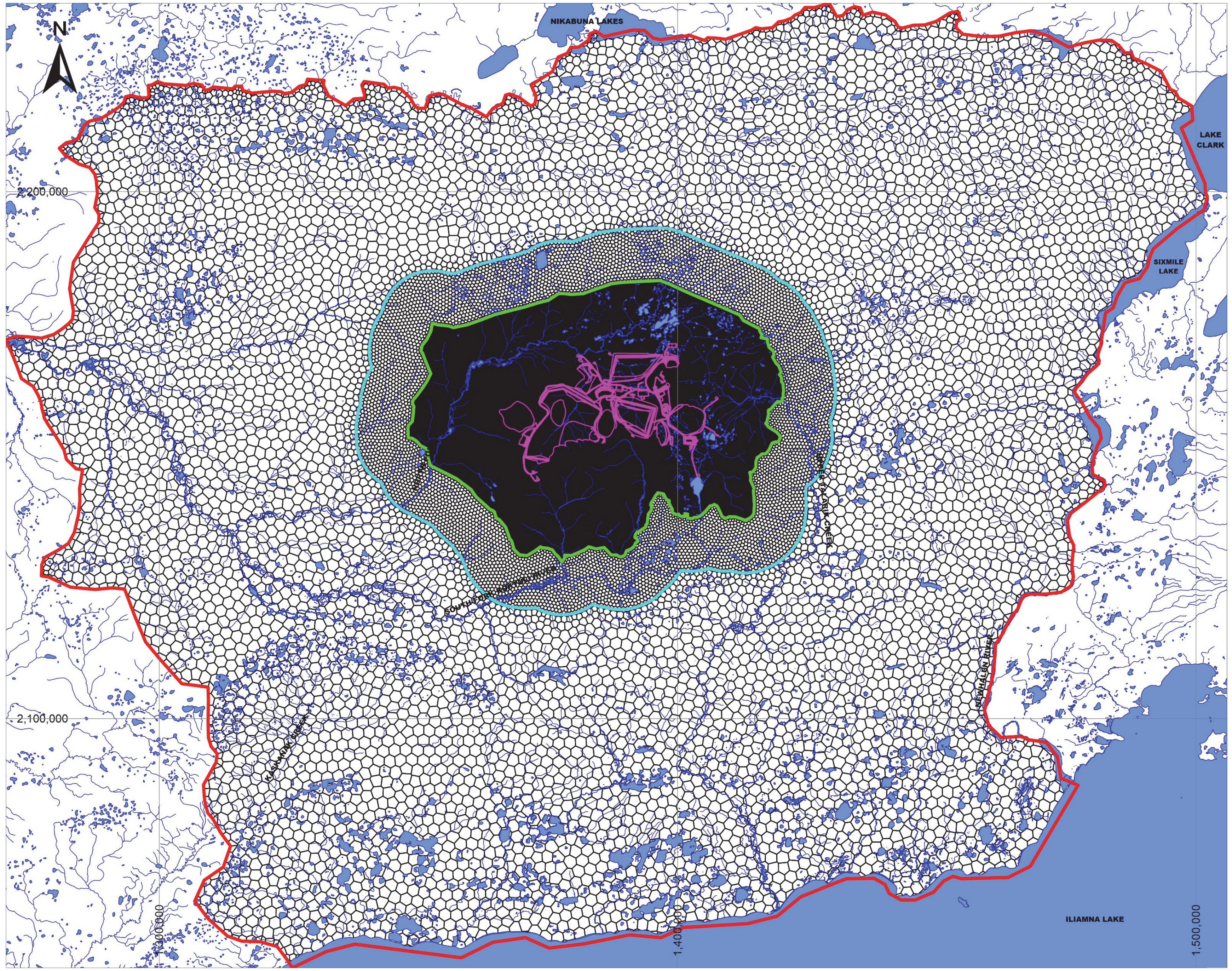

HYDROLOGY	
GENERAL ARRANGEMENT	
MODEL DOMAIN	
300 ft CELLS	
1,000 ft CELLS	

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
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PREPARED BY: CT	CHECKED BY: TWC	FIGURE TITLE: MODEL GRID
APPROVED BY: RT		PROJECT NO: 1872-002 / FIGURE NO: 5-1

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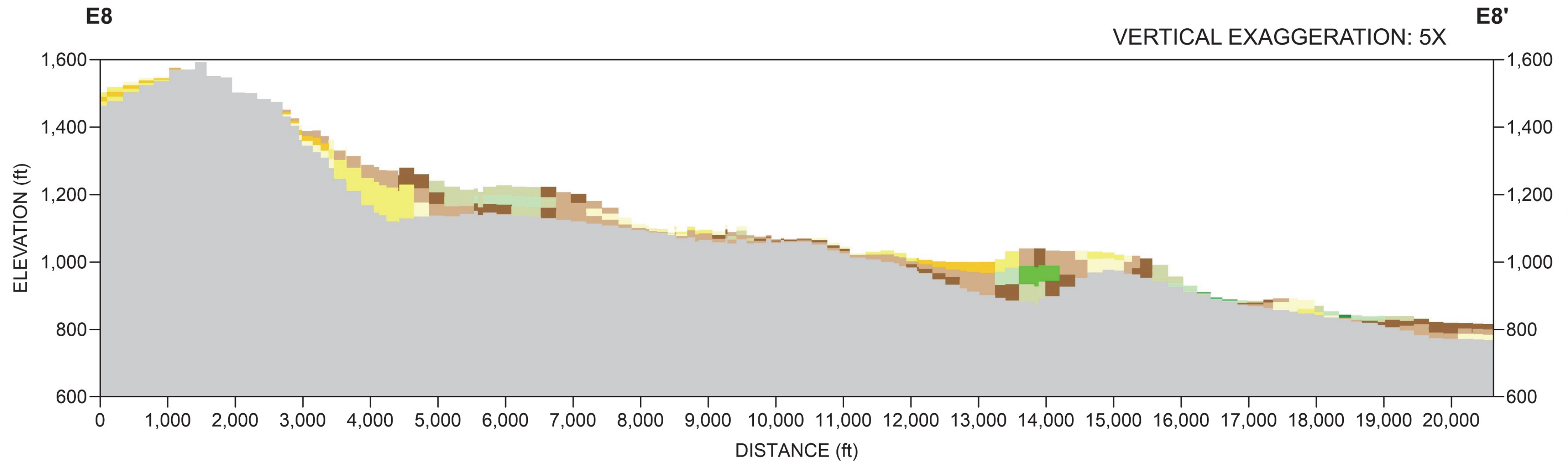

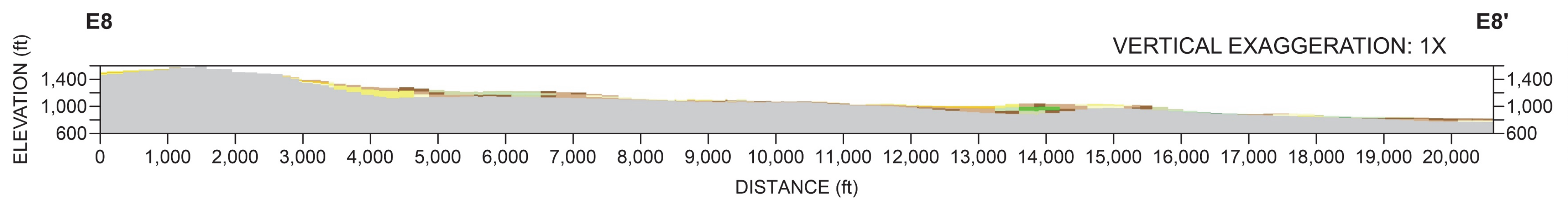

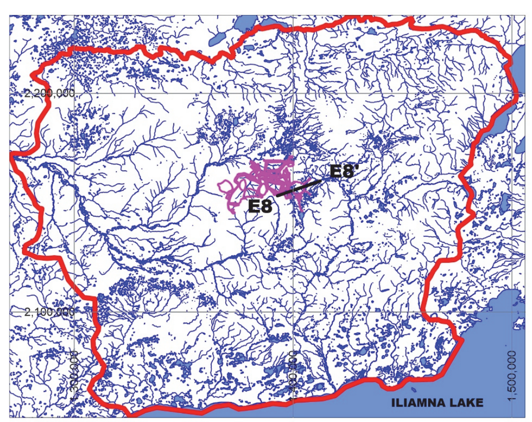

GENERAL ARRANGEMENT
MODEL DOMAIN
CROSS-SECTION
HYDROGEOLOGIC UNIT
SAND AND GRAVEL
SILTY SAND AND GRAVEL
CLAYEY/SILTY SAND AND GRAVEL
CLAYEY SAND AND GRAVEL
SANDY/GRAVELLY SILT
CLAYEY/SANDY SILT
SILT
CLAYEY SILT/SILTY CLAY
CLAY
BEDROCK

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED “PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL” AND DATED 05-24-2019.
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REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL

FIGURE TITLE: ASSIGNED HYDROGEOLOGIC UNITS ALONG SURFICIAL GEOLOGY CROSS-SECTION E-8

PROJECT NO: 1872-002

FIGURE NO: 5-2

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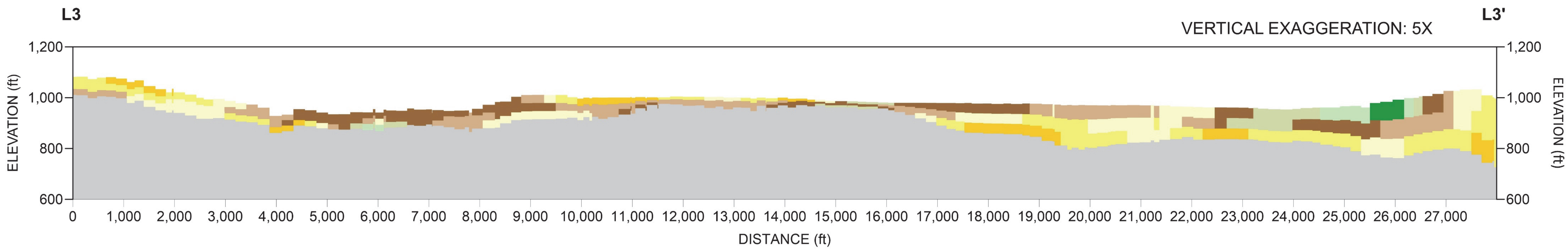

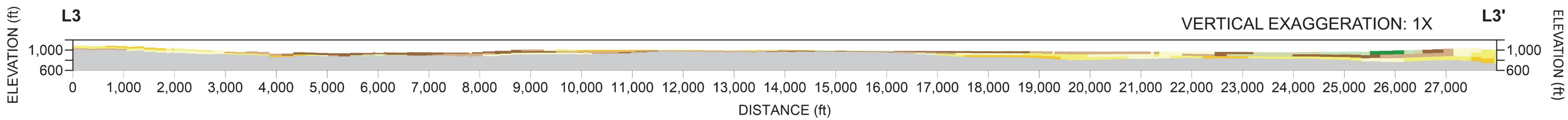

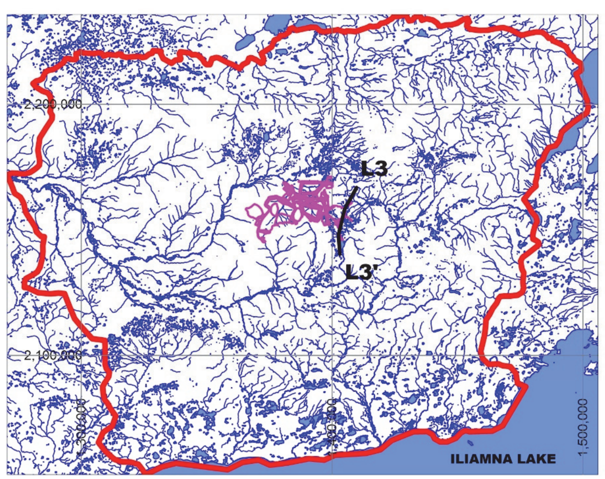

GENERAL ARRANGEMENT
MODEL DOMAIN
CROSS-SECTION
HYDROGEOLOGIC UNIT
SAND AND GRAVEL
SILTY SAND AND GRAVEL
CLAYEY/SILTY SAND AND GRAVEL
CLAYEY SAND AND GRAVEL
SANDY/GRAVELLY SILT
CLAYEY/SANDY SILT
SILT
CLAYEY SILT/SILTY CLAY
CLAY
BEDROCK

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
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PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: ASSIGNED HYDROGEOLOGIC UNITS ALONG SURFICIAL GEOLOGY CROSS-SECTION L-3
APPROVED BY: RT				PROJECT NO: 1872-002 / FIGURE NO: 5-3

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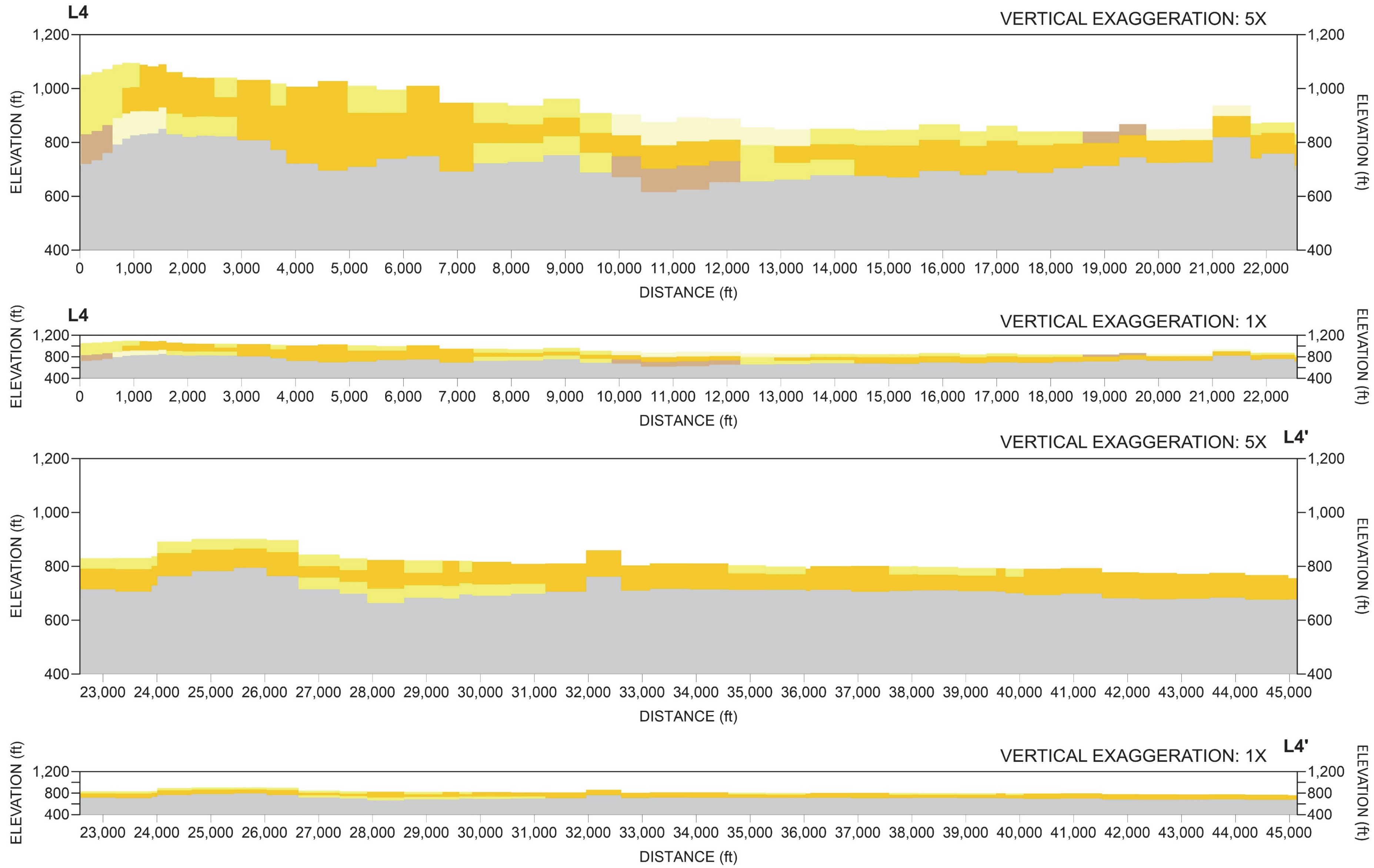

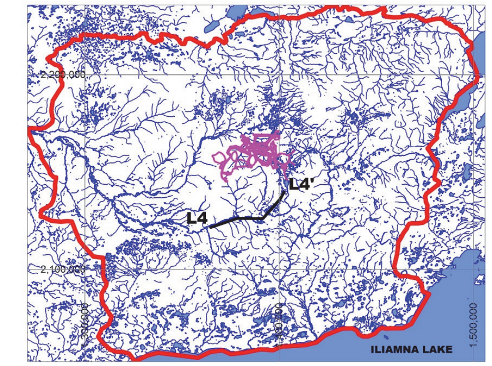

- GENERAL ARRANGEMENT
- MODEL DOMAIN
- CROSS-SECTION
- HYDROGEOLOGIC UNIT
- SAND AND GRAVEL
- SILTY SAND AND GRAVEL
- CLAYEY/SILTY SAND AND GRAVEL
- CLAYEY SAND AND GRAVEL
- SANDY/GRAVELLY SILT
- CLAYEY/SANDY SILT
- SILT
- CLAYEY SILT/SILTY CLAY
- CLAY
- BEDROCK

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED “PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL” AND DATED 05-24-2019.
4. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE: AS SHOWN	DATE: 05-24-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: ASSIGNED HYDROGEOLOGIC UNITS ALONG SURFICIAL GEOLOGY CROSS-SECTION L-4
APPROVED BY: RT				PROJECT NO: 1872-002 / FIGURE NO: 5-4

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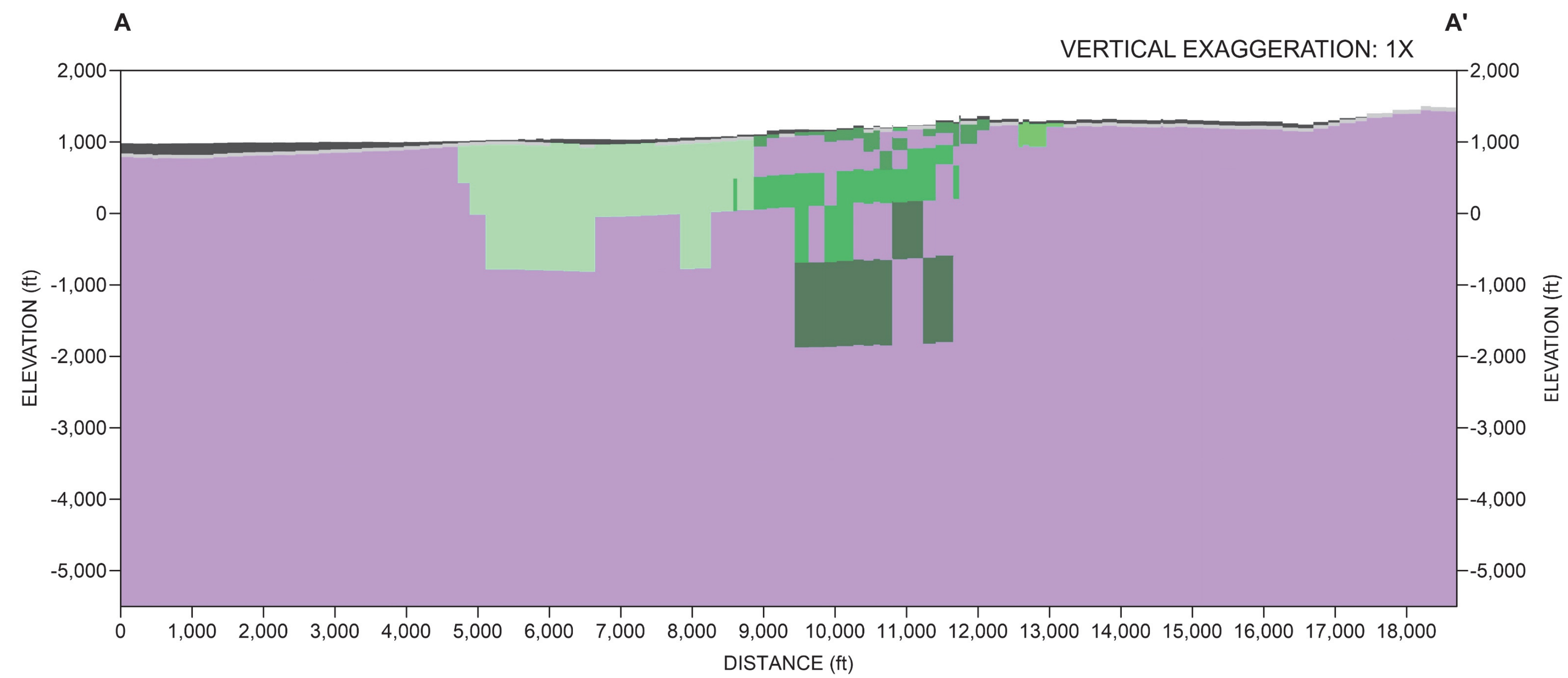

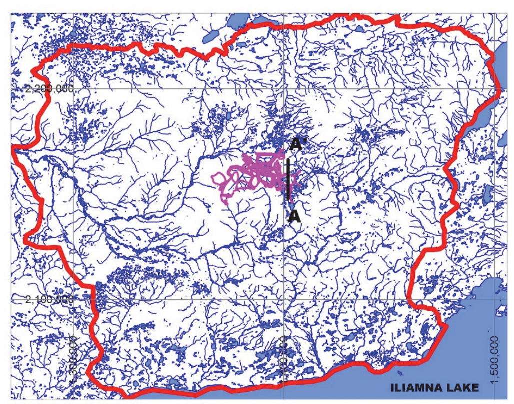

GENERAL ARRANGEMENT	PROJECT AREA BEDROCK (MODEL LAYERS 5 TO 12)
MODEL DOMAIN	CRETACEOUS GRANODIORITE SILL
CROSS-SECTION	CRETACEOUS GRANODIORITE PLUTON
UNCONSOLIDATED SEDIMENTS (MODEL LAYERS 1 TO 4)	CRETACEOUS DIORITE SILL
UNDIFFERENTIATED	CRETACEOUS MEGA BRECCIA
WEATHERED BEDROCK (MODEL LAYERS 1 TO 4)	CRETACEOUS GABBRO
UNDIFFERENTIATED	CRETACEOUS SEDIMENTARY XENOLITHS
REGIONAL BEDROCK (MODEL LAYERS 5 TO 12)	TERTIARY/CRETACEOUS UNDIFFERENTIATED
JURASSIC PLUTONIC (Jlmgr)	TERTIARY BASALT
JURASSIC VOLCANIC FLOWS, BRECCIA, TUFF, AND AGGLOMERATE (Jtk)	TERTIARY COBBLE CONGLOMERATE
CRETACEOUS/JURASSIC MARINE GRAYWACKE AND MUDSTONE (KJgn)	TERTIARY WACKE
CRETACEOUS GRANITIC (Klgr)	TERTIARY MUDSTONE-SILTSTONE
CRETACEOUS GRANITIC (Kmgr)	TERTIARY PEBBLE CONGLOMERATE
TERTIARY BASALT AND GREENSTONE (Trmb)	TERTIARY RHYOLITE
TERTIARY/CRETACEOUS VOLCANIC, UNDIVIDED (Tvme)	TERTIARY FELSIC FRAGMENTAL

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. PROJECT AREA GEOLOGY FROM GEOLOGICAL MODEL FILES RECEIVED FROM PEBBLE SEPTEMBER 12, 2018. REGIONAL GEOLOGY FROM WILSON ET AL. (2012).
4. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED “PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL” AND DATED 05-24-2019.
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SCALE: AS SHOWN	DATE: 05-24-2019	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC	FIGURE TITLE: ASSIGNED HYDROGEOLOGIC UNITS ALONG BEDROCK CROSS-SECTION A
APPROVED BY: RT		PROJECT NO: 1872-002 / FIGURE NO: 5-5

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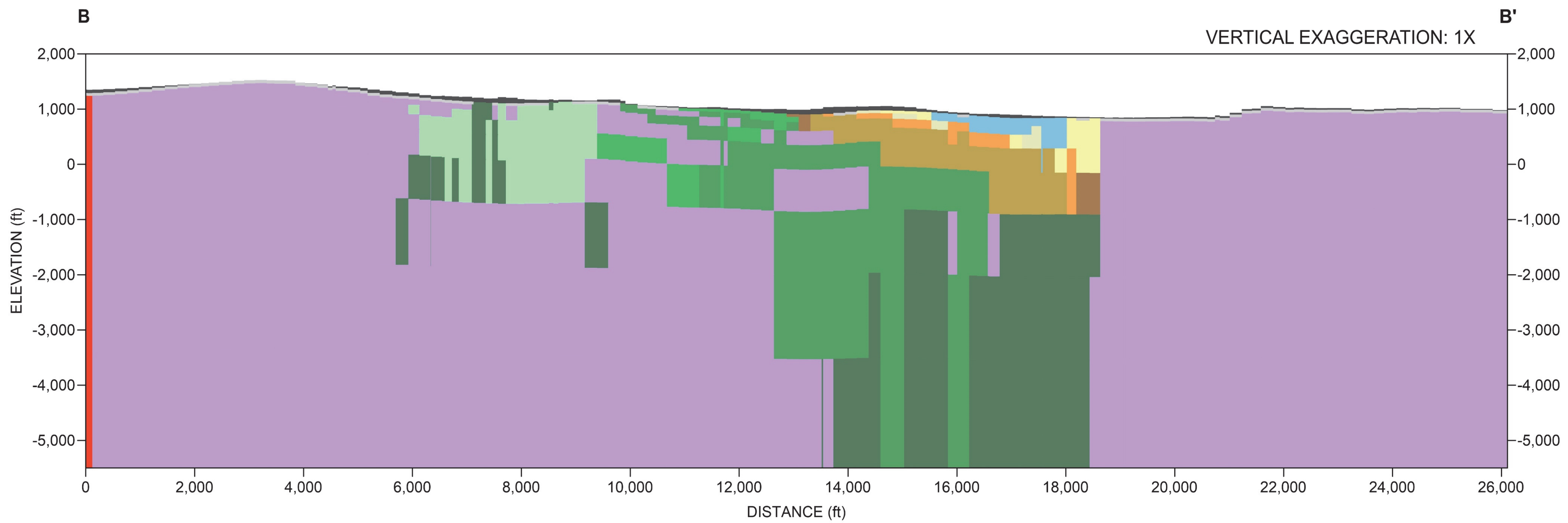

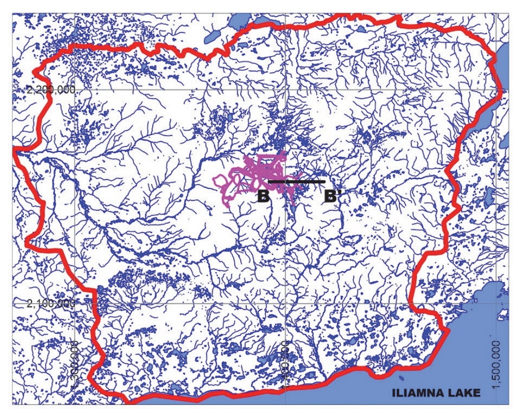

GENERAL ARRANGEMENT
MODEL DOMAIN
CROSS-SECTION

UNCONSOLIDATED SEDIMENTS (MODEL LAYERS 1 TO 4)
UNDIFFERENTIATED

WEATHERED BEDROCK (MODEL LAYERS 1 TO 4)
UNDIFFERENTIATED

REGIONAL BEDROCK (MODEL LAYERS 5 TO 12)
JURASSIC PLUTONIC (Jlmgr)
JURASSIC VOLCANIC FLOWS, BRECCIA, TUFF, AND AGGLOMERATE (Jtk)
CRETACEOUS/JURASSIC MARINE GRAYWACKE AND MUDSTONE (KJgn)
CRETACEOUS GRANITIC (Klgr)
CRETACEOUS GRANITIC (Kmgr)
TERTIARY BASALT AND GREENSTONE (Trmb)
TERTIARY/CRETACEOUS VOLCANIC, UNDIVIDED (Tvme)

PROJECT AREA BEDROCK (MODEL LAYERS 5 TO 12)
CRETACEOUS GRANODIORITE SILL
CRETACEOUS GRANODIORITE PLUTON
CRETACEOUS DIORITE SILL
CRETACEOUS MEGA BRECCIA
CRETACEOUS GABBRO
CRETACEOUS SEDIMENTARY XENOLITHS
TERTIARY/CRETACEIOUS UNDIFFERENTIATED
TERTIARY BASALT
TERTIARY COBBLE CONGLOMERATE
TERTIARY WACKE
TERTIARY MUDSTONE-SILTSTONE
TERTIARY PEBBLE CONGLOMERATE
TERTIARY RHYOLITE
TERTIARY FELSIC FRAGMENTAL

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. PROJECT AREA GEOLOGY FROM GEOLOGICAL MODEL FILES RECEIVED FROM PEBBLE SEPTEMBER 12, 2018. REGIONAL GEOLOGY FROM WILSON ET AL. (2012).
4. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED “PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL” AND DATED 05-24-2019.
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SCALE: AS SHOWN	DATE: 05-24-2019
PREPARED BY: CT	CHECKED BY: TWC
APPROVED BY: RT	

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REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL	
FIGURE TITLE: ASSIGNED HYDROGEOLOGIC UNITS ALONG BEDROCK CROSS-SECTION B	
PROJECT NO: 1872-002	FIGURE NO: 5-6

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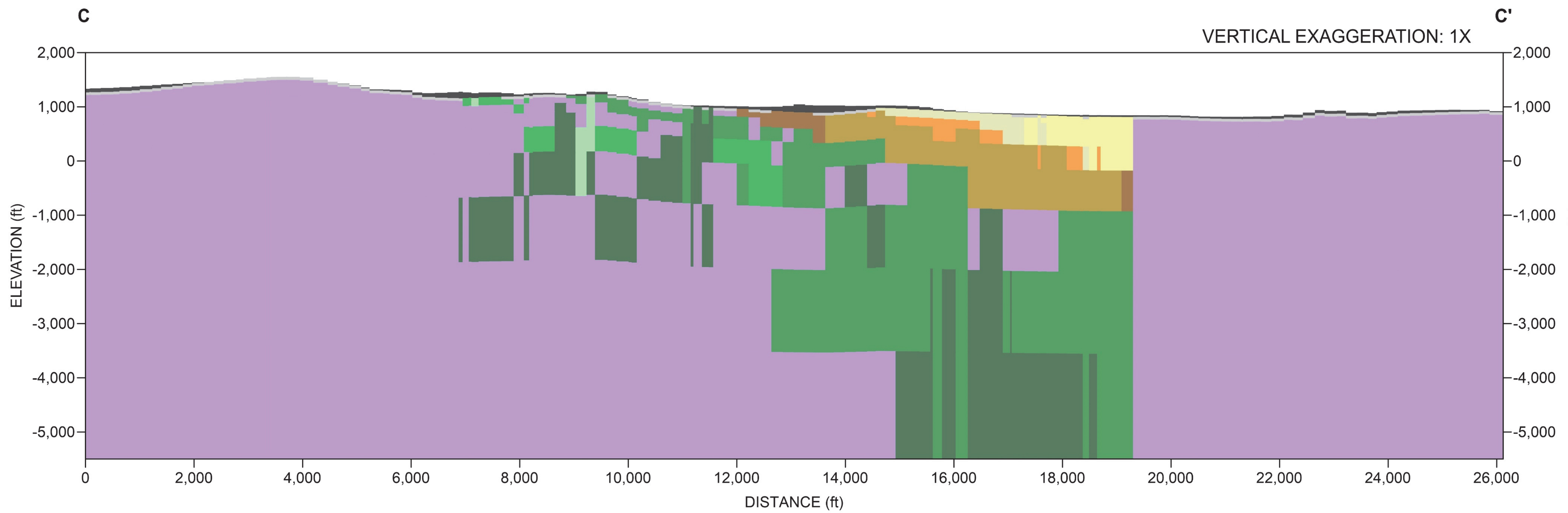

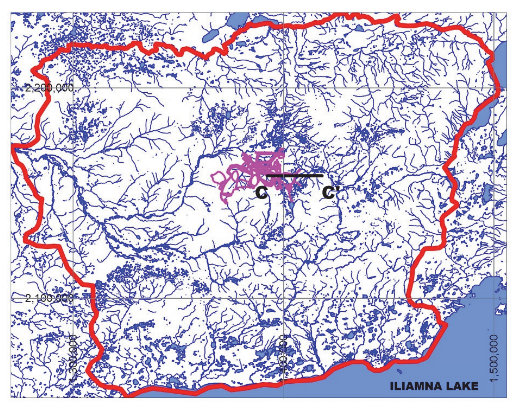

GENERAL ARRANGEMENT	PROJECT AREA BEDROCK (MODEL LAYERS 5 TO 12)
MODEL DOMAIN	CRETACEOUS GRANODIORITE SILL
CROSS-SECTION	CRETACEOUS GRANODIORITE PLUTON
UNCONSOLIDATED SEDIMENTS (MODEL LAYERS 1 TO 4)	CRETACEOUS DIORITE SILL
UNDIFFERENTIATED	CRETACEOUS MEGA BRECCIA
WEATHERED BEDROCK (MODEL LAYERS 1 TO 4)	CRETACEOUS GABBRO
UNDIFFERENTIATED	CRETACEOUS SEDIMENTARY XENOLITHS
REGIONAL BEDROCK (MODEL LAYERS 5 TO 12)	TERTIARY/CRETACEIOUS UNDIFFERENTIATED
JURASSIC PLUTONIC (Jlmgr)	TERTIARY BASALT
JURASSIC VOLCANIC FLOWS, BRECCIA, TUFF, AND AGGLOMERATE (Jtk)	TERTIARY COBBLE CONGLOMERATE
CRETACEOUS/JURASSIC MARINE GRAYWACKE AND MUDSTONE (KJgn)	TERTIARY WACKE
CRETACEOUS GRANITIC (Klgr)	TERTIARY MUDSTONE-SILTSTONE
CRETACEOUS GRANITIC (Kmgr)	TERTIARY PEBBLE CONGLOMERATE
TERTIARY BASALT AND GREENSTONE (Trmb)	TERTIARY RHYOLITE
TERTIARY/CRETACEOUS VOLCANIC, UNDIVIDED (Tvme)	TERTIARY FELSIC FRAGMENTAL

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. PROJECT AREA GEOLOGY FROM GEOLOGICAL MODEL FILES RECEIVED FROM PEBBLE SEPTEMBER 12, 2018. REGIONAL GEOLOGY FROM WILSON ET AL. (2012).
4. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED “PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL” AND DATED 05-24-2019.
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SCALE: AS SHOWN	DATE: 05-24-2019	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC	FIGURE TITLE: ASSIGNED HYDROGEOLOGIC UNITS ALONG BEDROCK CROSS-SECTION C
APPROVED BY: RT		PROJECT NO: 1872-002 / FIGURE NO: 5-7

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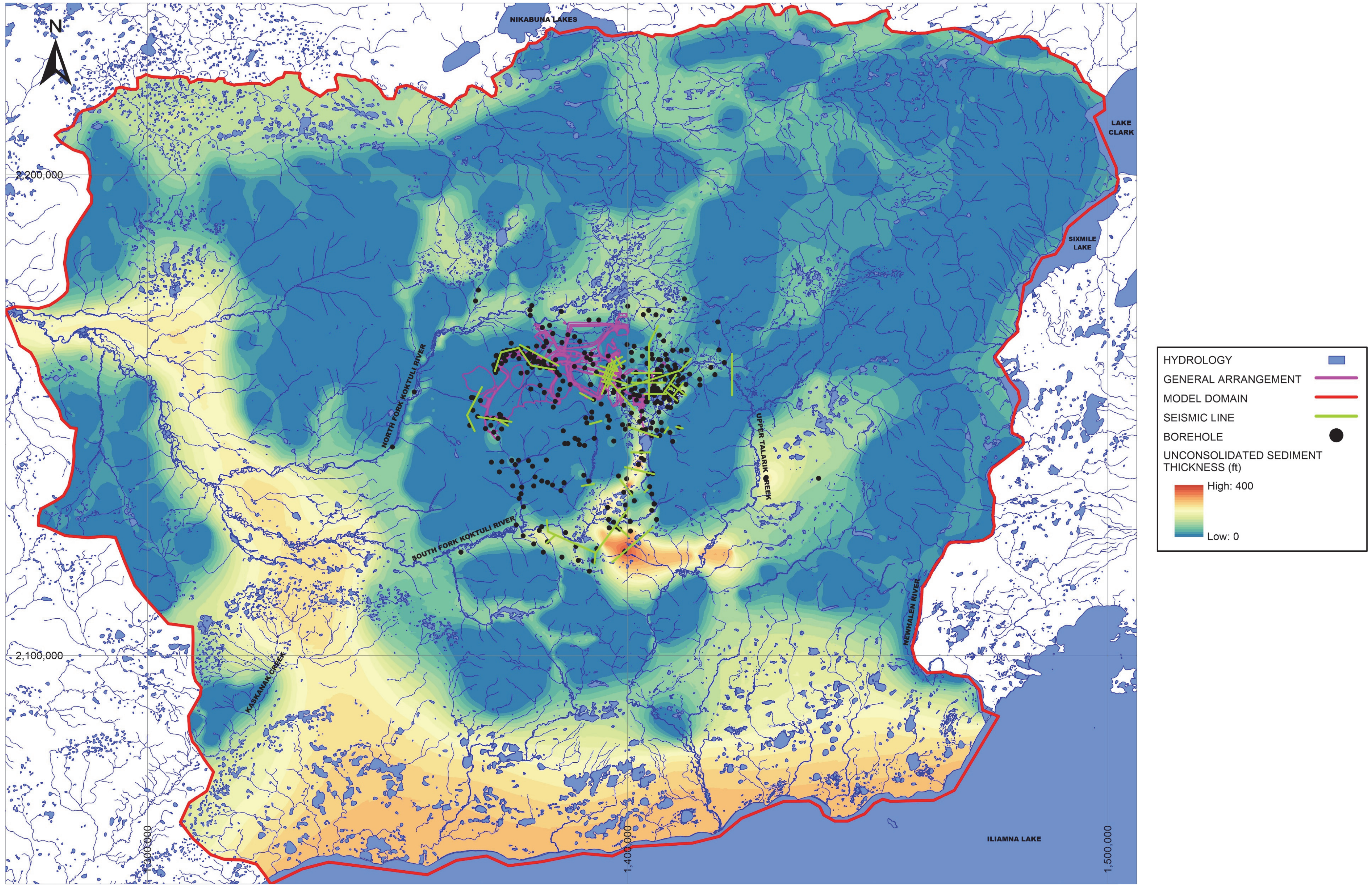

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
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SCALE: AS SHOWN	DATE: 05-24-2019
PREPARED BY: CT	CHECKED BY: TWC
APPROVED BY: RT	

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BGC

REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL

FIGURE TITLE: UNCONSOLIDATED SEDIMENT THICKNESS

PROJECT NO: 1872-002

FIGURE NO: 5-8

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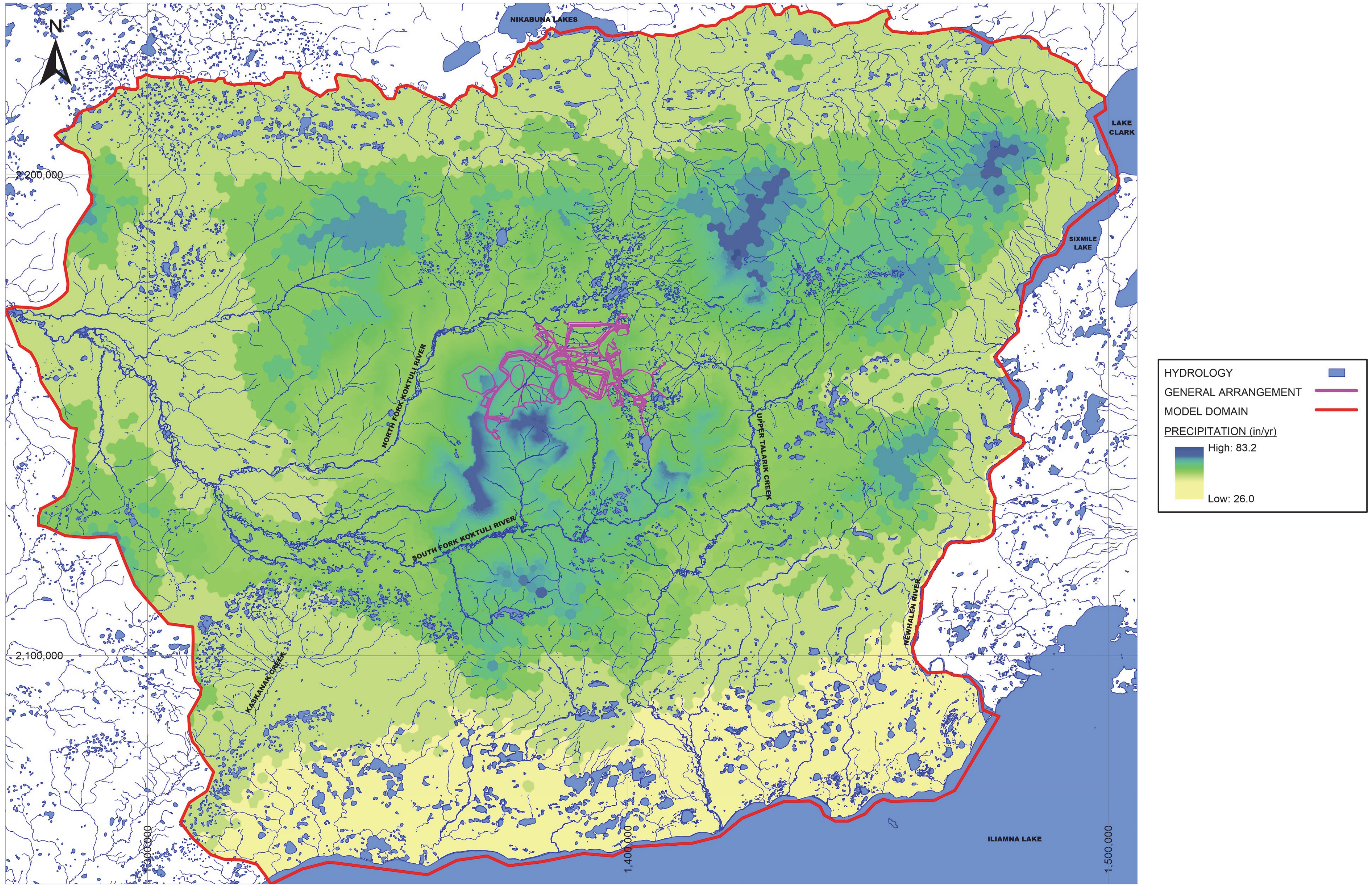

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
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SCALE: AS SHOWN	DATE: 05-24-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: PRECIPITATION
APPROVED BY: RT				PROJECT NO: 1872-002 / FIGURE NO: 5-9

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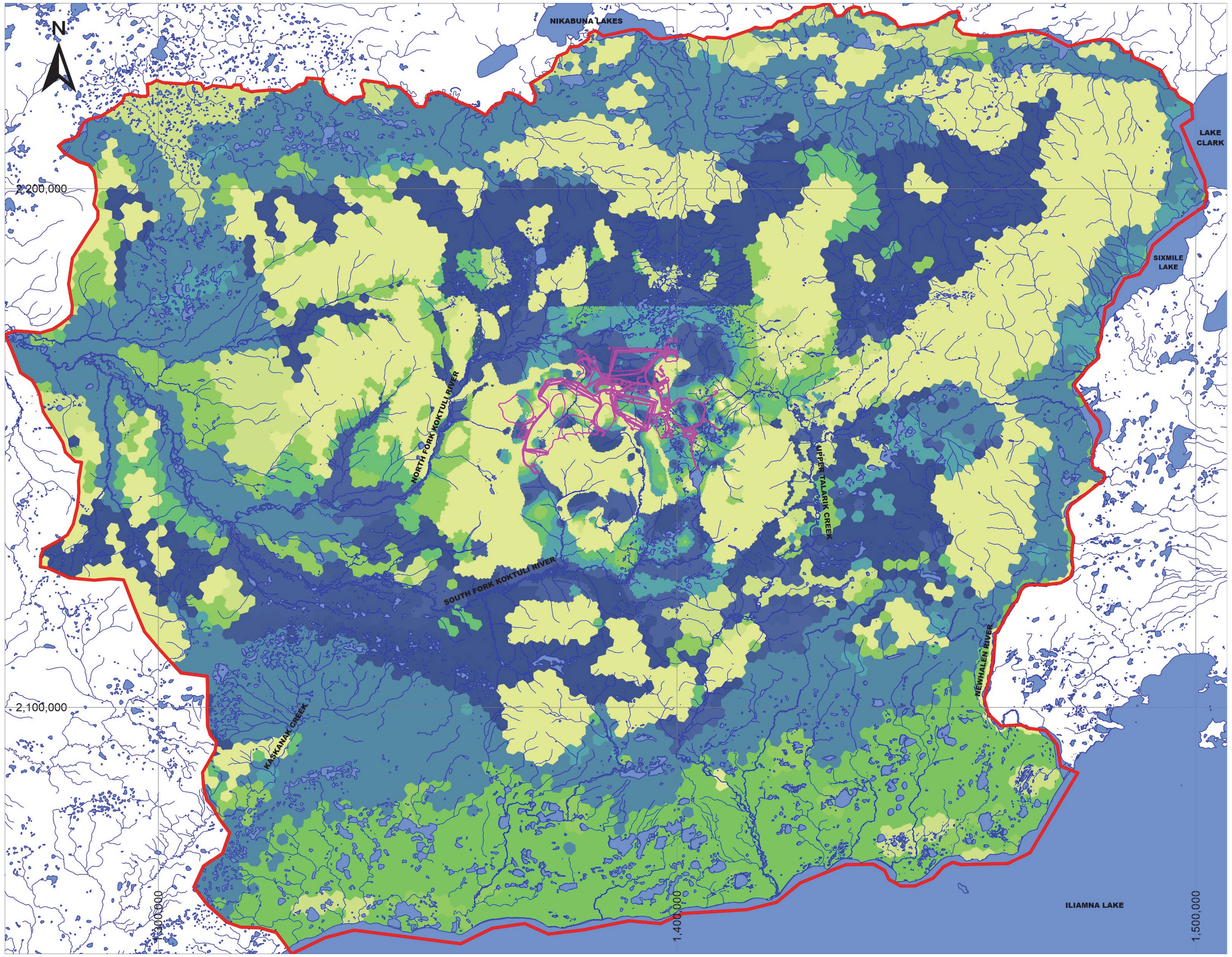

HYDROLOGY
GENERAL ARRANGEMENT
MODEL DOMAIN
GROUNDWTAER RECHARGE (in/yr)
High: 31.5
Low: 2.0

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
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SCALE: AS SHOWN	DATE: 05-24-2019	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC	FIGURE TITLE: GROUNDWATER RECHARGE
APPROVED BY: RT		PROJECT NO: 1872-002 / FIGURE NO: 5-10

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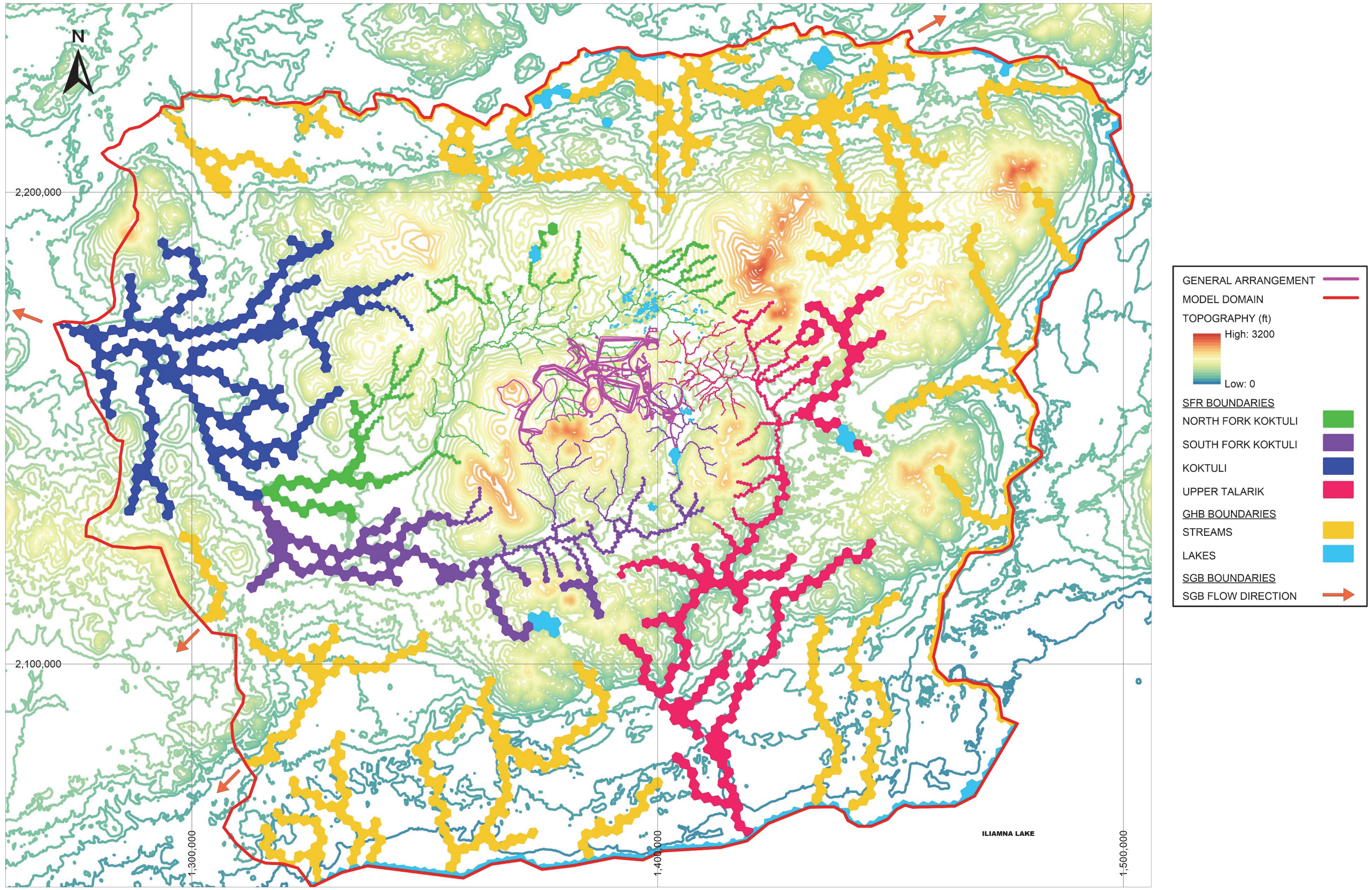

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. MODFLOW PACKAGE ACRONYMS: SFR = STREAM-FLOW ROUTING; GHB = GENERAL HEAD BOUNDARY; SGB = SPECIFIED GRADIENT BOUNDARY.
4. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
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SCALE: AS SHOWN	DATE: 05-24-2019	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC	FIGURE TITLE: BOUNDARY CONDITIONS
APPROVED BY: RT		PROJECT NO: 1872-002 / FIGURE NO: 5-11

THE pebble PARTNERSHIP

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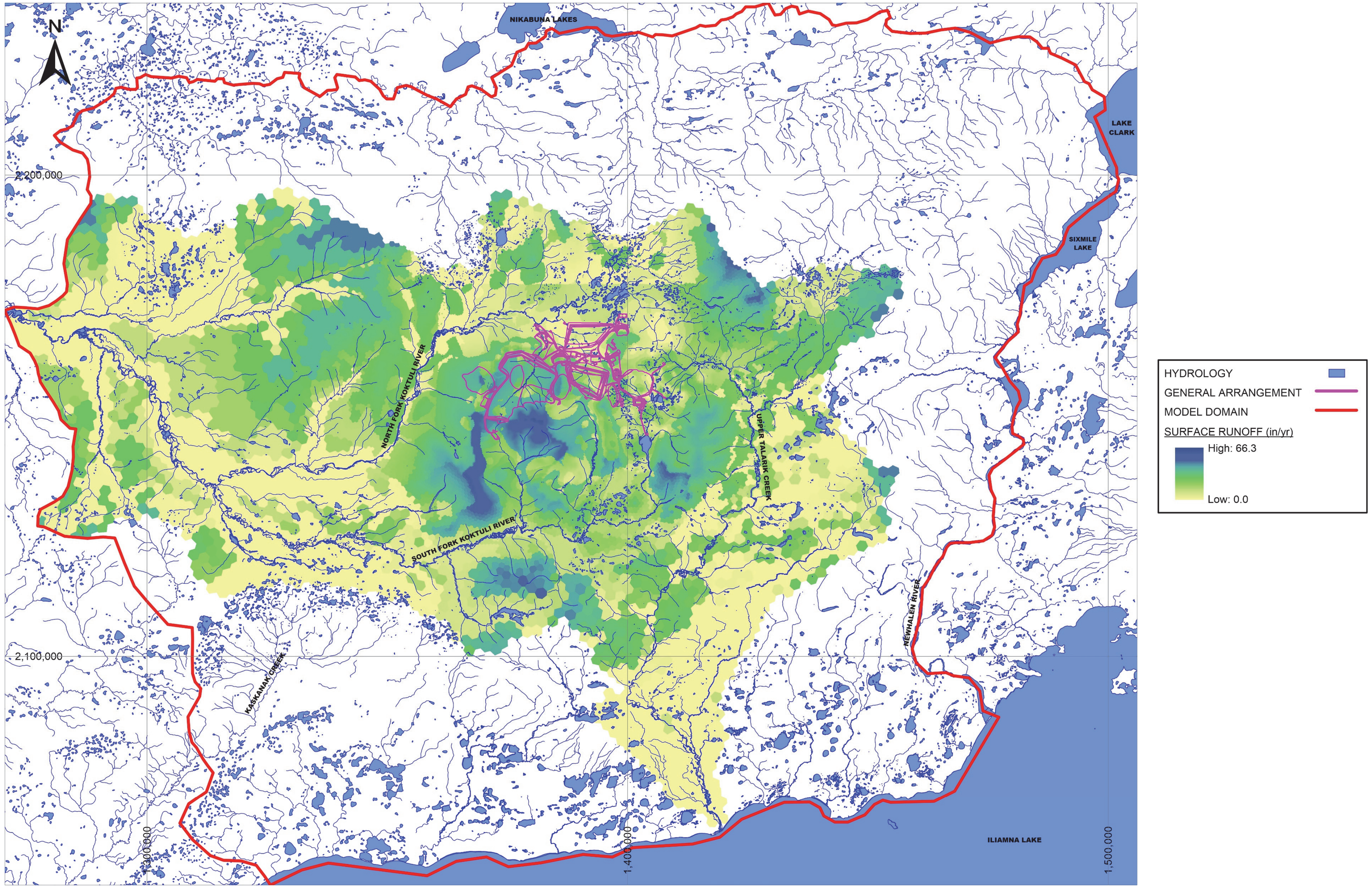

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
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SCALE: AS SHOWN	DATE: 05-24-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: SURFACE RUNOFF
APPROVED BY: RT				PROJECT NO: 1872-002 / FIGURE NO: 5-12

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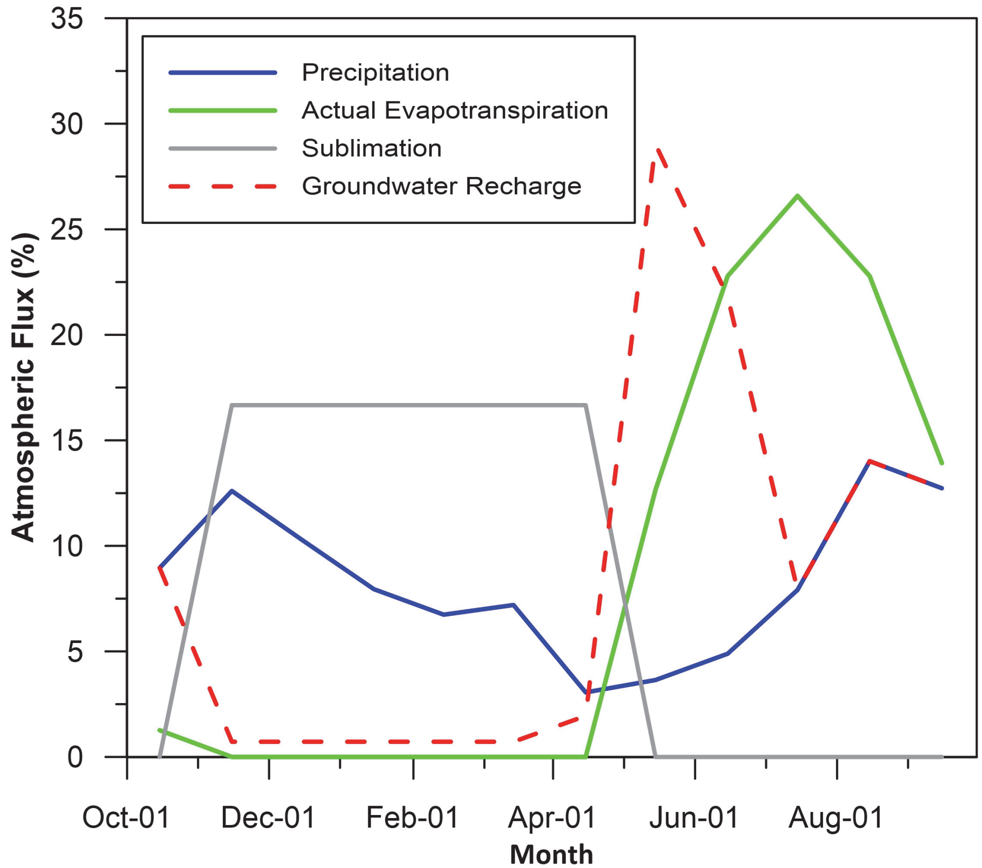

NOTES:
1. ACTUAL EVAPOTRANSPIRATION AND SUBLIMATION WERE REMOVED FROM THE TOTAL PRECIPITATION IN CALCULATIONS EXTERNAL TO THE MODEL.
2. EVAPOTRANSPIRATION SIMULATED BY THE MODEL (NOT SHOWN) VARIED SPATIALY BASED ON THE SIMULATED WATER TABLE DEPTH.
3. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
4. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE: AS SHOWN	DATE: 05-24-2019	THE pebble PARTNERSHIP	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC		FIGURE TITLE: DISTRIBUTION OF MONTHLY ATMOSPHERIC FLUXES
APPROVED BY: RT		BGC	PROJECT NO: 1872-002 / FIGURE NO: 6-1

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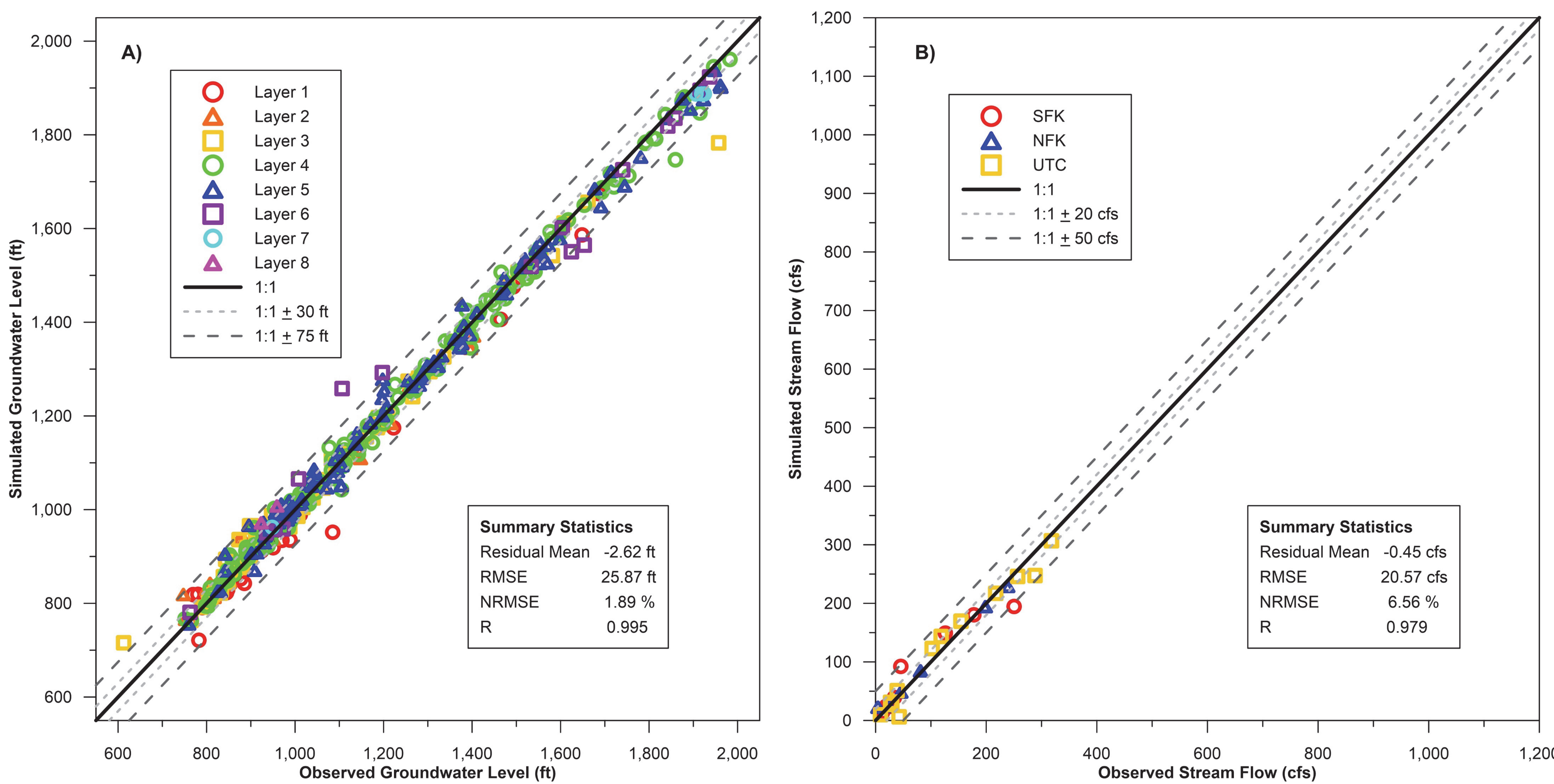

NOTES:
1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
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SCALE: AS SHOWN	DATE: 05-24-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: STEADY-STATE GROUNDWATER LEVELS (A) AND STREAM FLOWS (B) ALONG WITH SUMMARY STATISTICS
APPROVED BY: RT				PROJECT NO: 1872-002 / FIGURE NO: 6-2

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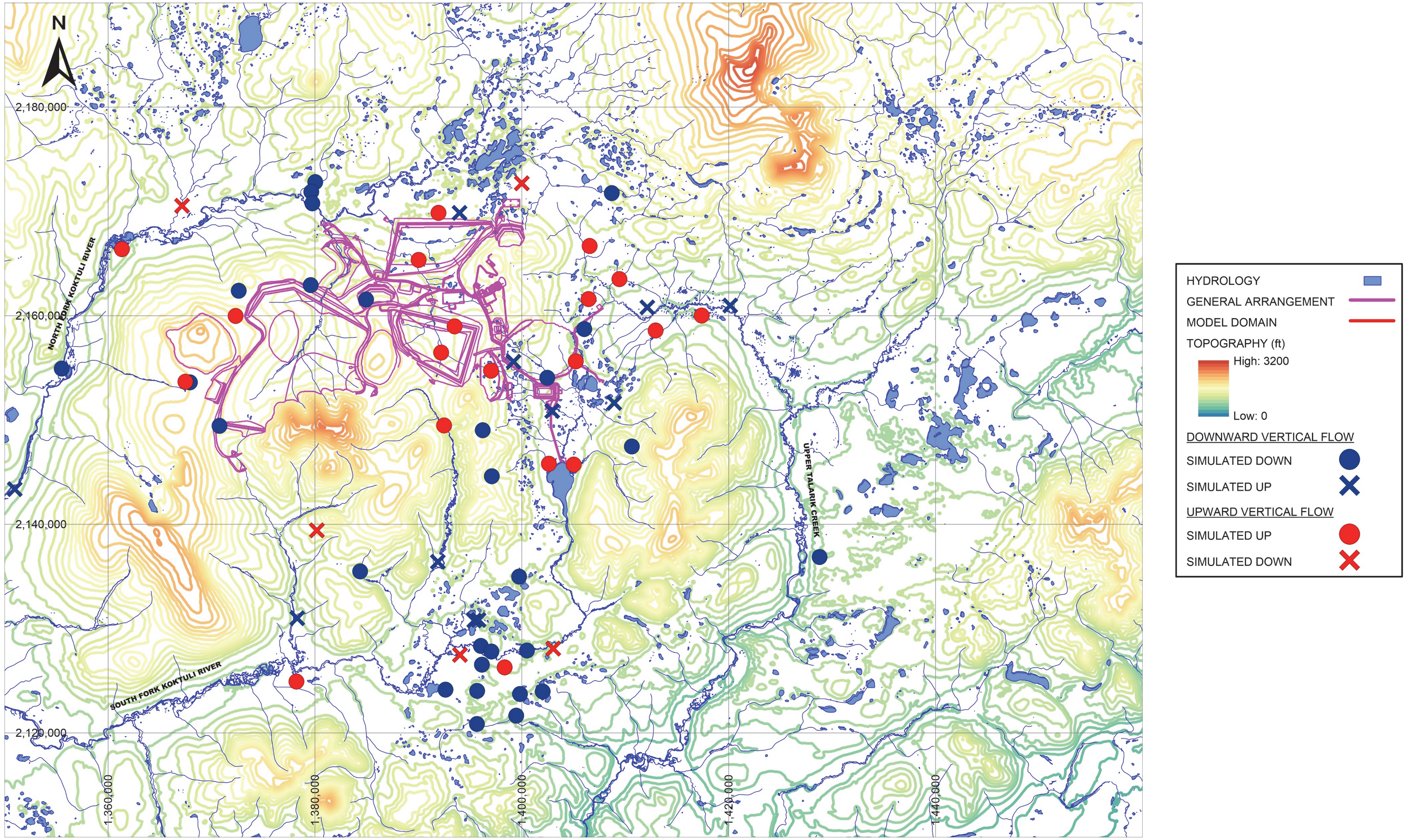

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. O'S INDICATED THAT SIMULATED VERTICAL FLOW DIRECTION MATCHES OBSERVED VERTICAL FLOW DIRECTION. X'S INDICATE THAT SIMULATED VERTICAL FLOW DIRECTION DOES NOT MATCH OBSERVED VERTICAL FLOW DIRECTION.
4. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE: AS SHOWN	DATE: 05-24-2019	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC	FIGURE TITLE: COMPARISON OF SIMULATED AND OBSERVED VERTICAL GROUNDWATER FLOW DIRECTIONS
APPROVED BY: RT		PROJECT NO: 1872-002 / FIGURE NO: 6-3

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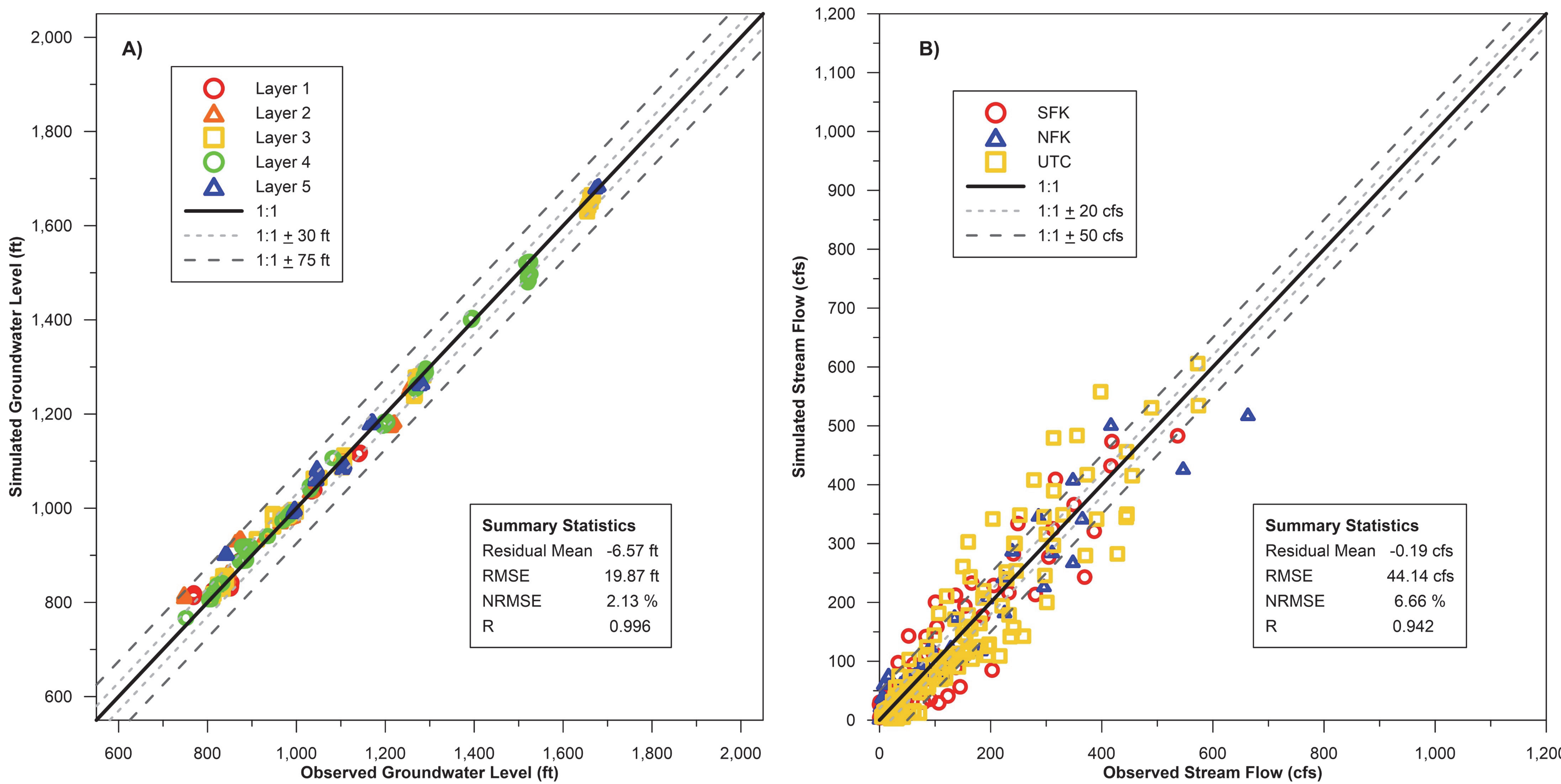

NOTES:
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SCALE: AS SHOWN	DATE: 05-24-2019
PREPARED BY: CT	CHECKED BY: TWC
APPROVED BY: RT	

THE pebble PARTNERSHIP

BGC

REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL	
FIGURE TITLE: TRANSIENT GROUNDWATER LEVELS (A) AND STREAM FLOWS (B) ALONG WITH SUMMARY STATISTICS FOR AVERAGE MONTHLY CONDITIONS	
PROJECT NO: 1872-002	FIGURE NO: 6-4

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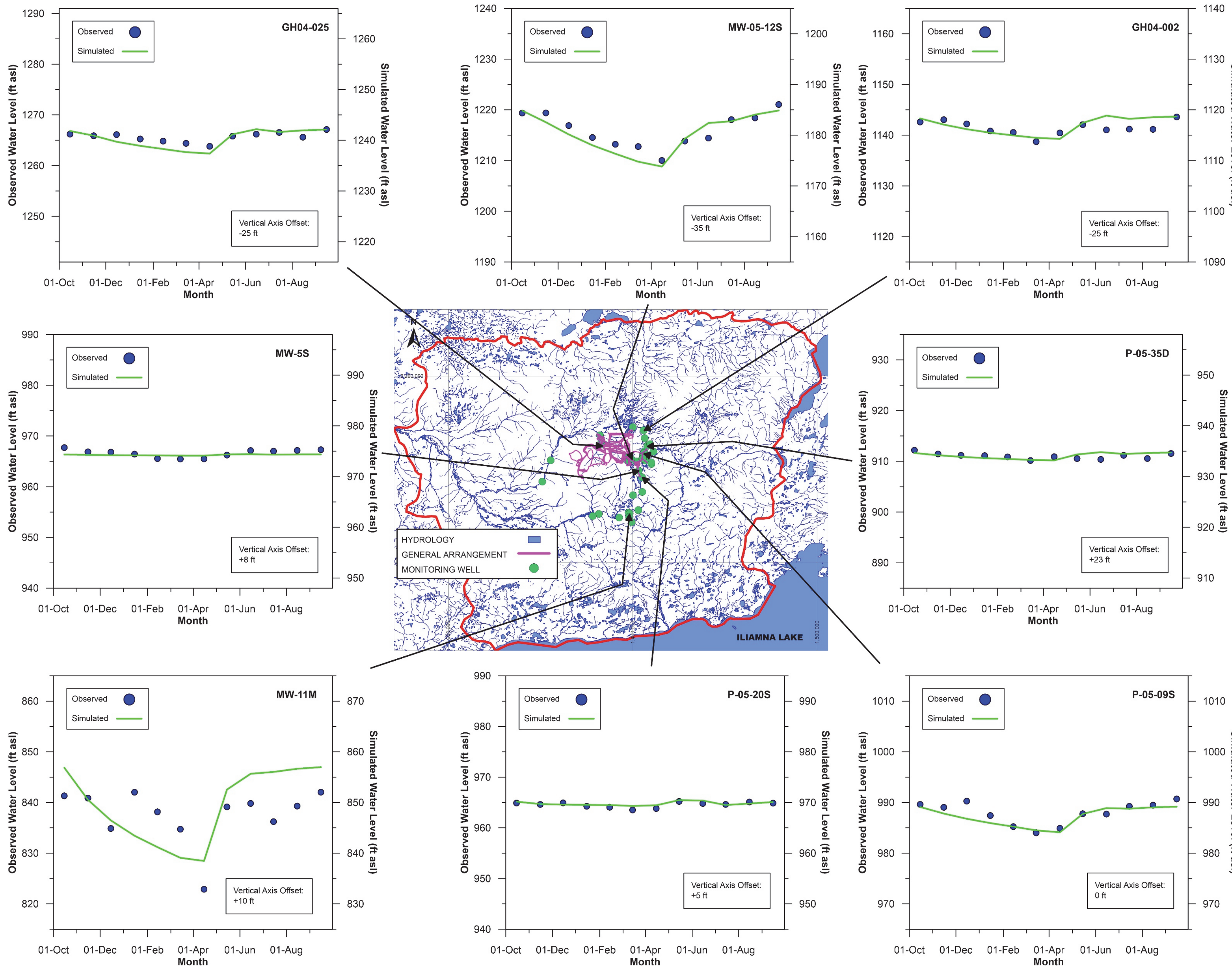

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. VERTICAL AXES FOR OBSERVED AND SIMULATED GROUNDWATER LEVELS ARE OFFSET. THE OFFSET IS INDICATED IN EACH PLOT.
4. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
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SCALE: AS SHOWN	DATE: 05-24-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: TIME SERIES OF SIMULATED AND OBSERVED AVERAGE MONTHLY GROUNDWATER LEVELS FOR UNCONSOLIDATED SEDIMENT LOCATIONS
APPROVED BY: RT				PROJECT NO: 1872-002 / FIGURE NO: 6-5

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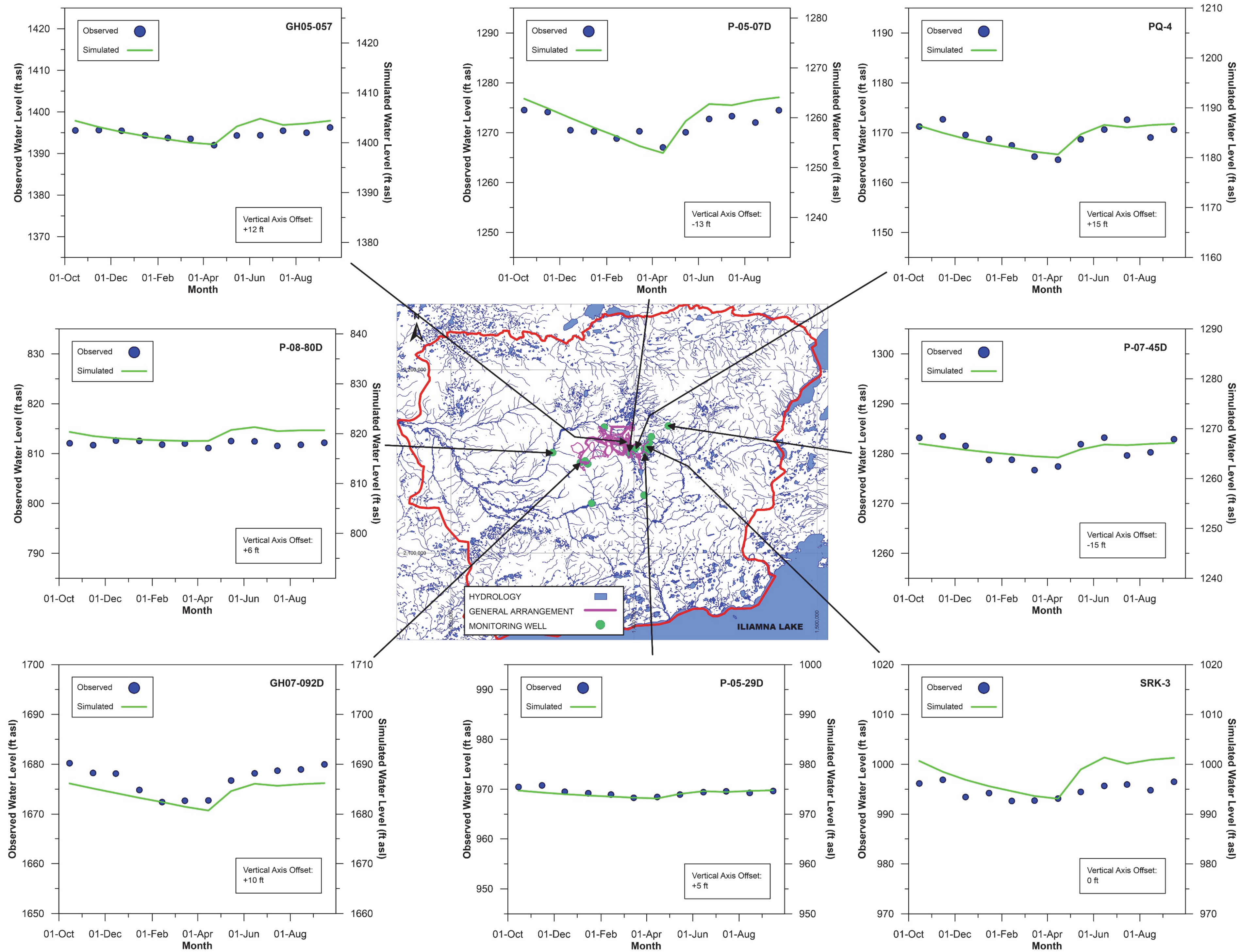

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. VERTICAL AXES FOR OBSERVED AND SIMULATED GROUNDWATER LEVELS ARE OFFSET. THE OFFSET IS INDICATED IN EACH PLOT.
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SCALE: AS SHOWN	DATE: 05-24-2019	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC	FIGURE TITLE: TIME SERIES OF SIMULATED AND OBSERVED AVERAGE MONTHLY GROUNDWATER LEVELS FOR BEDROCK LOCATIONS
APPROVED BY: RT		PROJECT NO: 1872-002 / FIGURE NO: 6-6

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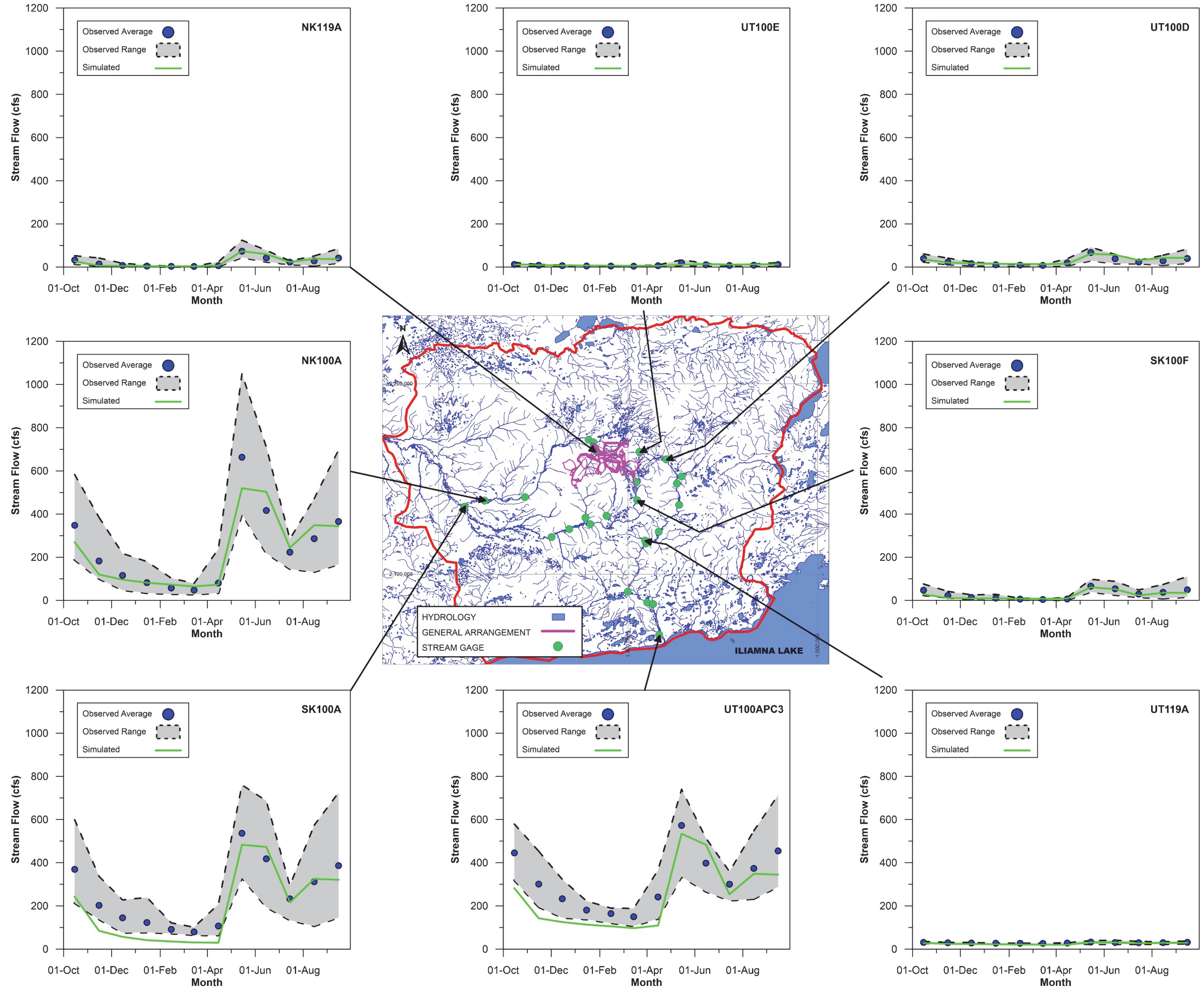

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
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SCALE: AS SHOWN	DATE: 05-24-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: TIME SERIES OF SIMULATED AND OBSERVED AVERAGE MONTHLY STREAM FLOWS FOR STREAM GAGING LOCATIONS
APPROVED BY: RT				PROJECT NO: 1872-002 / FIGURE NO: 6-7

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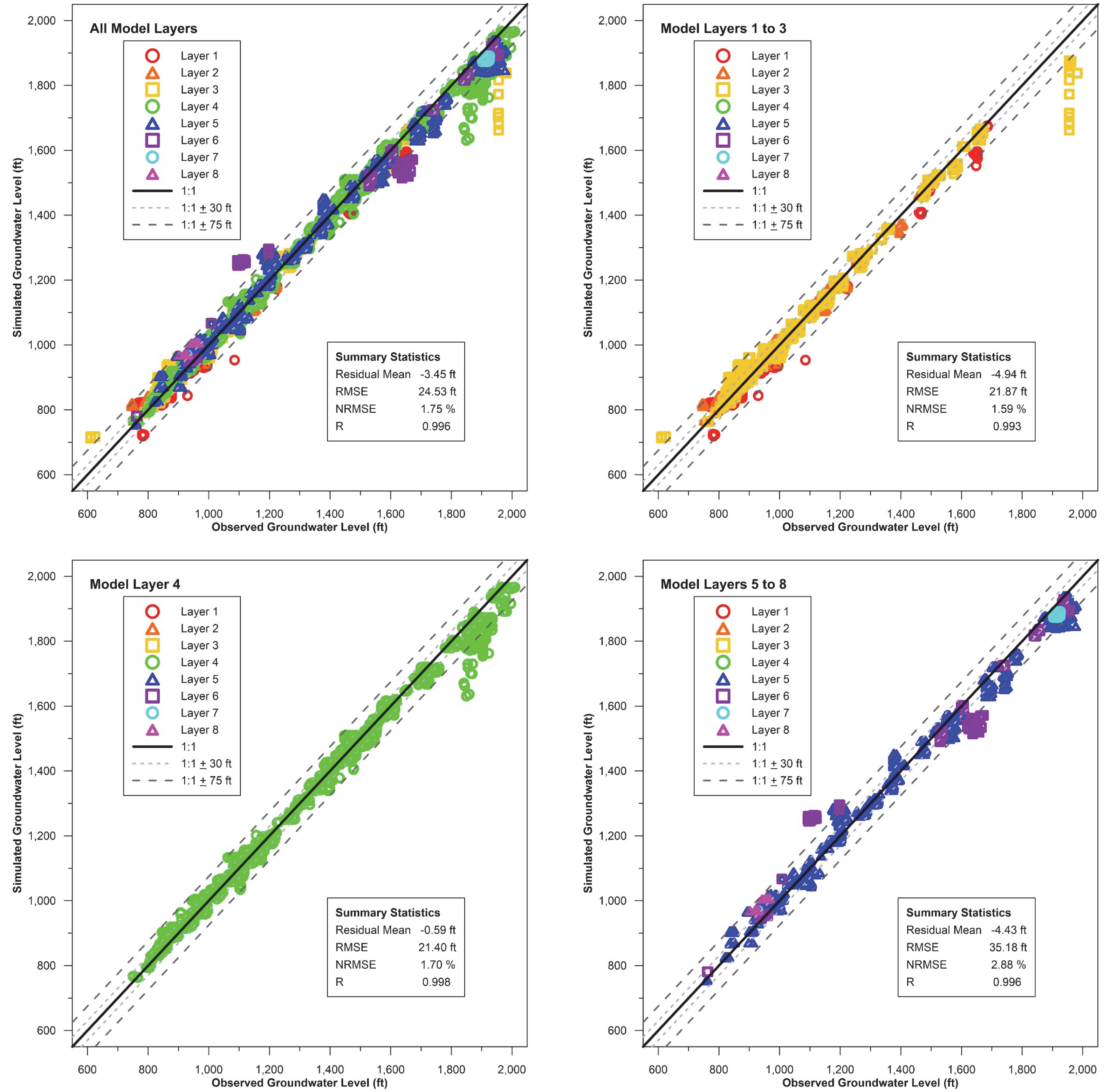

NOTES:
1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED “PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL” AND DATED 05-24-2019.
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SCALE: AS SHOWN	DATE: 05-24-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: TRANSIENT GROUNDWATER LEVELS ALONG WITH SUMMARY STATISTICS FOR 2004 TO 2012 CONDITIONS
APPROVED BY: RT				PROJECT NO: 1872-002 · FIGURE NO: 6-8

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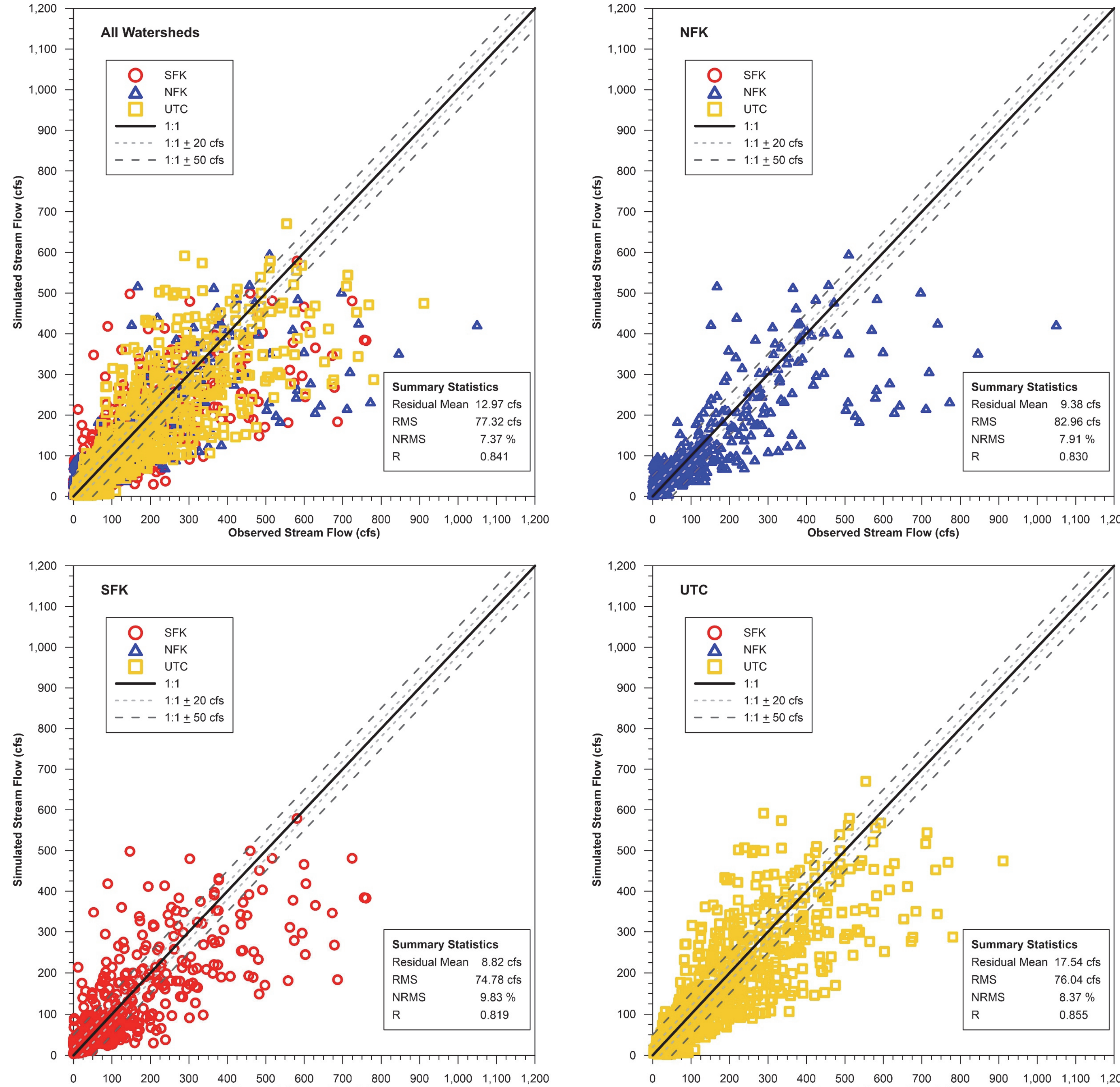

NOTES:
1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
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SCALE: AS SHOWN	DATE: 05-24-2019	REPORT TITLE:	PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC	FIGURE TITLE:	TRANSIENT STREAM FLOWS ALONG WITH SUMMARY STATISTICS FOR 2004 TO 2012 CONDITIONS
APPROVED BY: RT		PROJECT NO: 1872-002	FIGURE NO: 6-9

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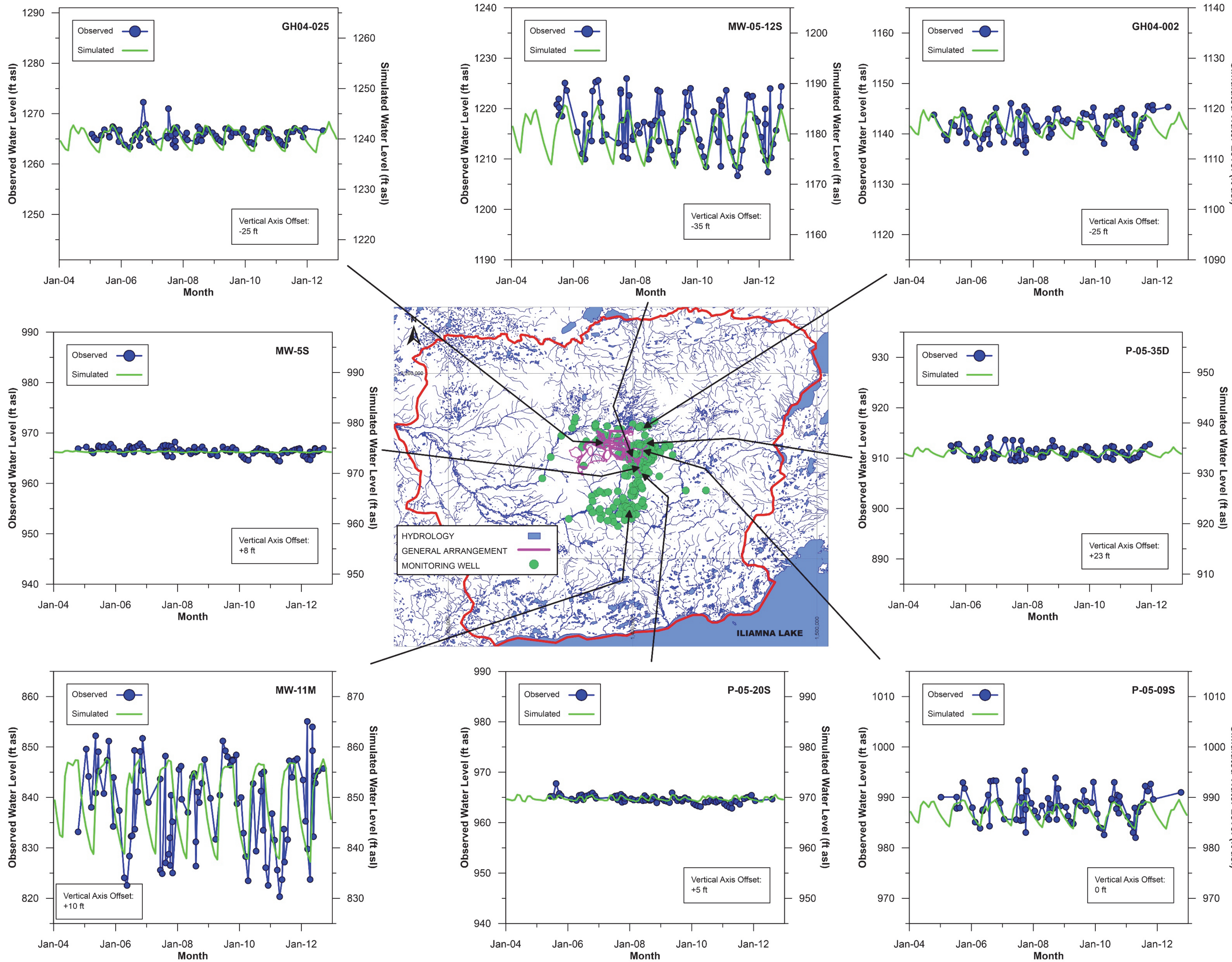

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. VERTICAL AXES FOR OBSERVED AND SIMULATED GROUNDWATER LEVELS ARE OFFSET. THE OFFSET IS INDICATED IN EACH PLOT.
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SCALE: AS SHOWN	DATE: 05-24-2019	THE pebble PARTNERSHIP	BGC	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC			FIGURE TITLE: TIME SERIES OF SIMULATED AND OBSERVED 2004 TO 2012 GROUNDWATER LEVELS FOR UNCONSOLIDATED SEDIMENT LOCATIONS
APPROVED BY: RT				PROJECT NO: 1872-002 FIGURE NO: 6-10

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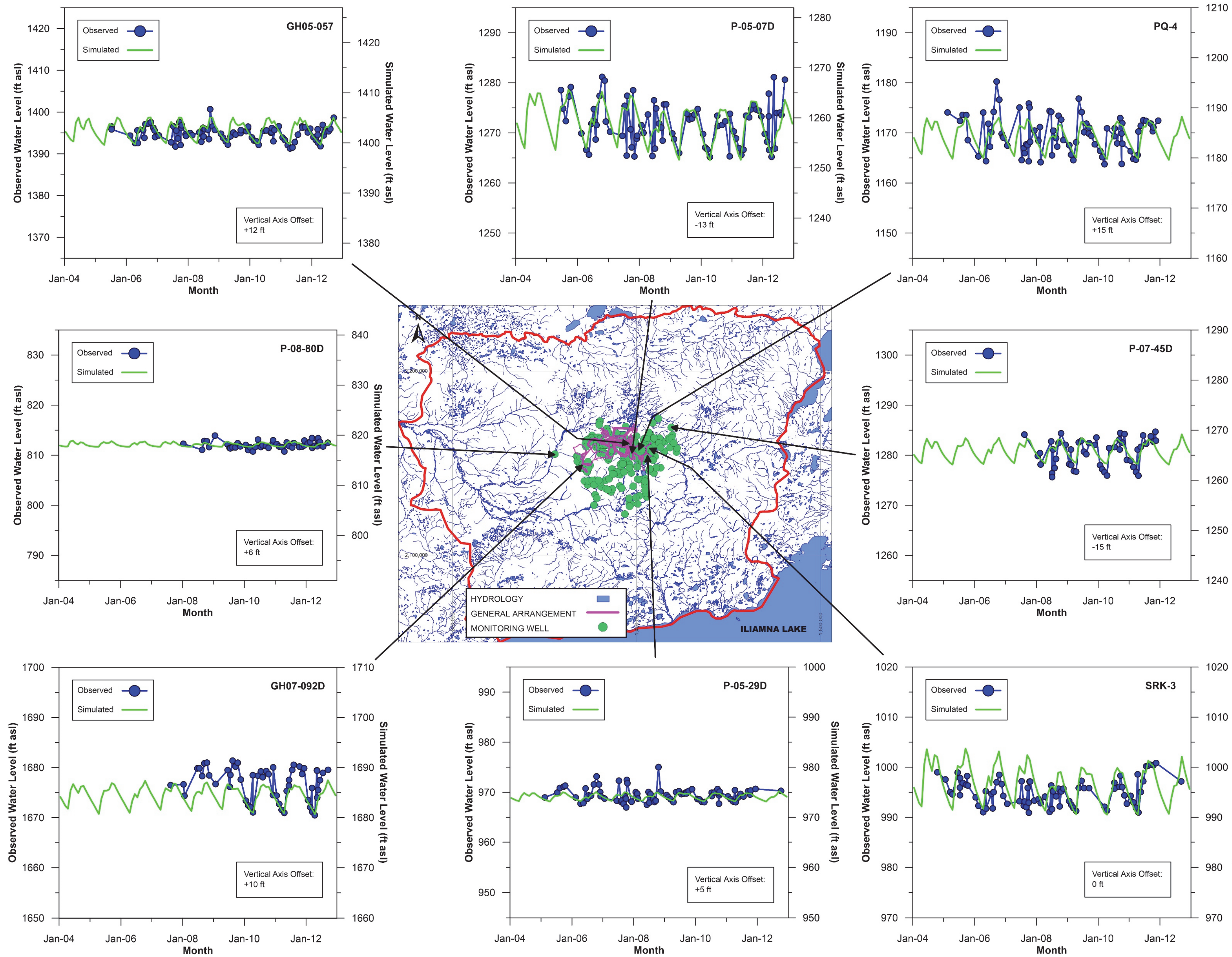

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
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SCALE: AS SHOWN	DATE: 05-24-2019	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL
PREPARED BY: CT	CHECKED BY: TWC	FIGURE TITLE: TIME SERIES OF SIMULATED AND OBSERVED 2004 TO 2012 GROUNDWATER LEVELS FOR BEDROCK LOCATIONS
APPROVED BY: RT		PROJECT NO: 1872-002 / FIGURE NO: 6-11

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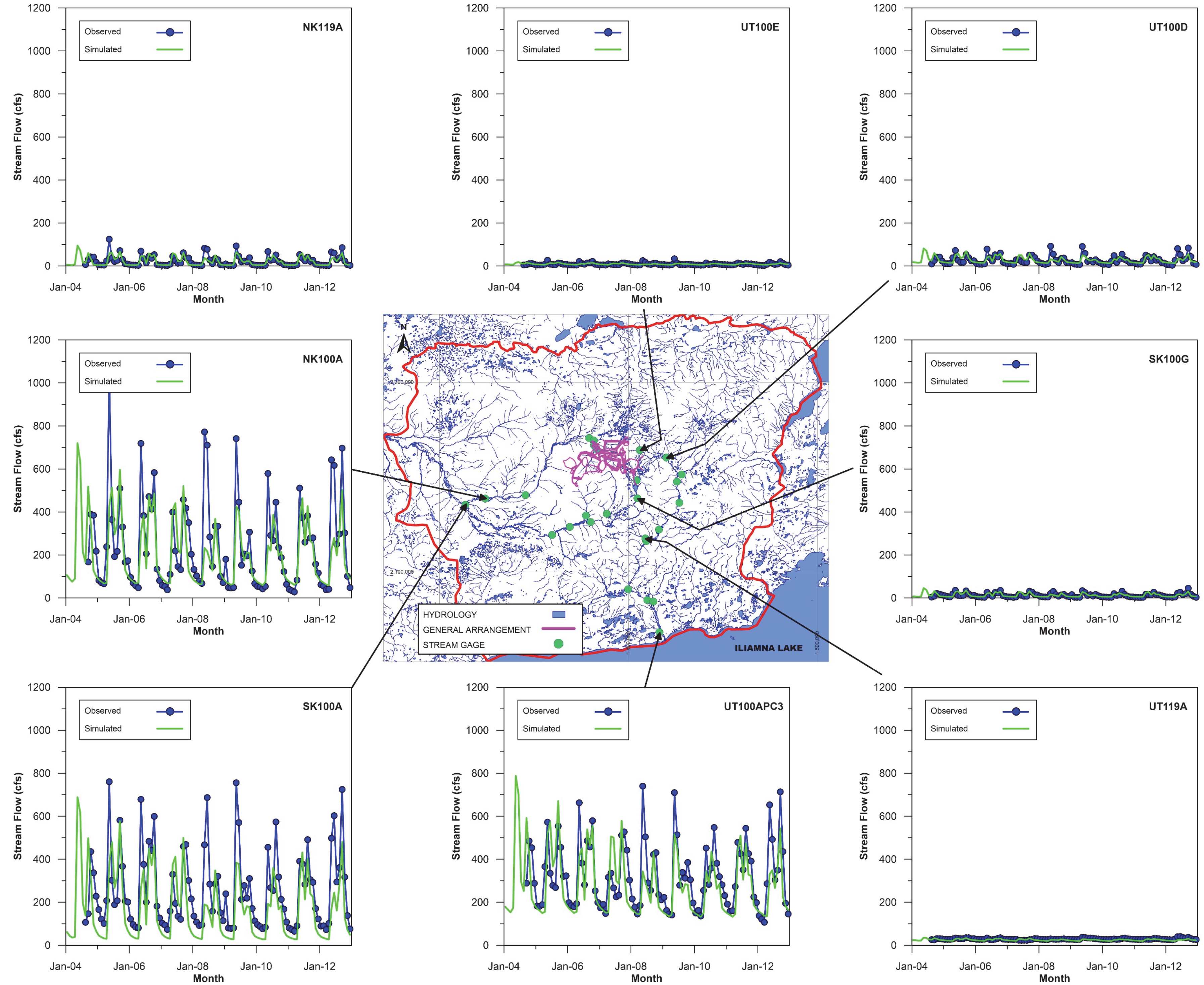

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1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
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APPROVED BY: RT	

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REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL	
FIGURE TITLE: TIME SERIES OF SIMULATED AND OBSERVED 2004 TO 2012 STREAM FLOWS FOR STREAM GAGING LOCATIONS	
PROJECT NO: 1872-002	FIGURE NO: 6-12

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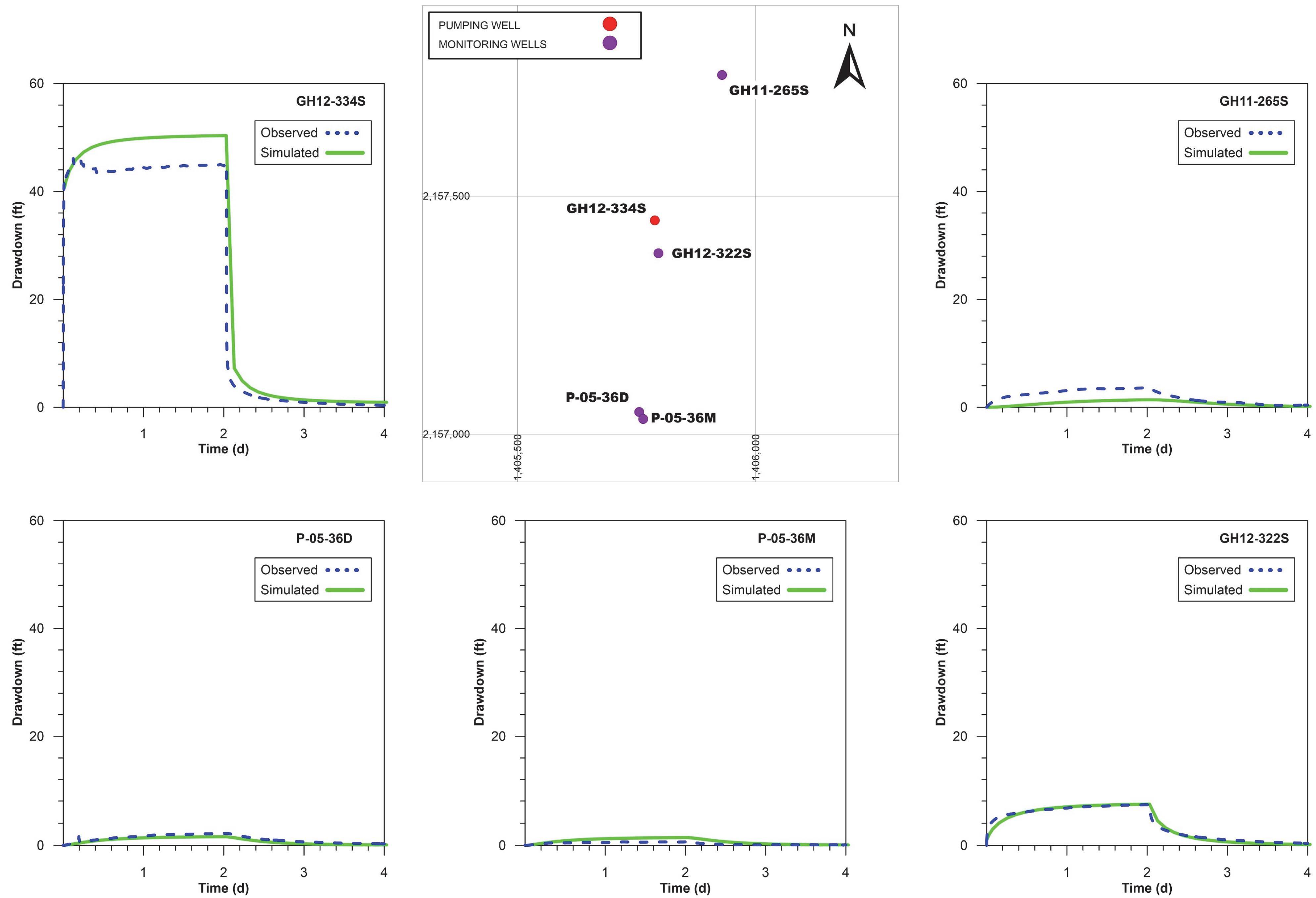

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. SEE FIGURE E-1 FOR PLAN MAP LOCATION.
3. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
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PREPARED BY: CT	CHECKED BY: TWC
APPROVED BY: RT	

REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL	
FIGURE TITLE: PUMPING TEST CALIBRATION RESULTS	
PROJECT NO: 1872-002	FIGURE NO: 6-13

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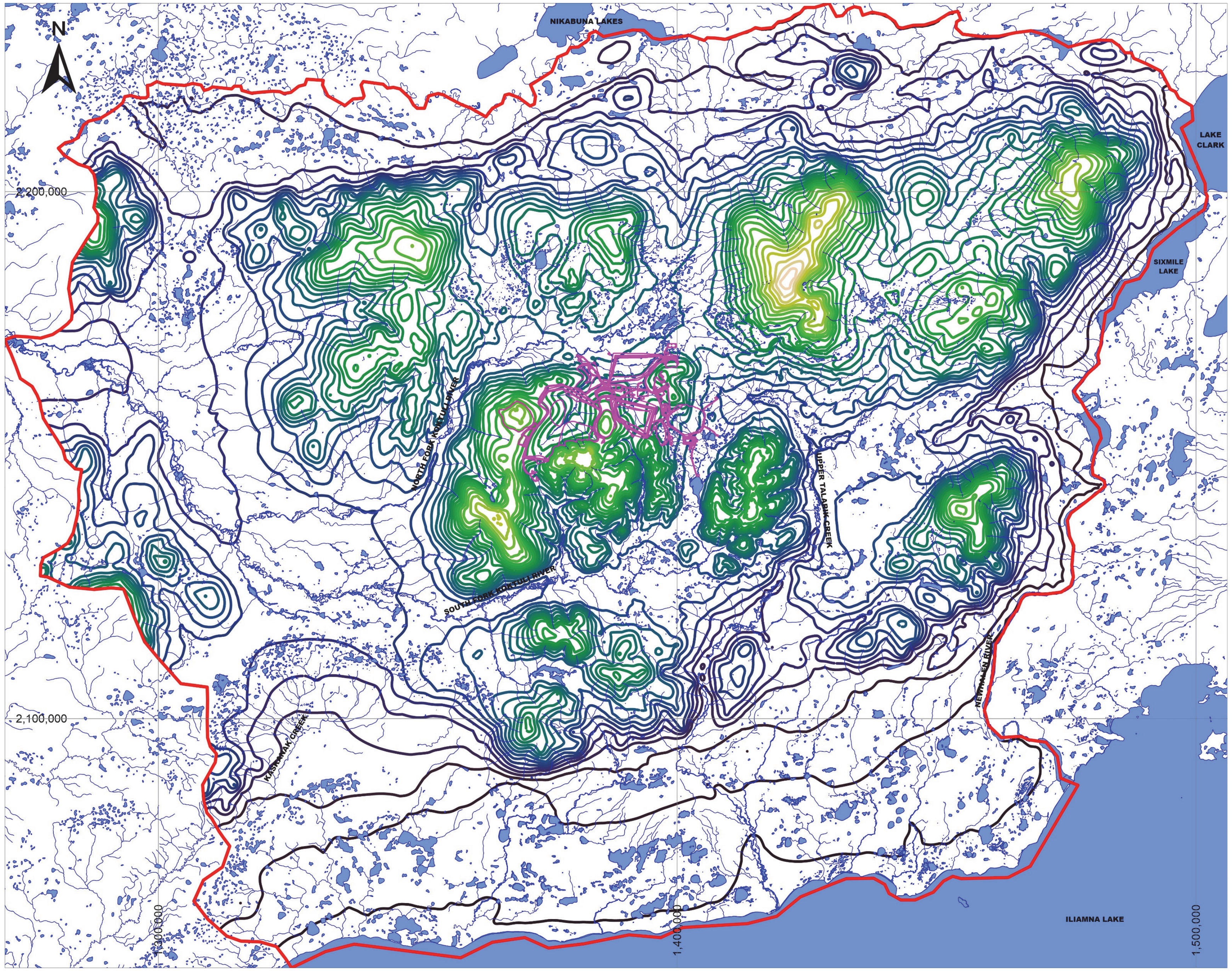

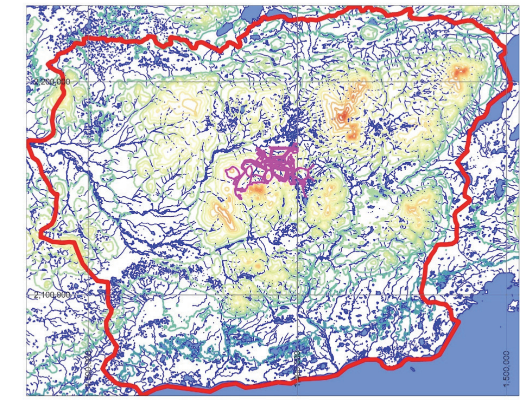

HYDROLOGY
GENERAL ARRANGEMENT
MODEL DOMAIN
WATER TABLE (ft)
High: 3000
Low: 0
TOPOGRAPHY (ft)
High: 3200
Low: 0

NOTES:
1. PROJECTION: NAD83 STATEPLANE ALASKA (FEET).
2. GENERAL ARRANGEMENT PROVIDED BY PLP DECEMBER 19, 2018.
3. CONTOUR INTERVAL 100 ft.
4. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "PEBBLE PROJECT: NUMERICAL GROUNDWATER FLOW MODEL" AND DATED 05-24-2019.
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SCALE: AS SHOWN	DATE: 05-24-2019	REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL	
PREPARED BY: CT	CHECKED BY: TWC	FIGURE TITLE: SIMULATED WATER TABLE: AVERAGE ANNUAL CONDITIONS	
APPROVED BY: RT		PROJECT NO: 1872-002	FIGURE NO: 6-14

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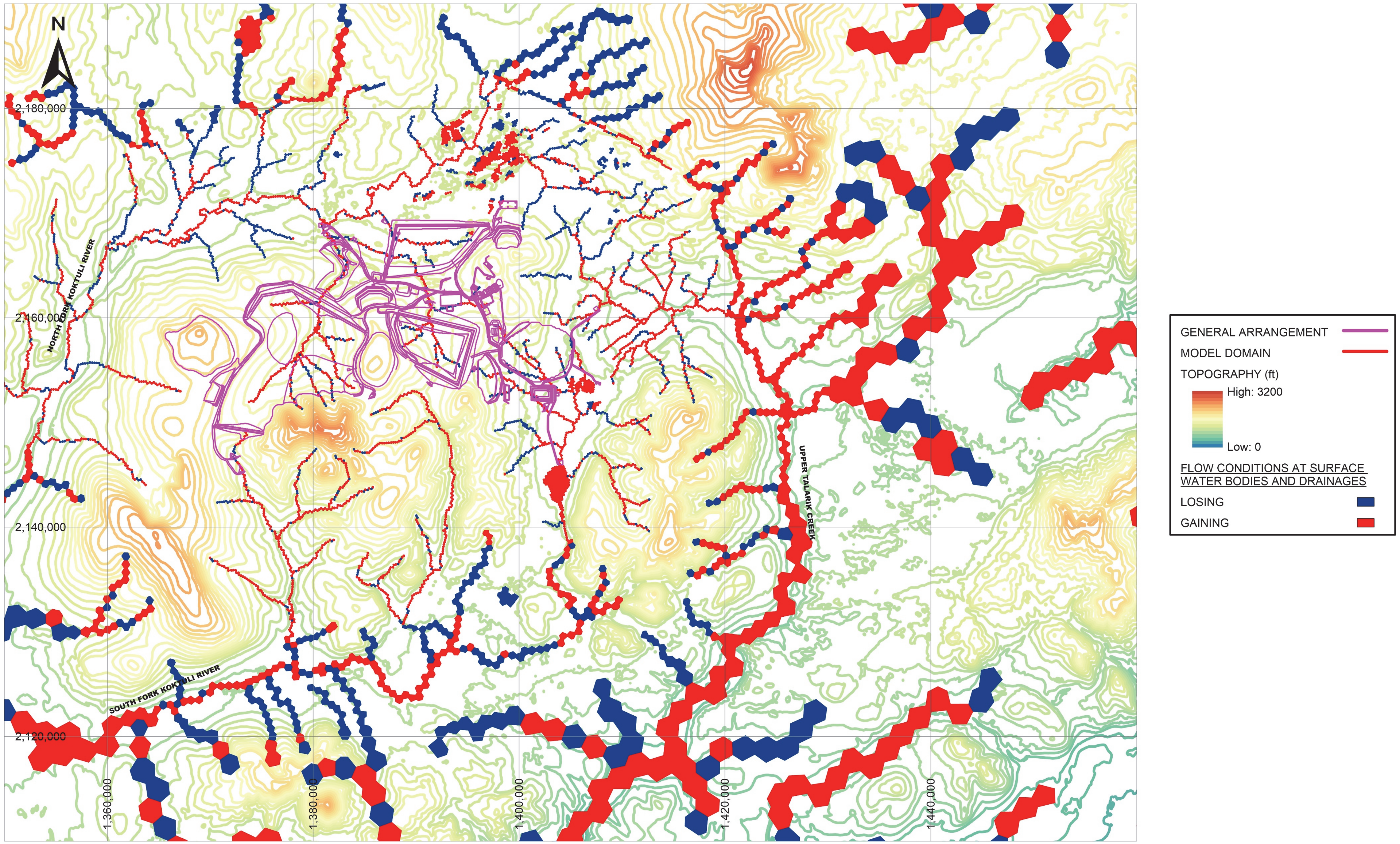

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SCALE: AS SHOWN	DATE: 05-24-2019
PREPARED BY: CT	CHECKED BY: TWC
APPROVED BY: RT	

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REPORT TITLE: PEBBLE PROJECT NUMERICAL GROUNDWATER FLOW MODEL	
FIGURE TITLE: SIMULATED GAINING AND LOSING SURFACE WATER BODIES AND DRAINAGES	
PROJECT NO: 1872-002	FIGURE NO: 6-15

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