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November 30, 2022

Our Reference: 33186

City of Pitt Meadows
Engineering Department
12007 Harris Road
Pitt Meadows, BC V3Y 2B5

Attention: Samantha Maki, P.Eng., Director of Engineering and Operations
Alina Torres, P.Eng., Manager of Engineering and Facilities

Reference: Preload Effect on Groundwater Levels – Evaluation using the Pitt Meadows Groundwater Flow Model

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ISL Engineering and Land Services Ltd. (ISL) was retained by the City of Pitt Meadows to oversee the development, calibration, and application of a numerical model of groundwater flow. The model was used to evaluate the potential impact of development-related preloading activities on shallow groundwater levels and to develop an associated risk map. Aqua Insight Inc. was retained by ISL to complete the numerical modelling and to produce a report outlining the findings, included herein.

Corporate Authorization

This document entitled "Preload Effect on Groundwater Levels Evaluation using the Pitt Meadows Groundwater Flow Model" has been prepared by Aqua Insight Inc. for the use of ISL Engineering and Land Services Ltd. (ISL) and the City of Pitt Meadows. The information and data provided herein represent ISL's professional judgment at the time of preparation. ISL denies any liability whatsoever to any other parties who may obtain this report and use it, or any of its contents, without prior written consent from ISL.

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GEOSCIENTIST
2022-11-30

Soren Poschmann, P.Geo.
Lead, Hydrogeology

Permit to Practice
ISL Engineering and Land Services Ltd.
RR Signature:
RR EGBC ID: 47333
Date: 2022-11-30
Permit Number 1000419
Engineers & Geoscientists British Columbia

Preload Effect on Groundwater Levels

Evaluation using the Pitt Meadows Groundwater Flow Model

September 2022

Report Prepared for:

City of Pitt Meadows

12007 Harris Road, Pitt Meadows, BC V3Y 2B5

Submitted By:

ISL Engineering and Land Services Ltd.

201-3999 Henning Drive, Burnaby, BC. V5C 6P9

In association with:

Aqua Insight Inc.

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FIGURES (FOLLOWING THE TEXT)

APPENDICES

1. INTRODUCTION

ISL Engineering and Land Services Ltd. in association with subconsultant Aqua Insight Inc. were retained by the City of Pitt Meadows to develop, calibrate, and apply a groundwater flow model to evaluate the potential impact of preloading on groundwater levels and develop a map of regions where there is a higher risk of preload impacts.

This report documents: 1) the groundwater flow model developed, 2) the simulated water level rise due to a typical development in different locations, and 3) interpretation of risks associated with groundwater level rise due to preloading throughout Pitt Meadows. The work culminated in development of a groundwater risk map for the City of Pitt Meadows which can be used to judge the potential water level rise risk associated with planned developments.

Details of the groundwater flow model development and calibration are documented in Appendix A.

1.1 Study Area

The City of Pitt Meadows (henceforth, "the City") is located in the eastern-central portion of the Greater Vancouver Area, at the confluence of the Pitt and Fraser Rivers (Figure 1). Numerous surface watercourses transect the rural lowlands to provide soil drainage as the groundwater level is close to ground surface throughout this area. Water levels within Pitt Meadows are managed by; 1) dikes adjacent to the Pitt and Fraser Rivers which act to isolate the City from elevated water levels and fluctuation within the Pitt and Fraser Rivers, and 2) large pumping stations (Kennedy and Baynes: Figure 2) which pump water to the Pitt and Fraser rivers, respectively. Most of the rural land use surrounding the City of Pitt Meadows is agricultural. Urban development has been historically focused on the elevated (Urban Upland) area associated with the Sumas Drift (Figure 3) but has been extending into the surrounding lowlands.

1.2 Study Objectives and Scope of Work

Pitt Meadows has a large distribution of highly compressible silts, clays and peats. Due to the highly compressible nature of the surficial geology in the area, upon development of buildings and infrastructure, grounds must be preloaded to stabilize the subsurface. As consolidation occurs, water contained within the pore space of the soil will be displaced due to increased pore pressure within the underlying and surrounding sediments, which will raise water levels temporarily until a new equilibrium condition is met. Neighbours of developments within Pitt Meadows that involved significant preloading and consolidation have experienced groundwater level rise causing inundated basements, and other issues with high groundwater levels. In addition, until the new equilibrium is achieved, displaced groundwater is also expected to result in an additional pumping requirement at the Kennedy Road and Baynes Road Pump Stations to maintain safe surface water levels.

The primary objective of this study was to evaluate the potential risk associated with developments that require preloading. To evaluate the potential risk, previous regional studies, surficial geological mapping and available borehole data were reviewed to determine regions with highly compressible material. The three-dimensional (3D) Pitt Meadows Groundwater Flow Model (henceforth, "the Groundwater Model") was also applied in some test cases to aid in estimating risk. The Groundwater Model was developed by the City in 2021 to evaluate potential groundwater level rise (ISL and Aqua Insight, 2021), and the calibration was revised in 2022. Details of the Groundwater Model calibration are described under Appendix A; however, a summary of the model structure, properties and boundary conditions are presented in this report. The Groundwater Model facilitates the evaluation of water level changes due to a change in stress (e.g., pressure build-up due to consolidation) anywhere within the model domain.

2. PHYSICAL SETTING

2.1 Geologic and Hydrogeologic Setting

Pitt Meadows is located in the Lower Fraser River Valley Delta (Clague and Luternauer, 1983). These formations include glacio-fluvial sediments as well as deltaic and outwash deposits from glacial meltwater at the close of the last glaciation (Armstrong, 1981). The sequence of deposits consists of large deltas and sub-aqueous fans constructed as piedmont glacial meltwater entered the sea, under variable historic sea level changes. The change in sea level resulted in periods of fine-grained deposits (silt and clay) interspersed with periods of coarse-grained deposits (sand and gravel). Clague and Luternauer (1983) report that it is typical in the region to find discontinuous patches of sand and gravel terraces on the flanks of the upland areas and suggest that such a terrace deposit is located at 15-20 m below ground surface in the Pitt Meadows area (herein referred to as the Dense Sand layer). They further report that the Pitt Meadows area was located at the delta front of the outwash train, resulting in sporadic distribution of outwash.

Figure 3 illustrates the mapped distribution of surficial geologic materials, which are dominantly composed of 1) Fraser River sediments, 2) Sumas Drift and 3) bog, swamp and shallow lake deposits (i.e., Peat). As part of the groundwater flow model development, cross-sections were generated using available borehole logs from the Government of British Columbia (2021), as well as site-specific boreholes throughout the City of Pitt Meadows (Figures 4, 5 and 6). Those cross-sections document the upper 40 m of a sediment package that has been logged to be as deep as 150 m thick based on borehole logs near Maple Ridge. Surficial sands (Sumas Drift) and Fraser River Delta terrace deposits (sand and gravel at 10 to 20 m below surface) act as regional aquifer units. The material overlying and underlying these sand deposits is dominantly recorded as fine-grained silt and clay deposits within interspersed thin layers of sand, consistent with a glacio-fluvial environment.

Water level data was collected from various sources including water well records (Government of British Columbia, 2021), and a regional water level database assembled from local geotechnical studies (ISL, 2020). Observed water levels range from very close to ground surface in the lowlands to 5 m below ground surface in the uplands. The Bog, Swamp and Shallow Lake Deposits (Figure 3) are transected by numerous ditches to enhance drainage in this area due to its naturally shallow watertable. The horizontal gradient follows topography and infers groundwater flow towards the Katzie Slough and the Pitt River. The vertical gradient is observed to be downward in the uplands and upward toward the Pitt and Fraser Rivers. Upward gradients were also observed along the Katzie Slough. Local measurements (i.e., slug tests) of hydraulic conductivities ranged from $3x10^{-6}$ to $5x10^{-5}$ m/s for sands, while silt and clay hydraulic conductivity was estimated in the range of $2x10^{-7}$ to $5x10^{-6}$ m/s (ISL, 2020).

2.2 Geotechnical Fill and Preloading

Many development sites in Pitt Meadows and surrounding areas have identified the need for preloading due to the compressible nature of the unconsolidated silty clays and Peat. Preloading is a method used to compress underlying material by applying a weight at the ground surface. Preload plans must be carefully developed because of the high compressibility of the peat and silty clays underlying Pitt Meadows, which have the potential to create differential settlement beneath buildings, which could lead to structural failure of building foundations.

In addition to the potential building structure issues, the compression of the underlying water-saturated geology will also result in the displacement of porewater contained within the soils, as it is the pores of the soil structure that are reduced during soil consolidation. This water displacement temporarily raises the water levels locally surrounding the preload area to generate the required hydraulic gradient for the displaced water to flow away from the preload area. Where there is a higher degree of water displacement, and/or where the hydraulic conductivity is limited, a larger water level rise will be experienced. Conversely, where the hydraulic conductivity is high, or there is a nearby stream that can readily receive the displaced water, the water level rise will be muted. The largest degree of impact is experienced where the watertable is close to ground surface. Consequently, the degree of water level impact depends on the site preload, local geologic conditions (i.e., geologic layers), local hydrogeologic conditions (i.e., depth to watertable and hydraulic conductivity), the distance to a surface water discharge feature, and the proximity to neighbouring properties or buildings.

The required timing and applied weight of preload is different for every project depending on variables such as the compressibility of the underlying material, the thickness of the underlying compressible material and the scale / weight of the planned development.

2.3 Conceptual Model of Hydrogeologic Changes

Preload is designed to compact a site's underlying sediments, which will force the pore water to be displaced and flow elsewhere. This is the generally accepted theory (*Terzaghi consolidation*) as it is assumed that the soil grains and water are incompressible. To expel the water out of the void space (i.e., porosity) of saturated clay beneath a preloaded area, the pore pressure (i.e., hydraulic head) will increase to create a sufficient hydraulic gradient to force the displaced volume of water to flow out of the consolidated soil into and through neighbouring unconsolidated soils. Within more-permeable sands and gravel zones, the amount of pressure build-up required to force water out of the pore space is less than that required within lower hydraulic conductivity units

The released volume of water will be equal to the volume of consolidation expected to occur. This displaced water volume is calculated as the product of the site area and the consolidation height. Since the depth to the watertable in Pitt Meadows is quite shallow, there is the potential to fully saturate the local ground surface by raising water levels in surrounding areas. Any such rise in groundwater levels could result in the creation of oversaturated soils in neighbouring agricultural fields and residential properties. This enhanced saturation could limit potential land uses, impact existing infrastructure, and increase storm event flood risk as it reduces the groundwater storage potential in the shallow subsurface. In addition, the released water will temporarily increase the volume of water that the Kennedy and Baynes Road Pump Stations need to remove; increased pumping volume will be temporary until a new equilibrium condition is achieved.

3. GROUNDWATER FLOW MODELLING

3.1 Model Description

A 3D groundwater flow numerical model was developed to simulate groundwater flow throughout the City of Pitt Meadows and the surrounding areas using the FEFLOW code (version 7.5; DHI WASY, 2021). The model was developed and calibrated for the City in 2021 (ISL and Aqua Insight, 2021) for investigation of potential groundwater issues, including issues related to water level rise resulting from development site preloading, and the calibration was refined in 2022.

The 3D model domain (Figure 7) extends from the Pitt River in the west to the uplands associated with the City of Maple Ridge in the east. The northern study area boundary follows the northernmost of the Lougheed Highway and the Katzie Slough and extends south to the Fraser River. The model extends from ground surface to an elevation of 40 m below mean sea level.

Appendix A provides a more detailed summary of the model construction and calibration. The model was constructed from available geologic and hydrogeologic information to represent the hydrostratigraphic units observed throughout the study area. Figures 4, 5 and 6 present cross-section locations and the distribution of hydrogeologic units (HGUs), respectively. These cross-sections illustrate the level of detail incorporated within the model, as well as the spatial continuity of mapped HGUs. Additional numerical simulation layers were used to subdivide HGUs to achieve an average model layer thickness of less than 2 m for water level change predictions.

The hydraulic conductivity of each HGU was generally set to be uniform throughout the model domain, except where heterogeneous conditions were necessary to match water level observations (Figures 7 and 8). Additional heterogeneity is expected to be present based on the depositional setting; however, to follow the “principle of parsimony” (Hill and Tiedeman, 2007), uniform parameter zones were generally applied.

Model boundary conditions (Figure 9) included specified heads within the Pitt and Fraser Rivers, representing average annual river stage elevation, channel elements representing streams and ditches with variable Manning roughness coefficients, and spatially variable groundwater recharge based on surficial soil variability. The streams and drainage ditches are dominantly conceptualized to be gaining streams in the Pitt Meadows area, meaning groundwater discharges into them. Figure 10 is a map of the rate at which groundwater is simulated to discharge into the stream at each stream node location. The greatest rates of groundwater discharge occur adjacent to the Sumas uplands; this is because groundwater is recharged in the uplands, then flows downgradient to the surrounding streams.

The model achieves an excellent match to observed water level data (Figure 11). Given that the data was collected at different times, and for different purposes, the model is not expected to match observed conditions at every observation point exactly; further it is noted that water levels observed in some wells may not have been at equilibrium, which is common in sites with thick fine-grained sediments. This results in measurement noise in some wells within the calibration dataset. The mean residual for the 135 observation points is -0.02 m, indicating that an excellent balance was achieved between simulated and observed water level elevation values. The mean residual (0.51 m) and root mean squared (RMS) residual

(0.65 m) indicate the level of fit to the observed data set and the expected potential residual, respectively. The normalizes root mean squared (NRMS) value of 7.7% is within the accepted range for a well-calibrated model, which is generally accepted to be 10% (Spitz and Moreno, 1996).

3.2 Preload Simulation Approach

As described in section 2.3, during consolidation a portion of the water within the pores of the HGUs underlying the fill area will be displaced as the soil structure is consolidated. A preload plan and groundwater monitoring plan were created by Geopacific (2021a, and 2021b) for a site to be developed by Censorio Group G.P. Inc at 19796 to 19818 Hammond Road. Development at this site has not proceeded, but the preload plan was used to apply to the model, as an example application.

Beyond the Censorio site, the model was also applied to evaluate potential water level rise at three other site locations. The locations (Figure 12) were strategically selected to demonstrate the impact of:

A. Differing geologic materials, specifically for areas where peat is mapped to exist
B. Differing hydrogeologic settings, specifically where a more transmissive (T) aquifer unit is present
C. Distance to a drainage feature

The Censorio development included a planned 15-week long preload with a thickness from 2 to 5.25 m. The estimated timing and load of the preload provided by Geopacific was used to estimate the amount of consolidation in the surficial peat using the Noto method (Hayashi et al., 2016). Peats at the Censorio site have an average thickness of 3 m and based on the Geopacific preload plan the estimated consolidation of the peat is 1 m. There will also be consolidation, to a lesser extent, in the underlying silts and clays. The settlement in the silty clays was estimated using data collected for nearby geotechnical studies (Golder, 2021).

A generalized approach was taken to apply preload to various sites and compare risk levels. Conditions at each site were simulated for a 2-year period, which included a 15-week preload period, and the period following preloading as water levels return to equilibrium conditions. Preloading was represented by an influx of water, representing the porewater volume displaced below each site. The volume of water displaced at each site was independently estimated based on the geologic units present beneath each site. To estimate the volume of water displaced, it was assumed that 30% consolidation of the pore volume would occur within peat layers, 3% within silty clays and 1% within sands; these assumed consolidation levels were extrapolated from available literature (i.e., Hayashi et al., 2016) and nearby site-specific investigations (i.e., Golder, 2021). The addition of this water volume was spread over 15 weeks. Simulated results of water level increases are presented in Figure 12 and Table 1.

Table 1: Description of Test Scenarios

Site ID	Geologic Setting	Hydrogeologic Setting (Transmissivity)	Closest Drainage Feature	Maximum Simulated Rise in Water level	Furthest Simulated Extent of Impact
Censorio	Peat	Moderate T	<50 m	1.6 m	240 m
A	No Peat	Moderate T	380 m	0.5 m	75 m
B	No Peat	High T	700 m	0.7 m	40 m
C	Peat	Moderate T	360 m	1.9 m	540 m

3.3 Preload Risk Factors

Based on the simulation analysis performed, the primary risk factors for preload water displacement were summarized into two factors: underlying geologic / hydrogeologic conditions, and the depth to the watertable. Figures 13 and 14 present maps of these two factors, which when combined, facilitate evaluation of the preload risk level.

For the geologic / hydrogeologic factors, the presence of shallow peat soils is considered the dominant factor for preloading due to its highly compressible nature. Peat is a very porous material and has potential to hold large quantities of water that will be displaced with consolidation. Without a nearby discharge feature or transmissive aquifer, this displaced water will increase water levels in surrounding areas. The Shallow Sand aquifer described in Section 2.1 is approximately 5-10 m below ground surface and acts as a regional aquifer with variable transmissivity. This unit is fairly continuous throughout Pitt Meadows but measured shallow water levels and borehole logs have been used to map areas where the unit has limited transmissivity. The exact distribution of where this unit pinches out or has lower transmissivity is uncertain; however, the distribution estimated through model calibration is mapped in Figure 13. Where a high transmissive aquifer is located below a site, the aquifer dissipates water from the preloaded site and prevents excessive water level rise in surrounding areas.

The lowlands of Pitt Meadows have many drainage ditches because the watertable is so close to ground surface (Figure 14). The closer the watertable is to ground surface, the greater the risk that changes in the watertable elevation will cause flooding. The watertable in the lowlands is typically within 2 m of the ground surface (on average). The watertable is even closer to ground surface in wetter seasons and periods of high precipitation; a 2m depth to watertable threshold accounts for this seasonable variability.

The combination of risk factors from the soil conditions and the depth to watertable facilitates the generation of a risk matrix, as presented in Table 2. This risk matrix was developed based on the experience gained through the model application to various sites throughout Pit Meadows.

Table 2: Preload Risk Matrix

<table>
<tr><th colspan="3" rowspan="3">Risk Estimation</th><th colspan="3">Depth to Watertable Risk Factor</th></tr>
<tr><th>> 4 m</th><th>2-4 m</th><th>< 2 m</th></tr>
<tr><th>Low Likelihood</th><th>Moderate Likelihood</th><th>High Likelihood</th></tr>
<tr><td rowspan="3">Soil Risk Factor</td><td>Peat</td><td>High likelihood</td><td>Significant Risk</td><td>Significant Risk</td><td>High Risk</td></tr>
<tr><td>Lower Transmissivity</td><td>Enhanced likelihood</td><td>Moderate Risk</td><td>Significant Risk</td><td>Significant Risk</td></tr>
<tr><td>Moderate to High Transmissivity</td><td>Moderate likelihood</td><td>Low Risk</td><td>Moderate Risk</td><td>Significant Risk</td></tr>
</table>

Table 2 reflects the following summary conclusions regarding potential water level rise:

1) For areas with a shallow watertable (i.e., < 2m) and the presence of peat, the greatest risk level is predicted.
2) Any area where peat is found in the subsurface has the potential to experience significant consolidation, and therefore water level rise.
3) Any area where the water level is within 2 m of ground surface has the potential to experience water level rise that could intersect the ground surface.
4) Areas where aquifers have lower transmissivity have a higher potential to experience significant water level rise.
5) Areas where the depth to water is > 4m and where no peat is located, and where there is a moderate to high transmissivity aquifer are expected to have low risk.

Figure 15 maps the spatial combination of the geologic and depth to watertable risk factors to illustrate the relative risk of groundwater level rise caused by preloading. This map was developed based on all of the available data at the time of this report and is subject to change as new understanding is developed (ie. if new data shows peat in a new area, the area's risk category may increase). Areas considered High Risk are areas where the watertable is shallow (<2 m bgs) and there is surficial peat. The areas with Low risk are those with a relatively deep watertable (>4 m bgs), which have no peat and are underlain by a moderate to high transmissivity aquifer. Other various combinations of the transmissivity, peat and depth to watertable form moderate and significant risk categories, as listed above.

3.4 Preload Test Scenarios

Figure 16 shows the simulated increase in water levels after 15-weeks of preloading at each of the test sites described in section 3.1 along with the assigned risk category described in section 3.2.

Test location C was simulated to have the largest impact if preloading were to occur there and this site is located within a High-Risk zone where there is peat, moderate transmissivity and a shallow watertable.

The Censorio site location was simulated to have the second largest water level rise impact area. This site also falls within a High-Risk zone, but responses at this site were buffered by the discharge feature directly adjacent to the site that allowed water to discharge to the Katzie Slough and thus avoid a larger area of impact.

Test Sites A and B were simulated to have the smallest areas of impact. Both Sites A and B are located within the designated Significant risk category because the watertable is less than 2 m below ground surface. Since there is a high transmissivity surrounding Site B, the area impacted by water level rise is smaller than that predicted at Site A.

It is noted that even within sites mapped as having the same risk level (Site C vs. Censorio, and Sites Site A vs. Site B) may not produce the same level of impact due to site-specific conditions including the local transmissivity and the proximity to potential surface drainage features. As such, the mapping developed should be used as a guide to judge the relative impact of a potential development. Where warranted based on property owners adjacent to a proposed development, the model can be utilized to simulate site-specific conditions to more accurately predict potential water level rise.

4. SUMMARY

A 3D numerical groundwater flow model was applied to evaluate the risk of water level rise due to preloading across Pitt Meadows. Available borehole logs, water levels and literature were reviewed to refine the regional conceptual model and groundwater flow model. The presence of peat, the local transmissivity, and the depth to the watertable were determined to be the largest factors in establishing the level of preloading risk to local water levels within Pitt Meadows. Such water level rise may lead to overly saturated ground conditions and inundation of basements or other sub-surface features. While preloading occurs, there may also be an increased pumping rate required at the Kennedy or Baynes Road Pump stations to remove the groundwater pushed out from consolidation.

A map of assigned risk levels was developed for the Pitt Meadows study area.

- High Risk areas occur where the watertable is less than 2 m below ground surface and there is surficial peat that has been logged in boreholes or mapped by the Geological Survey of Canada.
- Significant Risk areas include those where peat is present, or where the watertable is shallow (i.e., < 2m deep), or where there is limited transmissivity and a moderate watertable depth (i.e., 2-4 m below ground surface).
- Low Risk areas are located in the uplands, where the watertable is greater than 4 m below ground surface and there is no peat present.

This risk map has been developed with all available data. Should more data become available, the bounds of the risk level areas may be altered.

5. CLOSURE

We trust this information will provide the City of Pitt Meadows with valuable insights into the potential groundwater impacts associated with preloading.

Please contact the undersigned with any questions.

Report Prepared by:

Aqua Insight Inc.

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Hydrogeologist

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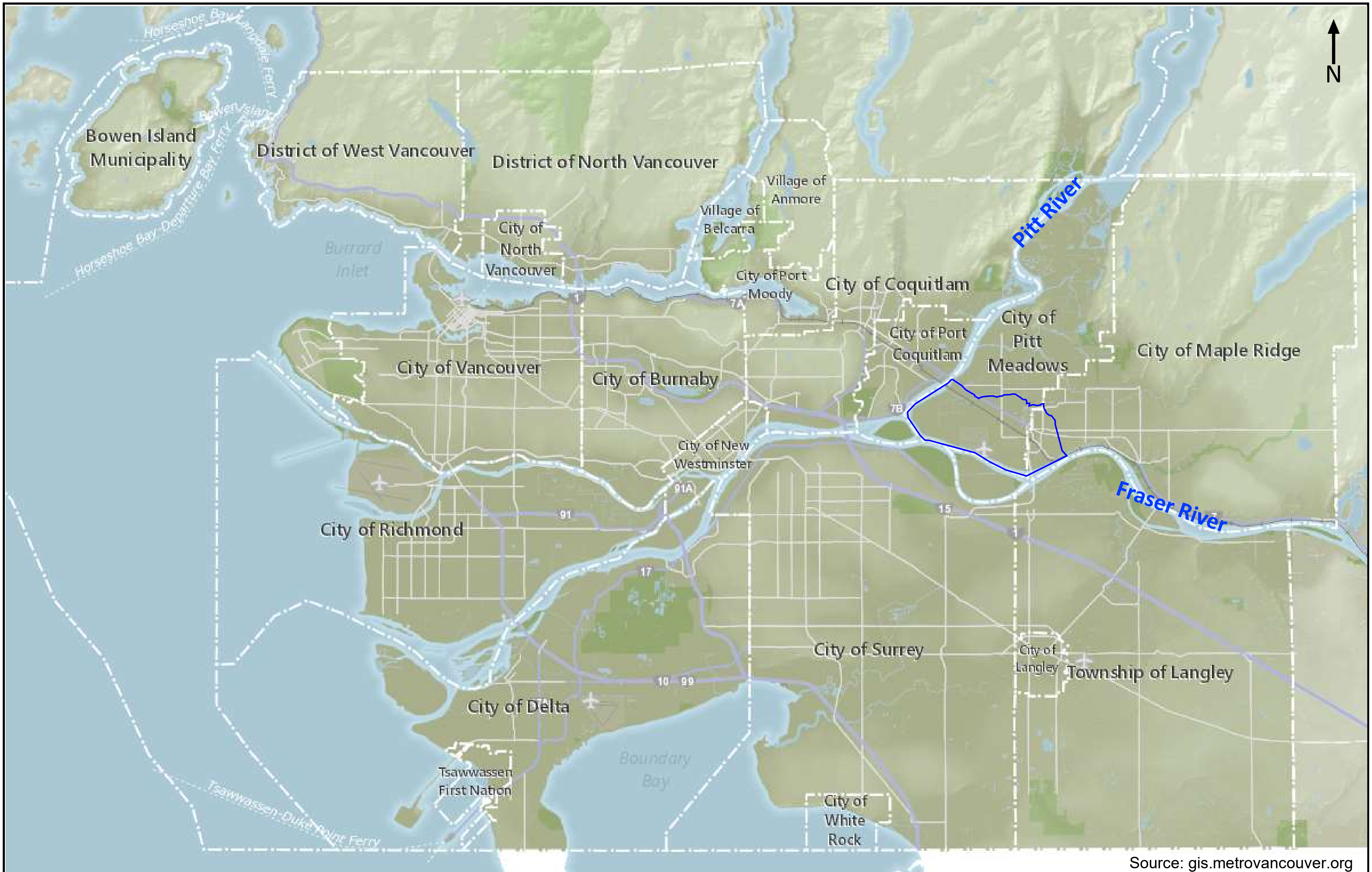
Figures



Study Area and Model Domain
Municipal Boundary
Road
Highway
Rail Line

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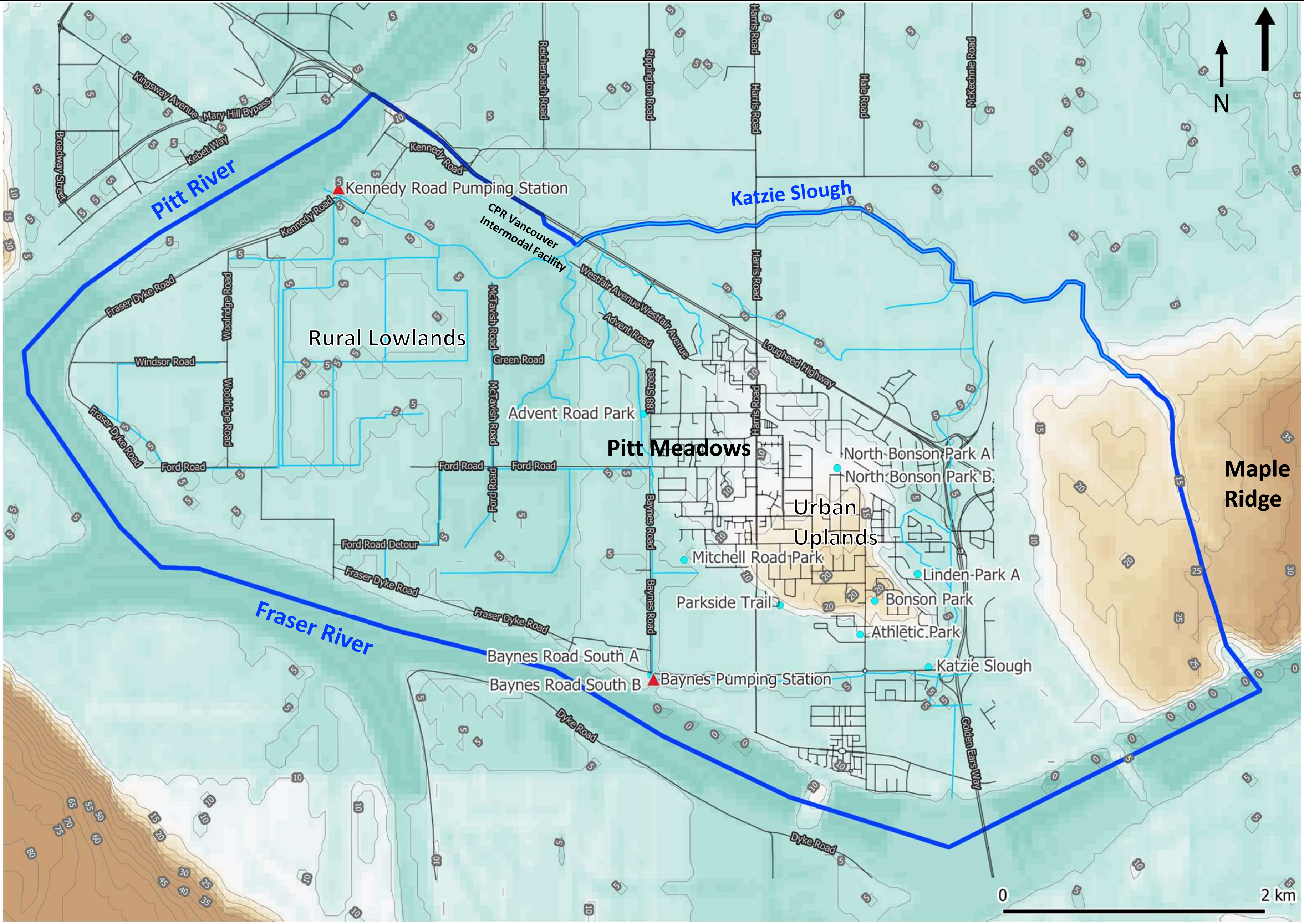
Pitt Meadows: Preload Effect on Groundwater Levels

Regional Location

ISL 35 YEARS

Aqua Insight

1



Contour Interval – 5 m
Study Area and Model Domain
Municipal Observation Well
Pumping Station
Watercourse
Road

Topography
30 masl
-5 masl

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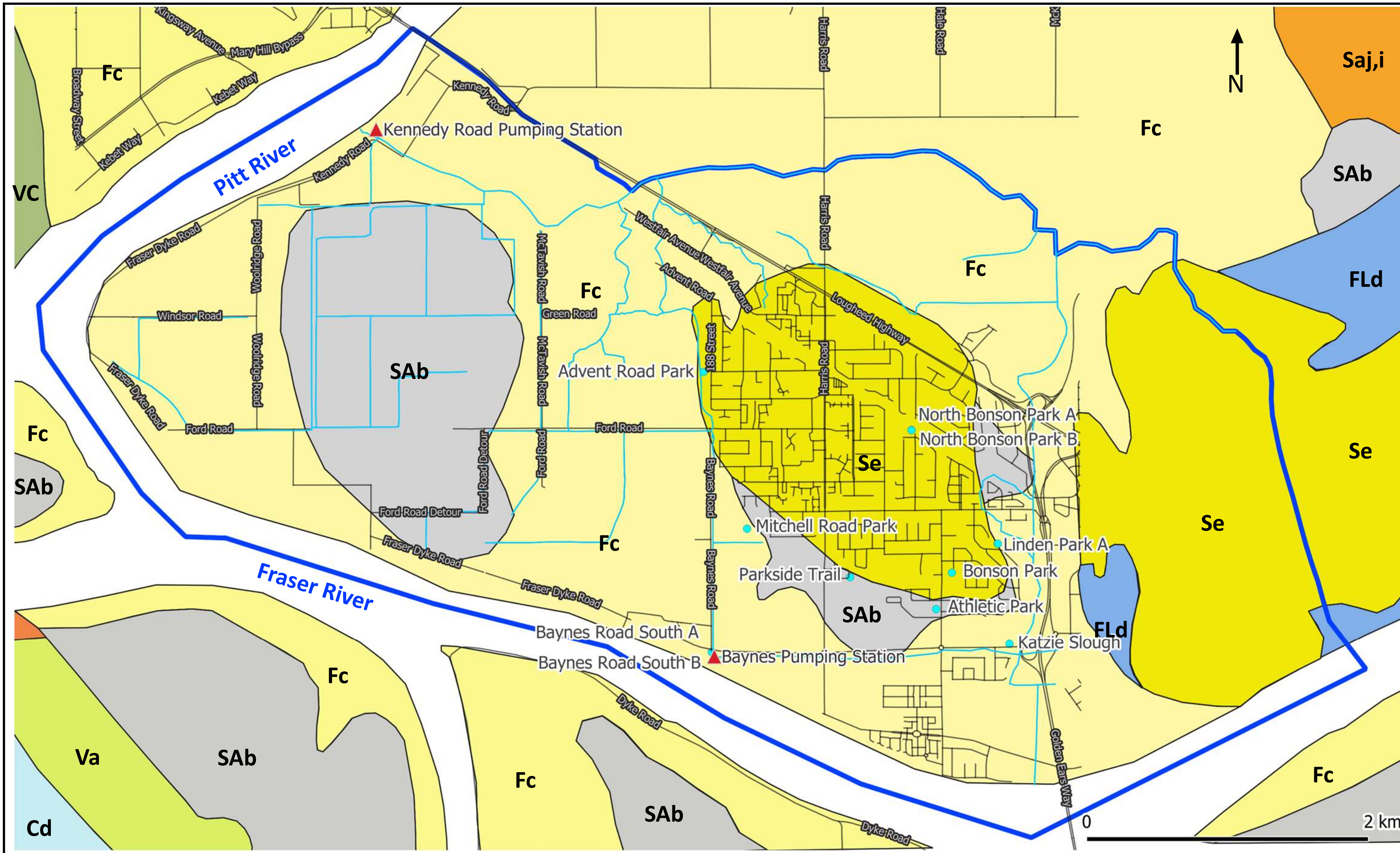
Pitt Meadows: Preload Effect on Groundwater Levels

Study Area and Ground Surface Topography

Aqua Insight

2



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- Model Domain
- Municipal Well
- Pumping Station
- Road
- Watercourse

Surficial Geology:

SAb	Bog, Swamp and shallow lake Deposits
SAji	Lowland and Mountain Stream Deltaic
Fc	Fraser River Sediments
Se	Sumas Drift
FLd	Fort Langley Formation
Cd	Deltaic and Fluvial Deposits
VC	Glacial Drift
Va	Till

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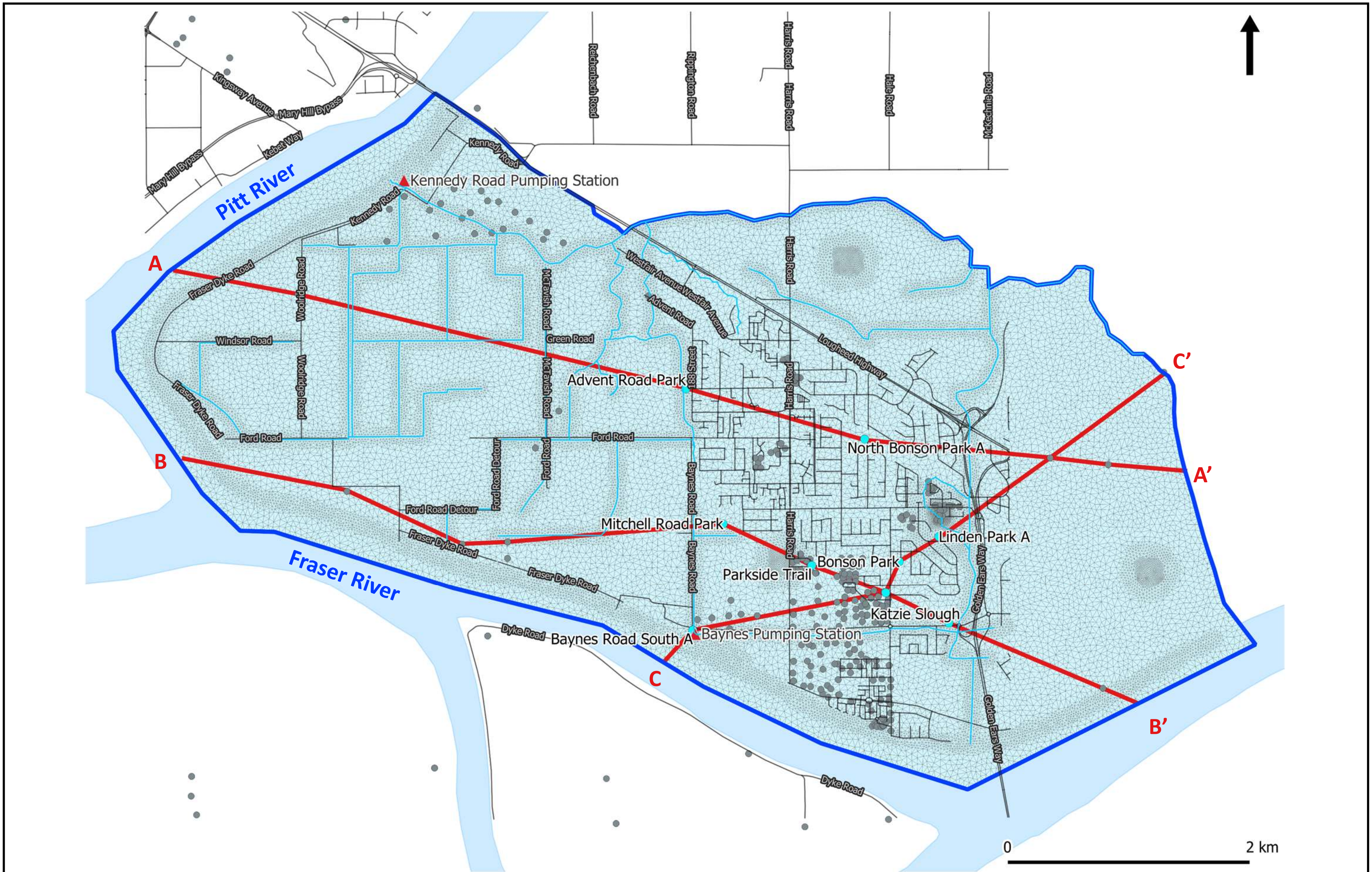
Pitt Meadows: Preload Effect on Groundwater Levels

Surficial Geology

ISL 35 YEARS Aqua Insight

3



Cross Section Location
Lithology Log
Model Domain
Model Element
Municipal Observation Well
Pumping Station
Road
Watercourse

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Pitt Meadows: Preload Effect on Groundwater Levels

Cross Section Locations

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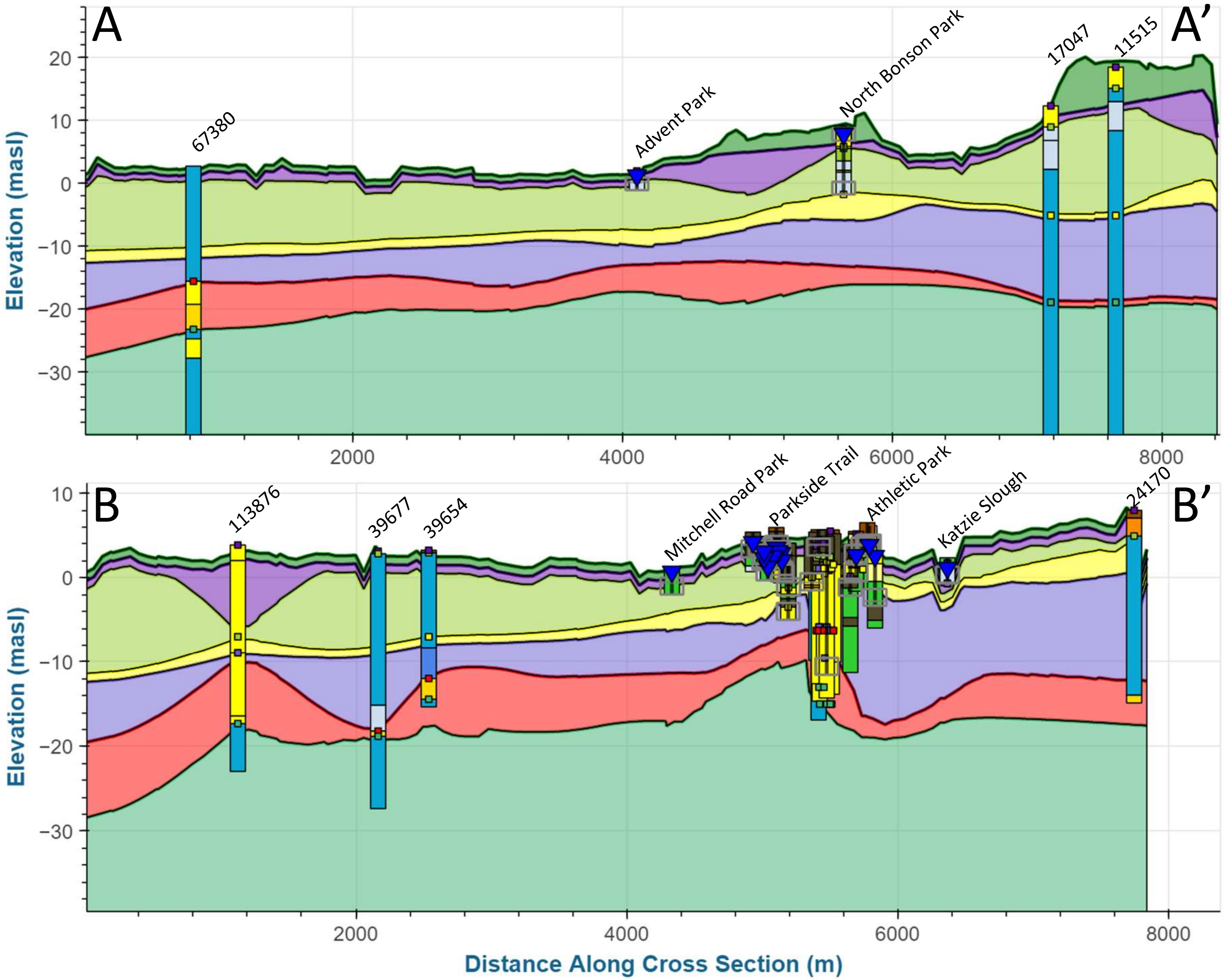

Borehole Lithology:

- Fill/Topsoil
- Peat/Organics
- Gravel
- Sand
- Silty Sand
- Silt
- Clay with Gravel
- Clayey Silt
- Clay

Hydrogeological Unit:

- Sumas Drift
- Shallow Clayey Silt
- Upper Sandy Silt
- Shallow Sand
- Middle Clayey Silt
- Dense Sand
- Lower Clayey Silt

- Well Screen
- Observed Water level

August 2022

Pitt Meadows: Preload Effect on Groundwater Levels

Cross Sections A and B

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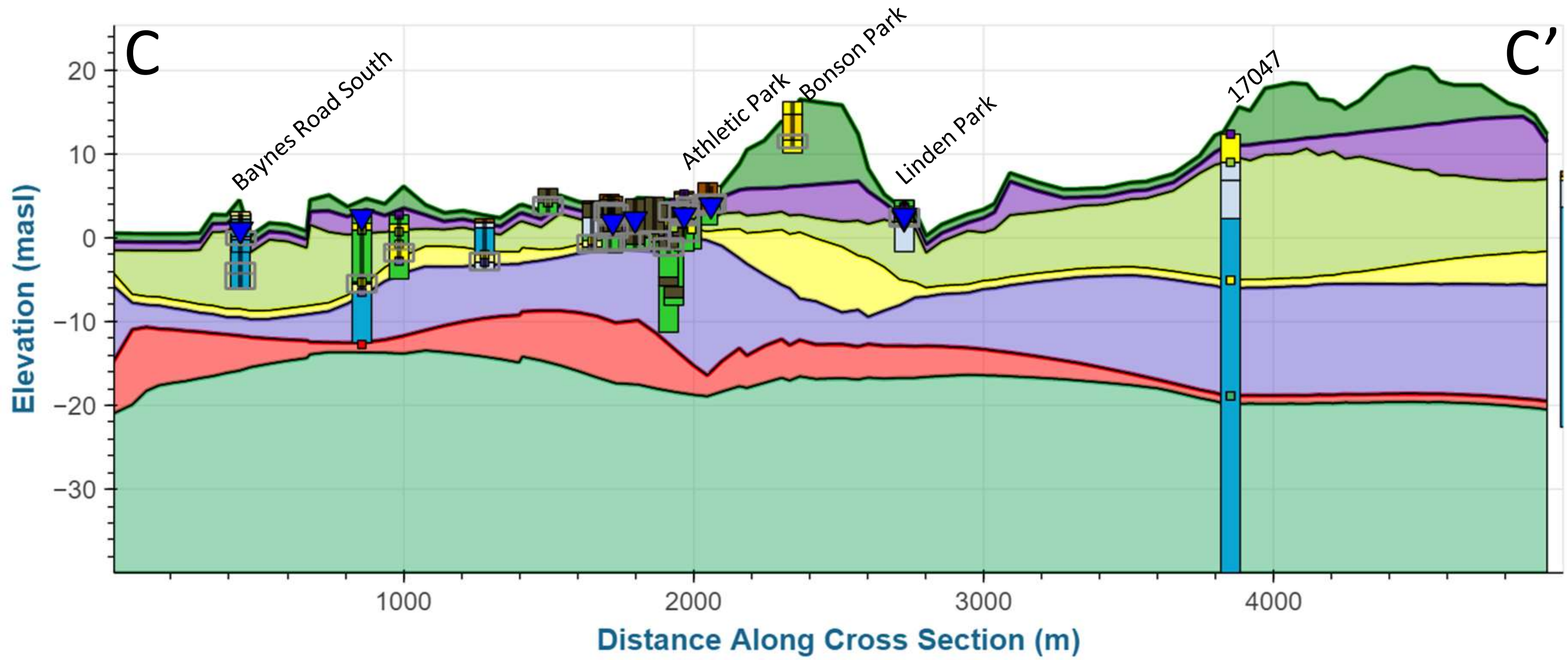

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- Lower Clayey Silt

- Well Screen
- Observed Water level

August 2022

Pitt Meadows: Preload Effect on Groundwater Levels

Cross Section C

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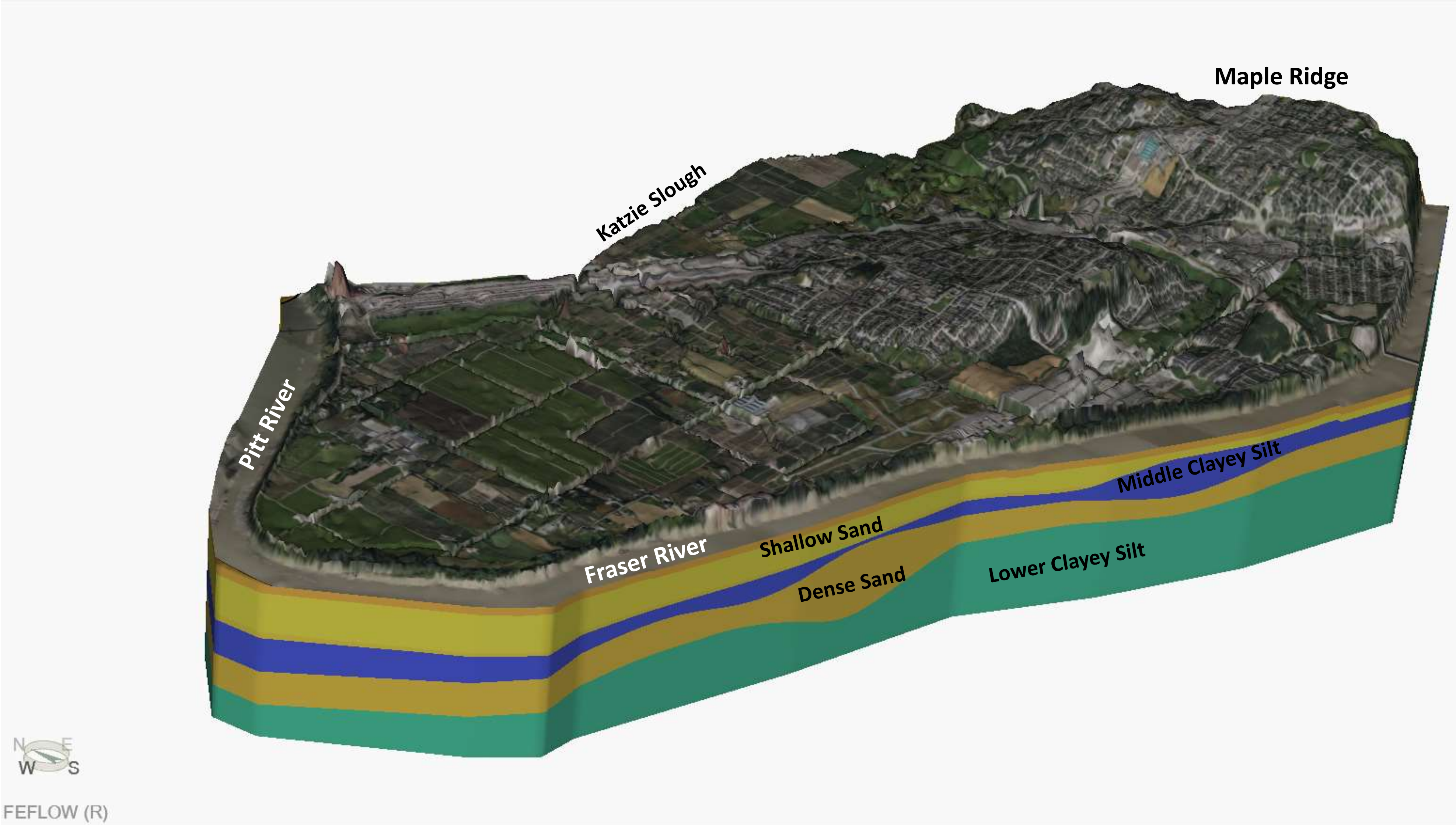
6



Horizontal Conductivity (m/s)

- 1×10^{-2}
- 1×10^{-3}
- 1×10^{-4}
- 1×10^{-5}
- 1×10^{-6}
- 1×10^{-7}
- 1×10^{-8}
- 1×10^{-9}

August 2022

Pitt Meadows: Preload Effect on Groundwater Levels

3D Groundwater Model Structure

ISL 35 YEARS

Aqua Insight

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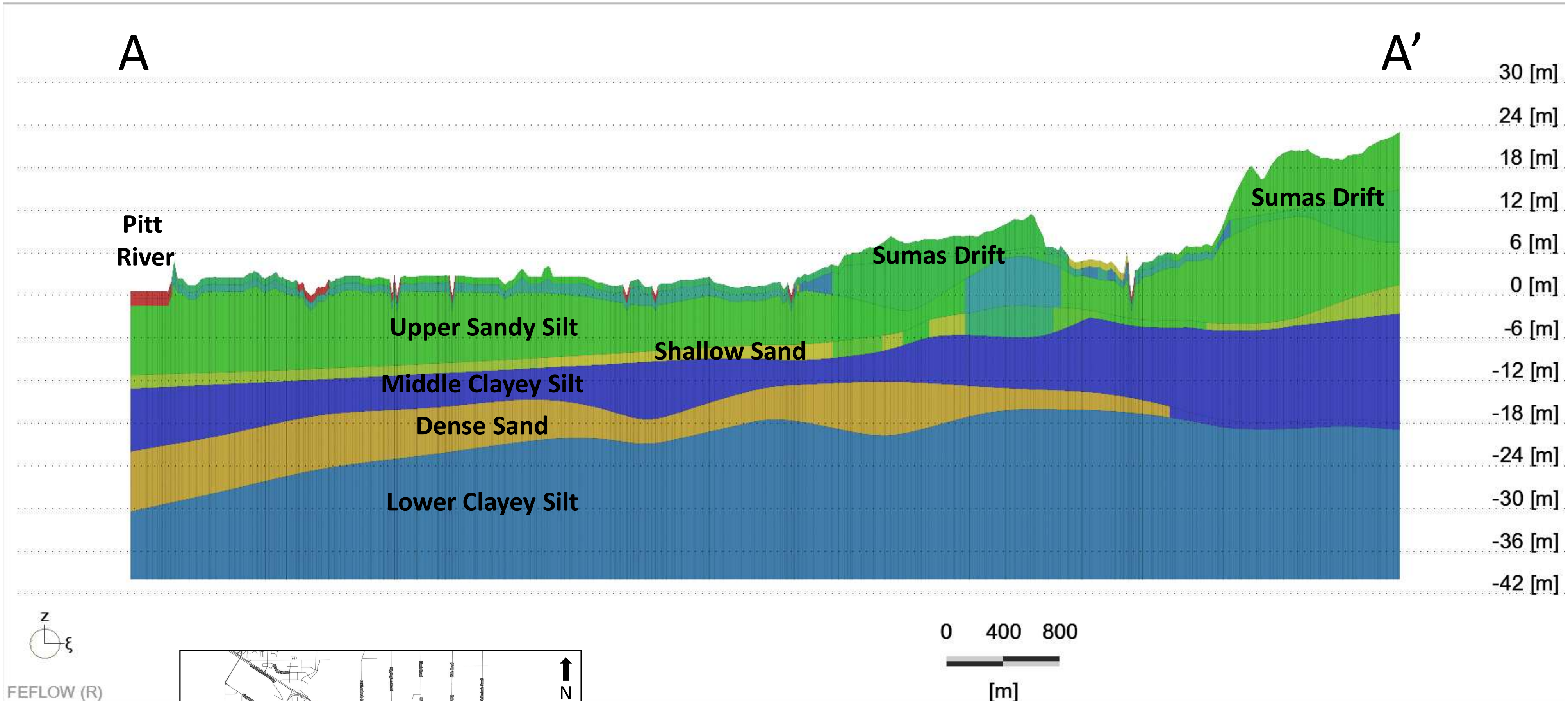

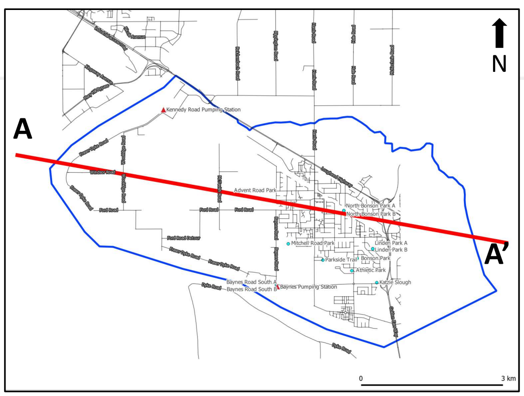

Vertical Exaggeration: 50x

Note: Cross section was cut through the groundwater flow model in FEFLOW.

Horizontal Conductivity (m/s)

- 1×10^{-3}
- 1×10^{-4}
- 1×10^{-5}
- 1×10^{-6}
- 1×10^{-7}
- 1×10^{-8}
- 1×10^{-9}

August 2022

Pitt Meadows: Preload Effect on Groundwater Levels

Regional Scale Model Cross Section

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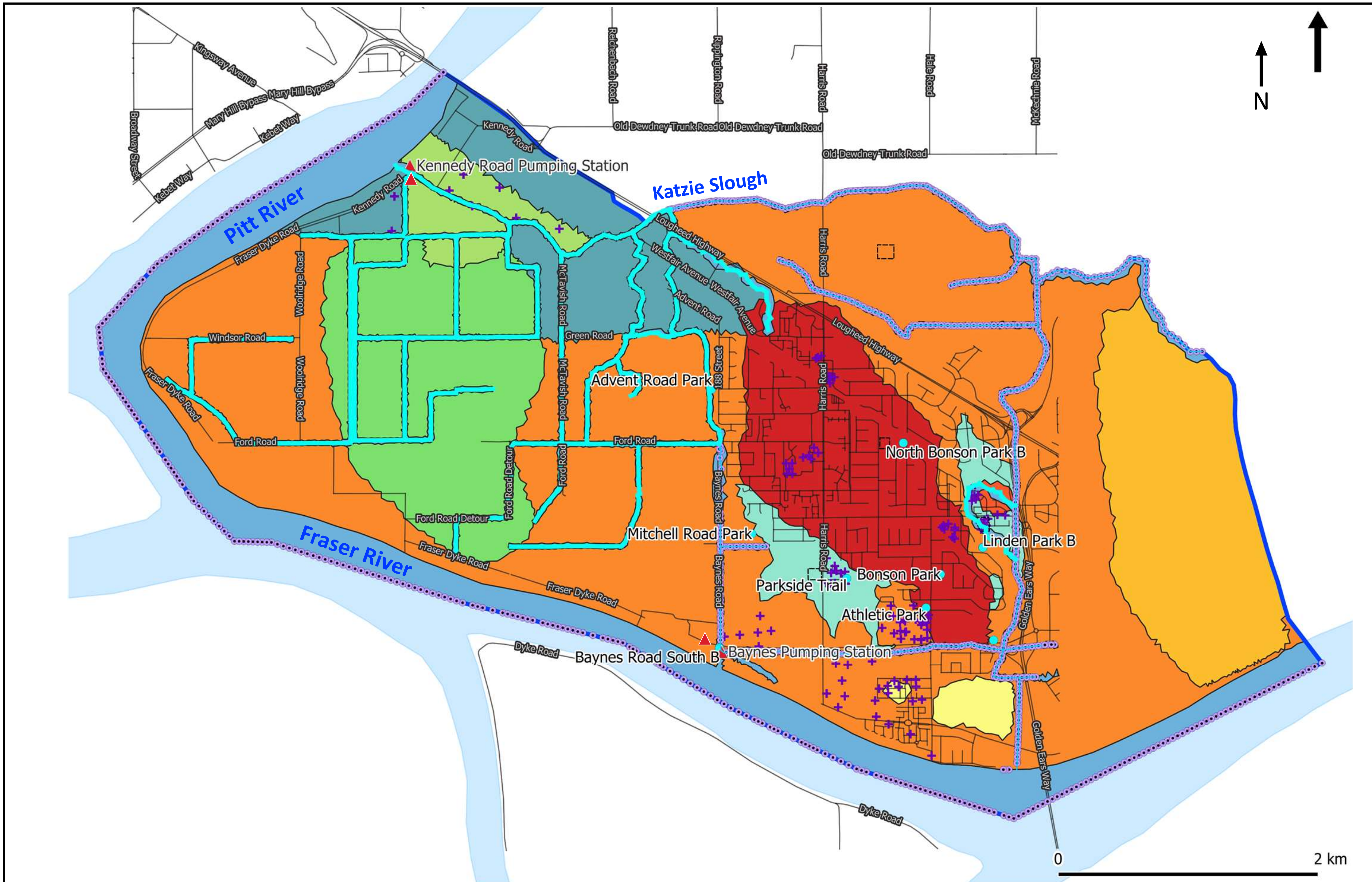

Specified Head BC
Drainage Ditch
Slough
Model Domain

Pumping Station
Road
Municipal Well
Observation Point

Surficial Recharge (mm/year):
0
75
150
180
270

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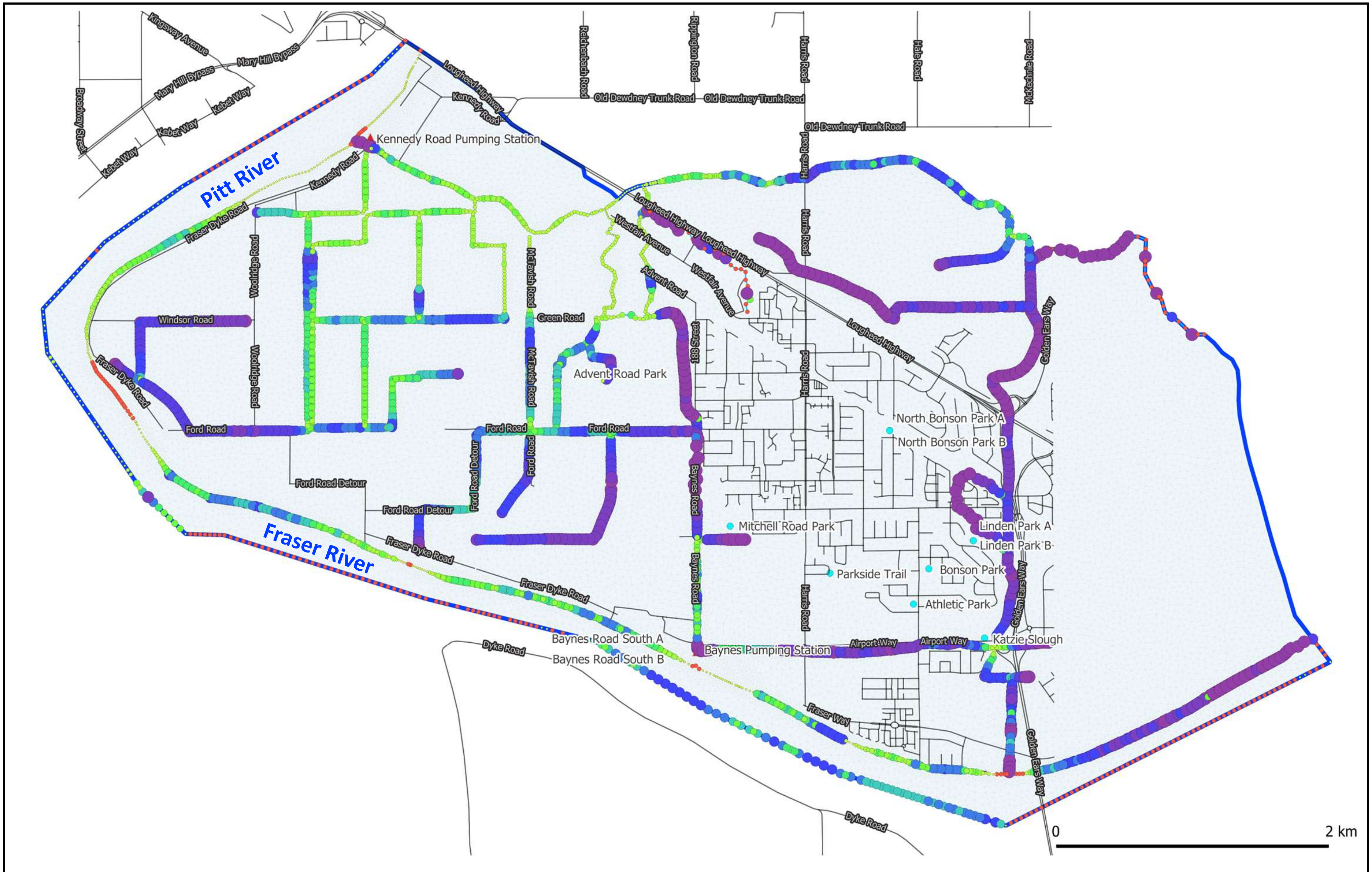
Pitt Meadows: Preload Effect on Groundwater Levels

Model Mesh and Boundary Conditions

ISL 35 YEARS Aqua Insight



— Model Domain	
△ Model Element	
● Municipal Observation Well	
▲ Pumping Station	
— Road	

Groundwater Discharge (m³/day)

2500

0

August 2022

Pitt Meadows: Preload Effect on Groundwater Levels

Groundwater Discharge Rate

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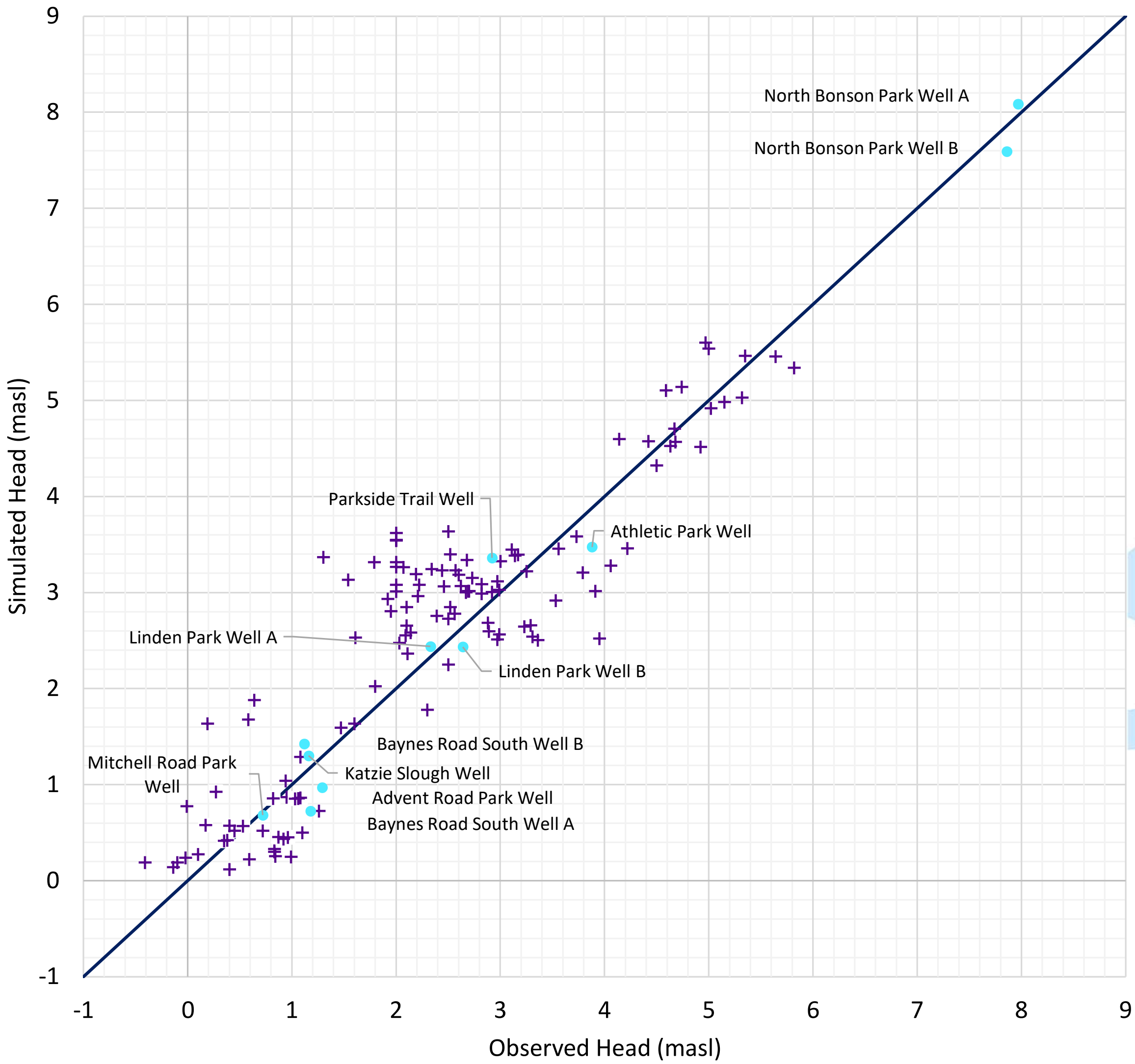
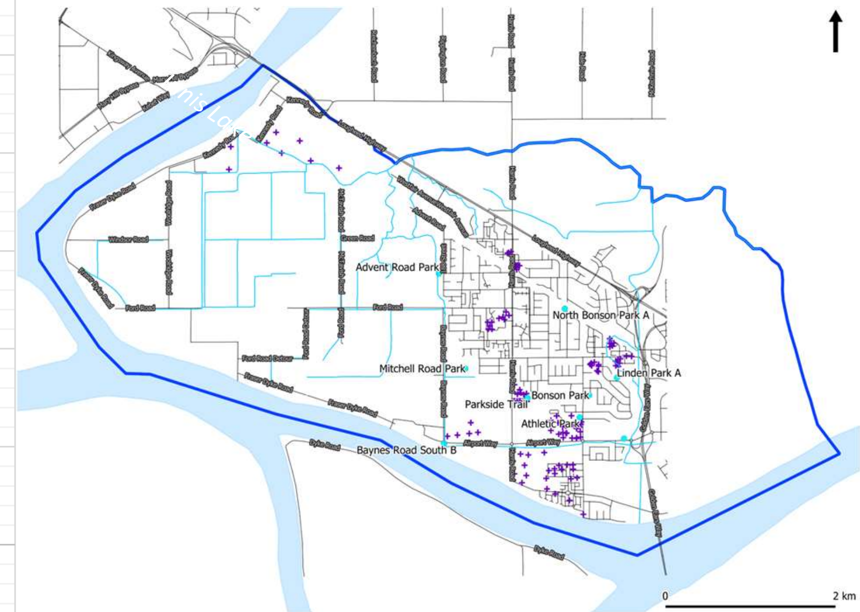


Residual Statistics	
Number of Observations:	135
Mean Residual:	-0.02
Absolute Mean Residual:	0.51
Root Mean Squared (RMS):	0.65
Normalized RMS:	7.7%



● Municipal Observation Well

+ 2021 Calibration Dataset

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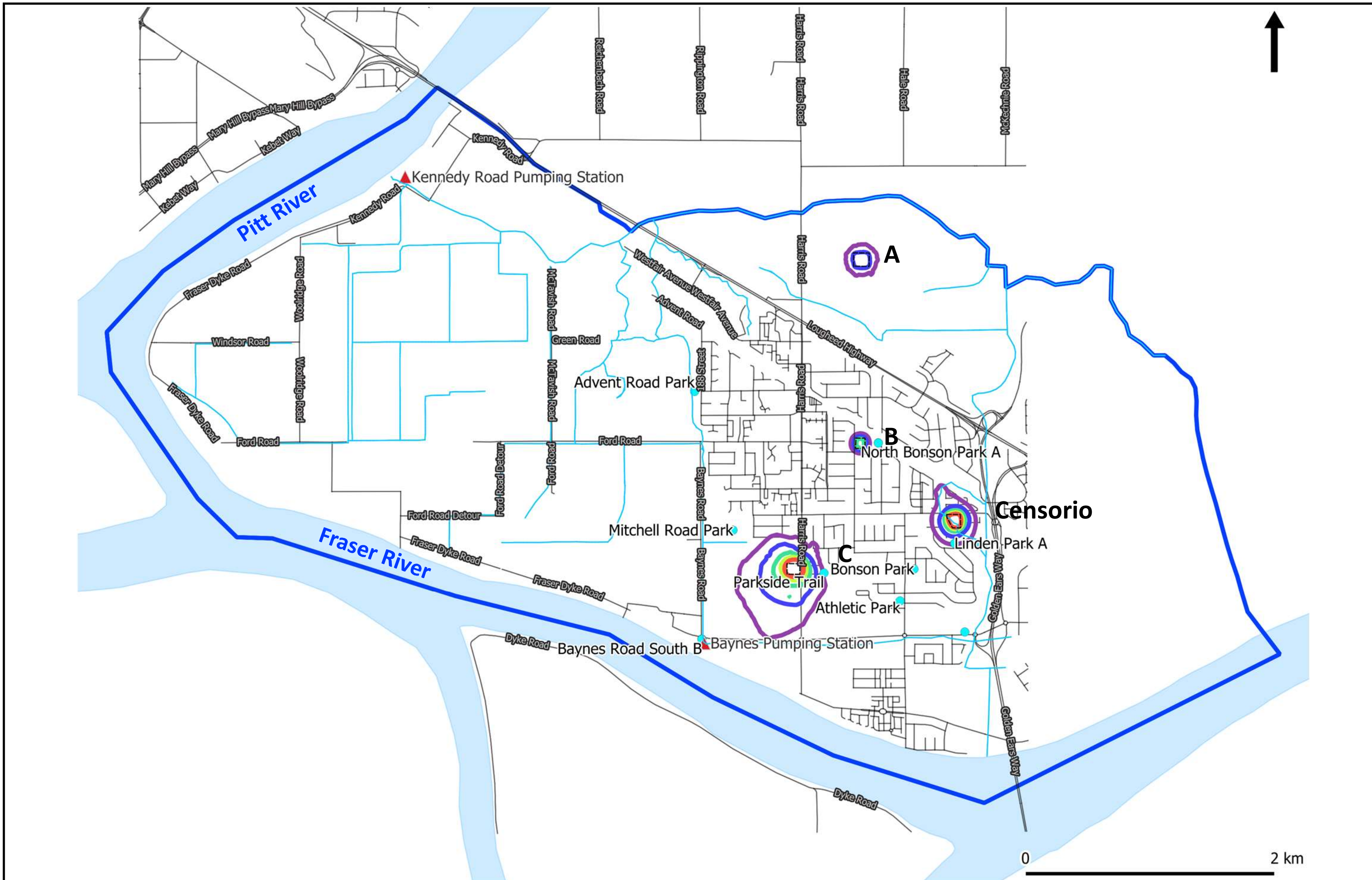
Pitt Meadows: Preload Effect on Groundwater Levels

Model Calibration Statistics

11



Municipal Observation Well
Pumping Station
Road
Watercourse
Model Domain
Test Site Location

Increase in Watertable(m):
0.1
0.25
0.5
0.75
1.0

August 2022

Pitt Meadows: Preload Effect on Groundwater Levels

Groundwater Level Rise Due to Typical Development

ISL 35 YEARS
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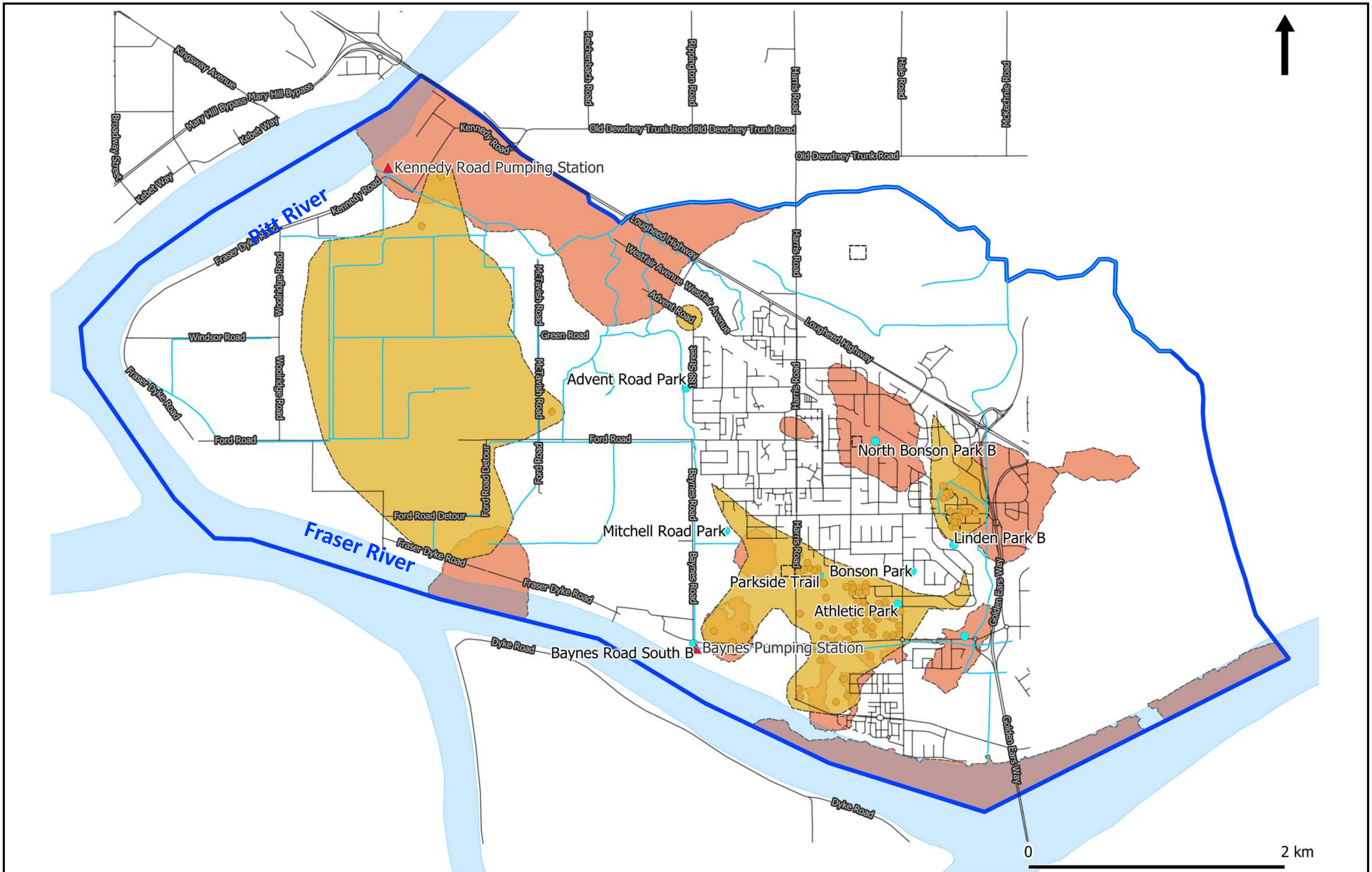

Shallow Peat
Limited Sand Transmissivity
Logged Peat
Municipal Observation Well
Pumping Station
Road
Watercourse
Model Domain
Test Site Location

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Pitt Meadows: Preload Effect on Groundwater Levels

Consolidation and Water Displacement Factors – Soil Conditions

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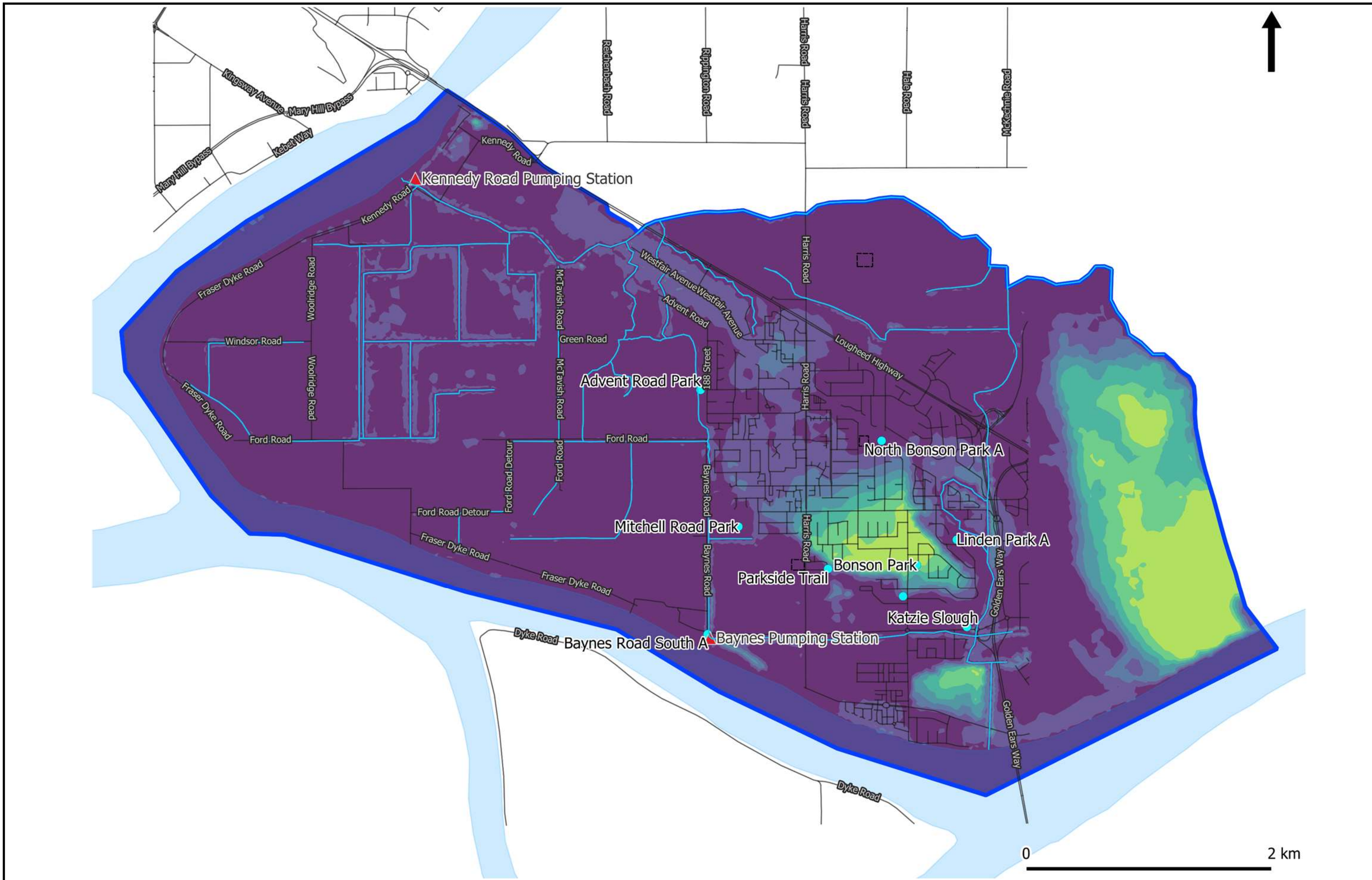


Depth to Watertable (m):
- 0.1 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- >14

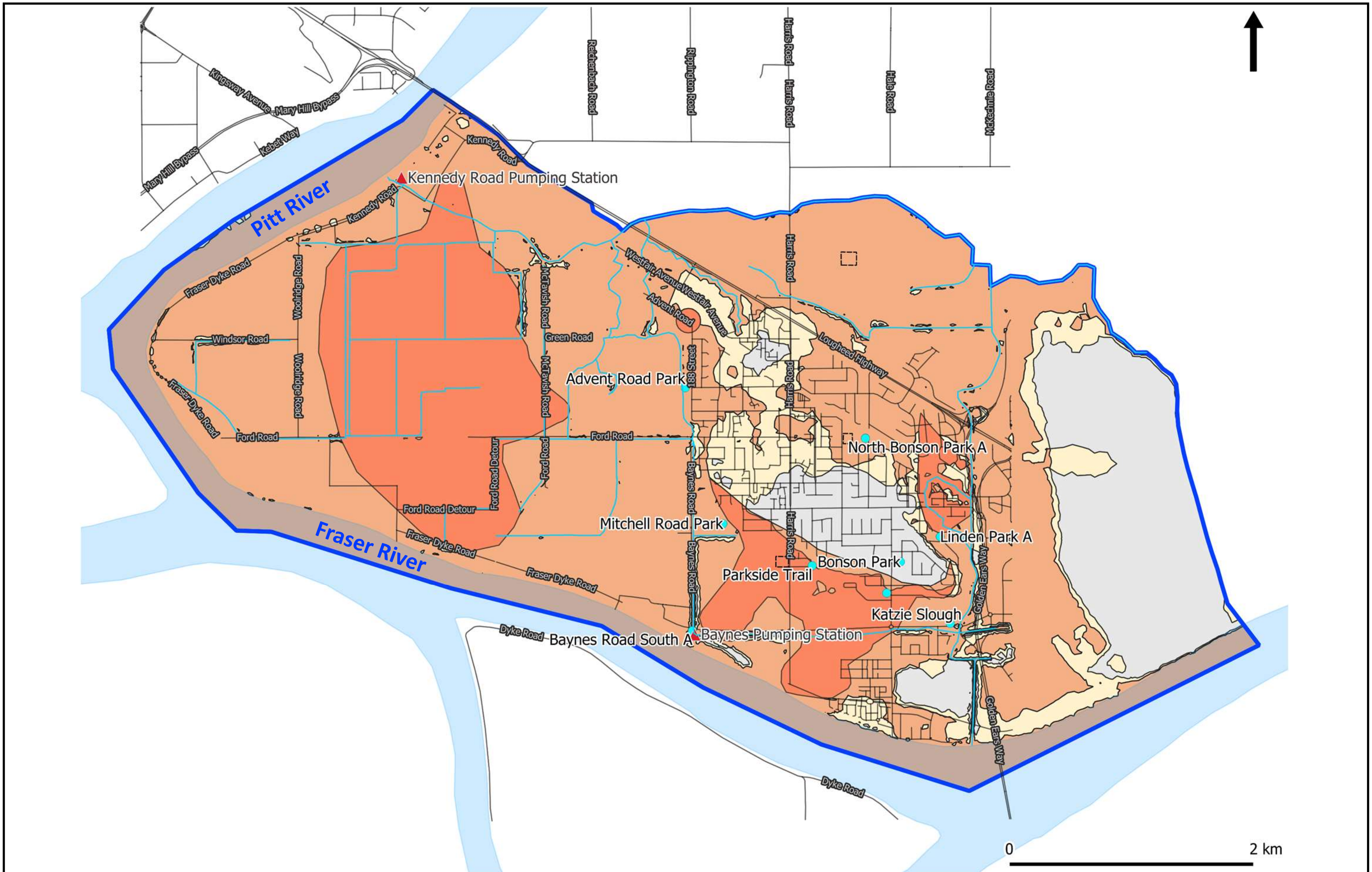
- Municipal Observation Well
- Pumping Station
- Road
- Watercourse
- Model Domain

August 2022

Pitt Meadows: Preload Effect on Groundwater Levels

Consolidation and Water Displacement Factors – Simulated Watertable Depth

ISL 35 YEARS | Aqua Insight | 14



Risk Level:

- High
- Significant
- Moderate
- Low

- Municipal Observation Well
- Pumping Station
- Road
- Watercourse
- Model Domain
- Test Site Location

August 2022

Pitt Meadows: Preload Effect on Groundwater Levels

Relative Risk of Groundwater Level Rise Caused by Preloading

ISL 35 YEARS Aqua Insight

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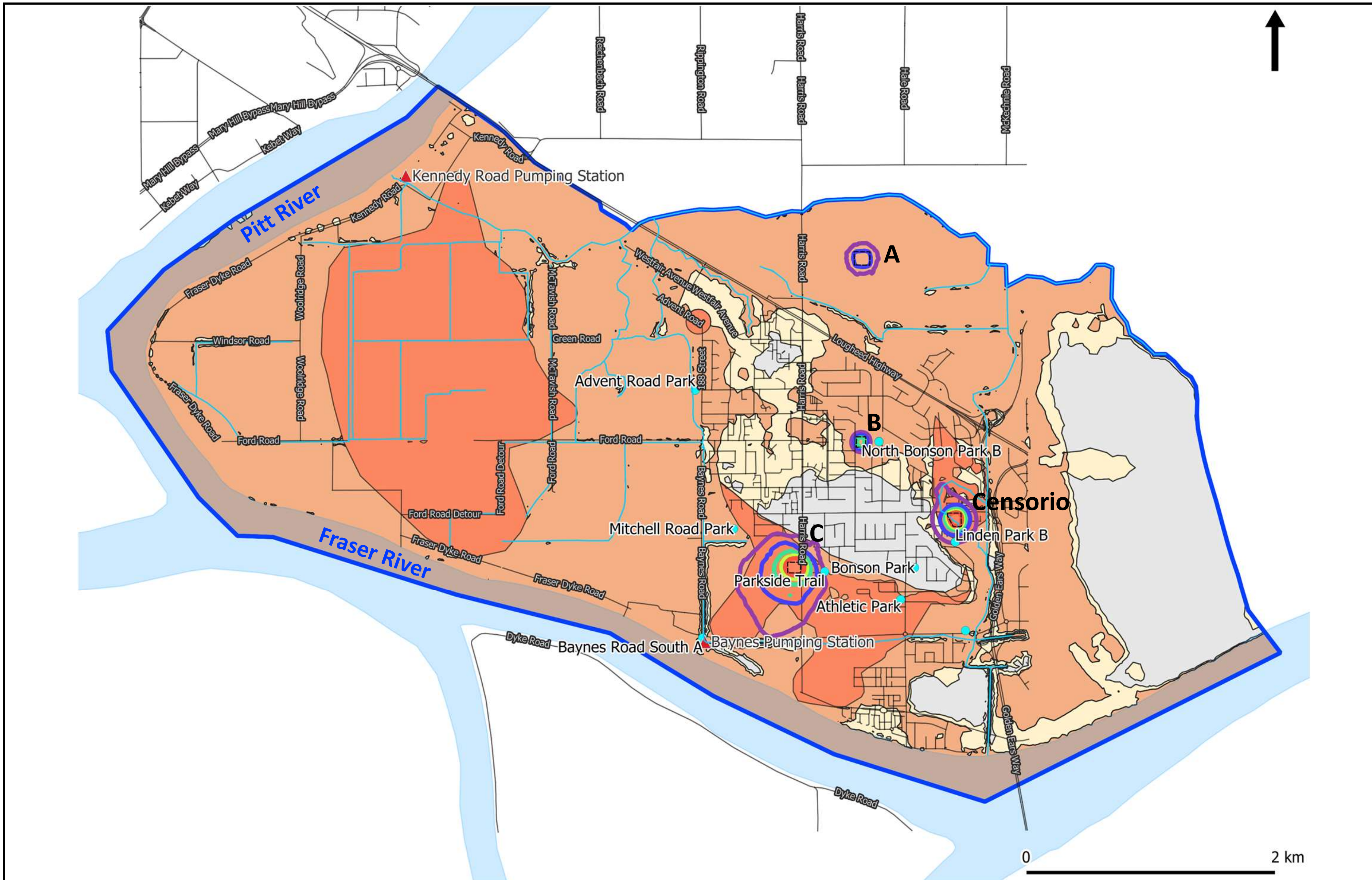

Risk Level:

- High
- Significant
- Moderate
- Low

- Municipal Observation Well
- Pumping Station
- Road
- Watercourse
- Model Domain
- Test Site Location

Increase in Watertable(m):

- 0.1
- 0.25
- 0.5
- 0.75
- 1.0

August 2022

Pitt Meadows: Preload Effect on Groundwater Levels

Demonstration of Risk Level Mapping

ISL 35 YEARS

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Appendix A
Model Details

Groundwater Flow Modelling Details

Table A1: Simulation Approach

Structural Element	Value
Flow Saturation State	Variably Saturated Media
Simulations	Steady-State

Table A2: Model Dimensions

Structural Element	Value	
Model Extent	9.4 km East-West by 5.7 km North-South	
Area	3.10 km^2	
Number of Elements	365,036	
Number of Nodes	210,992	
Element Diameter	Average	41.7 m
	Range	16 - 91.3 m

Table A3: Boundary Conditions

Hydrogeologic Unit	Feature	Flow	
		Type	Value
Fraser River Sediments	Recharge	Source	25 – 190 mm/year [1]
Sumas Drift	Recharge	Source	175 - 268 mm/year [1]
Organics	Recharge	Source	73 mm/year [1]
Fraser River Sediments	Watercourse [2]	Specified Head	0.1 – 7.9 m
		Discrete Feature (Manning Coefficient)	0.104 - 0.114 m$^{1/3}$/s
		Discrete Feature (Cross-Sectional Area)	2.25 m^2 (drainage ditches) - 14.5 m^2 (Katzie Slough)

Note: [1] Calibrated values applied, conceptual range was 0 - 300 mm/y.
[2] Boundary condition values derived from LiDAR elevation data and pump water elevation data.

Table A4: Fluid Flow Material Properties

Hydrogeologic Unit and Material	Zone Id	Hydraulic Conductivity			
		Conceptual Range [1] (m/s)	Observed Range [2] (m/s)	Calibrated Value [3] (m/s)	Vertical Anisotropy
Organic Deposits	140, 170, 190, 230	5x10^{-5} to 1x10^{-3}		1.6x10^{-5} to 4x10^{-4}	10
Upper Sandy Silt	100, 105, 108, 180, 200, 210, 290, 300, 308, 330, 340, 380, 385, 390, 395	1x10^{-8} to 1x10^{-4}	1.8x10^{-8} to 8.0x10^{-6}	8.9x10^{-9} to 3x10^{-4}	0 to 370

Hydrogeologic Unit and Material	Zone Id	Hydraulic Conductivity			
		Conceptual Range [1] (m/s)	Observed Range [2] (m/s)	Calibrated Value [3] (m/s)	Vertical Anisotropy
Sumas Drift	130, 150, 220, 250	$1x10^{--5}$ to $1x10^{--3}$	$2.7x10^{-5}$ $1.0x10^{-4}$	$1.0x10^{--5}$ to $1.5x10^{-4}$	1 to 10
Shallow Sand	400, 420, 430, 440, 450, 460, 470	$1x10^{--6}$ to $5x10^{--4}$		$2.9x10^{--6}$ to $5.0x10^{-4-}$	5
Middle Clayey Silt	500, 550	$1x10^{-8}$ to $1x10^{-4}$		$3.2x10^{--8}$ to $8.0x10^{--7}$	5 to 10
Dense Sand	600,650	$1x10^{--5}$ to $1x10^{--3}$		$8.0x10^{--4}$ to $9.0x10^{--4}$	5
Lower Clayey Silt	700	$1x10^{--8}$ to $5x10^{--7}$		$2.0x10^{--7}$	10

Note: [1] Derived from literature Freeze and Cherry (1979) and refined for site specific assessment.
[2] Observed range derived from various pumping test values
[3] Calibrated value of base case model (Section 3).

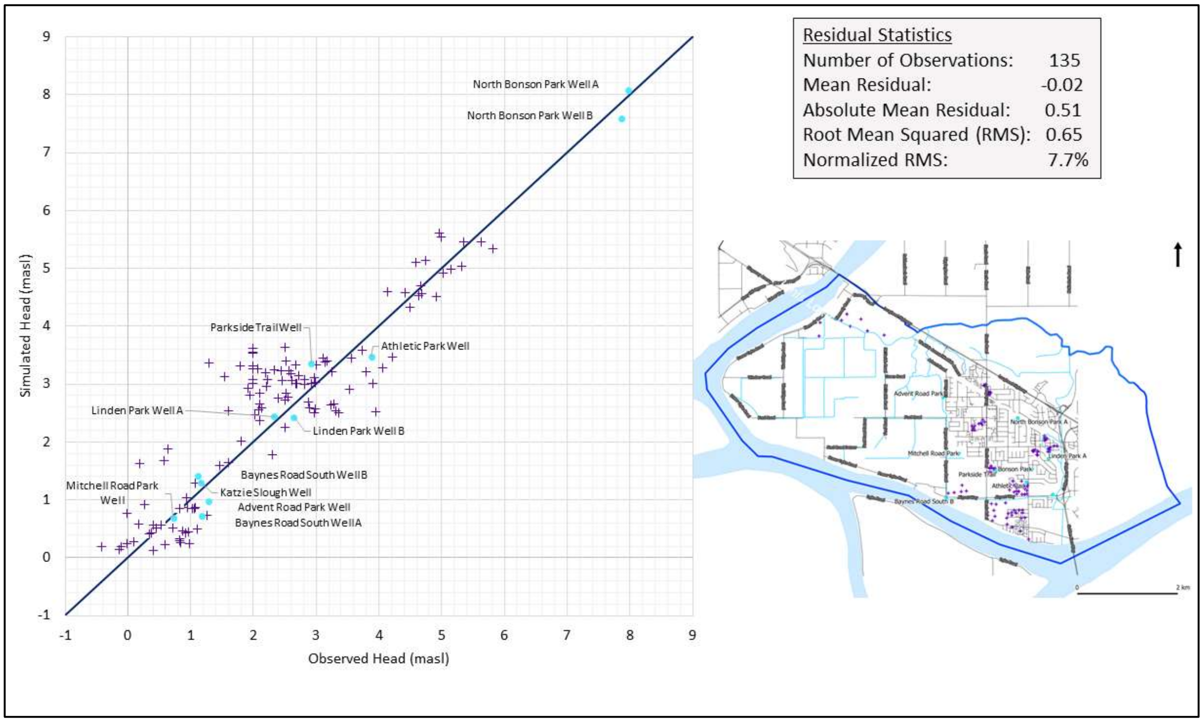

Figure A1: Scatter plot comparing Observed to Simulated Head for Calibrated Model

Table A6: Groundwater Head Residuals for Calibrated Base Case Model

Well Name	Easting	Northing	Elevation of Screen Midpoint (m asl)	Groundwater Head (m)		
				Measured	Simulated	Residual [1]
AH05	523274	5449978	0.9	2.6	3.0	0.4
AH06-1	522562	5452877	-1.3	2.4	2.2	-0.2
AH06-2	522546	5452869	2.0	2.6	2.3	-0.3
AH06-3	522588	5452888	2.0	2.5	2.3	-0.2
AH07-1	522447	5452107	3.2	5.8	5.1	-0.8
AH07-2	522492	5452123	3.5	5.6	5.2	-0.5
AH07-3	522509	5452093	-2.7	5.4	5.2	-0.2
AH-10	523193	5450837	-0.7	2.0	2.4	0.5
AH-11	523240	5450765	-0.3	3.0	2.1	-0.9
AH-11GP	523240	5450765	1.3	4.0	2.1	-1.9
AH-12	523362	5450241	-0.6	2.5	3.3	0.8
AH-13	523315	5450392	-0.8	2.7	2.6	-0.1
AH-13GP	523414	5450894	-2.3	3.2	3.0	-0.2
AH-14	523246	5450393	-0.6	2.9	2.6	-0.3
AH-15	523150	5450386	-0.6	2.7	2.7	0.0

Well Name	Easting	Northing	Elevation of Screen Midpoint (m asl)	Groundwater Head (m)		
				Measured	Simulated	Residual [1]
AH-16	523032	5450325	-0.7	2.9	2.5	-0.3
AH-17	523102	5450291	-0.9	2.7	2.9	0.2
AH-17GP	523139	5450885	-0.5	2.2	2.6	0.4
AH-18	523098	5450347	-0.7	2.8	2.8	-0.1
AH-18GP	523123	5450965	-0.6	2.5	2.8	0.3
AH-19	523182	5450340	-0.7	2.8	2.7	-0.1
AH1GP	523614	5451547	0.0	2.0	2.9	0.9
AH-1GP	523794	5451818	-3.8	-0.1	0.1	0.3
AH-1GPB	523403	5450716	-1.8	3.2	2.0	-1.2
AH-1T	522564	5452141	-1.0	5.0	5.3	0.3
AH-2	523106	5450053	-0.1	3.0	3.0	0.0
AH-20	523296	5450967	0.6	2.7	3.0	0.3
AH-21	523314	5450859	-0.7	2.4	2.8	0.4
AH-22	523226	5450857	-0.7	2.6	2.7	0.1
AH-22GP	523226	5450857	3.7	4.1	3.2	-0.9
AH-23	523408	5450866	-1.5	1.8	2.9	1.1
AH-24	523290	5450229	0.2	3.7	3.3	-0.4
AH-25	523317	5450342	-0.7	2.6	2.9	0.3
AH-25GP	523148	5450752	3.2	3.3	2.5	-0.8
AH-28GP	523055	5450794	-0.9	2.1	2.3	0.2
AH2GP	523597	5451494	0.3	2.0	3.1	1.1
AH-2GP	523775	5451785	-4.3	-0.4	0.2	0.6
AH-2GPB	523401	5450781	-4.4	3.5	2.4	-1.2
AH-2T	522530	5452182	3.2	5.0	5.2	0.2
AH-30GP	523056	5450913	1.0	1.9	2.6	0.7
AH3GP	523612	5451482	0.3	2.0	3.1	1.1
AH-3GP	523765	5451811	-4.0	-0.1	0.2	0.3
AH-3GPB	523399	5450834	-1.1	2.2	2.7	0.5
AH-41	523436	5449813	-0.8	0.6	1.8	1.2
AH4GP	523533	5451553	1.8	2.0	3.3	1.3
AH-4GP	523746	5451773	-2.4	0.0	0.2	0.3
AH-4GPB	523365	5450840	2.0	3.3	2.7	-0.5
AH5GP	523527	5451582	1.4	2.0	3.3	1.3
AH-5GP	523743	5451815	-1.4	0.1	0.3	0.2
AH6GP	523516	5451568	2.0	2.0	3.4	1.4

Well Name	Easting	Northing	Elevation of Screen Midpoint (m asl)	Groundwater Head (m)		
				Measured	Simulated	Residual [1]
AH-6GP	523745	5451869	-1.1	0.4	0.1	-0.3
AH-6GPB	523356	5450709	-3.4	2.9	2.0	-0.9
AH7GP	523565	5451595	3.6	3.0	3.1	0.1
AH-7GP	523304	5450706	-4.7	3.3	2.0	-1.3
AH-8	523200	5450711	-0.9	2.1	2.0	-0.1
AH8GP	523615	5451566	-0.1	2.0	2.8	0.8
AH-9	523196	5450771	0.8	1.6	2.1	0.5
AH95-1	521842	5450727	-3.9	2.3	1.7	-0.6
AH95-2	521960	5450741	-4.5	2.5	2.2	-0.3
AH95-3	522099	5450759	-2.4	2.1	2.6	0.5
AH95-4	522201	5450772	-5.5	2.5	2.6	0.1
AH95-6	522117	5450886	-4.2	2.1	2.7	0.6
AH95-7	522106	5450652	-5.5	1.8	2.0	0.2
BH00-1	523357	5450817	-10.2	3.0	2.6	-0.4
BH00-2	523355	5450701	2.2	3.0	1.9	-1.1
BH99-2	523233	5450761	0.5	3.4	2.1	-1.3
BH99-3	523232	5450846	1.2	3.9	2.6	-1.3
BH99-4	523343	5450847	1.1	3.8	2.7	-1.0
DH1	522341	5452019	-6.1	5.3	4.8	-0.6
DH2	522363	5452062	3.9	4.7	4.9	0.1
DH3	522316	5452062	4.3	5.2	4.7	-0.4
DH4	522322	5451981	4.2	5.0	4.7	-0.4
DH5	522365	5451980	3.9	4.6	4.8	0.3
TH15-01GP	522699	5450519	-0.7	0.9	1.0	0.1
TH15-02GP	522791	5450509	-1.6	0.0	0.7	0.8
TH15-03GP	522978	5450536	1.2	1.1	1.2	0.2
TH15-04GP	522747	5450387	-1.0	0.2	1.6	1.4
TH15-05GP	522628	5450288	1.5	1.6	1.6	0.0
TH15-06GP	522717	5450183	-2.5	1.5	1.6	0.1
TH15-07GP	523001	5450234	-0.9	2.0	2.4	0.4
TH15-09GP	523010	5450111	-2.2	2.1	2.5	0.4
TH15-10GP	522768	5450268	-3.0	0.6	1.7	1.1
TH17-01GP	523815	5451606	-5.0	1.1	0.5	-0.6
TH17-02GP	523816	5451553	-3.6	1.0	0.8	-0.1
TH17-03GP	523870	5451634	-1.9	1.0	0.2	-0.8

Well Name	Easting	Northing	Elevation of Screen Midpoint (m asl)	Groundwater Head (m)		
				Measured	Simulated	Residual [1]
TH17-04GP	523842	5451628	-5.0	0.8	0.3	-0.5
TH17-05GP	523860	5451582	-2.1	0.8	0.3	-0.5
TH17-06GP	523846	5451543	-6.3	1.3	0.7	-0.6
TH17-07GP	523834	5451588	-3.7	0.4	0.4	0.0
TH-1GP	522628	5452754	0.6	4.5	3.8	-0.7
TH-2GP	522655	5452678	3.5	4.7	4.2	-0.4
TH-3GP	522643	5452702	3.6	4.1	4.1	0.0
TH-4GP	522642	5452706	2.1	4.7	4.1	-0.6
TH-5GP	522647	5452723	2.3	4.9	4.0	-0.9
TH-6GP	522688	5452724	1.6	4.4	4.1	-0.3
TH-7GP	522665	5452728	2.0	4.6	4.0	-0.6
TP-01	522691	5451140	0.5	1.5	2.9	1.4
TP-02	522775	5451135	0.6	2.1	3.0	0.9
TP-03	522770	5451227	4.0	3.6	3.2	-0.4
TP-04	522770	5451192	3.3	3.1	3.1	0.0
TP-05	522738	5451215	2.9	2.5	3.2	0.6
TP-07	522703	5451234	0.7	1.3	3.1	1.8
TP-08	522662	5451137	2.3	2.2	2.9	0.7
TP-09	522626	5451140	2.7	2.7	2.8	0.1
TP1	524002	5451661	0.9	0.8	0.2	-0.7
TP-11	522663	5451218	2.1	2.3	3.0	0.7
TP-12	522691	5451271	1.9	3.1	3.2	0.1
TP-13	522628	5451330	3.4	4.2	3.3	-1.0
TP2	523942	5451666	-0.1	0.6	0.2	-0.4
SH_DCPT_MW20-04D	519726	5454161	-17.9	0.3	0.7	0.4
SH_DCPT_MW20-04S	519726	5454161	-1.9	0.5	0.5	0.0
SH_DCPT_MW20-08D	519901	5454042	-8.8	1.0	0.6	-0.4
SH_DCPT_MW20-08S	519901	5454042	-4.4	0.9	0.5	-0.5
SH_MW20-01D	519835	5454284	-7.2	1.1	0.9	-0.2
SH_MW20-01S	519835	5454284	-1.2	1.1	0.9	-0.1
SH_MW20-02D	520112	5454184	-7.8	1.0	0.8	-0.2
SH_MW20-02S	520112	5454184	-2.8	0.8	0.9	0.0
SH_MW20-03D	520572	5453866	-12.2	0.2	0.6	0.4
SH_MW20-03S	520572	5453866	-3.1	0.9	0.6	-0.3
SH_MW20-06D	520240	5453951	-7.1	0.4	0.5	0.1

Well Name	Easting	Northing	Elevation of Screen Midpoint (m asl)	Groundwater Head (m)		
				Measured	Simulated	Residual [1]
SH_MW20-06S	520240	5453951	-2.6	0.4	0.4	0.1
SH_MW20-10D	519303	5454116	-9.3	0.4	0.7	0.3
SH_MW20-10S	519303	5454116	-2.1	0.5	0.7	0.1
SH_MW20-14	519282	5453850	-2.9	0.7	0.5	-0.2
Athletic Park Well	523393	5450949	4.1	3.9	3.1	-0.8
Katzie Slough Well	523913	5450700	0.3	1.2	0.8	-0.3
Mitchell Road Park Well	522053	5451519	-1.0	0.7	0.6	-0.1
Advent Road Park Well	521744	5452632	-0.1	1.3	0.3	-1.0
Linden Park Well A	523830	5451413	2.4	2.3	2.4	0.1
Linden Park Well B	523831	5451413	2.4	2.6	2.4	-0.2
North Bonson Park Well A	523219	5452219	7.8	8.0	7.8	-0.2
North Bonson Park Well B	523219	5452218	-0.7	7.9	7.3	-0.6
Baynes Road South Well A	521803	5450643	-0.1	1.2	0.7	-0.5
Baynes Road South Well B	521803	5450640	-4.6	1.1	1.4	0.2
Parkside Trail Well	522783	5451175	1.1	2.9	3.1	0.2

[1] Residual calculated as simulated value less measured value.

Table A7: Fluid Balance for Base Case Calibrated Model

Element	Input (m^3/d)	Output (m^3/d)	Net (m^3/d)
Specified Head [1]	3,728	-15,257	-11,529
Source/Sink [2]	11,530		11,530
Storage Change [3]			
Imbalance [4]			0.0047 (<0.1%)

Note: [1] Specified Head boundary conditions represent lateral groundwater inflow from upgradient areas and groundwater discharge to streams.
[2] Source/Sink boundary conditions represent groundwater recharge applied to the top of the model.
[3] No storage component for steady-state simulation.
[4] Percent imbalance calculated as SumNet/SumInput*100. Percent imbalance of less than 0.1% indicates conservation of fluid.

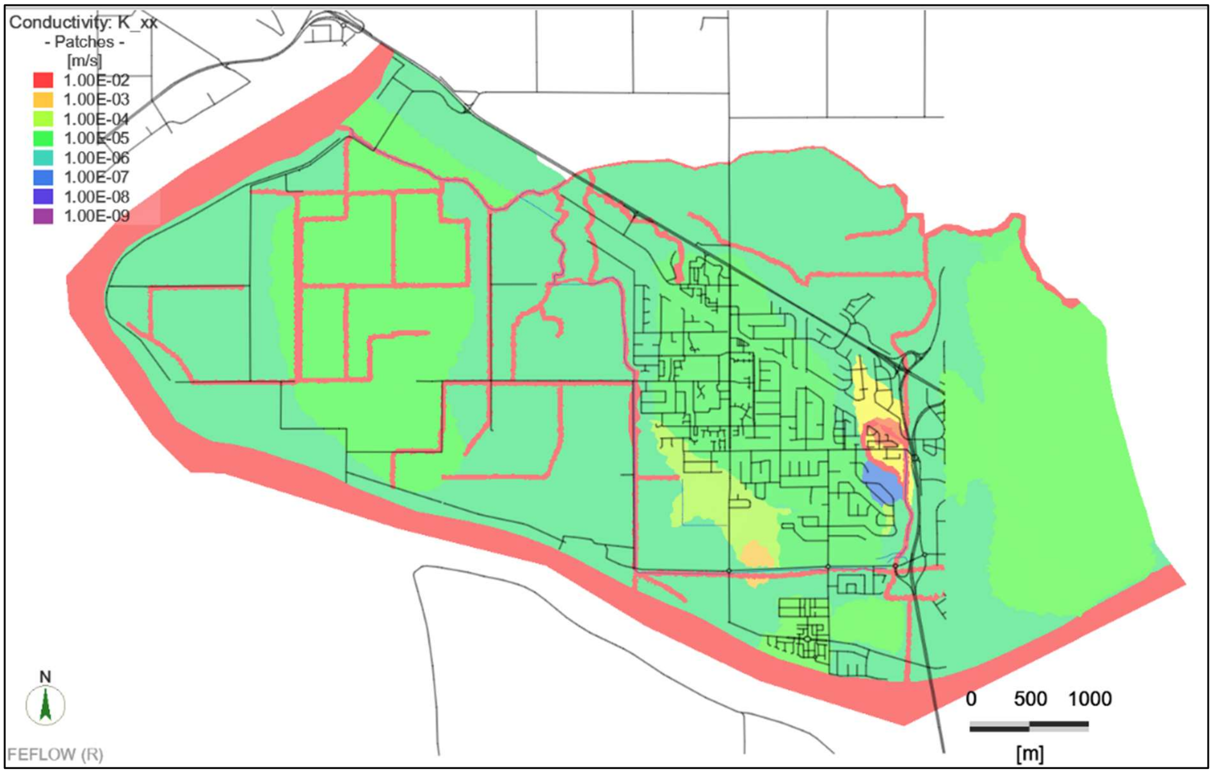

Figure A2: Distribution of Surficial Geology Hydraulic Conductivity (Model Layers 1-2)

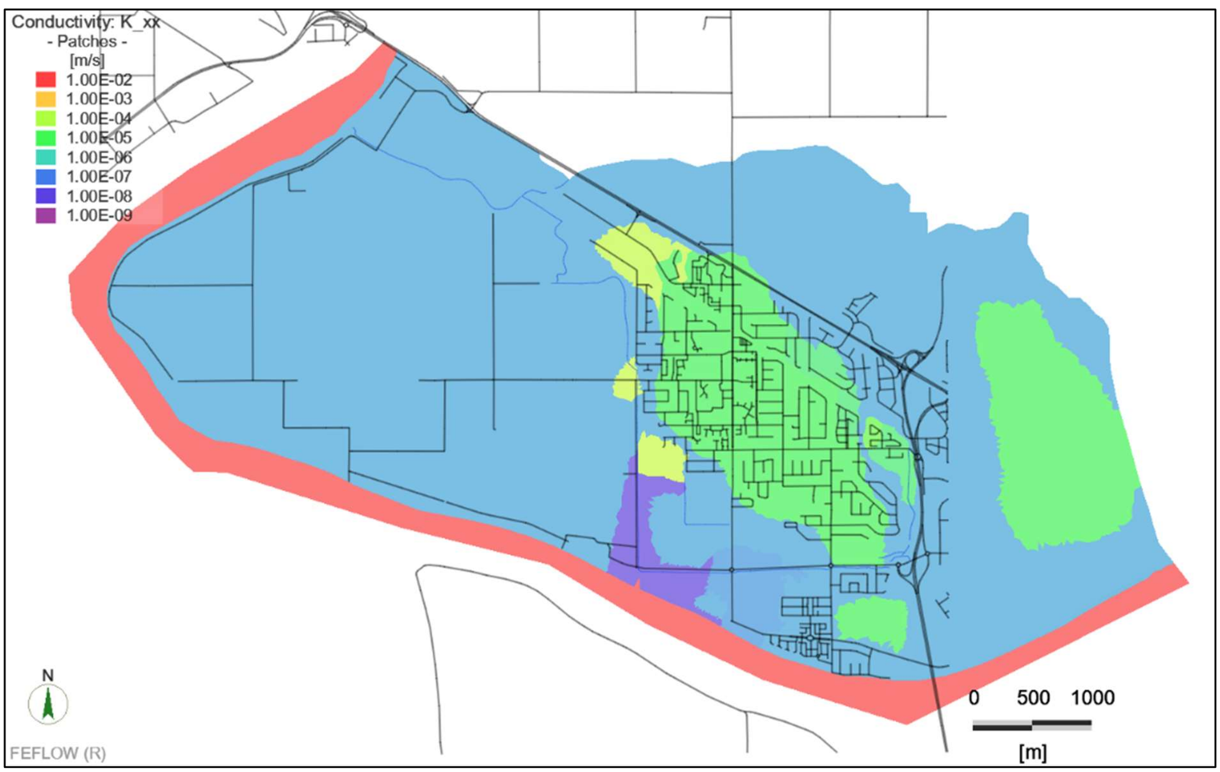

Figure A3: Distribution of Upper Sandy Silt Hydraulic Conductivity (Model Layer 3)

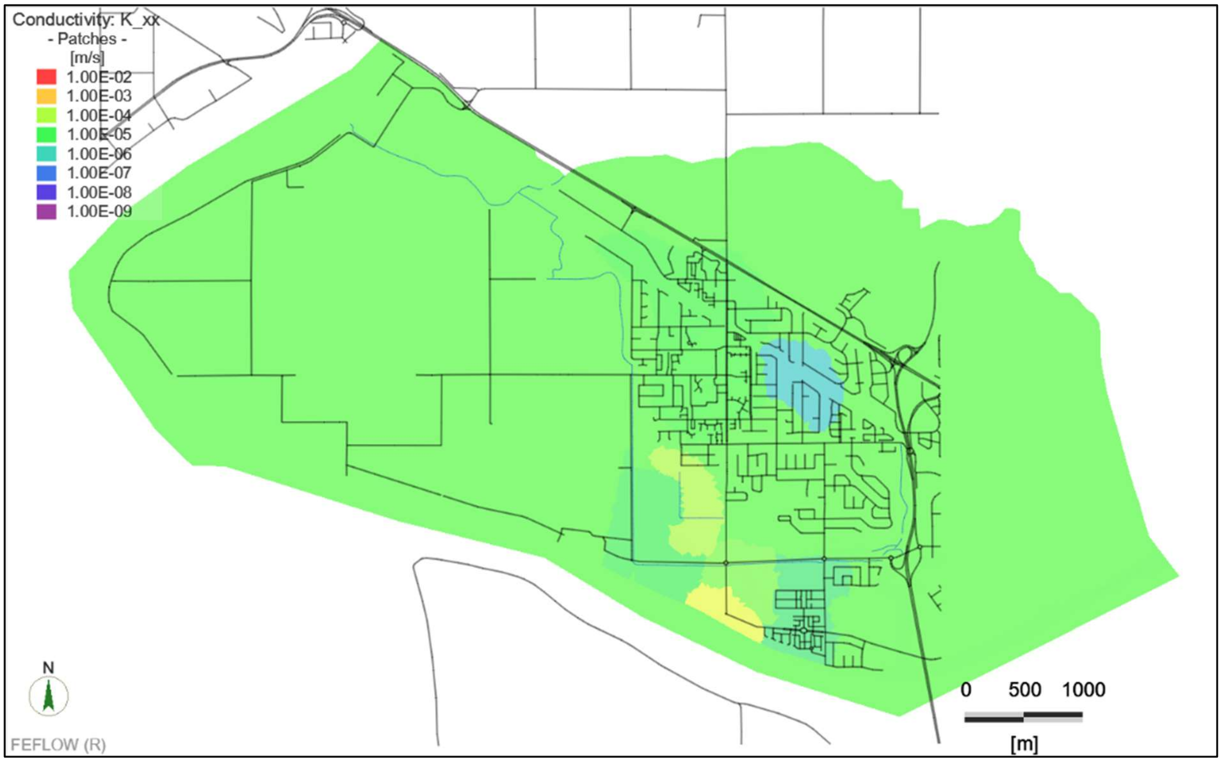

Figure A4: Distribution of Upper Sandy Silt Hydraulic Conductivity (Model Layers 4-13)

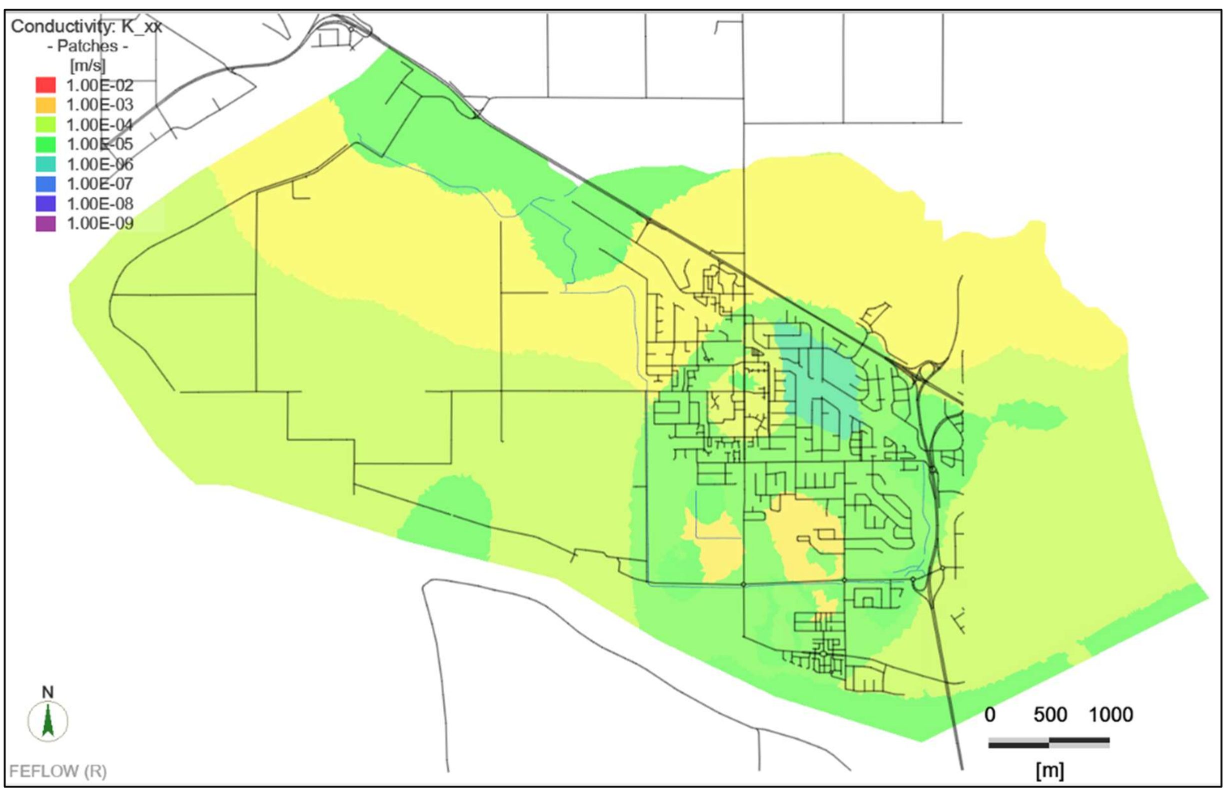

Figure A5: Distribution of Shallow Sand Hydraulic Conductivity (Model Layer 14)

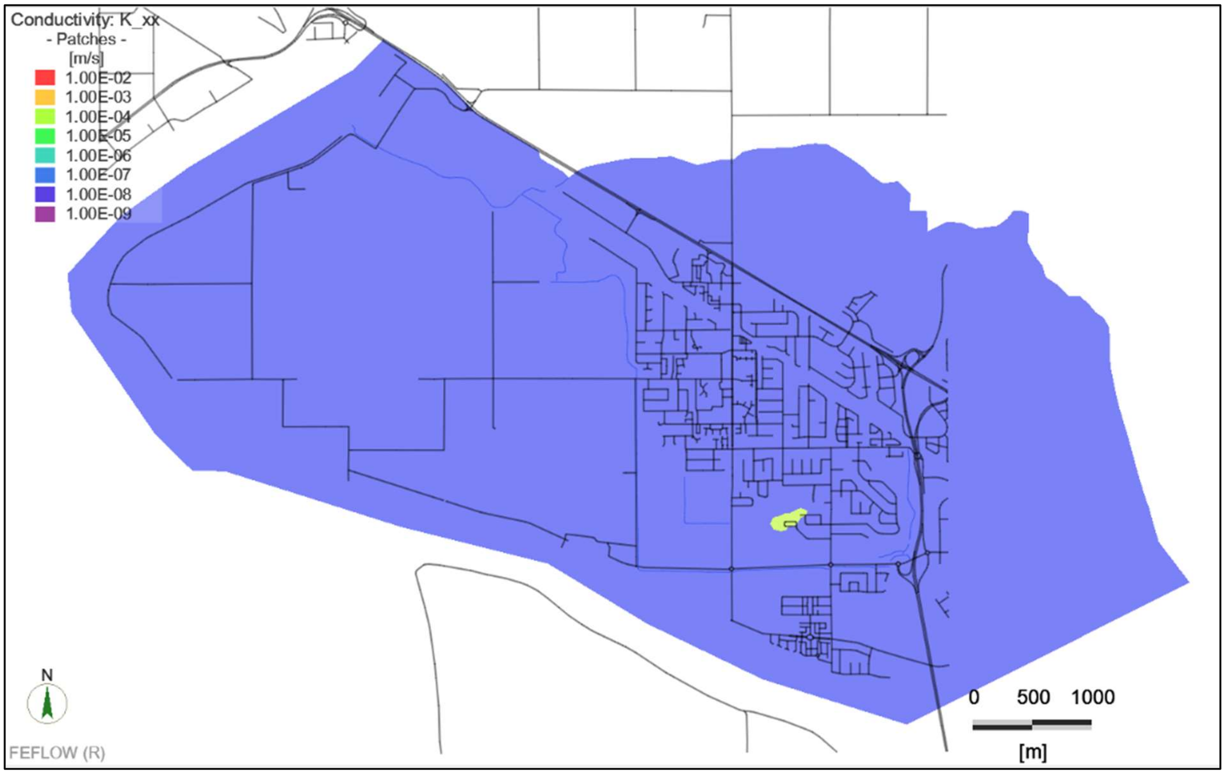

Figure A6: Distribution of Middle Clayey Silt Hydraulic Conductivity (Model Layers 15-19)

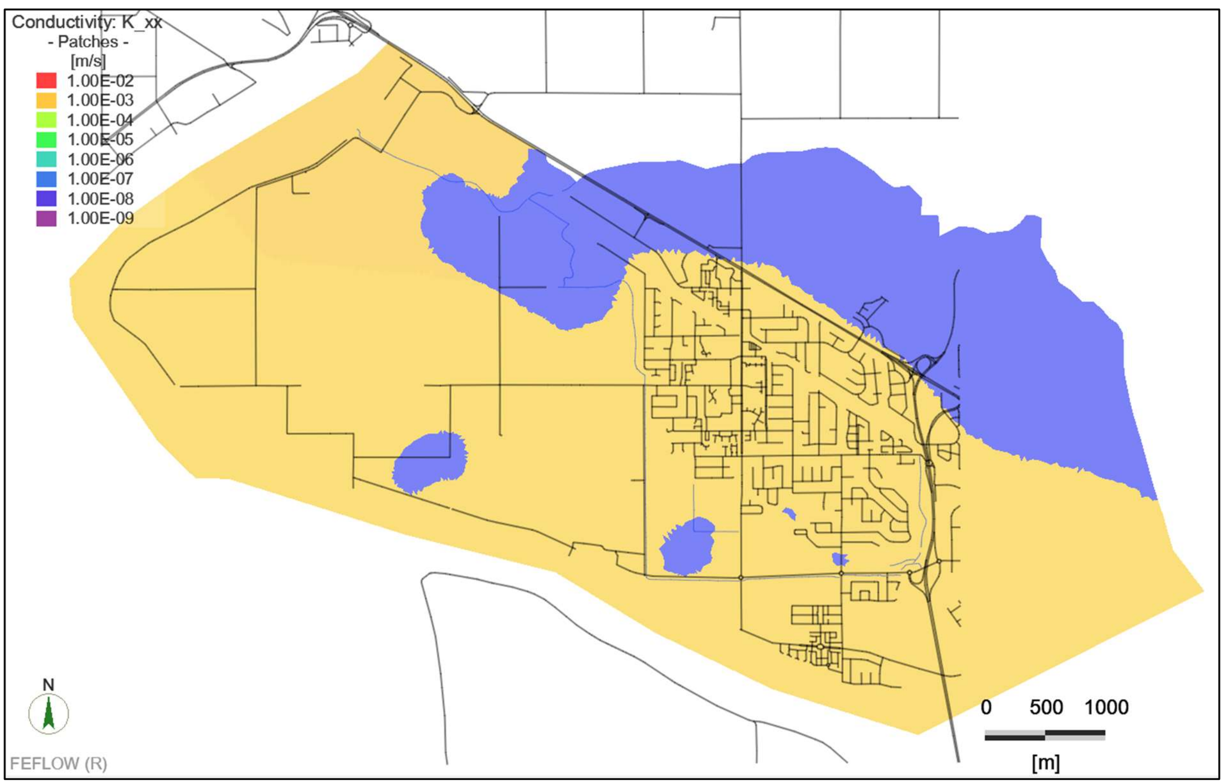

Figure A7: Distribution of Dense Sand Hydraulic Conductivity (Model Layers 18-19)

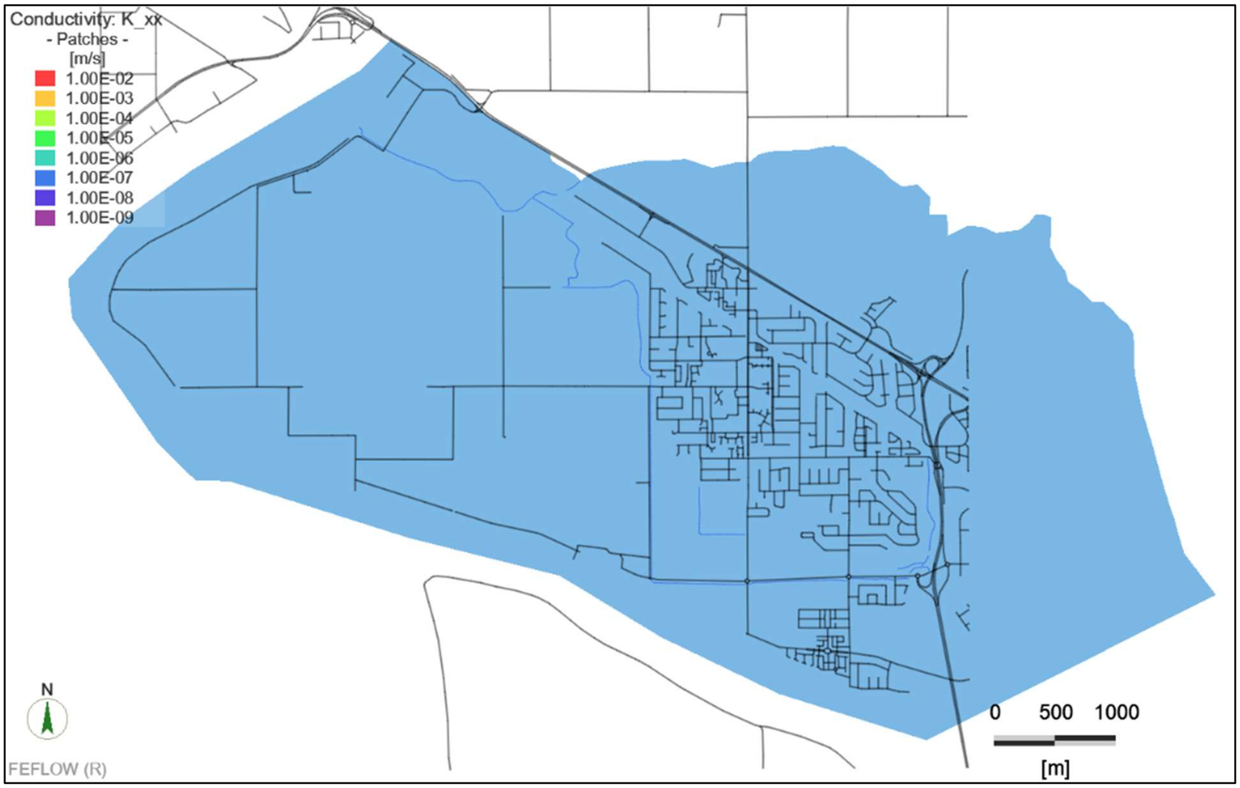

Figure A8: Distribution of Lower Clayey Silt Hydraulic Conductivity (Model Layers 20-32)