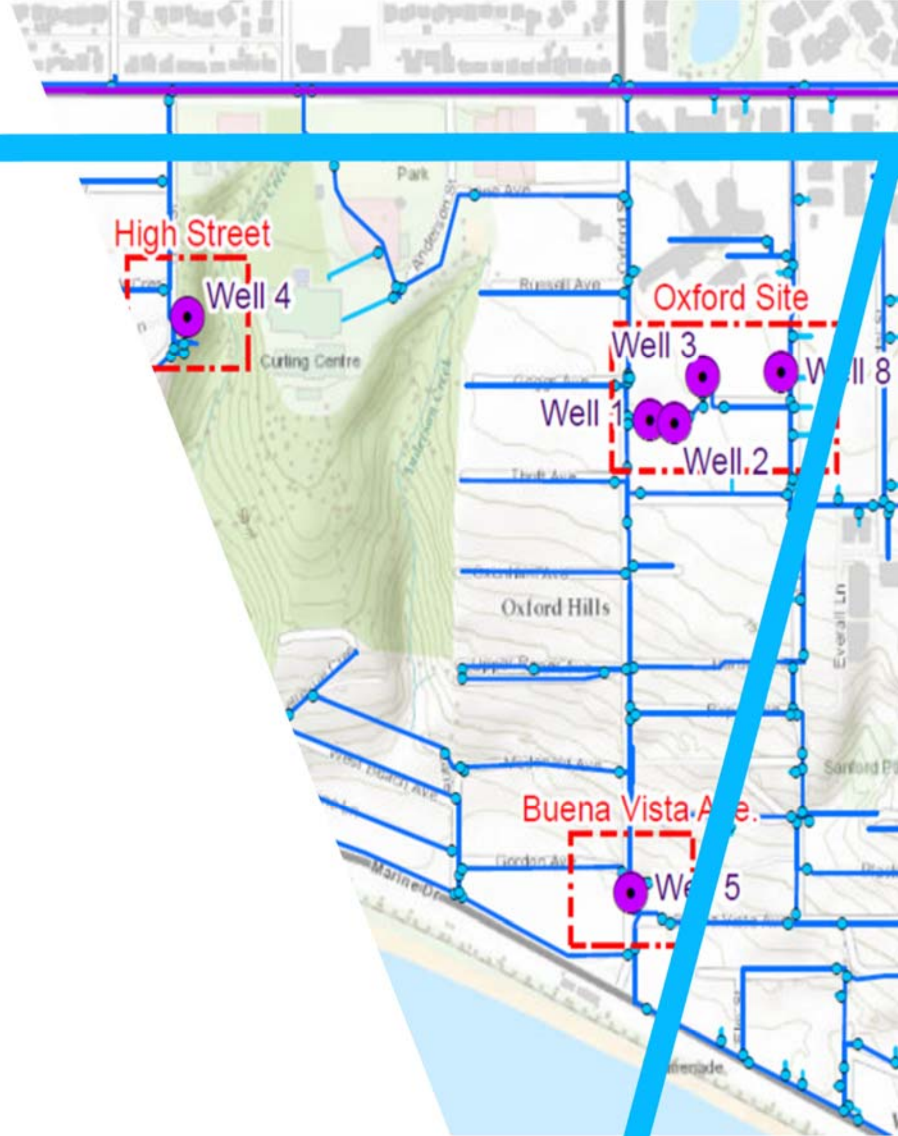

WHITE ROCK
City by the Sea!

Aquifer Protection Plan

19 June 2018

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Burnaby BC V5C 6S7
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307071-01216-00-WW-PLN-0001

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WorleyParsons Group

Disclaimer

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Rev	Description	Author	Review	Advisian Approval	Date
0	Issued for Use	Z. Hammond	L. Lyness	M. Scott	19-Jun-18

Executive Summary

Advisian (part of WorleyParsons Group) was retained by the City of White Rock (CoWR) to prepare an Aquifer Protection Plan (Plan) for the White Rock water supply system. The White Rock water supply system is located within the CoWR, British Columbia. It services a residential population of approximately 20,000 within a 600 hectare service area that includes the CoWR as well as Semiahmoo First Nation and a small portion of the City of Surrey.

The Sunnyside Aquifer is an important natural resource that is used as the water supply source for the CoWR. Population growth, climate change, sea level rise, and other users of the aquifer (e.g. future groundwater use by the City of Surrey) may put increasing pressure on the water supply system. This Plan has been developed as a key component in protecting the community's water supply source. Groundwater protection goals include stakeholder engagement, advancing the understanding of aquifer characteristics, protecting groundwater quality from contamination, and ensuring future withdrawals sustainably meet future demands.

Key outcomes of the Plan include development of a numerical groundwater model that has been used to delineate the well protection area and to simulate three future scenarios to inform future groundwater management. A total of 24 groundwater hazards have been identified and include threats to both quality and quantity aspects of the water supply. None of the groundwater hazards were considered to be a high risk. Groundwater hazards associated with groundwater quality have been assessed as low to moderate risk, while quantity hazards have primarily been assigned as moderate risks.

Risk assessment results reflect the natural protection provided by low permeability materials overlying the aquifer and highlight the existing uncertainty in aquifer recharge mechanisms with the need for a broader, regional strategy to manage this groundwater resource. Concerns with naturally occurring concentrations of manganese and arsenic in the aquifer have been largely mitigated by plans to build a treatment plant.

A groundwater management framework has been provided that includes various levels of government while also requiring support by the local community. The "voice for water" needs to be represented by multiple stakeholders to bring meaningful progress in attaining sustainability goals all within a forum that fosters innovation and collaboration. Groundwater management (mitigation and contingency planning) provided in this Plan focuses on approaches that can be implemented by the CoWR to augment existing measures (e.g. water restrictions, water metering). A combination of regulatory and "soft" tools has been included that address the urban setting of the aquifer with priority given to regional collaboration, continued due diligence in groundwater monitoring efforts, potential bylaw updates to enforce groundwater management and protection measures, communication with City of Surrey and targeted local businesses, promotion of waste stewardship, and public awareness campaigns.

The Sunnyside Aquifer extends beyond the CoWR municipal boundaries and an integrated management approach with the City of Surrey is required. A key initiative would be to promote and support regional approaches for groundwater protection to avoid fragmented management. This present work has identified several key data gaps that would be better addressed at the regional level rather than the individual municipal level, including but not limited to: regional groundwater model to investigate the hydraulic connection between aquifer systems and to inform boundary conditions of local models; recharge study and geochemistry investigations to better understand the flow system; climate change impacts on the hydrologic cycle to determine the effect on recharge; and saltwater intrusion modelling.

Table of Contents

Tables in Text

Figures in Text

Figures

Appendices

1 Introduction

1.1 General Background

Advisian (part of WorleyParsons Group) was retained by the City of White Rock (CoWR) to prepare an Aquifer Protection Plan (Plan) for the White Rock water supply system. The White Rock water supply system is located within the CoWR, British Columbia (BC) (Figure 1-1). It services a residential population of approximately 20,000 within a 600-hectare service area that includes the CoWR as well as Semiahmoo First Nation and a small portion of the City of Surrey (located on North Bluff Avenue and Bergstrom Road) (Stantec 2016).

Groundwater from the Sunnyside Aquifer is used as a water source for the water supply system. Water services in White Rock were provided by private owners until the system was acquired by the CoWR in October 2015. The CoWR is responsible for the operation of the water supply system, ensuring the quality and safety of the water supply.

Stresses associated with population growth, climate change, sea level rise, and other users of the aquifer have the potential to put increasing pressure on the water supply system. This Plan has been developed as a key component in protecting the community's water supply source by providing information about the characteristics of the aquifer (i.e., geometry, behaviour, and performance), investigating possible influences of future water use and natural events, identifying possible hazards to the groundwater supply in terms of both quantity and quality, while developing a long-term strategy for sustainable groundwater management that includes regional collaboration.

1.2 Groundwater Protection Goals

Groundwater protection goals established by the CoWR for the Plan include:

- Engage stakeholders to guide development of the Plan;
- Increase the knowledge and understanding of the Sunnyside Aquifer;
- Develop an action plan to protect groundwater quality from contamination; and
- Derive a sustainable approach to groundwater abstraction that meets future demands.

1.3 Study Area

The study area includes the extents of the provincially mapped Sunnyside Aquifer (Aquifer No. 57) and an additional buffer area to facilitate geological interpretation and development of the hydrogeological conceptual site model (CSM) and is presented in Figure 1-1. The study area is approximately 11,250 hectares (ha) and is bordered by the coastal waters of Semiahmoo Bay and Mud Bay along the southern and western extents respectively. The majority of the study area is located within an upland area referred to as the Surrey Uplands. The Surrey Uplands are bordered by lowlands that contain the Nicomekl River and Campbell River along the northern and eastern extents respectively.

The study area extends beyond the municipal boundary of the CoWR and includes a portion of the municipal boundary of Surrey. This Plan focuses on sustainable resource development specific to the water supply system for the CoWR. To achieve the overall objectives of the Plan, regional groundwater management measures have been identified and are discussed in Section 7.5.

1.4 Scope of Work

To meet the goals of the Plan, the following scope of work was undertaken:

- Stakeholder consultation:
  - Define a communication protocol and strategy for sharing information and soliciting feedback with stakeholders;
  - Establish and consult a Technical Working Group (TWG) consisting of technical experts and local government groups to provide feedback on the development of the plan through participation in two technical webinars; and
  - Track and respond to comments received from the TWG.
- Review previous studies and publicly available information related to the existing water supply system, physical setting, local water users, and contaminant inventory;
- Derive a conceptual hydrogeological model for the Sunnyside Aquifer to an extent enabled by the geologic and groundwater information available;
- Develop a 3-Dimensional numerical groundwater model and conduct model calibration and sensitivity analyses;
- Identify and evaluate future operational alternatives to meet future projected water demands to the year 2045;
- Define well protection areas based on the modelling results for both the current situation and a future water supply scenario;
- Evaluate the potential impact of current and future projected water demands, including potential impacts of climate change on groundwater availability;
- Summarize risks to the groundwater supply;
- Identify mitigation measures to reduce identified or possible risks to the groundwater supply;
- Develop contingency plans to enable CoWR to respond in a timely manner and in an adequately informed manner;
- Outline a long-term monitoring plan to verify and to support continual development of the Plan; and
- Make recommendations for regional initiatives to be considered to support sustainable groundwater management of the Sunnyside Aquifer.

1.5 Approach

The Ministry of Environment's Well Protection Toolkit (WPT) (BC MOE et al, 2006) was used to guide the development of the Plan. The WPT is a six-step process that includes the following:

- Step 1 – Form a Community Planning Team;
- Step 2 – Define the Well Protection Area;
- Step 3 – Identify Groundwater Hazards and Evaluate Risk;
- Step 4 – Develop Management Strategies;
- Step 5 – Develop Contingency Plans; and
- Step 6 – Monitor Results and Evaluate the Plan.

To meet the goals of the CoWR, steps 1 and 2 of the WPT were modified. Step 1 was modified to include development of a stakeholder engagement strategy that combined the use of a Technical Working Group (TWG) to guide development of the Plan along with community consultation to educate and inform the public about the Plan. Further details on stakeholder engagement are provided in Section 1.6. A risk assessment approach that incorporated elements in Module 1 and Module 7 of BC's Comprehensive Drinking Water Source-to-Tap Assessment Guideline was used to inform the development of management strategies.

The Sunnyside Aquifer is located within a complex geological sequence of glacial sediments and is partially bordered by coastal waters. As such, numerical modelling was deemed necessary by the CoWR for capture zone delineation. Step 2 also included delineation of the well protection area considering future water use. Sea-level rise and changes in recharge based on projected climate change conditions (precipitation and temperature) were also considered.

1.6 Stakeholder Consultation

A goal for the Plan is to obtain broad public acceptance from both the public and Provincial regulatory agencies. A summary of the goal, method, and timeframe for engagement of each stakeholder group is provided in Table A.

Table A Summary of Stakeholder Engagement

Stakeholder	Goal for Engagement	Method of Engagement	Timeframe
Local Residents, First Nations, Community Based Groups	Educate the public on the CoWR groundwater system and source protection planning. Provide opportunities to discuss the project outcomes.	▪ Project Website ▪ Post recordings from two webinars with the TWG ▪ Post TWG comment register	Throughout project
		▪ Open House	June 14, 2018

Stakeholder	Goal for Engagement	Method of Engagement	Timeframe
Government, First Nations, and Regulatory Agencies	Work directly to ensure that their concerns are fully understood and considered in decision making through invitation to participate in the TWG. Provide feedback about how their views influenced the decision-making process.	▪ Two webinars	Webinar 1: November 29, 2017 Webinar 2: February 15, 2018
		▪ Personal invitation to Open House	June 14, 2018
Mayor and Council	Keep informed on Project and Meetings.	▪ Updates from CoWR staff ▪ Final Aquifer Protection Plan and Consultation Report ▪ Presentation during council meeting.	Throughout project May 21, 2018 May 28, 2018

1.6.1 Project Website

A project website has been established and is maintained by the CoWR (https://www.whiterockcity.ca/EN/main/city/my-water/city-water-projects/aquifer-protection-plan.html). The website contains information on the project including recordings of the two webinars held with the TWG, the TWG comment tracking table, and key project milestones.

1.6.2 Technical Working Group

Technical experts and government authorities with interest/jurisdiction in the study area were invited to participate in the CoWR Aquifer Protection Plan TWG to support the development of the Plan. The roles and responsibilities for the TWG included being or sending a technical expert and/or government authority within the study area, attend and participate in two technical webinars, and provide input on the preparation, form, and content to support development of the Plan.

The first webinar presented information on existing conditions as well as the approach proposed for evaluating future water use. The second webinar presented the results of the future water use evaluation and resultant risk management assessment. Feedback from the TWG was considered during preparation of the draft Plan. Comments from the TWG and written responses from Advisian were tracked and made available to the public through the CoWR project website and herein as Appendix 1.

1.6.3 Public Open House

An open house to present the Plan is scheduled for June 14, 2018. The purpose of the open house is to educate and inform local residents about the Plan. The open house will be an opportunity for participants to personally discuss the Project or have questions answered by the Project team.

1.7 Previous Investigations and Water Management Initiatives

The following historical studies specific to groundwater in the study area have been reviewed in preparation of this Plan:

- Hydrogeological Assessment for White Rock Groundwater Supply (Piteau, 2010);
- Production Well No.7 Completion Report (Piteau, 2012);
- Production Well No. 8 Completion Report (Piteau, 2017);
- Letter dated August 22, 2016 Re: Update to Hydrogeological Assessment for White Rock Water Supply (Piteau, 2016);
- Arsenic in Groundwater in the Surrey-Langley Area (Wilson et al, 2008); and
- Surrey Ground Water Supply Study – Phase 1 Report (Gartner Lee Limited, 1999).

Existing studies/plans that have been prepared for the CoWR and can be integrated with groundwater management include the following:

- 2017 Water System Master Plan Update, Final Report (KWL and Water Street Engineering Ltd., 2017);
- Technical memorandum Re: City of White Rock Water Conservation Plan (KWL, 2016);
- City of White Rock Official Community Plan (CoWR, 2017);
- White Rock Water System Water Sampling Plan (CoWR, 2016); and
- EPCOR White Rock Arsenic Water Treatment Conceptual Study (Stantec, 2009).

In addition, the following regulatory controls are currently used by the CoWR to manage water use:

- Minimum Stage 1 outdoor water restriction from May 1 to October 15, with implementation of Stage 2 to Stage 4 water restrictions as needed (https://www.whiterockcity.ca/EN/main/city/my-water/conservation-and-restrictions.html);
- Water Service Bylaw 2015 No. 2117 that mandates water metering and water invoicing based on standard rates and excess consumption.

2 Water Supply System

2.1 Existing Well Network

The existing well network includes seven pumping wells located at four different sites as shown in Figure 2-1. The Oxford location includes Well No.1, Well No. 2, Well No. 3, and Well No. 8. The Merklin site includes Well No. 6 and Well No. 7. Well No. 4 is located at High Street, while Well No. 5 is located at Buena Vista Ave. The use of Well No. 5 for production purposes was discontinued in January 2017. There are no dedicated monitoring wells within the CoWR well network.

Well construction details are provided in Appendix 2. Well construction details are compiled from available borehole logs and well construction information provided by the CoWR. Wells are located approximately up to 1,400 m from the coastline at elevations of approximately 85 to 110 metres above sea level (masl) with drilling depths ranging from 98 to 146 metres below ground surface (mbgs).

The CoWR is in the processes of licencing a total of seven wells (i.e. all wells except for Well No. 5).

2.2 Groundwater Withdrawals

Monitoring equipment with connection to SCADA communications has been installed at all wells, except Well No. 4, to record groundwater use. Future monitoring upgrades to Well No. 4 are currently planned so as to provide measurements of groundwater withdrawals. Groundwater withdrawals are determined based on hourly pumping rate data summed to provide daily flow rates.

Daily flow rates from 2014 to 2016 (complete datasets) were reviewed to determine average withdrawals and the proportional use of each well on a monthly basis. A visual review of the hourly water level measurements was conducted to determine outliers prior to processing. Well No. 4 is used seasonally between May to August. For the purpose of this study, annual volumes for Well No. 4 were estimated using 2014 data and assumed to be evenly distributed between the four months of use with the same yearly operation.

Monthly groundwater withdrawals are shown in Figure A. Monthly groundwater withdrawals were generally similar from September to February for the time periods reviewed. However, monthly groundwater use was typically higher from March to August in 2015 and 2016 compared to 2014. A longer time period would need to be considered to more definitively determine temporal trends in groundwater use.

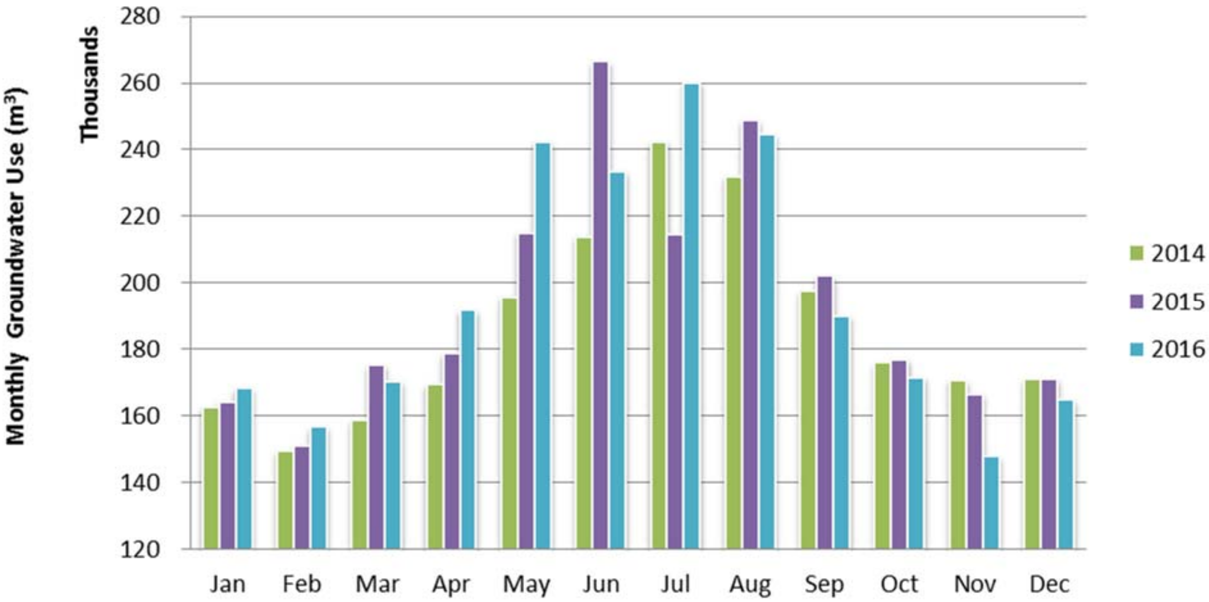
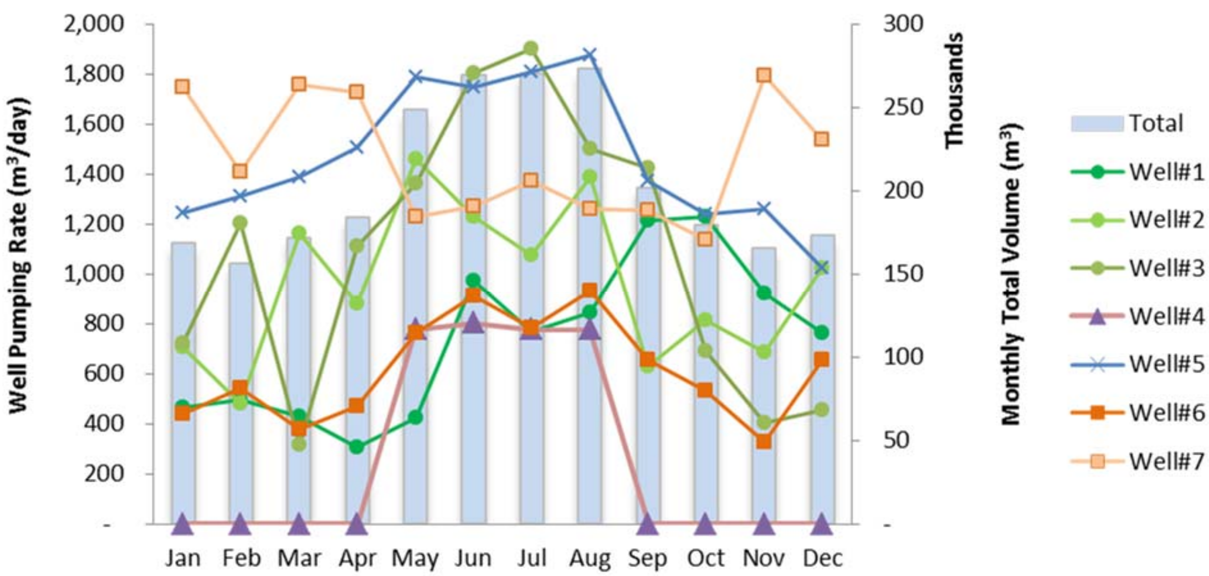


Figure A Average Monthly Groundwater Withdrawals (2014-2016)

Average monthly total volumes and well volumes are summarized in Figure B. Monthly groundwater extractions are typically below 200,000 m^3 but increase to about 260,000 m^3 to meet seasonal demands from May to August. The increase in demand is primarily attributed to lawn and garden watering (KWL, 2017). Average annual groundwater extraction is approximately 2.5 million m^3. Average daily pumping rates typically range from 400 to 1,800 m^3/day, but fluctuate during the year for each well.



Note: Wells colour-coded to reflect location. Oxford wellfield indicated in green, Merklin wellfield in orange.

Figure B Average Monthly Groundwater Withdrawals and Pumping Rates (2014-2016)

Average proportional yearly well use is shown in Figure C. Well No. 5 and Well No. 7 have the highest use at 22% each, followed by Well No. 2 and Well No. 3 at about 15% each, Well No. 1 at 11%, Well No. 6 at 9%, and lastly Well No. 4 at 4%. Well No. 5 has been taken off-line and Well No. 8 has been installed as a replacement well at the Oxford site.

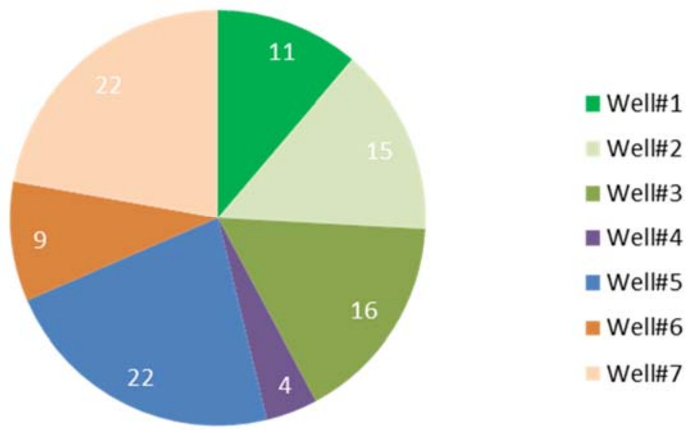


Figure C Average Yearly Proportional Well Use (2014-2016)

2.3 Groundwater Quality

Groundwater quality sampling for laboratory analysis is conducted every three months at the CoWR wells by CoWR staff. A detailed geochemical evaluation of groundwater quality parameters was beyond the scope of this report. The groundwater quality discussion herein focuses on concentrations of arsenic and manganese recognizing that these are above or near their respective Canadian Drinking Water (DW) Guidelines. Chloride concentrations were also considered given that the Sunnyside Aquifer includes a coastline setting. In 2010, under private ownership, E-coli was detected in the water supply system, triggering a 12-day boil water advisory issued by the Fraser Health Authority. It is understood that the microbial infection was isolated to one of the reservoirs at the Merklin Site and was not attributed to the groundwater itself.

Arsenic and manganese analytical results for groundwater samples collected at the CoWR wells from March 2015 to September 2017 are shown in Figure D and Figure E, respectively. Arsenic concentrations exceeded the DW guideline of 0.01 mg/L at Well No. 6 in 2016. The arsenic DW guideline is based on the maximum allowable concentration (MAC) protective of human-health. The highest concentrations of arsenic occur at wells with the deepest screens (Well No. 6, Well No. 7, and Well No. 5), which are generally installed 10 metres below the other wells. This suggests that arsenic concentrations may increase in the aquifer with depth.

A study on arsenic in groundwater in the Surrey-Langley area has been completed by the University of British Columbia (Wilson et al, 2008) for the Fraser Health Authority and the Ministry of Environment and Climate Change (formerly Ministry of Environment) to provide a greater understanding of the extent, concentrations and possible sources of arsenic in drinking water at private domestic wells. The study area included White Rock, but no groundwater samples were collected from wells screened in the Sunnyside Aquifer. In the Wilson et al (2008) study, a statistically significant relationship between arsenic and well depth was noted, with deeper wells having higher arsenic levels. The source of arsenic was associated with marine and glaciomarine surficial materials (Wilson et al., 2008).

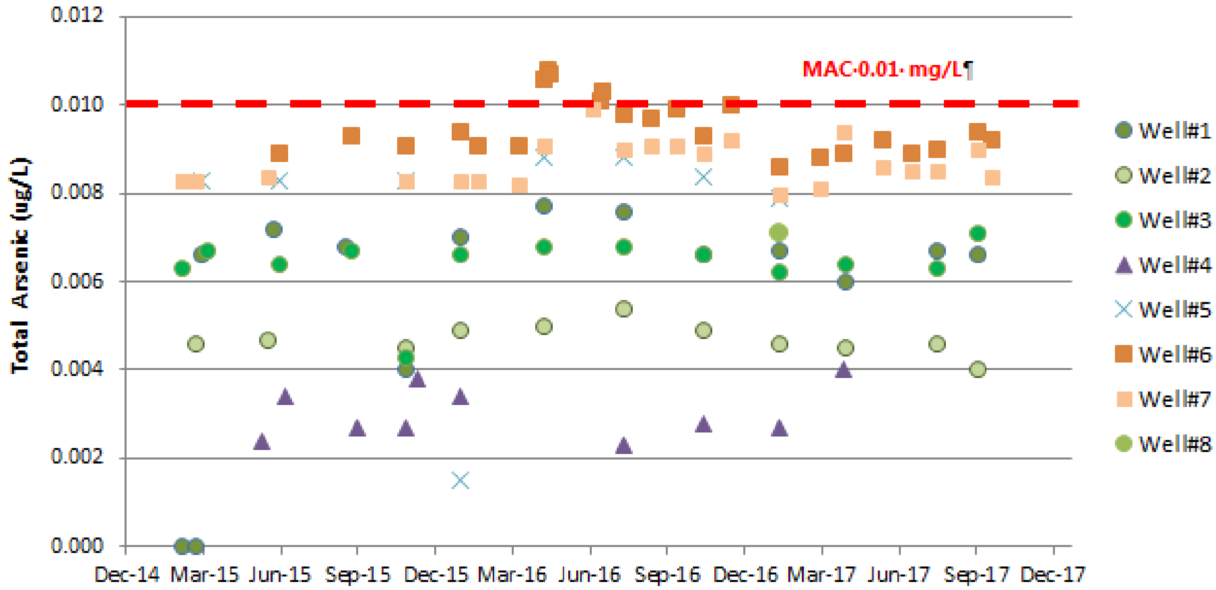


Figure D Total Arsenic Concentration at Wells (2015-2017)

Elevated concentrations of manganese relative to its DW guideline of 0.05 mg/L occur more frequently, with no obviously discernible trend noted based on depth or the spatial distribution of wells. The manganese DW guideline is based on an aesthetic objective (OB), implying less, or no risk, to human health if elevated concentrations occur.

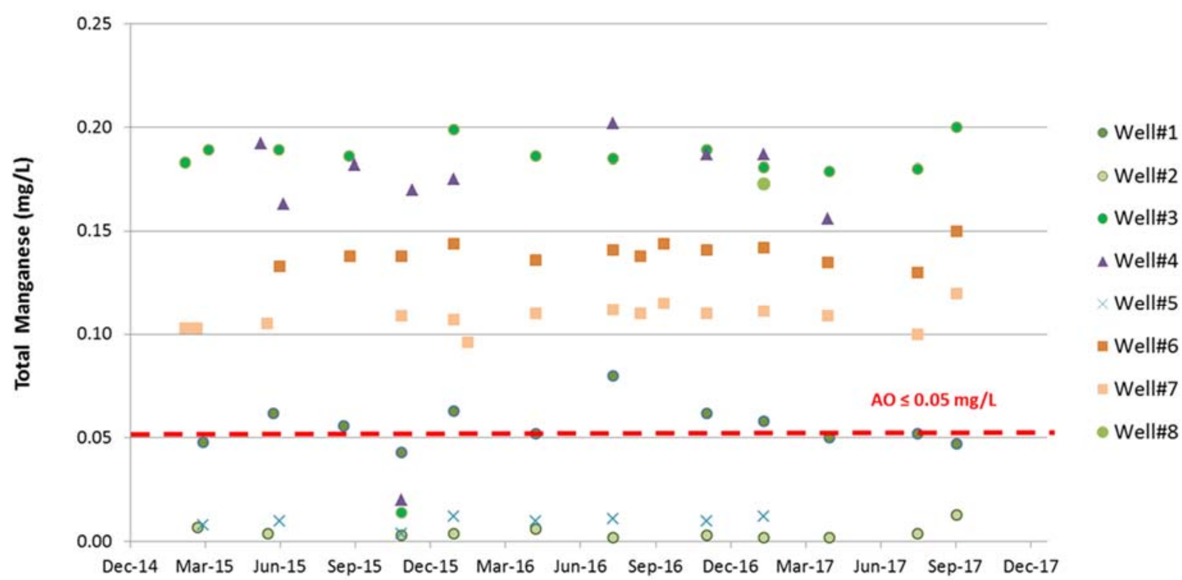


Figure E Total Manganese Concentration at Wells (2015-2017)

Chloride concentrations are below the DW of 250 mg/L at all wells. The average chloride concentration relative to distance from the coastline is presented in Figure F. This figure shows the highest chloride concentrations of 69 mg/L occur at MW No.5 which is also located the closest to the coastline (approximately 140 m). The remaining wells having groundwater with chloride concentrations below 25 mg/L. Chloride concentrations are much lower compared to typical saltwater concentrations of 19,400 mg/L (Pilson 2012) suggesting minimally impacts from saltwater intrusion.

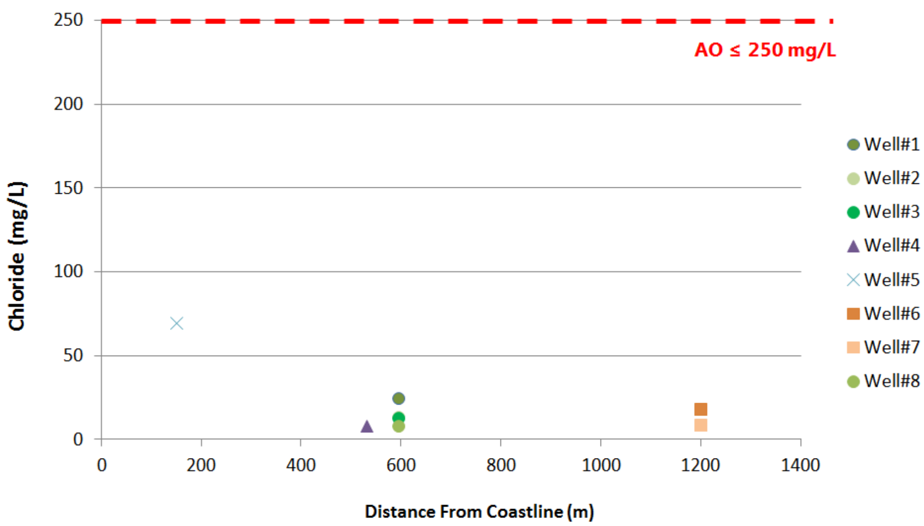


Figure F Average Chloride Concentration at Wells Relative to Coastline (2015-2017)

3 Climate Change

3.1 Current Climate

The CoWR is located within the Coastal Douglas Fir biogeoclimatic zone. The climate is generally characterized by mild winters. Climate conditions are strongly influenced by the Pacific Ocean with some orographic influences from Vancouver Island and the Olympic islands (cfcg.forestry.ubc.ca). Observed climate conditions for the CoWR are based on climate normals from 1981–2010 from the White Rock STP climate station (WMO ID 1108914), which is located in southeast White Rock at an elevation of 13 masl.

Monthly normals for temperature and precipitation are shown in Figure G. Daily average temperatures range from 3.8°C in December to 17.4 °C in August, with an annual average of 10.6 °C. Annual precipitation is about 1,100 mm, mostly in the form of rainfall. Snowfall can occur primarily between December to February, but only accounts for approximately 30 mm of annual precipitation. Approximately 50% of the annual precipitation occurs during the months of October to January, with November being the wettest month. Precipitation is lowest in July, August, and September, with monthly values near 40 mm.

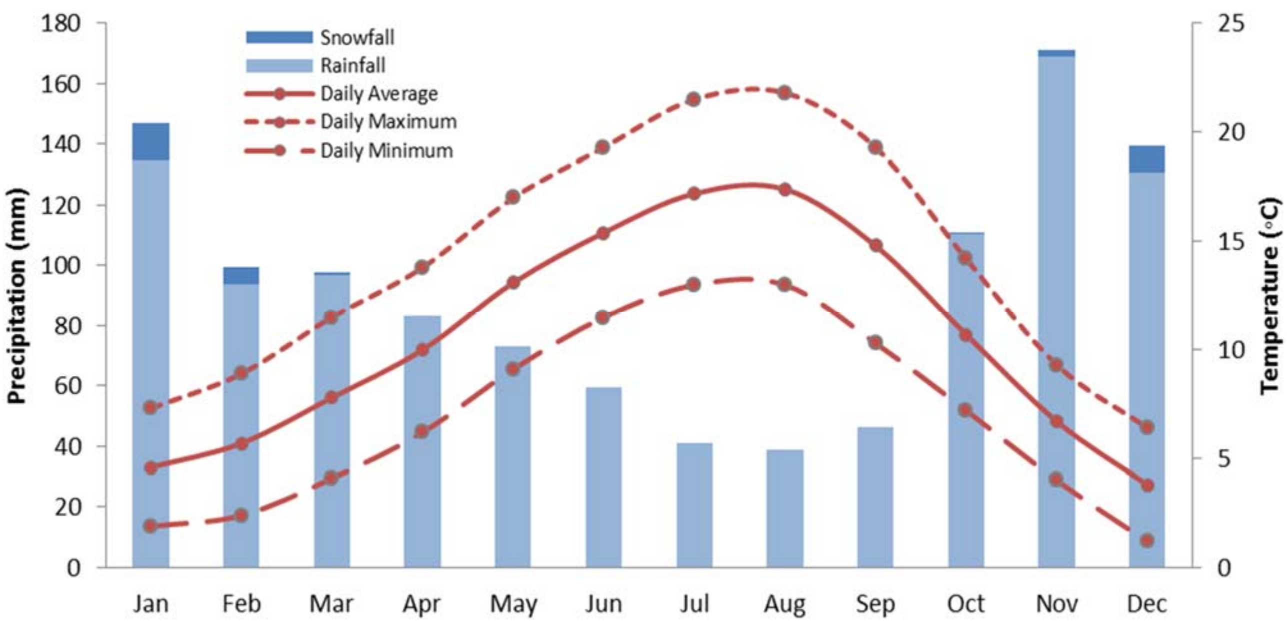


Figure G Temperature and Climate 1981-2010 Normals for White Rock STP (WMO ID 1108914)

3.2 Projected Climate

3.2.1 Approach

ClimateBC (version 5.5) was used to obtain projected climate in the vicinity of the White Rock STP climate station. This program provides downscaled output from three global climate models (GCMs) (CanESM2, CNRM-CM5, HadGEM2-ES) at a spatial resolution of 800 m x 800 m. The Representative Concentration Pathway (RCP) 8.5 emission scenario was selected for this study as this emission scenario represents "business as usual" for the remainder of the century. Consideration of this worst-case scenario is consistent with the planning approach used in the region and is considered prudent until global mitigation actions can align with commitments in the COP21 Paris Agreement (Metro Vancouver 2016).

Reference periods include baseline (1961-1990), the 2025s (2011-2040), 2055s (2041-2070), and the 2085s (2071-2100). Absolute changes in temperature and relative changes in precipitation between the baseline period and future time horizons were used to determine shift factors from the GCMs. To account for any GCM model bias, shift factors were applied to normals (1961-1990 for precipitation, 1971-2000 for temperature) for White Rock STP to project future climate conditions.

3.2.2 Results

Projected temperature and precipitation results in the vicinity of the White Rock STP climate station are discussed in this section. Projected monthly temperatures relative to current conditions are shown in Figure G. Monthly temperatures are projected to increase for all three future time periods. The current average annual temperature of 10.6 °C could increase to 12.4 °C in the 2025s, 14.2 °C in the 2055s, and 16.4°C in the 2085s. Changes in temperature (absolute °C) from baseline relative to the 2025s are shown in Figure H. This figure shows the greatest change in temperature is projected from April to August with increases of 2.3°C to 3.3°C.

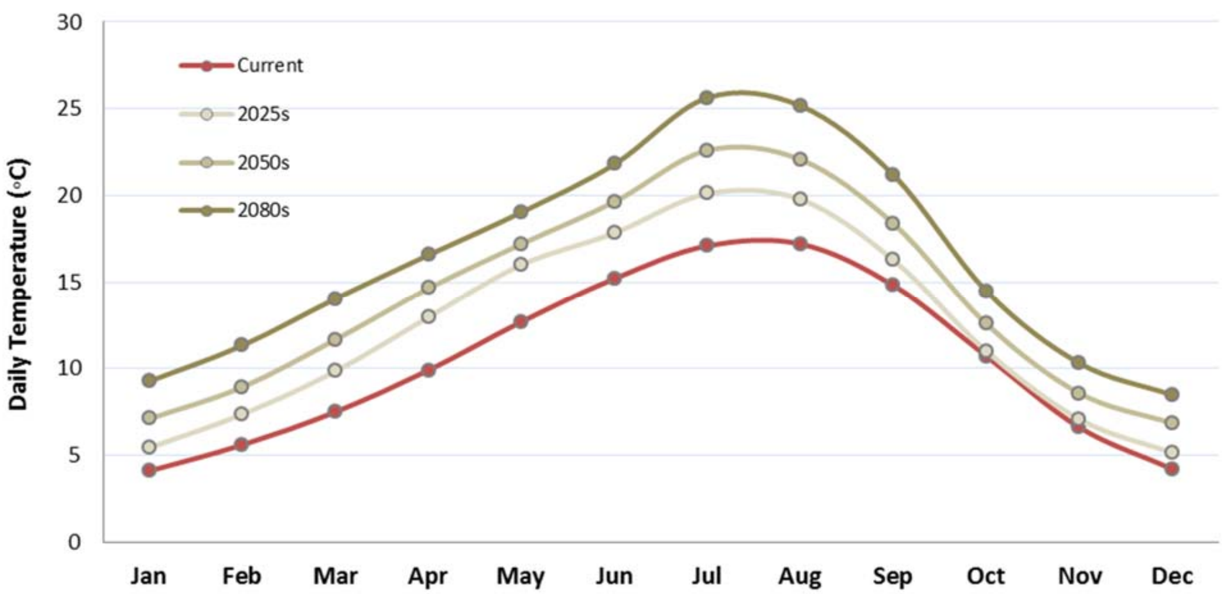


Figure H Current Temperatures (1981-2010 Normals) and Future Projections

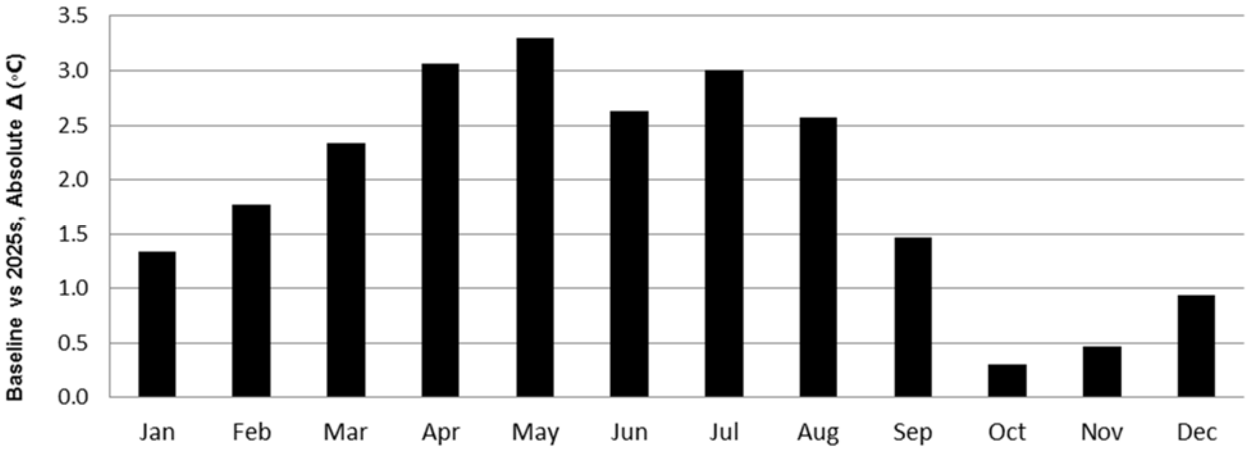


Figure I Absolute Differences in Temperature between Baseline and 2025s

Projected monthly precipitation relative to current conditions is shown in Figure J. Annual precipitation is projected to increase for all three future time periods relative to current conditions. The current annual precipitation of 1,108 mm is similar to the 1,100 mm in the 2025s and 1,140 mm in the 2055s and 2085s. Figure J shows monthly precipitation increases in the fall and winter months by up to 20 mm and decreases in the summer months by up to 30 mm. Changes in precipitation (relative %) from baseline relative to the 2025s are shown in Figure K. This figure shows the greatest increase in precipitation occurs in September and October while the greatest decrease occurs during the summer months (June, July, August).

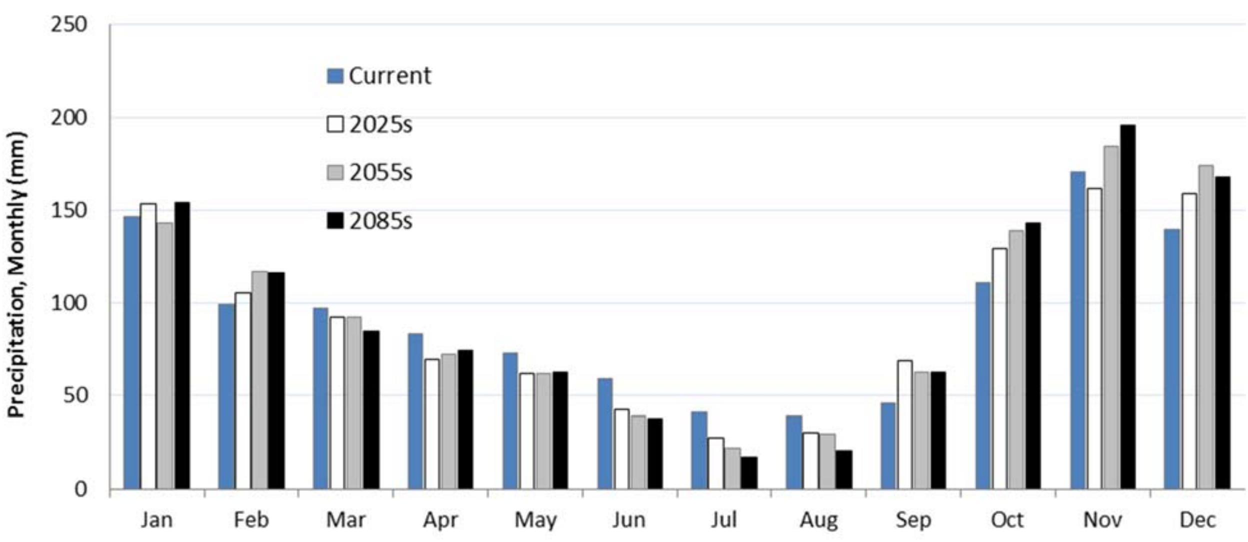


Figure J Current Precipitation (1981-2010 Normals) and Future Projections

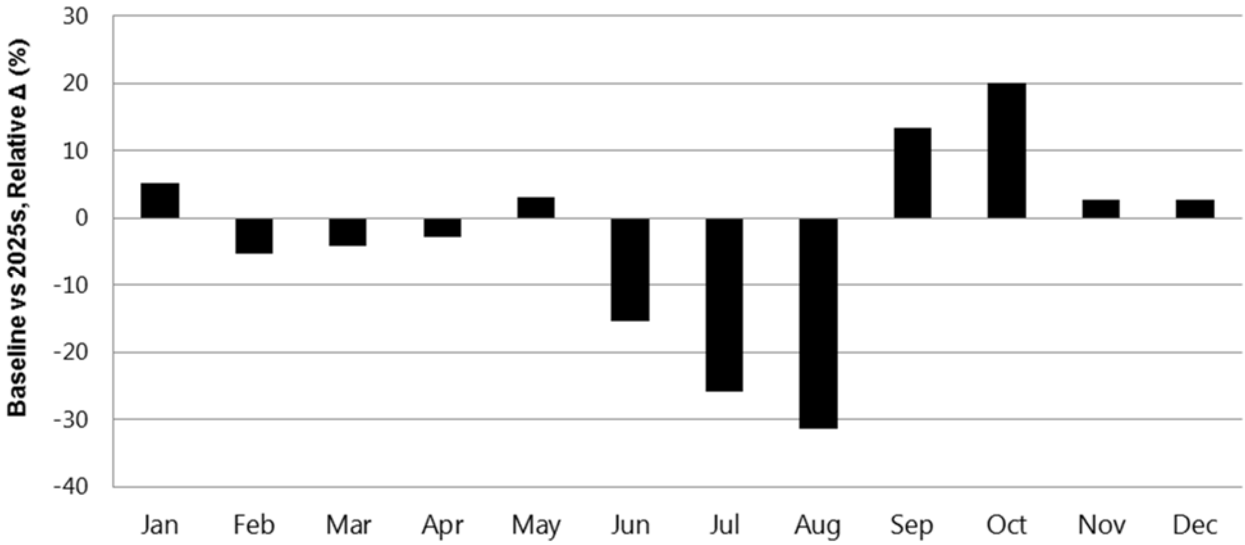


Figure K Relative Differences in Precipitation between Baseline and 2025s

Based on the above, climate conditions in White Rock are projected to get warmer and wetter on an annual basis. However, warmer and dryer conditions are projected for the summer months. With respect to the CoWR water supply system, this means there is potential for greater seasonal water demand because of more water use for watering lawns and gardens. The impact of climate change on groundwater recharge (which would impact groundwater availability) is anticipated to be minimal given that yearly changes in precipitation are not significant. A study of climate change impacts on the hydrologic cycle would provide a more accurate estimate of any changes to recharge.

3.2.3 Uncertainty

There are inherent limitations in representing complex climate processes in a GCM model. The current spatial resolution of GCMs and downscaling limitations may affect the accuracy of results. Downscaled GCM model bias was evaluated by comparing baseline data from ClimateBC to normals for the White Rock STP. Temperature normals for the baseline period were not available from the White Rock STP; therefore, a direct comparison was not possible. Monthly precipitation is reasonably reproduced based on relative differences of less than 20%. Shift factors have been used for the climate change projection to account for bias in downscaled GCM results.

4 Conceptual Model Development

A conceptual site model (CSM) provides a simplified, three-dimensional understanding of the essential features of the physical hydrogeological system and its hydraulic behaviour that forms the basis of the numerical model. This includes an understanding of the physical setting, including geological and hydrogeological framework, local water users, and land use.

4.1 Topography and Drainage

The study area is located within the Fraser Lowland and includes the South Surrey Uplands area surrounded by the sea and flat-bottomed valleys as shown in Figure 4-1. The South Surrey Uplands consists of unconsolidated deposits with rolling, hummocky surfaces ranging in elevation from approximately 10 to 117 metres above sea level (masl). The lower Nicomekl River-Serpentine River valley and the Campbell Creek valley are located along the northern and south-eastern extents of the Study Area in areas of relatively low relief.

Several creeks are located within the CoWR boundary, namely Coldicutt, Collingwood, Duprez, and Anderson. All creeks have continuous flow with the exception Anderson Creek, which has intermittent flows (CoWR Data Protal). Prominent creeks that drain the uplands area outside of the CoWR include Chantrell Creek, Elgin Creek, Old Logging Ditch, and Fergus Creek. No publically available discharge data and limited flow regime information are available for these creeks (FISS accessed on October 4, 2017). Many of the creeks have culvert installations with summer low flows identified as a potential constraint to fish habitat enhancement.

Major rivers within the study area include the Nicomekl River and Campbell River. The Nicomekl River extends from the hills east of Langley to Mud Bay, incorporating many tributaries and irrigation ditches. Campbell River passes through Langley and Surrey, entering Semiahmoo Bay at Semiahmoo Indian Reserve. The mouth and lower reaches of these rivers may be subject to tidal influences. Tide gates are known to exist along the lower reaches of the Nicomekl River, which may limit the upstream movement of saltwater during low summer flows (FISS accessed on October 4, 2017).

4.2 Geology

The Fraser Lowland has a very complex geological history involving several major glaciations separated by nonglacial intervals (Holland, 1976). The Fraser Lowland is underlain by a thick blanket of glacial sediments that mask bedrock topography in most places. Bedrock was encountered in only one well record (WTN 19876) within the Study Area at a depth of 297 m below ground surface (approx. -290 masl).

The Geological Survey of Canada surficial geology mapping for New Westminster (Map 1484A) (Figure 4-2) and geological cross-sections prepared using lithology described in well records were used to develop an understanding of subsurface conditions. Representative cross-sections are provided in Figure L with stratigraphic units discussed in the following sections.

4.2.1 Semiahmoo Drift

Some of the oldest surficial deposits in the Study Area originate from the Semiahmoo glaciation, believed to be similar in complexity and duration as the more recent Fraser glaciation (notes for GSC Map 1484A). Deposits from the Semiahmoo glaciation have been mapped along steep slopes in the western and southern extents of the study area (unit Pvf shown on Figure 4-2). Semiahmoo Drift consists of till, gravel, sand, and glaciomarine clay and silt deposited on the glacially depressed lowland surface. These sediments are covered by younger glacial sediments. The surface of this unit has been eroded during the interglacial period (Olympia interglaciation) separating the Semiahmoo glaciation and the most recent Fraser glaciation.

Within the Study Area, the Semiahmoo Drift is conceptualized as three separate units. The deepest unit consists of blue clay based on a limited number of wells that extend into this unit. The middle unit consists of sand and gravels approximated to be up to 25 m thick and generally thicker along the western and southern boundary of the study area. The upper unit of the Semiahmoo Drift consists predominantly of till and clay material up to 55 m thick within the South Surrey Uplands. In some areas, the Semiahmoo till unit is interpreted to be absent, creating hydraulic connection between the overlying Quadra Sand unit and the Semiahmoo sand and gravel unit.

4.2.2 Quadra Sand

The Semiahmoo Drift is overlain by a unit of sand, silt, and gravel referred to as the Quadra Sand. Quadra Sand was deposited by meltwater streams in front of glaciers advancing down what is now the Salish Sea during the early, or advance, phase of the Fraser glaciation about 30,000 to 20,000 years ago. Quadra Sand was subsequently overridden and cannibalized by glaciers, and the glacially eroded remnants of the unit were mantled by Vashon Drift. Quadra Sand outcrops have been mapped along steep slopes in the western and southern extents of the study area (unit Pva shown on Figure 4-2).

The Quadra Sand unit is conceptualized to be up to 30 m thick in the area with its surface generally encountered at about 60 to 80 masl within the South Surrey Uplands area. It is interpreted to consist of fine sand, silty sand, and sand with clay based on available lithology.

4.2.3 Vashon Till/Capilano Sediments

The last ice sheet in BC disappeared between about 16,000 and 11,000 years ago. As the Salish Sea became ice-free, the land surface in Fraser Lowlands was still depressed by the weight of the remaining ice, and it consequently was flooded by the sea. The sea level was up to 200 metres higher than it is today. Sediments deposited on this flooded surface as the deglaciation progressed are termed Capilano Sediments.

Capilano Sediments are the dominant surficial geologic unit in the Study Area (Figure 4-2, predominantly Cd with some Cb and Ca). They include gravel, sand, clayey silt, marine shells, and stones dropped from melting icebergs. Capilano Sediments are typically found above Vashon Drift and are inferred to be mostly 5 to 10 m thick in the study area. However, this unit is absent in some areas based on till outcrops that have been mapped, particularly along the northern, western, and southern extents of the study area as shown in Figure 4-2 (Vashon Drift, Va and Vb). The Vashon till unit is inferred to be aerially extensive in the South Surrey Uplands and typically 5 to 10 m thick in the western half of the study area. The thickness of this unit increases to upwards of 35 m in the eastern half of the study area but thins towards the north and east.

As deglaciation progressed, isostatic rebound occurred accompanied by a rapid fall in sea level. The Salish Sea surface reached its present level about 12,000 years ago, at which time Capilano Sediments and Vashon Drift were subject to erosion. Since then, modern (Salish, shown as SAb in Figure 4-2) sediments have accumulated on floodplains of present-day streams, including the floodplains of the Nicomekl and Serpentine Rivers located in the northern extents of the study area.

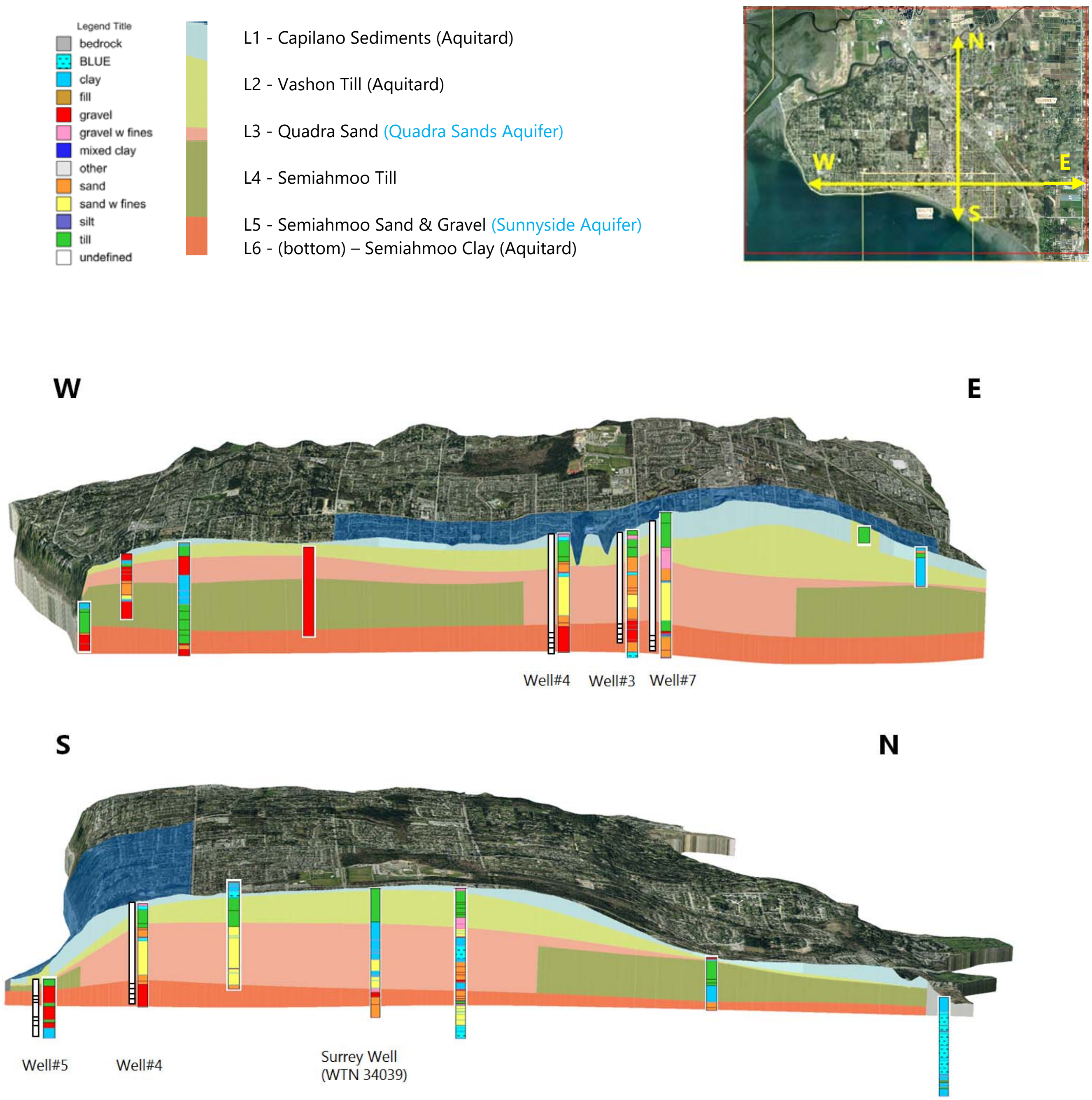


Figure L Representative Cross-Sections of the Study Area

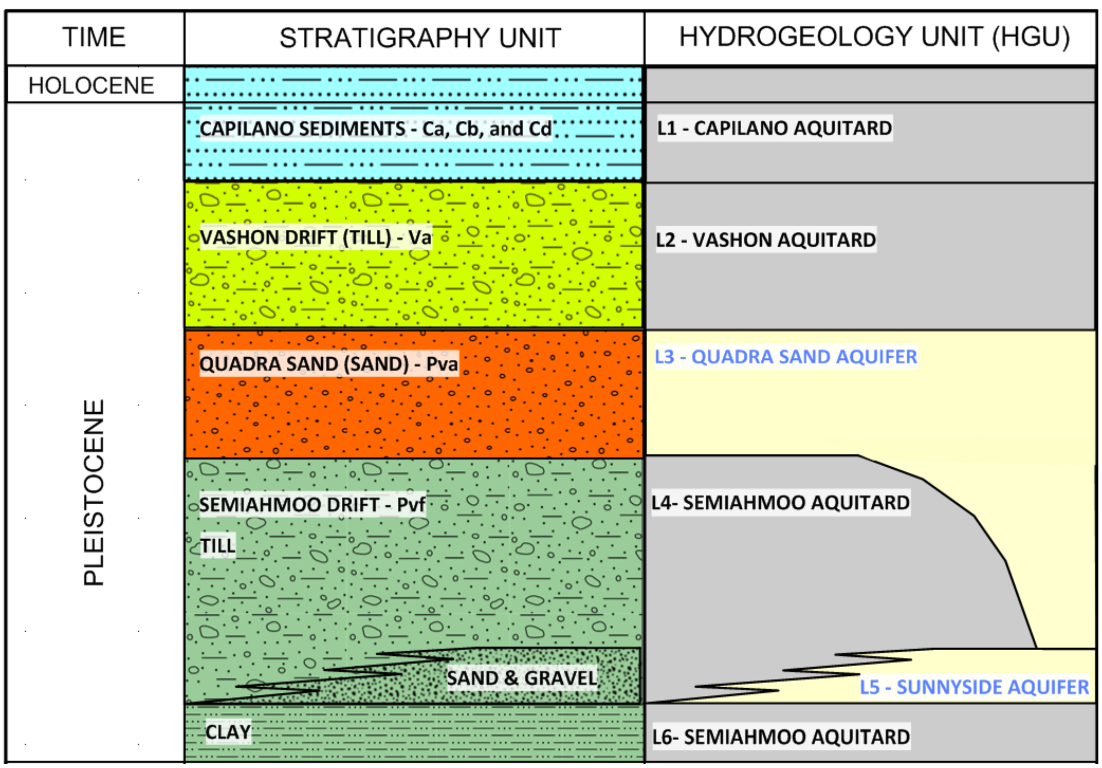
4.3 Hydrogeology

4.3.1 Hydrostratigraphy

The hydrostratigraphic column for the study area illustrating the age, stratigraphy, and corresponding Hydrostratighrapic Unit (HGU) is presented in Figure M. The hydrostratigraphic column was prepared with consideration of the geologic history of the region (Section 4.2). HGU units assigned to permeable deposits have been designated as aquifers while non-permeable deposits are inferred to be aquitards.

As shown in Figure M, the Sunnyside Aquifer is interpreted as the Semiahmoo Drift Sand & Gravel unit confined by the overlying Semiahmoo Drift Till. Where the Semiahmoo Drift Till is interpreted to be discontinuous, the Sunnyside Aquifer is possibly connected to the Quadra Sand Aquifer. The Quadra Sand unit is interpreted to contain permeable sediments and act as an aquifer; however, this unit has been noted as dry in some well records and could have limited saturated thickness given that the majority of wells are advanced through this unit and installed at greater depths.

The till and clay units of the Semiahmoo Drift are inferred to have low permeability materials that act as aquitards. Capilano Sediments and Vashon Drift overlie the entire system and are also interpreted to act as aquitards, inherently restricting the flow of groundwater through these units.



Note: Stratigraphy unit corresponds to Geological Survey of Canada Map 1484A terminology

Figure M Hydrostratigraphic Column

4.3.2 Aquifer Extents

The Sunnyside Aquifer extents used in this study are shown in Figure 4-3. The southern and western boundaries follow the coastline along Semiahmoo Bay and Boundary Bay, respectively. The northern boundary follows surficial geology mapping of Salish sediments along the Nicomekl River. Based on the available lithology information, the southeastern boundary is interpreted to extend to Campbell River. The eastern boundary of the aquifer coincides where geological discontinuities were originally interpreted based on lithology from well records; however, groundwater model calibration suggests the Sunnyside Aquifer is hydraulically connected to aquifer systems in the east.

There are several aquifers that have been identified through Provincial aquifer mapping efforts in the Surrey Uplands area as shown in Figure 4-3. The provincial mapping extents for the Sunnyside Aquifer (Aquifer No. 57) are shown for comparison purposes to the aquifer extents used in this Study. Details of the aquifers immediately adjacent to the east (Aquifer No. 56, 55, 54, and 53) and north (Aquifer No. 58) are summarized in Table B.

From Table B, mapped aquifers range in areal extent from 1.7 to 216 km^2. Aquifer material consists of sands and gravels. These unconsolidated aquifers have been classified as having moderate to high productivity, low vulnerability, and low to moderate demand. Both the Sunnyside Aquifer and Aquifer No. 56 are found in the Surrey Uplands while Aquifer No. 53 and No. 58 are located in the lowland areas. Regional studies are required to provide a better understanding of the possible hydraulic connections between these groundwater systems.

4.3.3 Groundwater Flow

Historic water levels from the WELLS database were used to determine groundwater flow in the Sunnyside Aquifer. Water levels from wells screened below the interpreted Semiahmoo Sand and Gravel unit were used. Water level and pumping data provided by the CoWR were also reviewed to determine early measurements (2012) for Well No. 1 and Well No. 2 during non-pumping conditions to augment the dataset.

Historic water levels were contoured in Surfer® using kriging techniques to characterize groundwater flow direction as a result of the hydraulic head contours (Figure 4-4). Hydraulic heads are inferred at approximately 10 masl along the eastern boundary of the aquifer. Groundwater is interpreted to flow in a general westerly direction with a component of flow to the south towards the CoWR and eventually discharging primarily to Semiahmoo Bay. Because the year and season in which water levels were recorded varies from well to well and historic pumping schedules were unavailable, there is uncertainty in the historic hydraulic head interpretation. However, the general trend for groundwater flow and direction seems reasonable.

The hydraulic gradients (metre of hydraulic head change over distance) across White Rock range from 0.002 to 0.008 m /m from WTN 81630 to Well No. 2 and WTN 16126 to Well No. 2, respectively, with an average of 0.005 m/m. Pumping tests have been completed at Well No. 7 (Piteau 2012) and Well No. 8 (Piteau 2017) to provide estimates of hydraulic conductivity for the Sunnyside Aquifer ranging from $9x10^{-4}$ to $3x10^{-2}$ m/s with a geometric mean $3x10^{-3}$ m/s. Assuming a porosity of 0.3, groundwater velocity is estimated to range from 0.6 to 70 m/day using minimum and maximum values of hydraulic conductivity and gradient values, or 4.2 m/day using geometric mean values for K and the average gradient.

Table B Regional Aquifer Mapping Details Summary

Aquifer No.	Aquifer Name	Aquifer Materials	Size (km^2)	Productivity	Demand	Vulnerability	Aquifer Classification	Type of Water Use	Quality Concerns	Quantity Concerns
53	Hazelmere Valley	Sand and Gravel	18.3	Moderate	Low	Low	IIIC	Multiple	-	-
56	NE of White Rock	Sand and Gravel	1.7	Moderate	Moderate	Low	IIC	Multiple	-	Isolated
57	Sunnyside	Sand and Gravel	40.2	High	Moderate	Low	IIC	Multiple	-	-
58	Nicomekl-Serpentine	Sand and Gravel	216	Moderate	Moderate	Low	IIC	Multiple	Regional	None

Note: Descriptors related to well yield (i.e. low, moderate, high), depth to water (shallow, moderately shallow, moderately deep, deep), aquifer productivity (i.e. low, moderate, high), aquifer vulnerability (i.e. low, moderate, high), and aquifer water demand (i.e. low, moderate, high) are based on the Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater (Berardinucci and Ronneseth 2002).

4.3.4 Recharge and Discharge

Recharge to the Sunnyside Aquifer has been conceptualized as occurring from a combination of infiltration in the South Surrey Uplands and surrounding lowlands as well as lateral inflow from the east. Early modelling results of the first iteration of the conceptual model (recharge only by infiltration) indicated the possibility for lateral inflow from the east and review of geological cross-sections supported this conceptual model update.

An infiltration rate of 258 mm/year has been estimated for the South Surrey Uplands based on land use, slope, and soil characteristics (Gartner Lee, 1999). Assuming an annual precipitation of 1,100 mm from the White Rock STP climate station (Section 3.1), this corresponds to approximately 23% of precipitation infiltrating into the subsurface. Recharge rates in the order of 20% of precipitation are typical; however, they could possibly be lower for the Sunnyside Aquifer given overlying materials that include Capilano Sediments and Vashon Drift at the surface. The Capilano Sediments include localized areas of more permeable materials (e.g. Ca and Cb) that may promote vertical movement of water; however, these materials are interpreted to be underlain by till.

The predominant south-westerly groundwater flow direction through the Sunnyside Aquifer implies hydraulic connection (i.e. lateral aquifer recharge) from aquifer systems to the east (Figures 4-3 and 4-4). The water level at WTN 74126 (located approximately 4 km east of the Sunnyside Aquifer) was used to estimate lateral aquifer inflow conditions from the east assuming hydraulic connection based on geological cross-section review.

Groundwater from the Sunnyside Aquifer is interpreted to primarily discharge to Semiahmoo Bay. The floodplain deposits within the Nicomekl/Serpentine River to the north are inferred as geologic discontinuities that impede groundwater flow based on well lithology. Lithology interpretations suggest a greater potential for connection with the Campbell River. Groundwater discharge could also occur along smaller perennial streams (continuous flow conditions). Licensed springs (No. C119211, C046684) along the northern slope of the Surrey Uplands indicate potential discharge areas for groundwater. Flow measurements or stream gauge data are not available to characterize surface-groundwater interactions.

4.4 Local Water Users

4.4.1 Registered Wells

Licensing groundwater for non-domestic use was recently regulated under the *Water Sustainability Act* (SBC 2014, Chapter 15); however, limited information for licensed wells is publically available at this time. Alternatively, registered water well records were reviewed to provide an indication of local water use. The locations of existing registered wells are shown on Figure 4-5. Most wells were constructed prior to regulation of well construction standards in 2005 (Groundwater Protection Regulation BC Reg 39/2016).

Based on a review of the 186 registered water well records in the study area, the majority of wells (52%) have an unknown use. Domestic use accounts for 43% of the registered wells. Five non-domestic and non-municipal wells are within the study area. Well construction details for these five wells are summarized in Table C.

Two of the wells registered as water supply wells (WTN 34039 and 88340) are owned by Surrey and are located north of the CoWR as shown in Figure 4-5. A high yield of 32 L/s (2,765 m^3/day; 520 USGPM) is

Table C Well Construction Details of Non-Domestic Wells within the Study Area

WTN	Method	Date	Easting UTM	Northing UTM	Ground Surface (masl)	Borehole Depth (mbgs)	Well Diameter (cm)	Water Depth (mbgs)	Well Yield (m^3/day)	Well Use	Comment
34039	Other	1976	513251	5432311	110.3	152.4	40.64	106.1	2,834	Water Supply System	City of Surrey
88340	Unknown	2006	511442	5432572	81.8	-	-	-	-	Water Supply System	City of Surrey
8792	Unknown	1950	508920	5431854	42.8	45.1	10.16	-	-	Irrigation	
3027	Drilled	1948	509714	5431164	76.3	24.4	10.16	22.9	59	Irrigation	
45419	Drilled	1980	510123	5431180	84.7	100.6	15.24	82.3	65	Irrigation	

Notes:
cm – centimetres
m – metres
masl – metres above sea level
mbgs – metres below ground surface
m^3/day – cubic metres per day
UTM – Universal Transverse Mercator (UTM), NAD83

reported for WTN 34039. Both wells are currently used in the summer months to augment flows in local creeks as necessary (per. communications with City of Surrey staff).

Three wells are registered for irrigation use. These wells are located outside the CoWR, within the southeast area of the Surrey Uplands. WTN 3027 is inferred to be screened within the upper Quadra Sands while the other two wells (WTN 8792 and 45419) are inferred to be screened within the Sunnyside Aquifer. Available yield estimates for WTN 45419 and WTN 3027 are approximately 0.7 L/s (60 m^3/day; 11 USGPM).

4.4.2 Surface Water Licensing

Surface water use in the study area generally occurs within the lowlands or along the perimeter slopes of the South Surrey uplands area (Figure 4-5). A total of 22 surface water licenses exist within the extents of the mapped Sunnyside Aquifer. Twelve licenses are active with details summarized in Table D. Points of surface water withdrawal are generally located along the northern portion of the mapped aquifer along April Creek, Chantrell Creek, Lark Pond, and Titman Creek. There are also licenses in the lowlands along Elgin Creek.

Table D Active Surface Water License Details within the Sunnyside Aquifer

Licence no.	Status	Stream Name	Quantity (L/s)	Purpose
C109576	Current	Chantrell Creek	n/a	Land improve: general
C107511	Current	Titman Creek	0.6	Stream storage: non-power
F021572	Current	Titman Creek	0.5	Stream storage: non-power
C112476	Current	Lark Pond	n/a	Land improve: general
C108649	Current	Chantrell Creek	n/a	Land improve: general
C107511	Current	Titman Creek	2.5	Lawn, fairway & garden
F021571	Current	Titman Creek	0.3	Lawn, fairway & garden
C107511	Current	Titman Creek	2.5	Lawn, fairway & garden
C109576	Current	Chantrell Creek	n/a	Land improve: general
C031827	Current	Chantrell Creek	0.05	Domestic
C102386	Current	April Creek	n/a	Land improve: general
C107511	Current	Titman Creek	0.6	Stream storage: non-power

4.5 Land Use

Land use planning for the City of Surrey (Surrey Official Community Plan 2013) and CoWR (City of White Rock Official Community Plan 2017) has been grouped into 10 categories as shown in Figure 4-6. Existing land use in the South Surrey Uplands has been designated primarily for urban development (urban/town centre, institutional and utility, residential, mixed employment, commercial land uses, and rural/suburban). Recreational land uses are shown in the western and eastern areas of the study area. Industrial land use is minimal and agricultural areas occur primarily in the surrounding lowlands. Within the CoWR, land use has primarily been designated for residential uses.

Based on the above, the majority of the land surface overlying the aquifer has been designated for urban development. Recharge to the aquifer may be influenced by components of the urban system (leakage from sewers, reduced recharge in areas covered by pavement and increased development density). Urban areas have a greater potential to restrict the downward movement of water.

Land use activities may pose a threat to groundwater quality as a result of spills, leaks, or surface application of possible contaminants (activities at industrial sites, application of salt during winter road maintenance, etc.). The presence of marine sediments and till above the Sunnyside Aquifer (Section 4.3) restricts the movement of contaminants originating at surface from infiltrating downwards into the Sunnyside Aquifer. As a result, the Sunnyside Aquifer is considered to have low vulnerability to groundwater pollution from surface hazards. This is consistent with Provincial mapping of the aquifer.

The Sunnyside Aquifer is also surrounded by agricultural land use in the lowlands. Intensification of agriculture activities is resulting in greater demands on groundwater and increasing the potential for contamination from fertilizer and pesticide applications (Council of Canadian Academies 2009). Given the potential for hydraulic connection of the Sunnyside aquifer to aquifers in the east, the management of agricultural lands and water resources in the lowlands is important to consider.

5 Well Protection Area

The well protection area is the area that should be managed and protected from potential contamination. To determine the well protection area, a groundwater model was constructed based on the conceptual understanding of the aquifer (Section 4). Calibration of the groundwater model was completed to ensure reasonable representation of the groundwater flow system. The calibrated model was then used to determine the well capture zone, the extents of which primarily define the well protection area.

An overview of the numerical groundwater model is included in this section. More detailed technical information on numerical model set-up, including calibration results and sensitivity analysis, is provided in Appendix 3. This section also defines the scenarios considered to evaluate future water availability and the migration of the saltwater/freshwater interface considering increased groundwater demand and the effects of climate change.

5.1 Numerical Modelling

Numerical models are effective tools to improve the understanding of the response of a complex aquifer system (i.e. change in hydraulic head) as a result of stresses to the system (i.e. groundwater extraction, reduction in recharge due to land use changes or climate change predictions, and/or sea level rise). A three-dimensional (3D) model which incorporates the sequence of aquifers and aquitards in the area is useful when it is necessary to understand complex interactions due to geological features and/or pumping activities (Jones and Mendoza, 2013). A 3D groundwater flow model was developed to assess the response of the Sunnyside Aquifer to current and future municipal groundwater extraction and climate change effects. A summary on the numerical model is provided below with technical details provided in Appendix 3.

The model was constructed and simulated using FEFLOW (Finite Element subsurface FLOW) Version 6.2 platform (DHI WASY 2013). FEFLOW uses the finite element analysis to solve the groundwater flow equation. The model was constructed to represent the six-layer hydrostratigraphy (Section 4.3.1) using five model layers. The bottom of the model represents the sixth HGU.

Steady-state calibration was conducted using water levels from the WELLS database and is generally interpreted to represent pre-development conditions. A limited transient calibration for the 2012 to 2017 groundwater use period based on dynamic groundwater monitoring data provided by the CoWR was conducted to confirm that water level trends were reasonably simulated given the model parameterization. Model calibration results reasonably represent observed heads, the conceptualized flow system, and water balance based on data limitations. Future data collection programs are required to refine the conceptual model and improve the basis for groundwater model construction. Sensitivity analysis results indicate that future data collection efforts should focus on recharge, the spatial distribution of hydraulic conductivity in the Sunnyside Aquifer, and developing a better understanding of the hydraulic connection with the aquifers in the east.

5.2 Scenario Development

The calibrated groundwater model was used to forecast conditions based on three scenarios, the CoWR pumping scenario, CoWR pumping scenario considering potential future effects of climate change, and cumulative effects of CoWR and City of Surrey pumping scenario considering potential future effects of climate change. A description of each scenario is provided below.

5.2.1 Scenario 1 - Baseline

Scenario 1 represents future groundwater use by the CoWR water supply system to 2045. Future groundwater use accounts for existing use, water losses, and use from future growth provided in KWL (2017).

Future Groundwater Use = Existing Use + Water Losses + Future Growth

Existing groundwater use is based on the current population (20,181) and floor space (72,500 m^2) for industrial, commercial, and institutional uses (collectively referred to as ICI). Existing water consumption is estimated at 195 L/person/day and ICI use at 13.9 L/m^2/day. Existing groundwater use to meet seasonal demand is estimated at 355,935 m^3/year. This results in a total of approximately 2.2 million m^3/year of existing groundwater use and is assumed to remain constant through to 2045.

Water losses of 236,520 m^3/year have been estimated under existing operations (KWL, 2017) and are assumed to be constant through to 2045.

Groundwater use to accommodate future growth is calculated as the higher range of projections for population (+7,348) and increases in in ICI floor space (+31,773 m^2) reported by Coriolis (2016). A water consumption rate of 140 L/person/day is used to define consumption from future population growth and applied assuming exponential growth at 1.09%. A rate of 5.5 L/m^2/day is used for additional ICI demand and assumed to occur at the beginning of the simulation period. Lower rates are consistent with previous water planning studies and have been applied to future growth to reflect new construction standards that include water efficient fixtures and appliances (KWL, 2017). Future seasonal use is calculated using a rate of 15.3 m^3/capita/year for population growth. ICI seasonal use was calculated at 18,718 m^3/year assuming a rate of 0.59 m^3/m^2/year. Seasonal use rates consider the proportional use of seasonal demand (peak summer day) between residential and ICI provided in KWL (2017).

Estimated yearly groundwater withdrawals to 2045 are shown in Figure N. Monthly groundwater withdrawals to show seasonal variations are provided in Figure O. The proportional use of each well on a monthly basis is provided in Figure P based on average withdrawals calculated from 2014 to 2016.

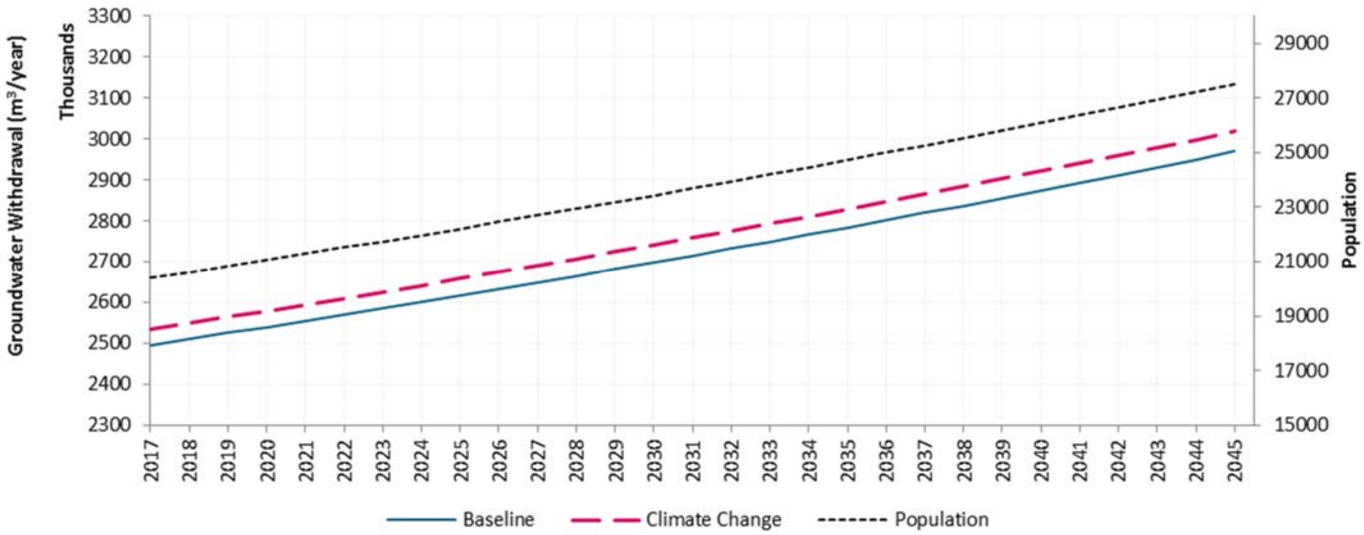


Figure N Projected Yearly Groundwater Withdrawals to 2045

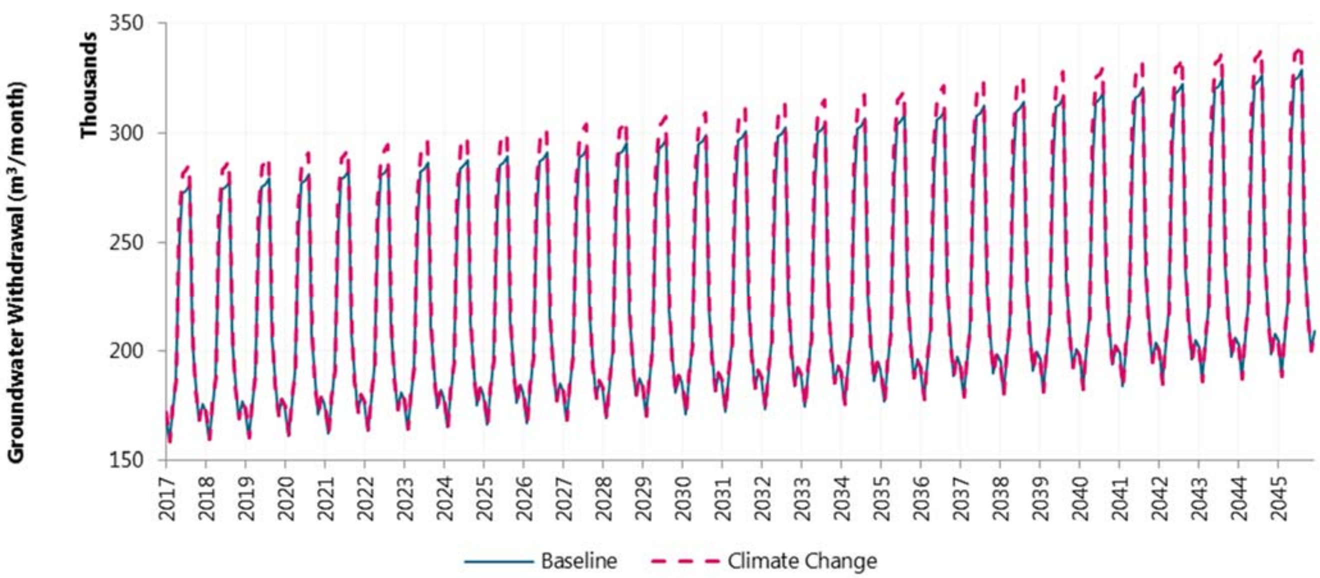


Figure O Projected Monthly Groundwater Withdrawals to 2045

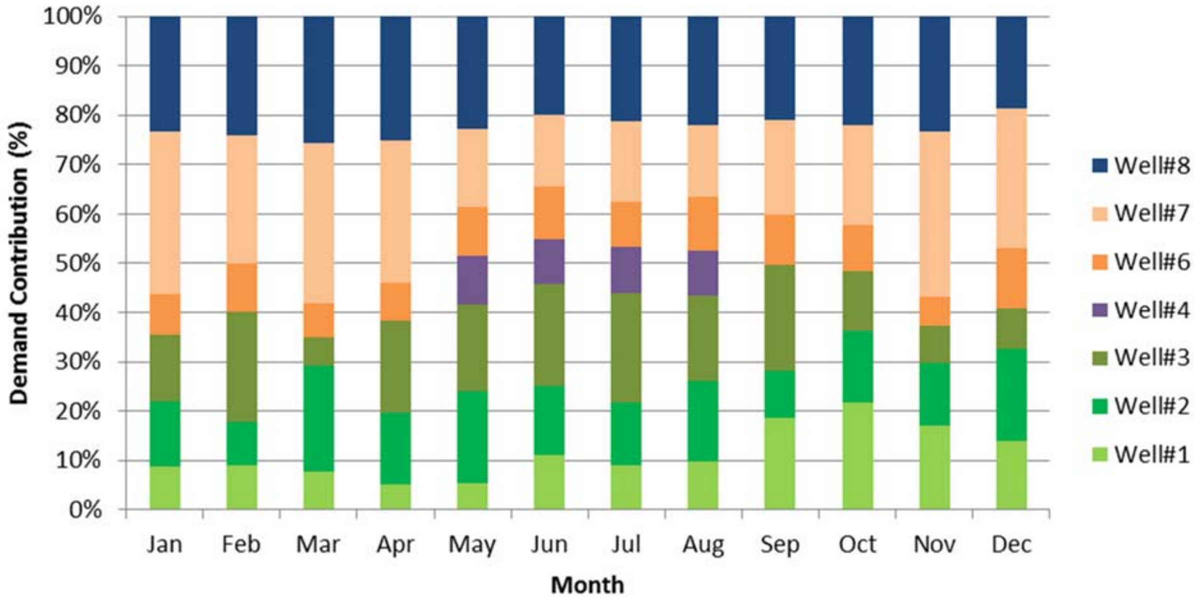


Figure P Average Monthly Proportional Well Use (2014-2016)

5.2.2 Scenario 2 – Climate Change

Scenario 2 represents future groundwater use by the CoWR water supply system to 2045 plus a 10% increase in seasonal use to be consistent with other water planning studies (KWL, 2017) to account for projected warmer and dryer conditions as a result of climate change (Section 3.2). Seasonal increases were applied from May to August. The project yearly and monthly groundwater withdrawals under the climate change scenario are shown in Figure N and Figure O, respectively. Scenario 2 also includes a sea level rise rate of 0.01 m/year based on Provincial climate change adaptation guidance (MOE, 2011), resulting in a predicted sea level increase of 0.28 m by 2045.

5.2.3 Scenario 3 – Climate Change & City of Surrey Pumping

The third scenario includes Scenario 2 plus future groundwater use planned by the City of Surrey. The City of Surrey has investigated the potential of developing a municipal groundwater supply source to reduce costs over the long-term and reduce reliance on the GVRD surface water supply system. The Sunnyside Aquifer has been identified as a potential source for municipal well field development (Gartner Lee, 1999). A groundwater exploration program in 2004/2005 identified the Fleetwood Sports & Leisure Centre located at 16555 Fraser Highway (Fleetwood) and the Sunnyside Acres Park located at 24 Ave and 146 St (Sunnyside) as viable groundwater development options. Development of the Fleetwood site was not considered further since it is outside of the Study Area.

Two groundwater wells (Sunnyside#2 and Sunnyside#3) have been constructed at the Sunnyside site (Figure 5-1). Future groundwater extraction from these wells is planned to commence in 2023. Extraction rates are based on estimated yields of 3,974 m^3/day and 2,419 m^3/day for Sunnyside #2 and Sunnyside #3, respectively. Well details are summarized in Table E based on information provided by Surrey. The total annual groundwater extraction of 2.1 million m^3/year for the City of Surrey ranges from approximately 20 to

40% less compared to projected groundwater extraction for the CoWR of 2.6 to 3.0 million m^3/year based on Scenario 2 values.

Table E City of Surrey Sunnyside Well Details

Well	Easting	Northing	Yield (m^3/day)	Annual Withdrawal (m^3/year)
Sunnyside#2	513311	5432360	3,974	1.3 million
Sunnyside#3	513252	5432311	2,419	0.8 million

Note: Easting and Northing (UTM, NAD83) approximated using City of Surrey COSMOS.

5.3 Well Capture Zone

The well capture zone defines the well protection area. This area is divided into 1-year, 5-year, and 10-year time of travel (TOT) areas to help determine the risk associated with groundwater hazards and to prioritize groundwater management measures. Forward particle tracking methods were used in the numerical model to determine the well capture zone and TOT areas.

Given that the aquifer is confined, the simulated well capture zone represents the area that contributes water to the wells from below the confining layer (i.e. does not represent recharge at surface). The TOT corresponds to the amount of time for contaminants to travel from the bottom of the confining layer to the wells. An estimate of the time for potential contaminants to infiltrate into the subsurface and move vertically through the overlying hydrostratigraphy is not accounted for. Chemical reactions along the flowpath are also not considered (attenuation, biological degradation, etc.).

The well capture zone for the CoWR wells was reviewed for all three simulated scenarios. Very little difference can be discerned between the three scenarios, suggesting that increases in groundwater withdrawal due to climate do not appear to impact the extent of well capture zones. The well capture zone is also not impacted by the current well network and extractions rates planned by the City of Surrey, indicating withdrawals to the City of Surrey wells are from different areas of the aquifer.

The well capture zone with the 1-year, 5-year and 10-year TOT areas are shown in Figure 5-1. For the Merklin site wells, the 10-year TOT extends to the eastern edge of the groundwater model, indicating that the well capture zone likely extends further east. A better regional understanding of the hydraulic connection between the Sunnyside Aquifer to aquifers systems to the east is required to expand the model domain and provide greater certainty in the well capture zone for the Merklin site wells.

5.4 Water Availability

Water availability was evaluated based on a review of drawdown near the end of the simulation period relative to simulated pre-development conditions (i.e. steady state calibration) and well hydrographs to visualize simulated heads in relation to screen intervals and the top of the aquifer for the CoWR wells.

Lateral and vertical extents of drawdown are presented in Figures 5-2 to 5-4 for Scenarios 1 through 3, respectively. Drawdown is calculated as the difference between aquifer levels on August 1, 2044 compared to pre-development conditions. This allows direct comparison of drawdown between the scenarios to provide an indication of relative impacts to the water table. Hydrographs showing simulated water levels at Well No.1 and Well No. 6 (corresponding to the Oxford and Merklin sites, respectively) are also included with drawdown. Hydrographs were used to identify local water level trends and to help identify potential impacts to operational criteria defined as at least 1 m above the top of screen.

For Scenario 1 (Figure 5-2), the drawdown area reflects the influence of pumping by CoWR wells on water levels of the aquifer. The greatest drawdown occurs at the Oxford site (2.5 m) which is expected given that pumping from this wellfield contributes to approximately 60% of the annual water demand during the simulations. The drawdown extends to the coastline, reflecting the hydraulic connection to the coast and highlighting the potential for saltwater intrusion. The hydrograph for Well No. 1 shows seasonal fluctuations in simulated water levels that remain above the aforementioned CoWR operational criteria. Slightly decreasing trends in future water levels were noted for all Oxford wells, suggesting the potential for operational issues in the long-term. Simulated water levels at Well No. 6 are over 10 metres above the well screen and indicate that confined conditions (i.e. no free drainage occurs) are maintained throughout the simulation with no long-term water level declines. However, a decreasing trend in water levels for Well No.7 was noted and likely is attributed to an increased pumping rate at this well.

For Scenario 2 (Figure 5-3), the spatial extents of the drawdown slightly decreases compared to Scenario 1. This is attributed to sea level rise and the influence it has on propagating higher water levels inland due to the confined condition of the aquifer. This does not necessarily mean more groundwater is available because higher sea levels could result in a greater potential for saltwater intrusion or upconing during pumping. The maximum drawdown of 2.5 m in the area of the Oxford well network is comparable to Scenario 1.

The drawdown shown on Figure 5-4 for Scenario 3 shows a larger drawdown area as a result of pumping at the City of Surrey Sunnyside wells. The drawdown increases to 3.0 m at the Oxford site; however, water level trends shown on the hydrographs for Well No. 1 and Well No. 6 are similar to Scenario 1 indicating no/minor additional impacts to operations due to pumping of the City of Surrey wells. Extension of the 0.1 m drawdown contour to the east has been inferred (dashed line) but the general drawdown pattern suggests greater influence with the eastern aquifer systems with concurrent operations of the municipal systems.

5.5 Saltwater Intrusion

The Sunnyside Aquifer is a coastal aquifer with hydraulic connection to Semiahmoo Bay. Classically, in such a setting a saltwater-freshwater interface will exist naturally with the more dense saltwater underlying freshwater. Groundwater pumping can result in the migration of saltwater into the aquifer (saltwater intrusion) and/or cause upconing. Upconing refers to the upward movement of the saltwater-freshwater interface in the vicinity of the pumping well.

The analytical solution under steady state condition by Callander (2011) was used to determine the position of the toe of the saltwater-freshwater interface. This solution is based on the analytical approach provided by Strack (1976) that provides the position of the saltwater-freshwater toe with pumping under steady state conditions. The analytical solution is a simplification of actual conditions; however, it provides context related to the risk of saltwater intrusion. The potential for upconing is not considered using this analytical solution.

Using this simplified approach, the saltwater-freshwater toe is calculated to be up to 80 m inland from the coastline using a pumping rate that combines all volumes extracted from the Oxford site in 2045. The Oxford site was selected because it contributes to 64% of the municipal water supply. The position of the saltwater-freshwater toe is calculated to migrate 2 m inland under Scenario 2, which includes sea level rise.

The Oxford site is approximately 600 m away from the coastline. Projected groundwater extractions show the capture zone is over 450 m from the coastline (Figure 5-1). Although drawdown under all scenarios extends to the coastline, discharge from the Sunnyside Aquifer to Semiahmoo Bay remains. In addition, chloride concentrations at Well No. 5 (located approximately 140 m from the coastline and contributing to upwards of 22% of the water supply before being taken offline and replaced with Well No.8) have been below 100 mg/L indicating minimal saltwater intrusion/upconing impacts. However, the potential for saltwater intrusion remains a concern given the coastal setting of the Sunnyside Aquifer. The risk associated with saltwater intrusion is assessed in Section 6.0.

6 Potential Risks to Aquifer Quality and Water Availability

6.1 Approach

The risk characterization approach used is based on guidance provided in the Comprehensive Drinking Water Source-to-Tap Assessment Guideline: Module 7 Characterize Risks from Source to Tap (Ministry of Healthy Living and Sport et al, 2010) and the BC Well Protection Toolkit (BC MOE, 2004). The risk characterization focuses on source water protection and includes a risk assessment of groundwater hazards related to both quantity and quality specific to the CoWR water supply 10-year capture zones. Priority rankings are assigned to risk-levels to prioritize management measures.

The distinction between groundwater hazards and risk is an important concept in risk assessment. Groundwater hazards have the potential to cause harm. Risk is a combination of the likelihood that a hazard will occur and cause harm within a defined time-period and the expected consequences of the harm if it were to occur (BC MOE, 2004).

DEFINITIONS

Hazard: An event, condition, action, or inaction that may pose a threat to human health or a sustainable supply of water.

Likelihood: A timebound estimate of the probability that a harmful event or condition would occur and that negative impacts would result.

Consequence: The nature and degree of impacts, severity and duration, if a hazard does occur.

Risk: Product of likelihood and consequence.

Source: BC MOE 2004

For CoWR source protection planning, likelihood is determined for events with the probability to occur and cause negative impact within the next 10 years. Aquifer vulnerability has been considered in the risk assessment and incorporated into the qualitative measures of likelihood. The Sunnyside Aquifer has been assigned low vulnerability rating based on the natural protective properties of the overlying confining layer of marine sediments/till. These natural containment materials are of low permeability and are inferred to be laterally continuous with an average thickness of more than 35 m (Section 4.2). Consequence is assigned based on the qualitative impact of the groundwater hazard to source water infrastructure costs, degradation of water quality relative to drinking water guidelines, groundwater availability, and duration and extent of operational implications.

6.2 Groundwater Hazards

Groundwater hazards include both quality (potential sources of contamination) and quantity (changes in groundwater flow) aspects of groundwater protection. Sources of potential contamination (e.g. those compiled in the contaminant inventory) within the 10-year capture zone were identified based on information contained within the publically available Sites Registry and synopsis reporting, waste discharge authorization databases, GIS information for municipal infrastructure, mapping of gas station, auto mechanic, dry cleaners, cemetery, golf course, recycling depot using information from the White Rock BIA business directory (http://whiterockbia.com/) and the Google Maps internet web-mapping service. Use of land for agricultural purposes east of the CoWR was also considered given the conceptual understanding that the Sunnyside Aquifer is hydraulically connected to adjacent aquifer systems in the east.

A total of 24 groundwater hazards were identified including 18 associated with groundwater quality and six associated with quantity (Appendix 4).

The 18 groundwater hazards identified for groundwater quality include agricultural land use to the east of the study area, a gas service station and dry cleaning business in Surrey, winter maintenance routes, transportation arteries (152 Street used as a trucking route and King George Blvd), nine Site Registry IDs (three with site profiles, six with no additional information), sanitary and storm sewers, potential contamination from residential land use (i.e. paint, solvents, and detergents), and four wells constructed prior to 2005 with an unknown status. Naturally occurring levels of arsenic and manganese, saltwater intrusion/upconing, and tsunami were also identified as groundwater hazards associated with potential water quality impacts.

The six groundwater hazards identified for groundwater quantity are associated with a lack of clarity surrounding the regional groundwater flow contributions into the Sunnyside Aquifer from adjacent aquifers, increased demand on the CoWR water supply as a result of potential seasonal water use inefficiencies by residents, and increasing groundwater withdrawals from the future expansion of the City of Surrey groundwater supply program.

6.3 Risk Assessment

6.3.1 Risk Assessment Framework

A summary of the qualitative measures of likelihood and consequence, the time period considered in the risk assessment, as well as the resultant risk matrix and priority rankings is provided herein.

Three qualitative descriptors are used to assess the likelihood that a harmful event or condition could occur from which a negative impact to the source water within the next 10 years as outlined in Table F. Three consequence levels were assigned based on the qualitative descriptors provided in Table G. The resultant risk matrix and priority ranking based on the product of likelihood and consequence is provided in Table H.

Table F Qualitative Measures of Likelihood

Level	Descriptor	Description	Probability of Occurrence in Next 10 Years
A	Likely	Will probably occur in most circumstances	71 – 100%
B	Possible	Will probably occur at some time	31 – 70%
C	Unlikely	Could occur at some time	0 – 30 %

Table G Qualitative Measures of Consequence

Level	Descriptor	Description
1	Minor	Little to no increase to operational cost, does not have a DW guideline or below detection limits, minimal impact to water availability/no water use conflicts, manageable disruptions to normal operations
2	Moderate	Increase to operational cost, aesthetic objective or below DW guideline, some impact to water availability and some water use conflicts, significant modification to normal operations but manageable
3	Major	Significant increase to operational cost or capital investment required, exceeds human-health DW guideline, decrease to water availability and increase in water use conflicts, operations significantly compromised with abnormal operation or no operation at all

Table H Risk Matrix and Priority Ranking

	CONSEQUENCE		
LIKELIHOOD	**Minor - 1**	**Moderate - 2**	**Major - 3**
Likely – A	Moderate (4)	High (2)	High (1)
Possible – B	Low (7)	Moderate (5)	High (3)
Unlikely - C	Low (9)	Low (8)	Moderate (6)

Notes:

1. Likelihood assigned A, B, or C based on descriptor.
2. Consequence assigned 1, 2 or 3 based on descriptor.
3. Priority ranking provided in brackets and used to prioritize risk for planning purposes. For example, a groundwater hazard that is likely to occur with a major consequence would have a high-risk classification with the greatest priority level (e.g. High (1)).

6.3.2 Risk Assessment Results

The detailed risk characterization table for CoWR source protection planning is provided in Appendix 4. A summary of risk assessment results is provided in Table I for both quality and quantity groundwater hazards. Further discussion of management measures for the CoWR to address priority risk areas is included in Section 7.2.1 .

Table I Summary of Risk Assessment Results

	CONSEQUENCE		
LIKELIHOOD	**Minor - 1**	**Moderate - 2**	**Major - 3**
Likely – A	1 – Quantity 1 - Quality	0 – Quantity 0 - Quality	0 – Quantity 0 - Quality
Possible – B	1 – Quantity 0 - Quality	3 – Quantity 1 - Quality	0 – Quantity 0 - Quality
Unlikely - C	0 – Quantity 8 - Quality	1 – Quantity 7 - Quality	0 – Quantity 1 - Quality

Table I shows there are no groundwater hazards with a high-risk classification (no risk assessment results in the red zone). Due to the natural protection provided by the overlying material of the aquifer or because of existing mitigation measure that have been implemented by the CoWR (i.e. water treatment to remove natural occurring levels of arsenic and manganese), hazards associated with groundwater quality have been assessed to be a low to moderate risk. Groundwater quantity hazards have been assessed to have mostly moderate risks. Moderate risks for quantity are a result of one or more of the following:

- Uncertainty about future water withdrawals from neighbouring municipalities and agricultural or industrial use;
- Lack of awareness or disregard for seasonal water restrictions;
- Inefficient water use (i.e. inefficient/leaky toilets, leaky pipes, inefficient irrigation systems, high water demand landscaping); and
- Uncertainty in the broader hydraulic nature of the aquifer (e.g. need better resolution of aquifer recharge), resulting in a greater likelihood of occurrence from a conservative viewpoint.

7 Sustainable Groundwater Management

Development of groundwater management strategies is a priority for the CoWR given the community's reliance on groundwater as a drinking water source. The CoWR has a responsibility as a water system operator/supplier to undertake source water protection, both from contamination and from water availability perspectives. At the same time, the CoWR has an interest to manage water quantity as to not unduly disturb the natural processes of the flow system. Therefore, the main outcomes for the sustainable groundwater management of the CoWR source water include the groundwater protection goals for the CoWR (Section 1.2) but also include:

- Management of water quantity to meet the needs of all users (including the environment);
- Preservation of water quality for the benefit of all users (including the environment); and
- Maintenance of the hydraulic integrity of regional flow systems.

Sustainable groundwater management is predicated on the interaction of the following factors:

- A management framework identifying roles and responsibilities of different agencies for groundwater management;
- Mechanisms to protect the resource (i.e. policies, initiatives, regulations, education);
- A financial framework to fund groundwater management activities; and
- Mechanisms for data collection, assessment, and reporting to facilitate science-based decision-making and performance monitoring.

These factors are discussed herein, forming the basis of the Plan.

7.1 Groundwater Management Framework

Figure Q summarizes the groundwater management framework for this Plan by identifying the different stakeholders and defining their roles and responsibilities. Within British Columbia, the provincial government administers the legal requirements under the *Water Sustainability Act* (2016), *Drinking Water Protection Act* (2001), *Environmental Assessment Act* (2002), and *Environmental Management Act* (2004) related to groundwater use, protection, protection of human health, and protection of the environment. The Province has a responsibility to monitor groundwater resources across the province through the Provincial Groundwater Observation Network of Wells and make this information available to stakeholders, which they do through the WELLS database and interactive web-mapping services. As well, the provincial government should define budgets and funding sources to support groundwater protection activities across the province.

Local governments have the ability to implement various mechanisms for source water protection. These include strategic decisions (implementation of a drinking water treatment regime), regulatory mechanisms (zoning and development permit areas), non-regulatory mechanisms (public education), and financial mechanisms (incentive programs, water use fees, or enforcement fines). In addition, local governments must define a financial framework to budget for source water protection programs and continue data collection, assessment, reporting, and performance monitoring.

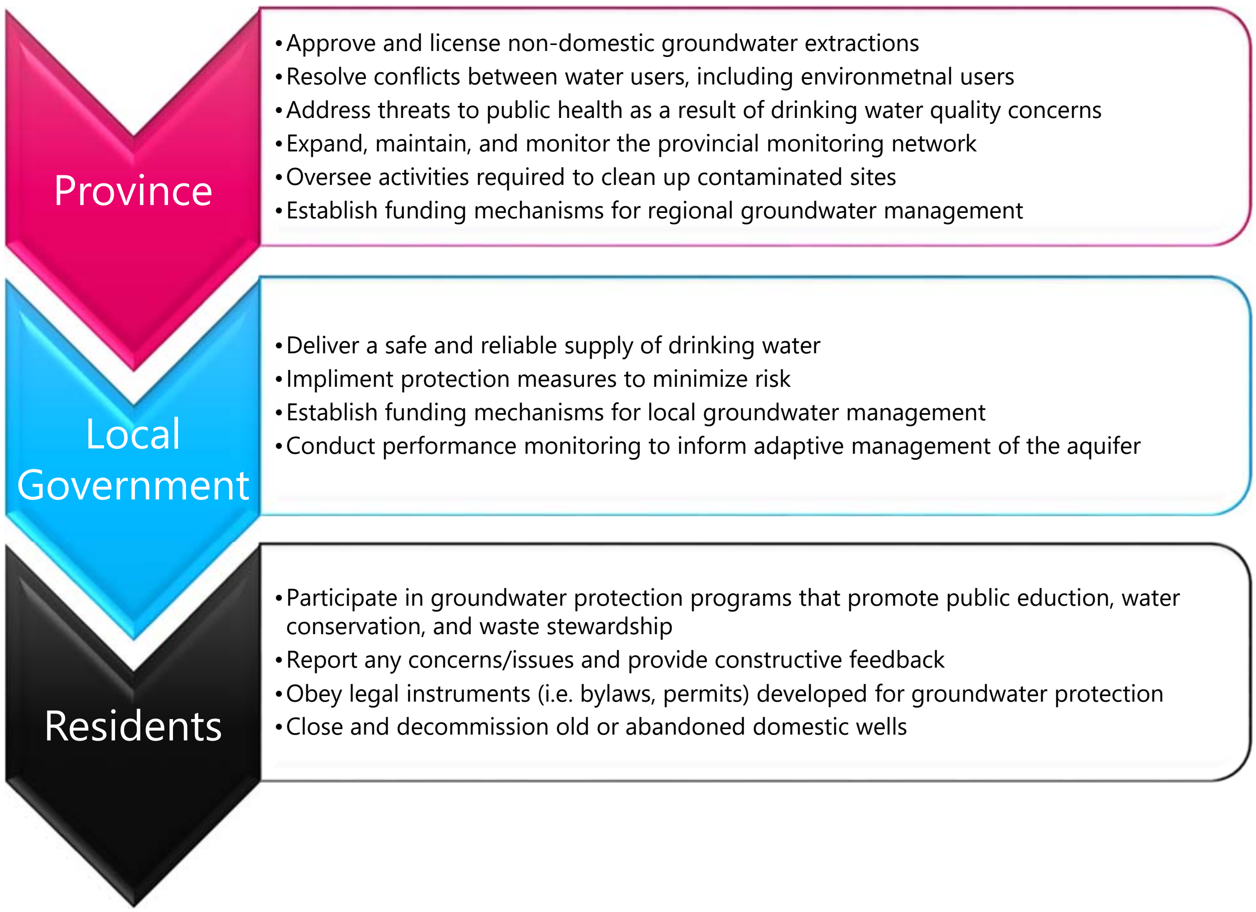


Figure Q Role and Responsibilities in Groundwater Management

7.2 Mitigation & Contingency Planning

Mitigation and contingency planning can be used by the CoWR to facilitate source water protection. Management options focus on prevention and include a variety of approaches to counteract potential for contaminant introduction to the well capture zone and conflict between groundwater users, including the environment, within the jurisdiction of the CoWR.

The well capture zone as well as the aquifer extends beyond the CoWR municipal boundaries. Thus, a collaborative approach with the City of Surrey, as well as other stakeholders, is required to integrate groundwater protection in land use planning and to develop a broader regional strategy for sustainable aquifer development. Mitigation and contingency planning specific to the CoWR is provided in Sections 7.2.1 and 7.2.2, respectively, with recommended long-term monitoring and reporting and regional initiatives for sustainable groundwater management included in Sections 7.3 and 7.5, respectively.

7.2.1 Mitigation Planning

This section provides a list of recommended mitigation measures (Table J) beyond those already implemented by the CoWR (i.e. well field operation and maintenance plans) to minimize the risk of groundwater hazards identified in Section 6.3.2. Mitigation measures are ordered by priority. Professional judgement was used to assign priorities for mitigation planning based on the risk characterization and number of groundwater hazards addressed through the mitigation taking into consideration:

- What and where the most critical challenges for the water supply system are;
- Direct resources most immediately towards actions that have the highest potential to reduce risk;
- Protect unimpaired areas from degradation; and
- Identify areas where there is a need to coordinate multiple remedial/protective priorities.

Table J Recommended Mitigation Measures to Reduce Identified Groundwater Risks

Priority	Mitigation Measure	Risk No.[1]	Description/Rationale for Mitigation Measure
1	Promote/ support collaborative approaches to groundwater management	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 16, 21, 22, 23	The CoWR relies on the Sunnyside Aquifer as a water supply source. The aquifer and capture zones extend beyond the municipal boundaries of CoWR. The need for several regional studies have been identified to refine conceptual model and modelling tools that support decision-making and include: ▪ Define goals, objectives, roles and responsibilities for regional groundwater management ▪ Regional groundwater model to investigate hydraulic connection between aquifer systems and inform boundary conditions of local models; ▪ Recharge study and geochemistry evaluations to better understand flow system; ▪ Detailed assessment on the effect of climate change and land use on the hydrologic cycle to better understand the impact on recharge; and ▪ Establish a regional monitoring network that includes climate stations, stream gauge stations, and dedicated groundwater monitoring wells. Promoting/supporting collaborative approaches to groundwater management with multiple stakeholders at various levels of government is a key strategy for the CoWR with a view to ensure sustainable groundwater use.
2	Updates to CoWR	3, 7, 8, 14, 15,	The majority of the Sunnyside Aquifer occurs below urban development within the CoWR boundary. Several groundwater

Priority	Mitigation Measure	Risk No.[(1)]	Description/Rationale for Mitigation Measure
	monitoring program	17, 18, 22, 23, 24	hazards associated with potential sources of contamination have been identified within the well capture zone (gas station, dry cleaning business, site registry, sanitary/storm water sewer system). Natural protection from contamination of the groundwater is provided where an overlying confining layer exists (e.g. capping of clay). The overall risk is considered low; nevertheless, periodic sampling of a comprehensive list of potential contaminants of concern related to groundwater quality hazards is recommended as a mitigation (early detection) measure. Potential contaminants of concern related to agriculture land use east of the CoWR should also be analysed given that the Sunnyside Aquifer is conceptualized to be hydraulically connected to adjacent aquifer systems to the east that occur below agricultural lands. Natural concentrations of arsenic and manganese are found in the Sunnyside Aquifer. A review of drawdown at the time of sampling during the analysis of water quality results is recommended to determine trends, if any, in arsenic and manganese concentrations due to well operations (introduction of oxidizing conditions as a result of daily cycles of drawdown). The aquifer is located in a coastal setting and the CoWR well network is located over 600 m from the coastline. Continued monitoring of sodium and chloride is required to evaluate any saltwater impacts. Analysis of boron could help in determining the source of salt given winter road maintenance activities in the area. An observation well is recommended between the existing production well network and coastline to help monitor for potential saltwater impacts. Installation of a downgradient observation well would also help refine CSM development. Ion balance should be calculated as a quality assurance/quality control measure for raw groundwater samples. Oxidation-reduction potential should also be monitored in the raw groundwater to understand the geochemical environment of the natural system. Ideally, a dedicated monitoring well in close proximity to each pumping well network is used for continuous water level measurement and to support characterization of aquifer quality and for early detection of possible contamination. Pumping wells can serve a dual purpose by acting as observation wells when they are not pumping. Efficient and effective data management is increasingly more important as large sets of data are collected. A coordinated effort should be made by the CoWR to develop an electronic database of

Priority	Mitigation Measure	Risk No.(1)	Description/Rationale for Mitigation Measure
			water levels, groundwater use (pumping), and groundwater quality information to facilitate data analysis/sharing of information. Decommission Well No.5. This well is no longer used by the City. The well is old and was constructed prior to the Groundwater Protection Regulation; therefore, may not comply with current standards.
3	Zoning bylaw review	5, 11, 14, 15, 17	Ideally, zoning for groundwater protection directs development away from well capture zones and prohibits potentially polluting uses (Okanagan Water Board, 2006). However, the majority of land in CoWR and immediately to the north in the City of Surrey has already been developed for urban uses with established zoning. It is recommended that zoning in the well protection area be reviewed to identify if land uses that have the potential to pollute have been permitted. This review can target activities listed in Schedule 2 of the Contaminated Sites Regulation (CSR).
4	Incorporate groundwater protection into OCP	14, 15, 17, 18	An OCP has been prepared for the CoWR that includes policies for growth and land use as well as Development Permit Area (DPA) guidelines. The management of water and land use should be fully integrated (Council of Canadian Academics, 2009). Incorporation of groundwater protection in the OCP is recommended. This could include explicit policies for groundwater protection, incorporation of groundwater protection into existing policies, or development permit areas for groundwater protection. DPA designations in the OCP have special development guidelines. Aquifer protection can be included in existing DPAs or a separate policy developed so that permits with specific conditions to protect the aquifer are issued. For example, the City of Cranbrook has established an Aquifer Protection DPA designation to protect groundwater used as a municipal water supply against possible contamination from land use and development activities. It specifically targets properties zoned for commercial or industrial use and activities listed in Schedule 2 of the Contaminated Sites Regulation (CSR) (BC Reg. 375/96) (Section 20, https://cranbrook.civicweb.net/filepro/documents/567?preview=3134).
5	Groundwater protection signage	9, 10, 14, 15, 17, 18, 20	Signage to protect groundwater is recommended. Signs can target the well capture zone but can also be placed throughout the CoWR to promote awareness and public responsibility. An appropriate caption should be designed and carried forward as a trademark for groundwater protection in CoWR. Collaboration with the City of Surrey would be beneficial given that the capture zone extends north

Priority	Mitigation Measure	Risk No.(1)	Description/Rationale for Mitigation Measure
			of the CoWR and the Sunnyside Aquifer occurs below both communities. It may be beneficial to include a telephone number for reporting observed instances of improper handling of potential contaminants or bylaw violations related to water conservation.
6	Public awareness	5, 20	Support and commitment from the local community is an important aspect of groundwater management. The CoWR has a number of communication initiatives to provide information to community members (website dedicated to water, open houses). Continued engagement with the community is recommended to promote groundwater protection and water conservation. Unbiased opinion polls are recommended to better understand public perception and to help develop targeted approaches to keep the public engaged. Additional public engagement activities could include pop-up displays at local markets/community events, school programs, community groundwater protection group, and/or groundwater resource centre at the public library.
7	Rebate program	5	Water conservation is an important component of groundwater protection, particularly during the summer season when demand is greatest. Future climate change projections include warmer and dryer summer conditions. Water conservation efforts are already being implemented by the CoWR (water invoicing based on metering, watering restrictions, leak detection). Rebate programs could also be offered that promote replacement of outdated appliances (toilets, washing machines, dishwashers), drought-tolerant landscaping, and efficient irrigation systems with timers to ensure watering is done within water restriction timeframes.
8	Follow-Up with City of Surrey	9, 10, 11	A partnership in groundwater protection with the City of Surrey is essential for optimal aquifer management. With respect to minimizing risk of groundwater hazards in the well capture zone, the following correspondence with the City of Surrey is recommended: ▪ Review of zoning in the area of the well capture zone within the City of Surrey to identify if land uses that have the potential to pollute have been permitted. This review can target activities listed in Schedule 2 of the CSR. ▪ Obtain support/permission or collaborate on signage initiatives to promote groundwater protection focusing on the well capture zones but possibly extending to recharge areas of the aquifer.

Priority	Mitigation Measure	Risk No.[1]	Description/Rationale for Mitigation Measure
			▪ Review winter road maintenance practices.
9	Integrated water management planning considerations	3, 9, 10, 16	Stormwater water management strategies that promote infiltration may require special consideration with respect to soil permeability (potential for poor drainage), ensuring acceptable quality of infiltrating waters, and that infiltrating waters do not negatively impact groundwater conditions (e.g. change in redox conditions that result in mobilization of metals, increase in water table that may affect slope stability, etc.) (Gessner et al, 2014).
10	Targeted local business activity follow-up	9, 10	Chevron Service Station (1776 Martin Dr, Surrey) and Courtesy Cleaners (1959 152 St, Surrey) provide services that are regulated activities under the CSR. These businesses are located within the well capture zone. Correspondence with these businesses is recommended to provide well protection information, to ensure best management practices are in place, and to determine if any emergency plans have been prepared in the event of a spill. In addition, follow-up with the Province on the status of Registry Site IDs 6184, 14507, and 18637 is recommended.
11	Residential Hazardous Waste Collection Initiatives	20	Residential land use overlies part of the aquifer. Environmental stewardship of household hazardous waste should be promoted to minimize releases into the sanitary sewer or in outdoor areas. Hazardous waste collection information is currently available on CoWR website, https://www.whiterockcity.ca/EN/meta/faqs/solid-waste.html. However, more information regarding drop-off locations and materials that are accepted could be provided. This information can be obtained by contacting the RCBC Recycling Hotline 604-732-9253. In addition, community residential waste collection events could be organized by CoWR to facilitate proper disposal and promote awareness in the community.

Note:

1 Refer to Appendix 4 to cross-reference the Risk No. referenced.

7.2.2 Contingency Planning

The purpose of contingency planning is to provide a coordinated response in the event of a contamination event. In general, contingency measures specific to groundwater in emergency situations could include the following:

- Ensure groundwater contingency planning is incorporated into emergency response planning for the CoWR water supply system.
- The CoWR should be included in emergency response plans as an emergency contact for polluting land uses that have been permitted within the well capture zone or upgradient from the pumping well network in general.
- The CoWR should ensure notification from the Province when spill reporting occurs in the area of the well capture zone or within the aquifer extents in general.
- None of the groundwater quality hazards were deemed to have a high risk based on available information; therefore, threats are considered to be unlikely. The movement of any contamination from the surface is anticipated to take years to decades to reach the wells, if at all. Nevertheless, the following contingency measures could be implemented if deemed necessary:
  - Sampling of potential contaminants of concern (dependent on nature of spill) to evaluate any impacts with consideration of expectations regarding contaminant fate;
  - CoWR wells impacted by the threat could be temporarily or permanently taken off-line;
  - New pumping well(s) could be strategically placed to avoid impact from contamination;
  - A groundwater barrier could be installed between the pumping wells and contaminant plume;
  - Connection to the Metro Vancouver drinking water distribution system. This contingency measure has already been investigated by the CoWR and was found to be very costly to implement; and
  - The CoWR is currently working on an agreement with the City of Surrey to establish an emergency water supply.

7.3 Financial Framework

Successful source water protection requires a commitment to provide adequate funding to support the mitigation and contingency planning and implementation defined in Section 7.2.1. Committed funding is needed to conduct monitoring and technical studies to support the Plan, for consultation activities, for resourcing the team with appropriate level of professionals, and ongoing management of the source protection program. Specialized funding may be required to provide incentives such as a rebate program for replacing old household appliances or to encourage the clean-up of a contaminated site.

CoWR has already secured capital funds for the Total Water Quality Management Project, which includes disinfection of distribution system, upgrades to the Oxford and Merklin Street Sites, arsenic and manganese treatment system, water main flushing programs, and development of this Plan.

To fund the Plan, provincial and federal funding mechanisms should be explored. The CoWR may consider collaborations with academic institutions to secure NSERC and/or other academic focused grants.

Collaborations with other regional stakeholders (i.e. the City of Surrey, Semiahmoo First Nations and the Province) may help to secure larger federal government grands to support regional-scale management.

7.4 Performance Monitoring and Reporting

The CoWR has an existing water monitoring program that is comprehensive for evaluating parameters for drinking water treatment. Nevertheless, following the implementation of management strategies as discussed in Section 7.2.1, performance monitoring is required to ensure effectiveness of the governance process and provide a means for investigation and event closure (Figure R). Implicit in this system is the concept that as new groundwater quality and quantity knowledge is generated, the Plan is updated and ensuing decisions are adapted accordingly.

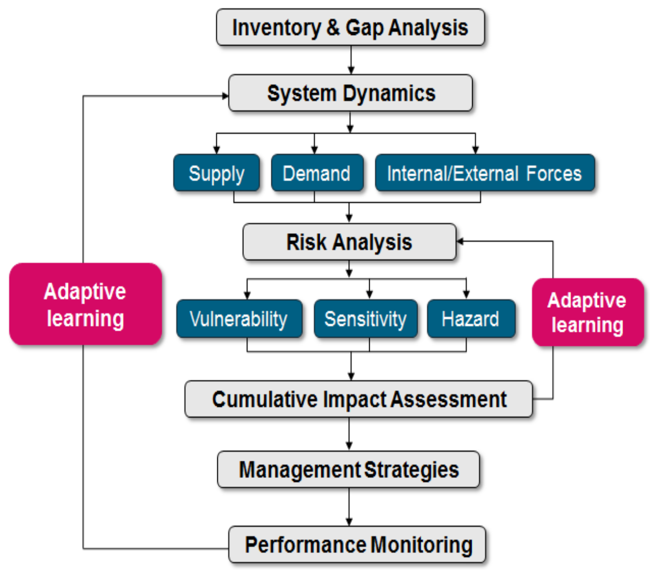


Figure R Systematic Assessment Process

Evaluation and reporting are also central to this process to ensure desired outcomes are being met. If not, there needs to be feedback into management actions to address the issues that are preventing the desired outcomes from being met. Adaptive management principles allow for adjustments to desired outcomes, indicators, and assessment processes to honour increasing knowledge and awareness of the Sunnyside Aquifer system.

Suggested performance monitoring metrics for the implementation of the Plan include, but are not limited to:

- DW guideline exceedances;
- Pumping well operational criteria exceedances;
- Annual/seasonal water consumption (m^3) per capita;
- Value and number of rebates offered each year;
- Reported number of seasonal water restriction bylaw violations observed by bylaw officers or reported by CoWR residents;
- Performance metrics for CoWR water project website (i.e. traffic to educational materials);
- Results of opinion polls targeting CoWR residents regarding groundwater protection awareness;
- Number of awareness events throughout the community related to aspects of groundwater protection (i.e. hazardous waste collection drives, pop-up educational displays); and
- Funding.

Analytical results of groundwater samples are added to the CoWR water project website on a regular basis. An annual water report is currently prepared to summarize operational and management information on the CoWR water supply system. Performance monitoring metrics can be established to meet the needs and objectives of the CoWR and incorporated into existing reporting. Alternatively, dashboards could be defined for various consumers of the data, the public, CoWR council members, and CoWR utilities staff. Automation of the data collection metrics and development of an effective data management system would minimize reporting efforts over the long term and provide a near real-time snapshot of the performance of the Plan. This would also allow for efficient implementation of corrective actions to mitigate possible risks to the Sunnyside Aquifer.

7.5 Regional Initiatives

As previously discussed, the Sunnyside Aquifer is continuous beyond the extents of the CoWR municipal boundaries; delineated source water protection zones (well capture zones) extend beyond the CoWR municipal boundaries requiring collaborative management with the City of Surrey to protect from potential contamination; and along with some smaller groundwater users, the City of Surrey plans to development a groundwater supply from the same aquifer to sustain population demands and environmental flows. Thus, overall sustainability, in terms of both water supply resilience and water of good quality, has a broader context than purely jurisdictional.

Governance of the aquifer solely at a jurisdictional, property or boundary level has an inherent potential to pose correspondingly fragmented management of what is a spatially-continuous unit. Recognizing this potential detraction, optimum overall management of such a transboundary unit would best be achieved by ensuring that a spirit of cooperation, to the best interests of all aspects pertaining to sustainability, is fostered. To that end, a key initiative would be to establish a coordination committee who would (i) view the aquifer in its' broad distribution and sustainability, while (ii) also representing the water-supply requirements, utilization preferences and socio-economic constraints and resources of the stakeholder entity each committee member answers to.

In addition to jurisdiction-level groundwater abstraction management, a complementary aquifer-level outlook is desirable. This outlook will help the CoWR achieve the desired outcomes for sustainable groundwater management as described in Section 7.1 in the face of likely changes of priorities within the region. Municipalities responsible for the security and quality of drinking water supply will need to incorporate a planning component that addresses change. This Plan, for instance, addresses select change scenarios as supported by computer model-assisted prediction in regard to projected outcomes associated with population growth forecasts (both within the CoWR and the City of Surrey), sensitivity of aquifer recharge to climate change, and sensitivity of the aquifer system to sea level rise. Advantageously, the scenarios that were simulated address the aquifer at the regional level and the TWG consisted of regional water managers.

The work conducted herein is expected to directly enhance management of the aquifer at a municipal and regional level. An example would be the inventory of potential-contaminant sources. By the same token, this present work has identified several key data gaps that would be better addressed at the regional level rather than the individual municipal level.

7.5.1 Command of Regional-Scale Influences

To be in a position whereby decision-making is of a sufficiently-informed nature at the municipal level, a wider understanding of the aquifer, as facilitated by this present report, is essential. For the future, given that priorities and plans can be expected to evolve, the insights and contributions provided by this report will need to be updated in response to influential changes that emerge and new data that become available.

The establishment of a Regional Observation Well Network can be viewed as the single most important complementary support mechanism to optimized management of Sunnyside Aquifer. The Province may be able to provide funding for installation and monitoring as part of the Provincial Observation Well Network. In addition, each stakeholder could, for example, contribute to the overall network by establishing or otherwise designating wells from within its' own jurisdiction. Private residential wells could be included, particularly where coverage is otherwise found to be sparse.

Monitoring at the regional scale is prudent for various reasons, including:

- The amount of groundwater present in the aquifer (as represented by the elevation of the groundwater surface) is adequately tracked temporally such that:
  - Expected trends and/or annual cycles in water levels can be tracked and used to facilitate understanding of the aquifer system;
  - Conversely, observations wells can provide early indication of potential groundwater quantity or quality issues before impacting the well field. In turn, adequately-informed forward planning and/or timely decision-making is enabled; and
  - Decadal-to-subcentennial level future long-range planning and management, in the context of subcentennial-to-centennial multifactorial pressures like climate change, can similarly be accommodated in a properly-informed manner.
- Periodic upgrading of the Conceptual Hydrogeological Model is facilitated by on-going data acquisition. In turn, properly-informed forward planning and/or decision-making is enabled in respect to changing societal values, new opportunities or constraints, emerging environmental initiatives and new regulatory mandates,

In respect to sustainability aspects of groundwater quality, hydrochemistry complements water level monitoring, assisting with:

- Confirming the temporal stability of key naturally-occurring hydrochemical constituents at the aquifer level such that water quality at points-of-extraction will continue to meet expectations across corresponding travel timeframes;
- Early detection of any unexpected time-composition trends of a sub-regional nature such that the source or originating mechanism can be identified. If warranted, a properly-informed management response can be devised; and
- Potentially assist with identifying emerging time-composition trends of a more regional nature.

7.5.2 Role of the Regional Committee

A need for coordination at the aquifer level is evident from the information presented in this Plan. It is recommended that the TWG established to inform the development of this Plan pursue an opportunity to develop a Regional Groundwater Committee. Each committee member can bring together the priorities and/or driving influences of the stakeholder he or she represents, while at the same time facilitating a balanced approach to aquifer management to the benefit of all participants.

A Regional Groundwater Committee can guide the following activities or contributions:

- Coordinating the management actions of individual municipal-supply service providers in respect to what is a trans-jurisdictional mutually-shared aquifer or aquifer system;
- Assist service providers in attaining sustainable outcomes by synchronizing otherwise individual efforts both to optimally abstract groundwater and to monitor corresponding aquifer performance; and
- Advocate the introduction of a regional observation well network such that routinely-acquired, but essential, spatial-temporal readings (i.e. water level and water quality data) can be collected. In turn, behavioural aspects of the aquifer can be more fully determined, while overall performance in respect to multi-stakeholder abstraction will be monitored adequately at the aquifer level.

7.5.3 Responsibility of the Regional Groundwater Committee

The responsibility of the Regional Groundwater Committee could be to champion regional level initiatives (e.g. regional observation well network), canvass for and coordinate corresponding input from stakeholder (e.g. allocation of wells for such a network), and oversee the design, technical content derivation and implementation of each initiative. In some circumstances, the committee may need to canvass for financial resources in support of a given initiative.

It is recommended that the committee will:

- Be led and supported by the BC Provincial Government through participation from key members from Fraser Health Authority, FLNRO, and the ENV;
- Assign a working group who will administer individual initiatives, which are recommended to include:
  - Planning and implementation of a regional observation well network and monitoring program;
  - Developing a regional climate change strategy;
  - Conducting a targeted recharge study to improve the understanding of inputs to the aquifer system and could include installation of stream gauge stations to characterize discharge to surface waters, and an assessment of historic and future land use and land cover on recharge; and
  - Integrated groundwater resource management and land use planning including a cumulative effects assessment of long-term pumping.
- Working groups will facilitate periodic (e.g. annual) communication of data and/or results such that dissemination of information and/or documentation to individual stakeholders is effective.

8 Conclusions

The Sunnyside Aquifer is an important natural resource that is used as the water supply source for the CoWR. Population growth, climate change, sea level rise, and other users of the aquifer (e.g. future groundwater use by the City of Surrey) may put increasing pressure on the water supply system. This Plan has been developed as a key component in protecting the community's water supply source. Groundwater protection goals include stakeholder engagement, advancing the understanding of aquifer characteristics, protecting groundwater quality from contamination, and ensuring future withdrawals sustainably meet future demands.

Key outcomes of this plan include development of a numerical groundwater model that has been used to delineate the well protection area and to simulate three future scenarios to inform future groundwater management. A total of 24 groundwater hazards have been identified and include threats to both quality and quantity aspects of the water supply. None of the groundwater hazards were considered to be a high risk. Groundwater hazards associated with groundwater quality have been assessed as low to moderate risk, while quantity hazards have primarily been assigned as moderate risks.

Risk assessment results reflect the natural protection provided by low permeability materials overlying the aquifer and highlight the existing uncertainty in aquifer recharge mechanisms with the need for a broader, regional strategy to manage this groundwater resource. Concerns with naturally occurring concentrations of manganese and arsenic in the aquifer have been largely mitigated by plans to build a treatment plant.

A groundwater management framework has been provided that includes various levels of government while also requiring support by the local community. The "voice for water" needs to be represented by multiple stakeholders to bring meaningful progress in attaining sustainability goals all within a forum that fosters innovation and collaboration. Groundwater management (mitigation and contingency planning) provided in this report focuses on approaches that can be implemented by the CoWR to augment existing measures (e.g. water restrictions, water metering). A combination of regulatory and "soft" tools have been included that address the urban setting of the aquifer with priority given to regional collaboration, continued due diligence in groundwater monitoring efforts, potential bylaw updates to enforce the importance of groundwater, communication with City of Surrey and targeted local businesses, promotion of waste stewardship, and public awareness campaigns.

Committed funding is required to successfully undertake source water protection. The CoWR may consider collaborations with academic institutions to secure NSERC and/or other academic focused grants. Collaborations with other regional stakeholders (i.e. the City of Surrey, Semiahmoo First Nations and the Province) may help to secure larger federal government grants to support regional-scale management. Specialized funding could also be obtained to provide community incentives such as rebate programs for replacing old household appliances, promoting drought tolerant landscaping and efficient irrigation systems, or to promote proper disposal of household hazardous waste.

The Sunnyside Aquifer is continuous beyond the extents of the CoWR municipal boundaries and an integrated management approach with the City of Surrey is required. A key initiative would be to promote and support regional approaches for groundwater protection to avoid fragmented management. This present work has identified several key data gaps that would be better addressed at the regional level rather than the individual municipal level, including but not limited to: regional groundwater model to investigate the hydraulic connection between aquifer systems and to inform boundary conditions of local models; recharge study and geochemistry investigations to better understand the flow system; climate change impacts on the hydrologic cycle to determine the effect on recharge; and saltwater intrusion modelling.

9 Closure

We trust that this report satisfied your current requirements and provide suitable documentation for your records. If you have any questions or require further details, please contact the undersigned at any time.

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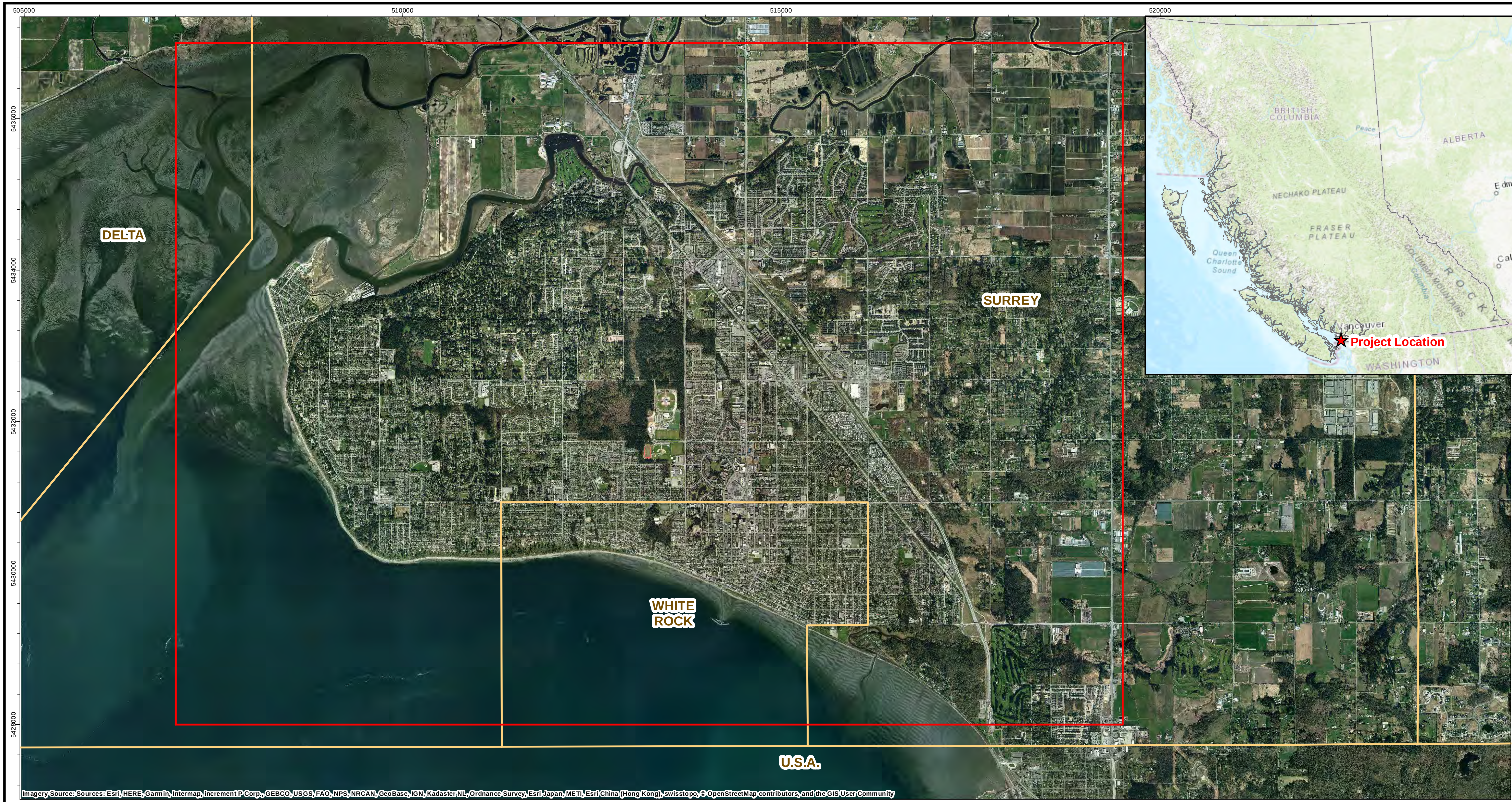
Figures



Legend

- Study Area
- Municipal Boundary

N

0 1 2

Kilometres

1:50,000

NAD 1983 UTM Zone 10N

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

PROJECT LOCATION AND STUDY AREA

Date: 25-MAY-18	Drawn by: Y.M.	Edited by: Z.H.	App'd by: Z.H.
		WorleyParsons Project No. 307071-01216	
		FIG No 1-1	REV 0

OneWay to zero harm

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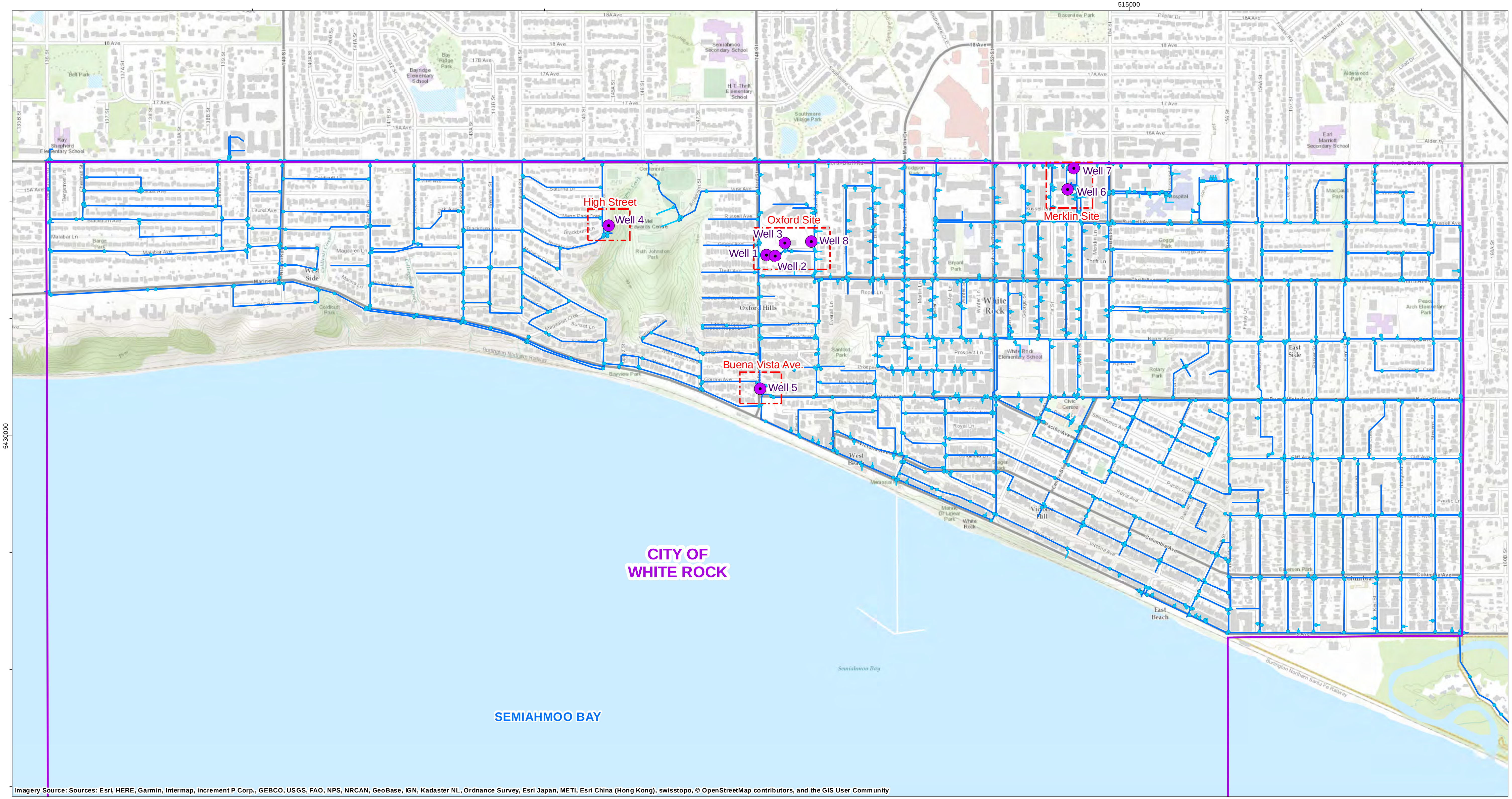

Legend

- City of White Rock Boundary
- City of White Rock Groundwater Well
- Water Valve
- Water Main
- Water Service Lateral

N

0 200 400
Metres
1:13,000
NAD 1983 UTM Zone 10N

Source:
- Water distribution system from City of White Rock

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

WHITE ROCK WATER SUPPLY SYSTEM

Date: 25-MAY-18	Drawn by: Y.M.	Edited by: Z.H.	App'd by: Z.H.

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FIG No 2-1 | REV 0

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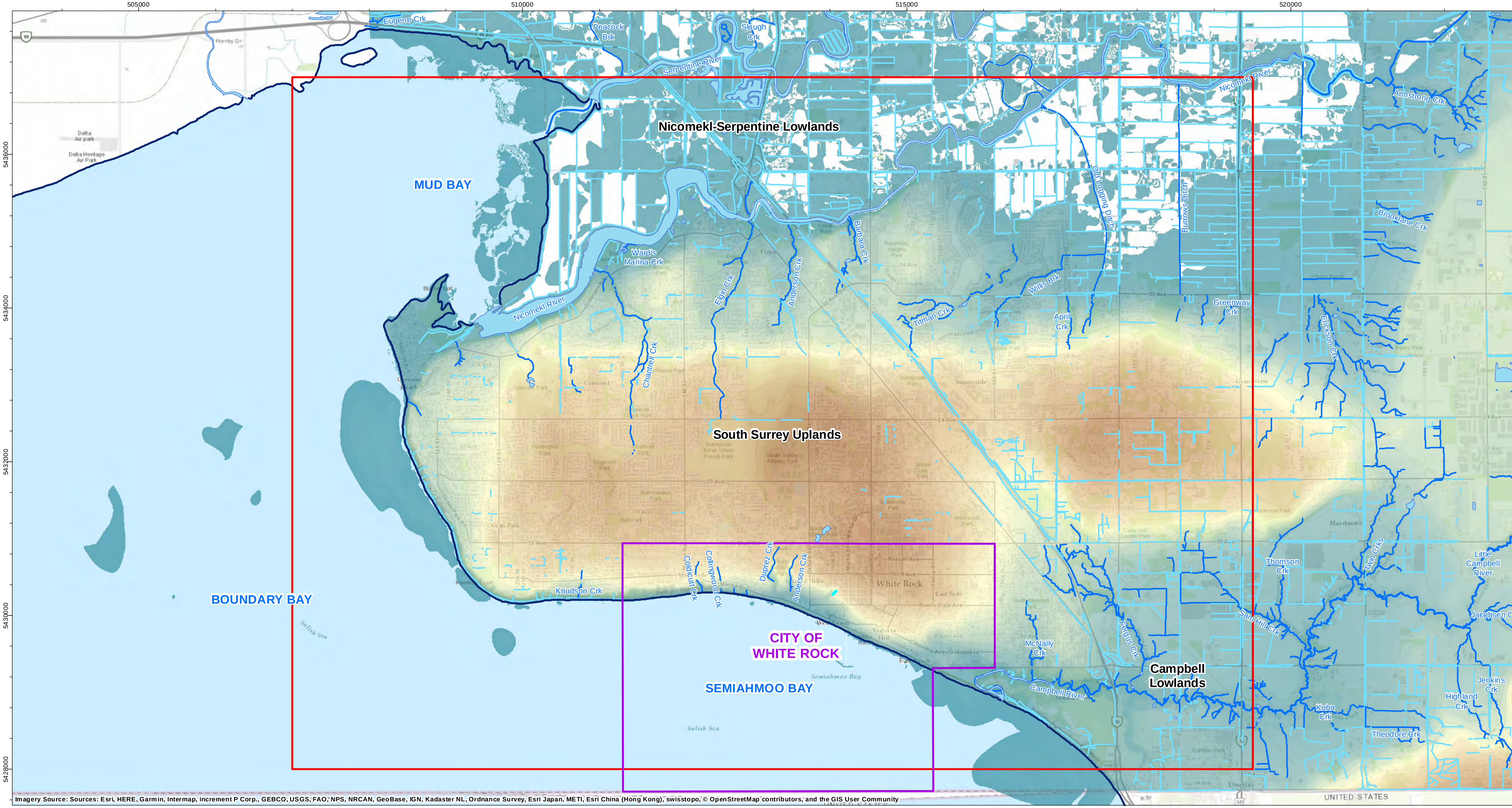

Legend

- Study Area
- City of White Rock Boundary
- Lake/Waterbody
- Coastline
- River
- Creek
- Ditch

Elevation (m)

High : 125.415

Low : 0

Source:
- Surface water features from City of White Rock and City of Surrey.
- Elevation data is a combination of DEMs from City of White Rock, City of Surrey, and CHS Marine Chart 3463

N

0 1 2

Kilometres

1:50,000

NAD 1983 UTM Zone 10N

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

TOPOGRAPHY AND DRAINAGE

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FIG No 4-1 REV 0

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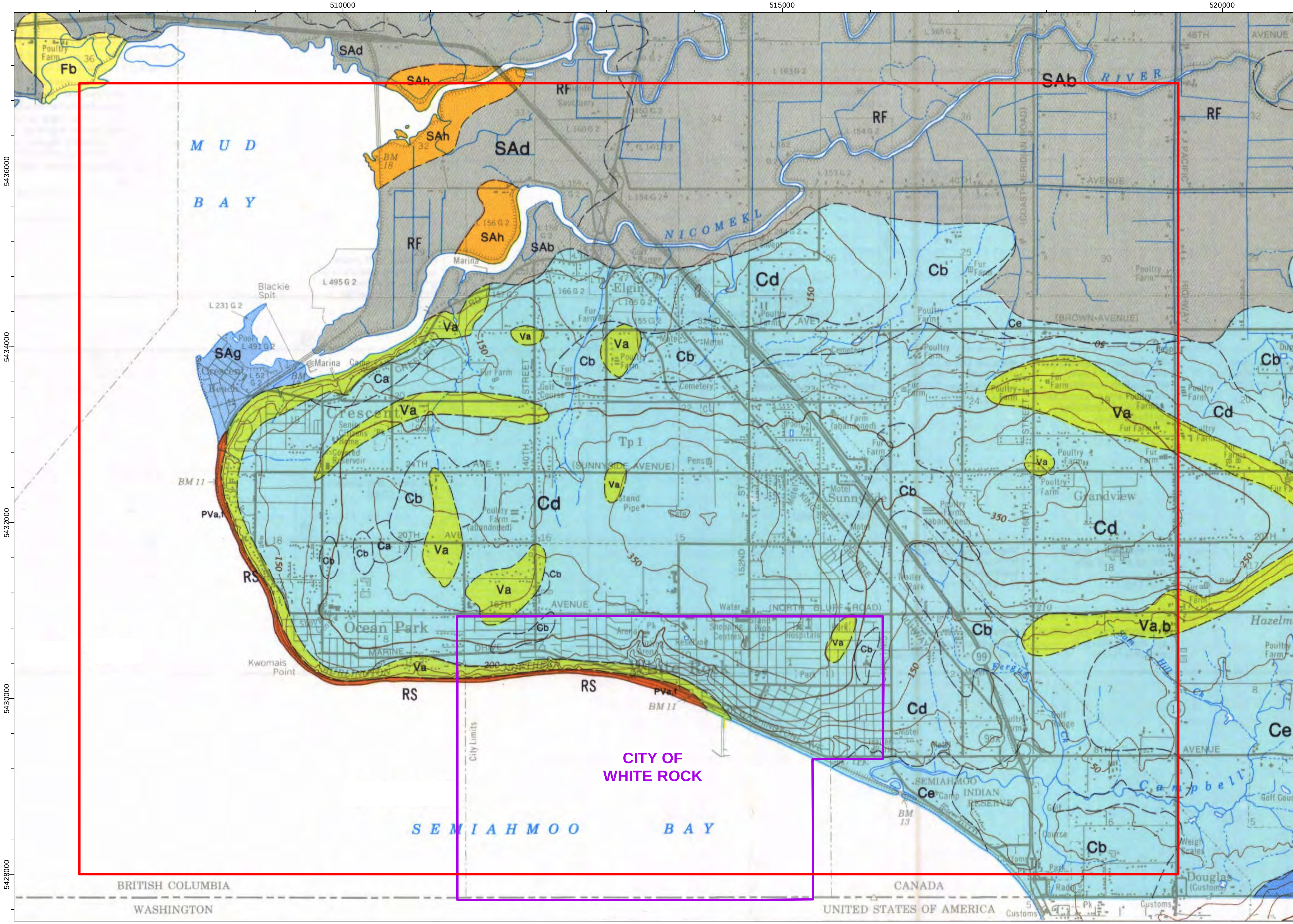

SURFICIAL GEOLOGY LEGEND

SAb-e — *Bog, swamp, and shallow lake deposits:* SAb, *lowland peat up to 14 m thick, in part overlying* Fb, c; SAc, *lowland peat up to 1 m thick underlying* Fb *(up to 2 m thick);* SAd, *lowland organic sandy loam to clay loam 15 to 45 cm thick overlying* SAg and Fd; SAe, *upland peat up to 8 m or more thick*

SAf, g — *Marine shore sediments (beach deposits):* SAf, *sand to sandy loam up to 2 m thick overlying estuarine, fossiliferous, fine sand and clayey silt, 10 to 185 m thick (*Fe of Lithologic Units *and Environments of Deposition);* SAg, *medium to coarse sand and gravel up to 8 m thick*

SAh-k — *Lowland and mountain stream deltaic, channel fill, and overbank sediments:* SAh, *lowland stream channel fill and overbank sandy loam to clay loam, also organic sediments up to 8 m thick;* SAi, *mountain stream marine deltaic medium to coarse gravel and minor sand up to 15 m or more thick;* SAj, *mountain stream channel fill sand and gravel up to 8 m thick;* SAk, *lowland stream channel fill sand to gravel and minor silt and clay up to 5 m thick*

FRASER RIVER SEDIMENTS

Fa-d — *Deltaic and distributary channel fill sediments overlying and cutting estuarine sediments and overlain in part of the area by overbank sediments:* Fa, *channel deposits, fine to medium sand and minor silt occurring along present day river channels;* Fb, *overbank sandy to silt loam up to 2 m thick overlying 15 m or more of* Fd; Fc, *overbank silty to silt clay loam normally up to 2 m thick overlying 15 m or more of* Fd; Fd*, *deltaic and distributary channel fill (includes tidal flat deposits) sandy to silt loam, 10 to 40 m thick interbedded fine to medium sand and minor silt beds; may also contain organic and fossiliferous material*

FORT LANGLEY FORMATION

FLa-e — *Glacial and deltaic sediments:* FLa, *lodgment and flow till with sandy loam matrix containing clasts of* FLc; FLb, *outwash and ice-contact gravel and sand containing clasts of* FLa, c; FLc, *glaciomarine stony clayey silt to silty sand 8 to 90 m thick, commonly thinly bedded and containing marine shells;* FLd, *marine silty clay to fine sand commonly containing marine shells;* FLe, *proglacial deltaic gravel and sand*

CAPILANO SEDIMENTS *(Chronologically equivalent to Sumas Drift and Fort Langley Formation, see Lithologic Units and Environments of Deposition)*

Ca-e — *Raised marine, deltaic, and fluvial deposits:* Ca, *raised marine beach, spit, bar, and lag veneer, poorly sorted sand to gravel (except in bar deposits) normally less than 1 m thick but up to 8 m thick, mantling older sediments and containing fossil marine shell casts up to 175 m above sea level;* Cb, *raised beach medium to coarse sand 1 to 5 m thick containing fossil marine shell casts;* Cc, *raised deltaic and channel fill medium sand to cobble gravel up to 15 m thick deposited by proglacial streams and commonly underlain by silty to silty clay loam;* Cd, *marine and glaciomarine stony (including till-like deposits) to stoneless silt loam to clay loam with minor sand and silt normally less than 3 m thick but up to 30 m thick, containing marine shells. These deposits thicken from west to east.* Ce, *mainly marine silt loam to clay loam with minor sand, silt, and stony glacio-marine material (see* Cd*), up to 60+m thick. In many of the upland areas sediments mapped as* Cc *and* Cd *are mantled by a thin veneer (less than 1 m) of* Ca

VASHON DRIFT

Va,b — *Till, glaciofluvial, glaciolacustrine, and ice-contact deposits:* Va, *lodgment till (with sandy loam matrix) and minor flow till containing lenses and interbeds of glaciolacustrine laminated stony silt;* Vb, *glaciofluvial sandy gravel and gravelly sand outwash and ice-contact deposits*

PRE-VASHON DEPOSITS

PVa-h — *Glacial, nonglacial, and glaciomarine sediments:* PVa, *Quadra fluvial channel fill and floodplain deposits, crossbedded sand containing minor silt and gravel lenses and interbeds;* PVb, *Quadra (?) glaciofluvial deposits, deltaic, and crossbedded sand to gravel (may be in part* Vb*);* PVc, *Quadra marine interbedded fine sand to clayey silt believed to be off shore equivalents of* PVa; PVd, *Coquitlam till, glaciomarine (?), and glaciolacustrine deposits;* PVe, *Cowichan Head fluvial, organic colluvial, and bog and swamp sediments;* PVf, *Semiahmoo till, glacio-fluvial, glaciomarine, and glaciolacustrine deposits;* PVg*, *Highbury fluvial and bog and swamp deposits;* PVh*, *Westlynn glaciofluvial sandy gravel*

UNDIVIDED PRE-VASHON DEPOSITS

UPV — *Till, glaciofluvial, glaciolacustrine, fluvial, marine, and organic sediments*

Legend

- Study Area
- City of White Rock Boundary

N

0 1 2
Kilometres
1:50,000
NAD 1983 UTM Zone 10N

Source:
Surficial Geology from Geological Survey of Canada, Map 1484A

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

SURFICIAL GEOLOGY

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		FIG No 4-2	REV 0

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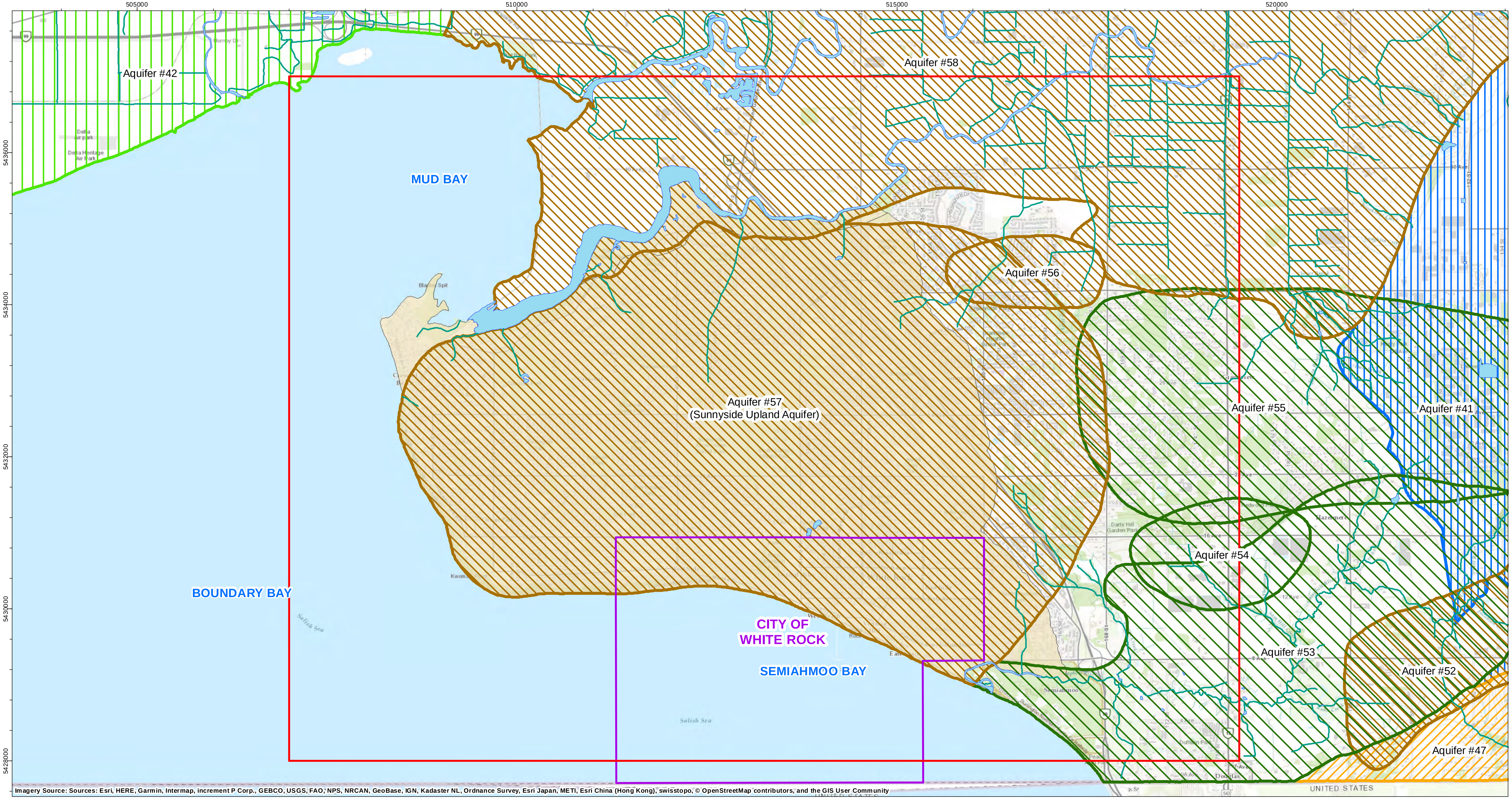

Legend

- City of White Rock Boundary
- Groundwater Model Domain

Aquifer Class

- IA
- IIB
- IIC
- IIIA
- IIIC

Source:
Aquifer from DataBC

N

0 1 2
Kilometres
1:50,000
NAD 1983 UTM Zone 10N

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

MAPPED AQUIFERS AND GROUNDWATER MODEL DOMAIN

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		WorleyParsons Project No. 307071-01216	
		FIG No 4-3	REV 0

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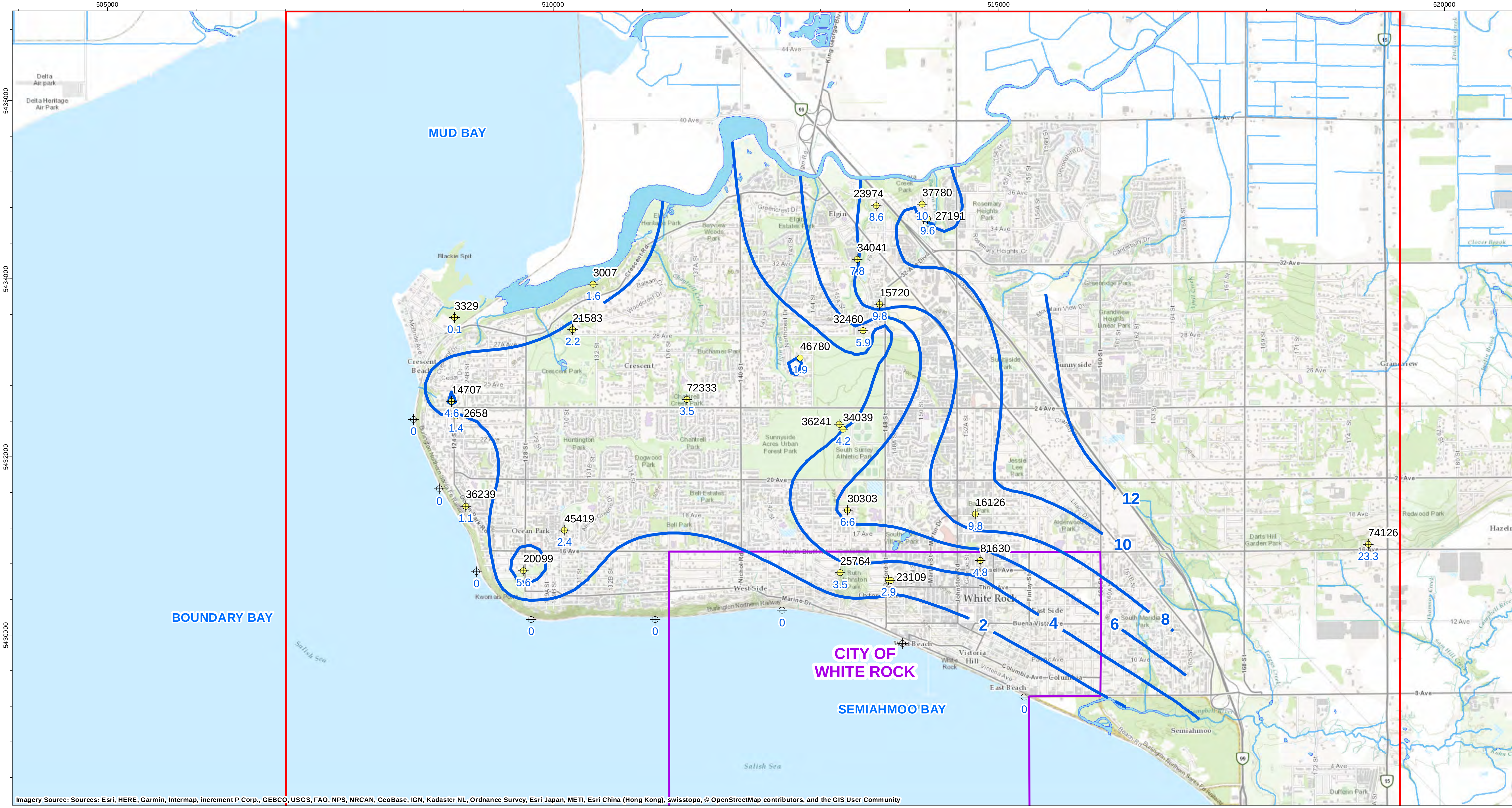

Legend

- City of White Rock Boundary
- Control Points
- Registered Wells
- Hydraulic Head Contours (masl)

N

0 1 2

Kilometres

1:43,126

NAD 1983 UTM Zone 10N

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

HYDRAULIC HEAD CONTOURS (1946-2012)

Date: 25-MAY-18	Drawn by: Z.H.	Edited by: Z.H.	App'd by: M.S.

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WorleyParsons Project No. 307071-01216

FIG No 4-4

REV 0

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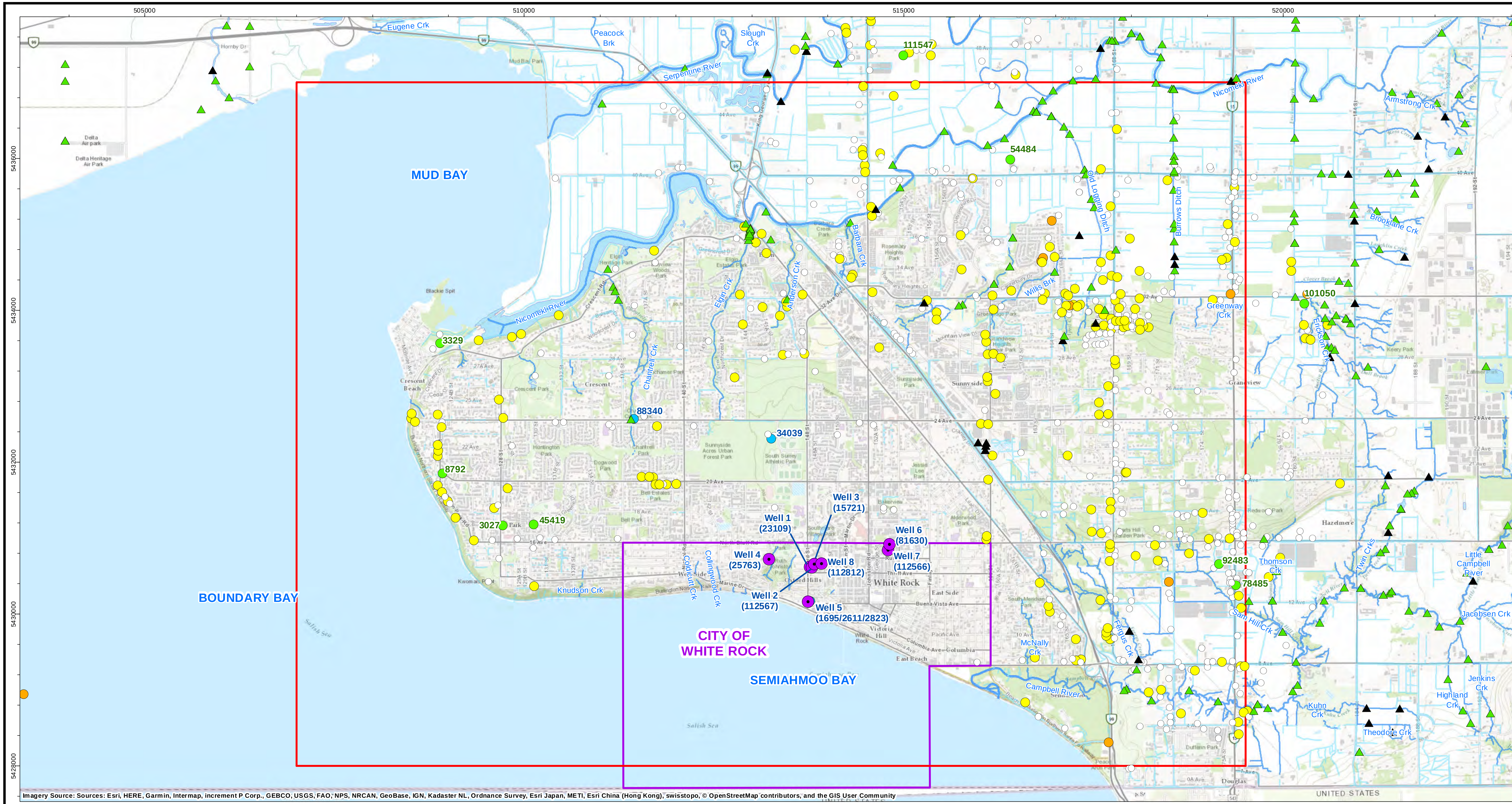

Legend

- Study Area
- City of White Rock Boundary
- City of White Rock Groundwater Well

Surface Water Points of Diversion (By Status)

- Active Application
- Active Licence
- Active Application and Licence
- Inactive

Registered Well

- Commercial and Industrial
- Irrigation
- Private Domestic
- Water Supply System
- Others

Source:
Groundwater Wells from DataBC

N

0 1 2
Kilometres
1:50,000
NAD 1983 UTM Zone 10N

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

WATER USERS

Date: 25-MAY-18	Drawn by: Y.M.	Edited by: Z.H.	App'd by: Z.H.

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WorleyParsons Project No. 307071-01216

FIG No 4-5 REV 0

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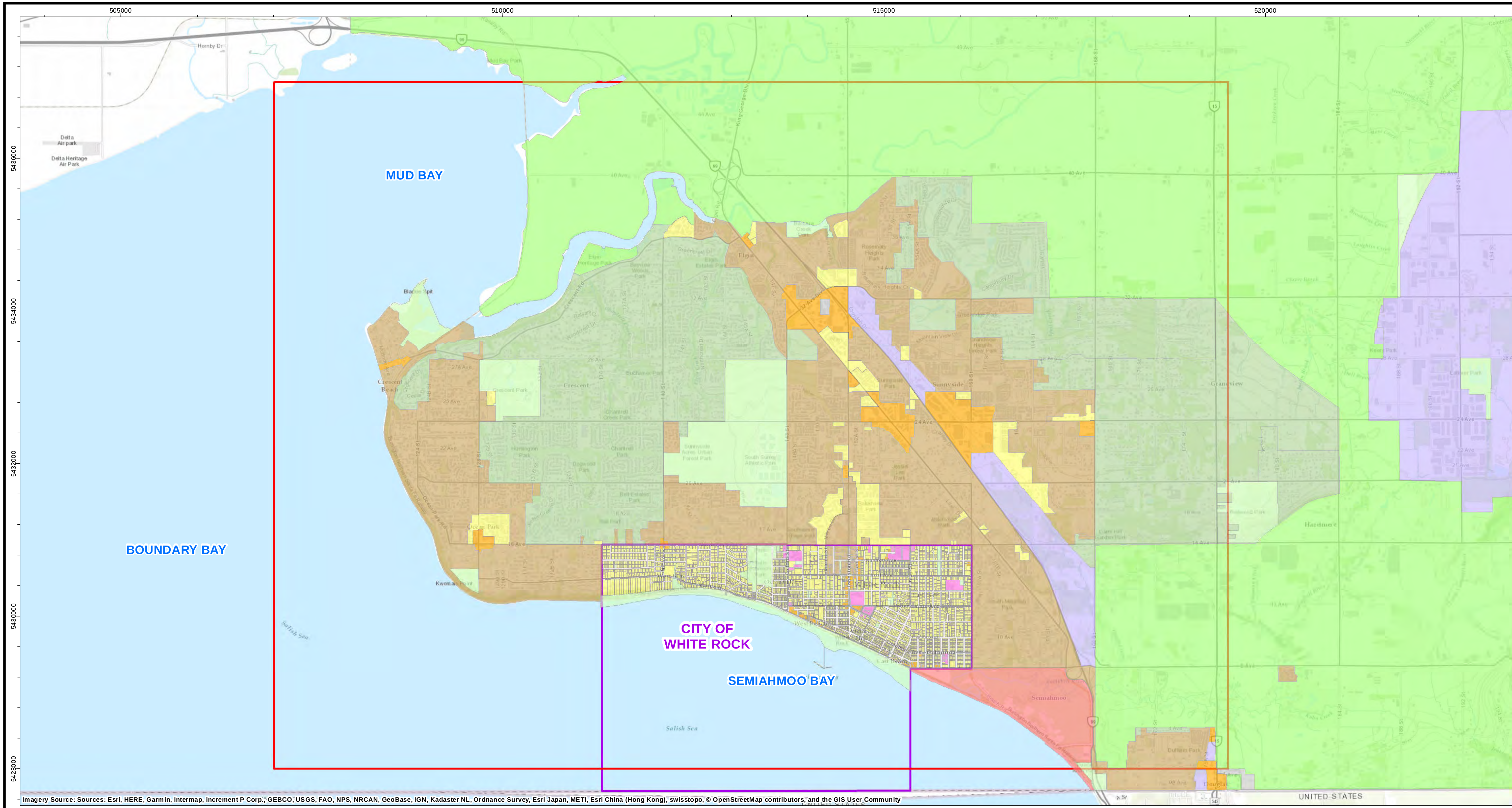

Legend

- Study Area
- City of White Rock Boundary

Land Use

- Agricultural
- Commercial
- First Nations Reserve
- Industrial
- Institutional and Utility
- Mixed Employment
- Recreational
- Residential
- Rural / Suburban
- Urban / Town Centre

Source:
Surrey Official Community Plan 2013
City of White Rock Official Community Plan Draft 2017

N

0 1 2
Kilometres
1:50,000
NAD 1983 UTM Zone 10N

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

LAND USE

Date:	25-MAY-18	Drawn by:	Z.H.	Edited by:	Z.H.	App'd by:	M.S.

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WorleyParsons Project No. 307071-01216

FIG No 4-6 REV 0

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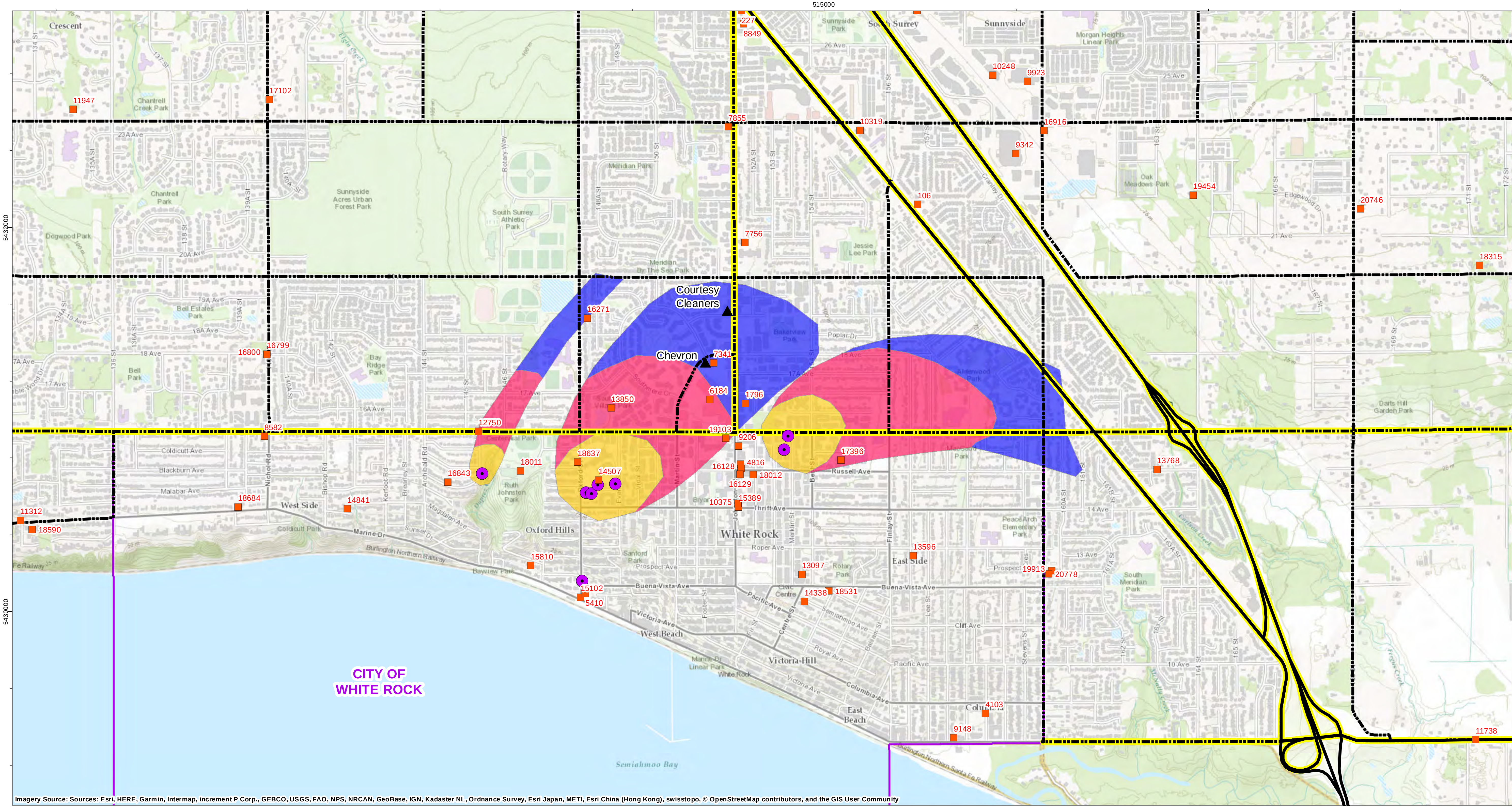

Legend

- Study Area
- City of White Rock Boundary
- City of White Rock Groundwater Well
- Sites Registry
- Waste Discharge Authorization Location
- Commercial Use of Interest
- Major Road
- Winter Maintenance Route (1st Priority)
- Truck Route

Well Capture Zone

- 1-yr Time of Travel (TOT)
- 5-yr TOT
- 10-yr TOT

N

0 1 2
Kilometres
1:20,000
NAD 1983 UTM Zone 10N

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

WELL CAPTURE ZONE AND CONTAMINANT INVENTORY

Date:	Drawn by:	Edited by:	App'd by:
25-MAY-18	Z.H.	Z.H.	M.S.

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WorleyParsons Project No. 307071-01216
FIG No 5-1
REV 0

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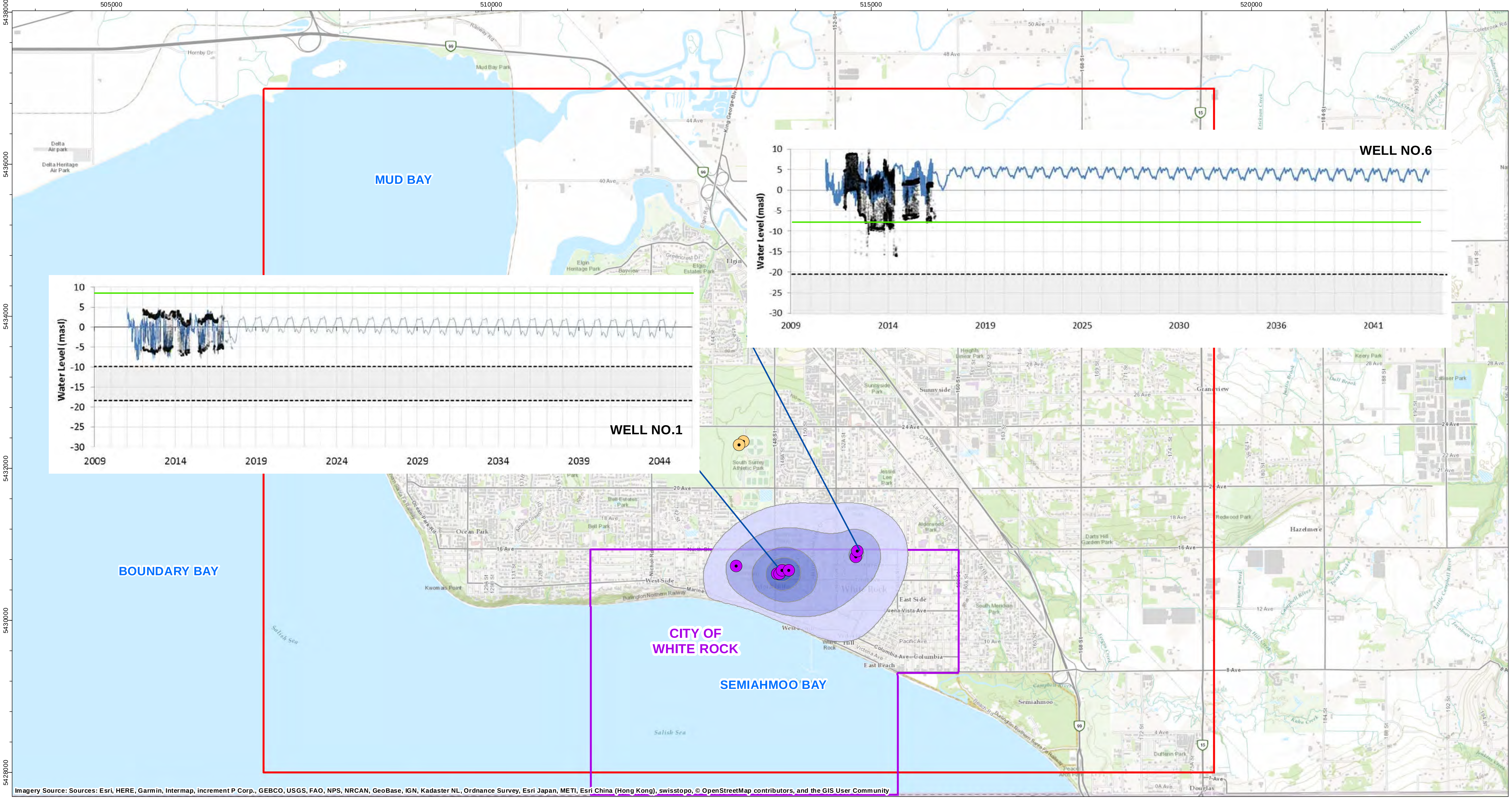

Legend

- Study Area
- City of White Rock Boundary
- City of White Rock Well
- City of Surrey Sunnyside Well

Drawdown 1 August 2044 (Relative to Steady State)

- 0.1
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3.0

- Simulated
- Observations
- Screen top
- Screen Bot
- Approx. Top of Aquifer

N

0 1 2

Kilometres

1:50,000

NAD 1983 UTM Zone 10N

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

SCENARIO 1 (BASELINE)
DRAWDOWN AND HYDROGRAPHS

Date: 25-MAY-18	Drawn by: Z.H.	Edited by: Z.H.	App'd by: M.S.

WorleyParsons Project No. 307071-01216

FIG No 5-2 REV 0

OneWay to zero harm

Advisian WorleyParsons Group

USER NAME: zidra.hammond ISSUING OFFICE: CALGARY GIS

PLOT DATE & TIME: never never SAVE DATE & TIME: 22/04/2018 3:08:52 PM

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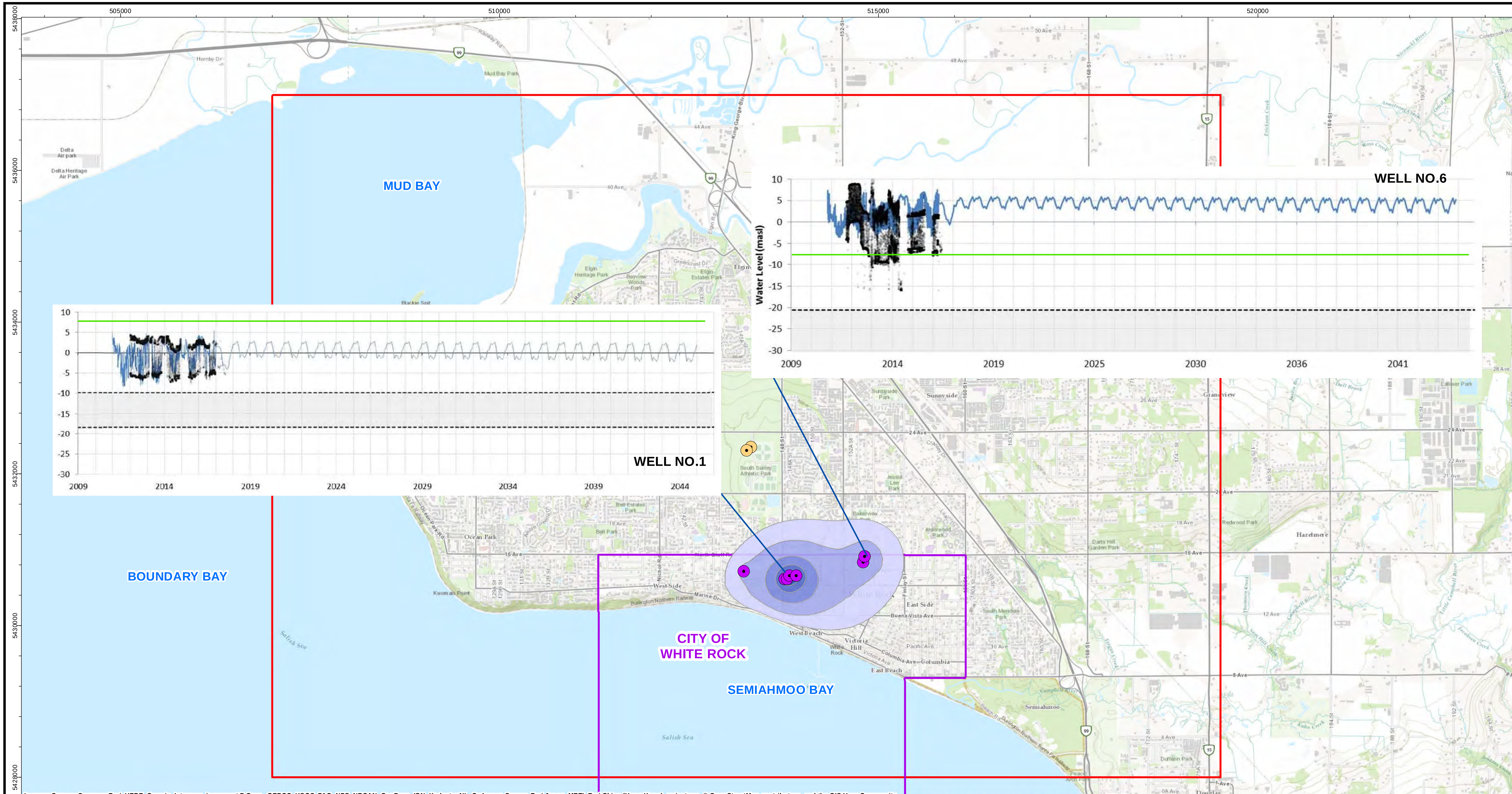

Legend

- Study Area
- City of White Rock Boundary
- City of White Rock Well
- City of Surrey Sunnyside Well

Drawdown 1 August 2044 (Relative to Steady State)

- 0.1
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3.0

- Simulated
- Observations
- Screen top
- Screen Bot
- Approx. Top of Aquifer

N

0 1 2 Kilometres
1:50,000
NAD 1983 UTM Zone 10N

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

SCENARIO 2 (CLIMATE CHANGE)
DRAWDOWN AND HYDROGRAPHS

Date:	Drawn by:	Edited by:	App'd by:
25-MAY-18	Z.H.	Z.H.	M.S.

WorleyParsons Project No. 307071-01216

FIG No 5-3 REV 0

OneWay to zero harm

Advisian WorleyParsons Group

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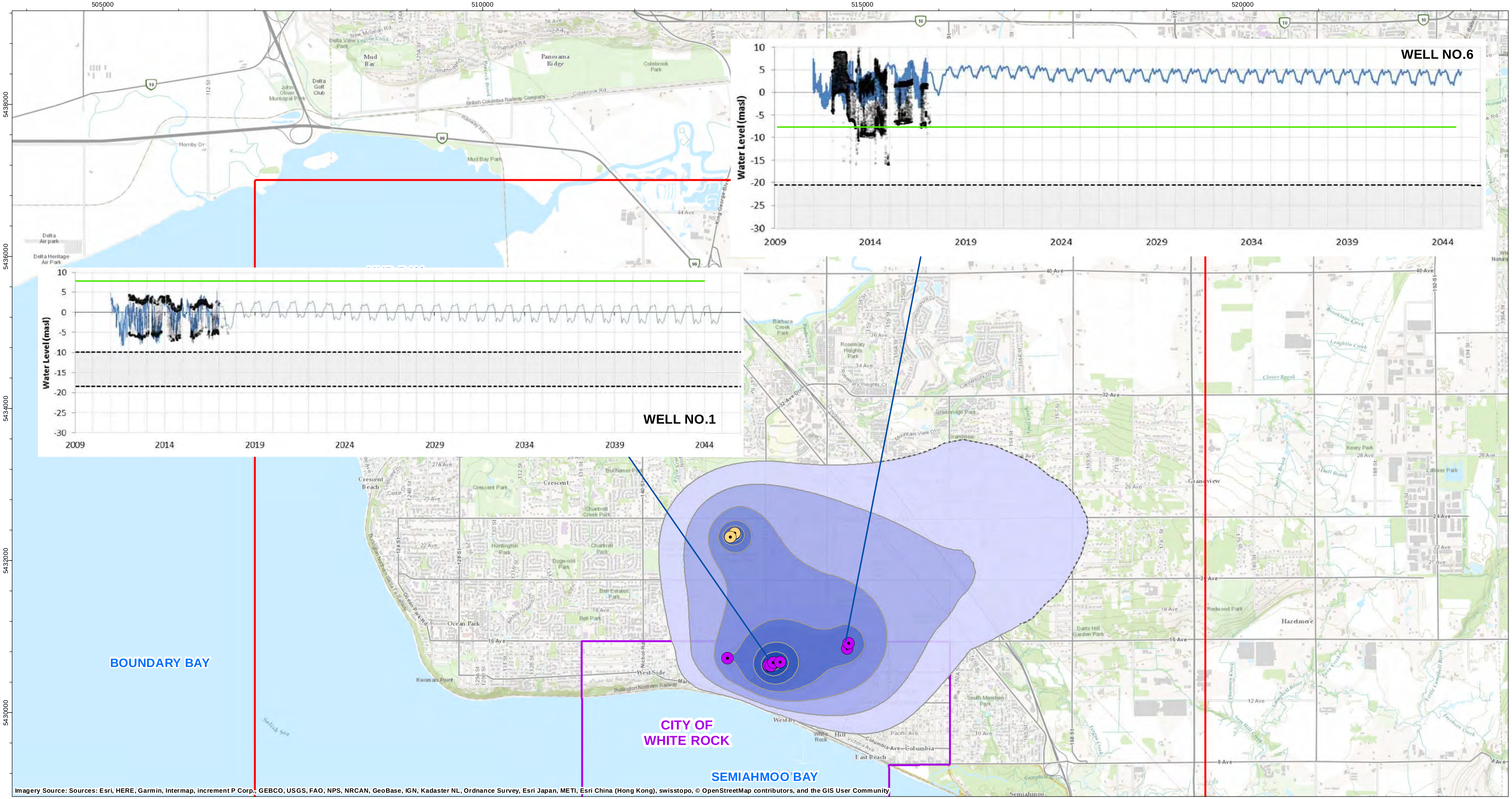

Legend

- Study Area
- City of White Rock Boundary
- City of White Rock Well
- City of Surrey Sunnyside Well

Drawdown 1 August 2044 (Relative to Steady State)

- 0.1
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3.0

- Simulated
- Observations
- Screen top
- Screen Bot
- Approx. Top of Aquifer

N

0 1 2
Kilometres
1:50,000
NAD 1983 UTM Zone 10N

CITY OF WHITE ROCK
AQUIFER PROTECTION PLAN

SCENARIO 3 (CLIMATE CHANGE & SURREY)
DRAWDOWN AND HYDROGRAPHS

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25-MAY-18	Z.H.	Z.H.	M.S.

OneWay to zero harm

Advisian WorleyParsons Group

WorleyParsons Project No. 307071-01216

FIG No 5-4

REV 0

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Appendix 1 Technical Working Group Comment Tracking Table

Technical Working Group Comment Tracking Table

ID #	Commenter	Agency/ First Nation	Format Received	Date Comment Received	Comment Received	Response	Action	Assigned To	Due Date
1	Jeff Arason	City of Surrey	Webinar	29-Nov-17	The City of Surrey appreciates consideration of their potential groundwater use in future modelling activities and is interested in continued engagement.	The City of White Rock looks forward to continued engagement with the City of Surrey.	No action	n/a	n/a
2	Mike Simpson	FLNRO	Webinar	29-Nov-17	Work to date (conceptual model and numerical model) is well done. Limitations of WELLS database is recognized.	The City of White Rock looks forward to continued engagement with FLNRO.	No action	n/a	n/a
3	Mike Simpson	FLNRO	Webinar	29-Nov-17	What extraction values will be used in the model?	Groundwater extraction will focus on the City of White Rock's groundwater well network to delineate well capture zones and advance development of the Aquifer Protection Plan (the Plan). Advisian is working with the City of White Rock to determine appropriate extraction values to model future use, but it will be built on the understanding of the current use collected from SCADA data for the City of White Rock wells. SCADA data was provided to Advisian by City of White Rock. Well#8 was recently connected to the system and is currently operational. Well#4 has been upgraded and is being connected to the SCADA system. Historically, Well#4 was manually operated and has been upgraded to include a flow metre. City of White Rock is actively working to improve data collection efforts to understand groundwater use and inform decision making.	Define the future water use scenario based on historic (SCADA) and projected water demand.	Advisian	Webinar #2
4	Mike Simpson	FLNRO	Webinar	29-Nov-17	How did you determined well use and the volume of groundwater being extracted for registered wells given that wells may or may not exist?	Verification of well use and groundwater extraction for registered wells has not been completed as part of the project (e.g., survey) or has been limited (City of Surrey contacted to confirm current water use). It is anticipated that under the requirements of the Water Sustainability Act, better information will become available on groundwater use. This would not address residential use but will identify large groundwater users (e.g. non-residential users including irrigation, water supply, commercial/industrial). A detailed water budget may be included in future phases of the Plan. A primary objective of the project is to delineate well capture zones. It is anticipated that pumping from other wells will not impact well capture zone delineation because the identified non-residential users are generally located greater than 2 km from the City of White Rock well network and are not upgradient in the Sunnyside aquifer.	Confirm well capture zones do not extend to registered wells screened within the Sunnyside Aquifer.	Advisian	Webinar #2
5	Mike Simpson	FLNRO	Webinar	29-Nov-17	It is understood that the location of the registered wells may not impact groundwater modelling of the capture zones for the City of White Rock well network.	A greater understanding of groundwater users may be required if a capture zone extends to registered wells screened within the Sunnyside Aquifer. A larger regional strategy may be required if a capture zone extends beyond the model limits.	No action	n/a	n/a

Technical Working Group Comment Tracking Table

ID #	Commenter	Agency/ First Nation	Format Received	Date Comment Received	Comment Received	Response	Action	Assigned To	Due Date
6	Marc Zubel	Fraser Health Authority	Webinar	29-Nov-17	The City of White Rock appears to be on the right track to understanding the aquifer system and the approach appears to be reasonable. Impressed and encouraged by the work done to date.	The City of White Rock looks forward to continued engagement with the Fraser Health Authority.	No action	n/a	n/a
7	Marc Zubel	Fraser Health Authority	Webinar	29-Nov-17	Water quality is a big issue and the limited availability of historical water quality data is recognized. Water quality data is available from sampling of the City of White Rock wells which could potentially be used to identify any trends in water quality and any impacts to water quality from operations (e.g., extraction rates, recharge considerations).	There is currently limited data to understand the spatial relationship of water quality in the aquifer. Based on the available data, there seems to be a relationship with higher arsenic concentrations at greater well depths. Water quality can provide additional lines of evidence to support conceptual model development but this is currently limited. The City of White Rock is interested in understanding water quality trends and any impacts to/from the operation of the water supply system. East side wells (Well#6, Well#7) have higher arsenic, manganese, and ammonia concentrations compared to the west side wells (Well#1, Well#2, Well#3, and Well#8). Groundwater from Well#4 has slightly more iron and that may be useful for the application of arsenic removal. Historical analytical data is available from 2015 to present.	Update water quality review to determine any seasonal trends or impacts to/from operations.	Advisian	Webinar #2
8	Marc Zubel	Fraser Health Authority	Webinar	29-Nov-17	The contaminant inventory assessment should include time of travel and potential contaminant events that may occur. Signages and a public notification process for anything that occurs in the aquifer should also be outlined.	This has been noted. Potential contaminant events, notification, signage, and travel times will be addressed when the capture zone is defined. Management strategies and communication methods to protect the aquifer will be outlined in the Plan.	Draft management strategies and communication methods.	Advisian and City of White Rock	Webinar #2
9	Marc Zubel	Fraser Health Authority	Webinar	29-Nov-17	The public open house is a good opportunity to advance the City of White Rock's public education strategy. Previous aquifer protection plans have included discussions on setting up a community groundwater protection committee. Unclear if this is being considered or how effective these community groups are.	The City of White Rock will work to ensure that public concerns are fully understood and considered in development of the Plan through the following methods of engagement: 1) a dedicated website will be used to provide updates on development of the Plan (https://www.whiterockcity.ca/EN/main/city/my-water.html); 2) City of White Rock email and phone contact details as indicated on the website; 3) recordings of webinars with the Technical Working Group and comment tracker available on the website; 4) a public open house to educate, inform, and gather input and feedback from local residents to finalize the Plan; and 5) presentation of the Plan to the City of White Rock Council.	No action	n/a	n/a
10	KK Li	City of Surrey	Webinar	15-Feb-18	The two Sunnyside wells (#2 &#3) are located in the Sunnyside park. The City of Surrey intends to start pumping in 2023. Pumping will be continuous.	Comment noted.	No action	n/a	n/a

Technical Working Group Comment Tracking Table

ID #	Commenter	Agency/ First Nation	Format Received	Date Comment Received	Comment Received	Response	Action	Assigned To	Due Date
11	KK Li	City of Surrey	Webinar	15-Feb-18	The City of Surrey has not conducted modelling studies to quantify the aquifer drawdown as a result of long-term pumping.	Agree that this would be an important path forward to confirm predicted modelling results. The City of Surrey wells (Sunnyside #2 and #3) were not used to calibrate the groundwater model as drawdown information is not available. As City of Surrey advances this work, and through a coordinated efforts with the City of White Rock, improvements of the understanding of the aquifer system will assist future planning.	No action	n/a	n/a
12	Lucien Lyness	Advisian	Webinar	15-Feb-18	With respect to potential risks to the water supply as a result of contamination, does the 10 year capture zone consider attenuation of a contaminant, or does it represent water molecule travel time only?	Attenuation protential has not been considered at this time. For the purpose of the Aquifer Protection Plan, potential higher risk land use activities within the 10 year capture zone are being identified. Risk classification is conservative in that it does not consider attenuation. Consideration is given to the the presence or absence of confining materials that act as a barrier to potential contaminant migration into the aquifer. A management action that may be considered for the protection plan is the implementation of a montioring program.	No action	n/a	n/a
13	Lucien Lyness	Advisian	Webinar	15-Feb-18	The regional perspective is necessary, as depicted from the compound drawdown cones, both the City of Surrey and City of White Rock draw upon the aquifer. From a stakeholder perspective the regional perspective should be considered and monitoring at that scale is required.	Also important to understand that the definition of the eastern boundary of the groundwater model is very important as it controls lateral flow into the aquifer from adjacent aquifers. A regional perspective would improve the characterization of this boundary.	No action	n/a	n/a
14	KK Li	City of Surrey	Webinar	15-Feb-18	Certainly a regional effort is a good idea to understand the impact of water withdrawals from the aquifer. Monitoring of some of the observation wells may be critical to confirm model assumptions for recharge and groundwater flow. It was mentioned that there are a few observation wells, are those wells documented in the report? Can you elaborate on the current monitoring effort?	The provincial government maintains data for active observation wells and this is available from their website. There is no provincial observation well within the Sunnyside aquifer as the Sunnyside aquifer is currently defined.	No action	n/a	n/a
15	Saad Jasim	City of White Rock	Webinar	15-Feb-18	Work conducted to date to better understand the aquifer system and develop management strategies to protect it is a crucial part of the public education program for the City of White Rock residents. Posting these webinars to the website, hosting a public open house, and presenting the work at conferences is all an effort to inform the public of the issues that are being addressed.	Comment noted. The Technical Working Group webinars as well as the comment tracking table are available on the City of White Rock website. A public open house presenting the Aquifer Protection Plan is planned.	No action	n/a	n/a

Technical Working Group Comment Tracking Table

ID #	Commenter	Agency/ First Nation	Format Received	Date Comment Received	Comment Received	Response	Action	Assigned To	Due Date
16	KK Li	City of Surrey	Webinar	15-Feb-18	Your suggestion of regional groundwater committee or something similar would be really useful. The committee may need to develop a guideline or framework to review future development land use in the region and determine how that may effect the capture zone or recharge, which in turn may impact the water quality of the aquifer.	It is recommended that integration and collaboration happen at multiple levels between municipal water and infrastructure groups and be inclusive of regional and Provincial representatives.	No action	n/a	n/a
17	Saad Jasim	City of White Rock	Webinar	15-Feb-18	We do not want a misinterpretation of the potential risk to groundwater due to current registered sites. It is not a future mitigation action to define the potential risk to the aquifer from these sites. We need some understanding of the status and potential contaminants of concern of the registered sites. Some investigation will be required to understand the risk as the way the risk is currently presented is too general.	Publically available information is limited, providing only the location of registered sites. For a detailed report, a request will need to be made to the MOE to understand the site status and potential contaminants of concern. This request needs to be made through BC Online and will have cost implications. A budget will be prepared to request this information to improve the understanding of the registered sites.	Request site registry status from the BC Online Site Registry	Advisian	20-Apr-18
18	KK Li	City of Surrey	Webinar	15-Feb-18	Key is what is the likelihood that the contaminant will reach the aquifer.	Review the likelihood definitions to confirm that they appropriately define travel to the aquifer (i.e presence and thickness of a confining layer).	Review and potentially revise likelihood definitions	Advisian	20-Apr-18
19	Marc Zuber	Fraser Health Authority	Webinar	15-Feb-18	In terms of in your matrix you mentioned “possible effects” as opposed to “potential effects”. Is there a difference between those two words? The way I look at it is that what you’re saying here is that whatever’s going on that those site registries is possible that it’s going to contaminate the aquifer. But if I see the word “potential” then it may be that there may be potential there but it may not be possible for that contaminant to get into the aquifer. So I don’t know, maybe that might help to clarify the liklihood definition.	Review the likelihood definitions to confirm that they appropriately define travel to the aquifer (i.e presence and thickness of a confining layer).	Review and potentially revise likelihood definitions	Advisian	20-Apr-18

Appendix 2 City of White Rock Water Supply Well Construction Details

City of White Rock Water Supply System
Well Construction Details

CoWR Well No.	Well Tag No.	Status	Date Constructed	Location	Easting	Northing	Ground Elev. (masl)	Borehole Depth (mbgs)	Casing Diameter (cm (inch))	Well Depth (mbgs)	Screened Interval (mbgs)			Screen Length (m)	Aquifer Material	Stratigraphic Unit	Top of Aquifer (mbgs)	Confining Lithology	Confining Stratigraphy	Yield* (m^3/day)
1	23109	Active	1974	Oxford Site	513758	5430619	84.7	103.0	50.8 (20)	103.0	94.5	to	103.0	8.5	Sand & Gravel	Semiahmoo S&G	76.83	Silty sand/blue clay	Semiahmoo Till	2,376
2	112567	Active	1980	Oxford Site	513787	5430615	84.7	102.4	40.6 (16)	101.8	91.4	to	99.4	7.9	Sand & Gravel	Semiahmoo S&G	76.83	Silty sand/blue clay	Semiahmoo Till	1,866
3	15721	Active	1959	Oxford Site	513820	5430660	90.5	118.9	30.5 (12)	104.7	103.0	to	104.7	1.7	Sand & Gravel	Semiahmoo S&G	82.93	Fine sand/blue clay	Semiahmoo Till	2,601
4	25763	Active	1977	High Street	513218	5430719	81.47	97.5	35.6 (14)	96.9	86.0	to	96.9	10.9	Sand & Gravel	Semiahmoo S&G	73.17	Silty sand/blue clay	Semiahmoo Till	1,728
5	2823	Decom	1947	Buena Vista Ave.	513737	5430161	6.1	63.4	20.3 (8)	63.4	34.1	to	53.6	19.5	Gravel	Semiahmoo S&G	15.55	Till	Semiahmoo Till	2,678
6	81630	Active	1991	Merklin Site	514789	5430843	110.5	143.6	24.5 (10)	142.2	131.0	to	142.2	11.2	Sand	Semiahmoo S&G	119.21	Till (inferred)	Semiahmoo Till	1,823
7	112566	Active	2012	Merklin Site	514809	5430916	111.6	146.3	30.5 (12)	146.2	139.0	to	145.2	6.2	Sand	Semiahmoo S&G	119.21	Fine sand/silt/till	Semiahmoo Till	2,670
8	112812	Comm	2016	Merklin Site	513911	5430665	97.5	120.1	30.5 (12)	119.1	109.2	to	119.1	9.9	Sand	Semiahmoo S&G	90.85	Silt/clay	Semiahmoo Till	2,212

Notes:
* Comments received from CoWR on the Aquifer Protection Plan 50% Draft Report (October, 2017)
Well construction details for Well No. 1 to Well No. 6 from Piteau 2010, Well No. 7 from Piteau 2012, and for Well No. 8 from Piteau 2017.
Screened interval for Well No. 5 based on Precision 2009 (screened below lower sand and gravel).
Comm – recently commissioned
Decom – to be decommissioned
masl – metres above sea level
mbgs – metres below ground surface
m - metres
cm – centimeters
inch - inch
m3/day – cubic metres per day

Appendix 3 Groundwater Modelling Technical Memorandum

Advisian
Address Line 1
Address Line 2 Address Line 3
Phone Number
Fax Number

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www.advisian.com

Memorandum

To:	Saad Jasim, City of White Rock	**Date:**	25 May 2018
CC:	Margaret Scott, Lucien Lyness	**From:**	Zidra Hammond, Matthew Webb
Doc No:	307071-01216-00-WW-MEM-0001	**File Loc:**	Burnaby
Subject:	Groundwater Model Development	**Project:**	307071-01216

1. Introduction

Advisian (part of WorleyParsons Group) was retained by the City of White Rock (CoWR) to prepare an Aquifer Protection Plan (Plan) for the White Rock water supply system. A 3D numerical model (model) was used to support development of the Plan. The model was used to define the well protection area and to assess the response of the Sunnyside Aquifer to current and future groundwater extraction as well as climate change impacts on water availability.

This technical memorandum has been prepared to provide supplemental technical details on model documentation that were not included in the Plan. This includes details on the numerical model parameterization, calibration, sensitivity analysis, and model limitations. The conceptual site model (CSM), scenario development, and groundwater model results are presented in the Plan.

2. Data Sources

A summary of the data sources used to develop the numerical model is presented in Table 1.

Table 1 Data Sources

Data Type	Description/Title	Reference
Report	Production Well No.7 Completion Report	Piteau Associates Engineering Ltd., 2012
Report	Production Well No. 8 Completion Report	Piteau Associates Engineering Ltd., 2017
Report	Surrey Ground Water Supply Study – Phase 1 Report	Gartner Lee Ltd., 1999
SCADA	White Rock water supply system	Aquifer Protection Data.xls provided by CoWR

Data Type	Description/Title	Reference
	monitoring data, includes water levels and pumping rates from 2012-2017 for Well#1 to Well#7.	
Map	Surficial Geology, New Westminster, West of Sixth Meridian, British Columbia (1:50,000)	Armstrong, J E; Hicock, S R, Geological Survey of Canada, "A" Series Map 1484A, 1980, 1 sheet, https://doi.org/10.4095/108874
Geographic Dataset	British Columbia digital geology (1:250,000 to 1:50,000) including bedrock and faults	Cui, Y., Miller, D., Schiarizza, P., and Diakow, L.J., 2017. Ministry of Energy, Mines and Petroleum Resources, BC Geological Survey Open File 2017-8.
Geographic Dataset	Topography	Digital elevation map (DEMs) from the City of White Rock and Surrey GIS portals.
Geographic Dataset	Drainage	Surface water features from the City of White Rock and Surrey GIS portals.
Geographic Dataset	WELLS database, standardized based on Advisian algorithm	BC Data Catalogue: WHSE_WATER_MANAGEMENT.GW_WATER_WELLS_WRBC_SVW WHSE_WATER_MANAGEMENT.GW_WATER_WELLS_LITHOLOGY_SP
Climate	Climate normals 1981–2010, White Rock STP climate station	WMO ID 1108914

3. Numerical Model

3.1 Code Selection

The modelling was conducted using FEFLOW (Finite Element subsurface FLOW) Version 7.0 (DHI WASY 2017). FEFLOW was developed by WASY GmbH Institute for Water Resources Planning and Systems Research and is distributed by the Danish Hydrology Institute (DHI). The program uses finite element analysis to solve the groundwater flow equation.

The key reasons for using FEFLOW include the following:

- Widely accepted model to solve complex groundwater problems;
- Efficient refinement around irregularly shaped features (e.g., rivers, coastline);
- Efficient local refinement around discrete features like wells;

- Parallel computing capabilities;
- High quality graphics and GIS integration; and
- Expandable to simulate density-dependent flow and transport, a potential requirement for future model applications.

3.2 Groundwater Modelling Guidelines

Groundwater modeling was conducted using the following guidelines:

- American Society for Testing and Materials (ASTM) D 5447-93. Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem.
- ASTM D 5490-93. Standard Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information.
- Wels C., Mackie D., and Scibek J., April 2012. Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities.

3.3 Domain and Grid

The CSM presented in the Plan provides the basis for numerical model development. Physical boundaries were used to define the model domain shown in Figure 1. The model domain to the west and south is defined by the location of the coastal waters of Semiahmoo Bay and Mud Bay. The domain extents to the north and southeast are defined by the location of the Nicomekl River and Campbell River respectively. The model boundary along the east is primarily based on the inferred extent of the Sunnyside Aquifer based on initial geologic interpretations.

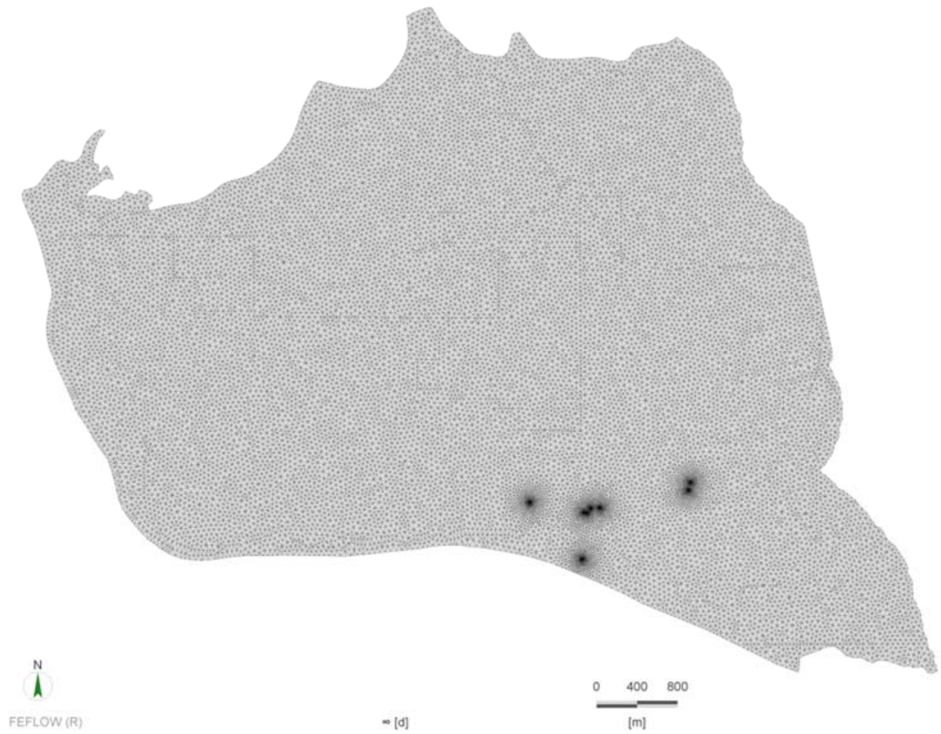

Figure 1 Model Domain and Mesh

To develop a robust finite element mesh (mostly Delaunay triangles; Diersch 2014), the minimum element internal angle target was set to 30 degrees, Delaunay triangle criteria were enforced, and non-supermesh elements were smoothed following mesh generation in order to minimize the number of obtuse angles. Only 1% of the final mesh triangles contained an angle greater than 90 degrees. The average node spacing in the majority of the model domain is approximately 50 m, but is refined down to 0.15 m next to pumping wells. The model mesh is shown in Figure 1.

3.4 Model Layers

The model layering is summarized in Table 2. This follows the hydrostratigraphic framework presented in the Plan. The Sunnyside Aquifer has been divided into three layers. Three layers were used to more accurately represent the top and bottom screen elevations of the CoWR wells which do not coincide with the vertical extents of the Sunnyside Aquifer. Elevations were interpolated out over 250 m so that L5a, L5b, and L5c were one third of the Sunnyside Aquifer thickness for the remainder of the modelled aquifer extents.

Table 2 Model Layering

Model Layer Number.	Hydrogeology Unit (HGU)
L1	Capilano Aquitard (Surficial Geology)
L2	Vashon Aquitard
L3	Quadra Sand Aquifer
L4	Semiahmoo Aquitard
L5a	Sunnyside Aquifer
L5b	
L5c	

The top elevation of each layer was contoured using the kriging algorithm in Surfer Version 15.3.307 (Golden Software Inc. 2018). The elevation of each layer surface is shown in Figure 2 to Figure 6.

The elevation of the bottom of the model is shown in Figure 7. The bottom of the model coincides with low permeability material (e.g. clay) from the Semiahmoo Drift. It is interpreted to act as a no flow boundary. Limited borehole information was available to define this unit.

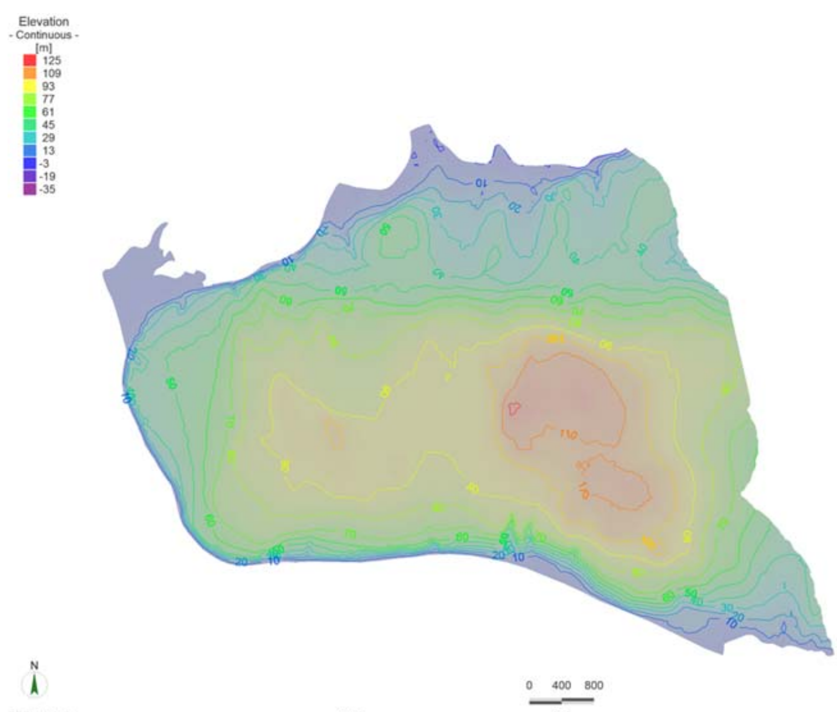

Figure 2 Layer 1 Surface Elevation

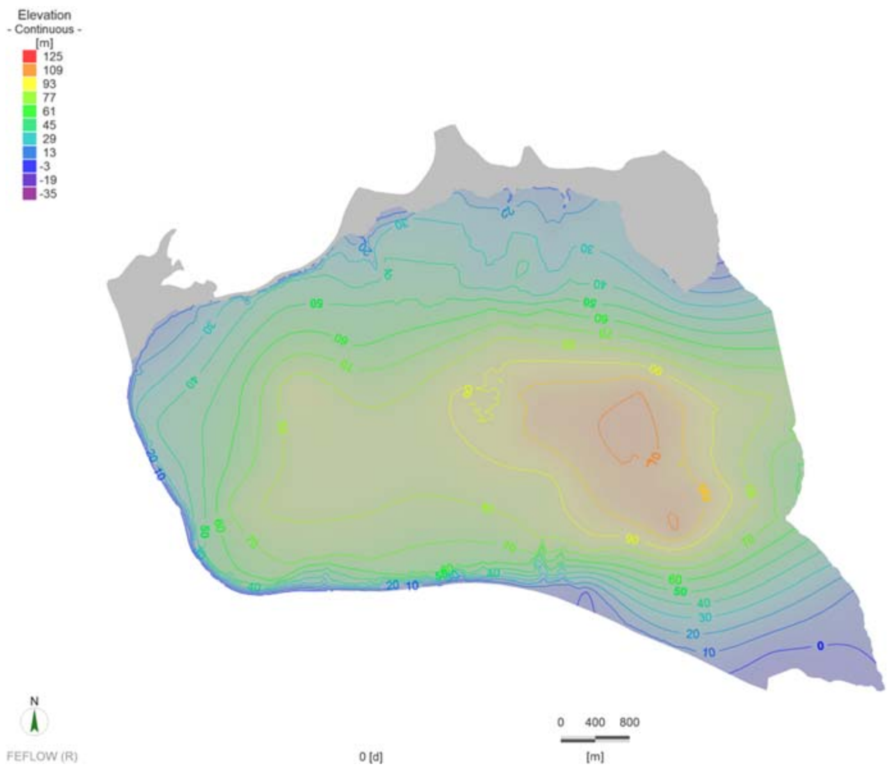

Figure 3 Layer 2 Surface Elevation

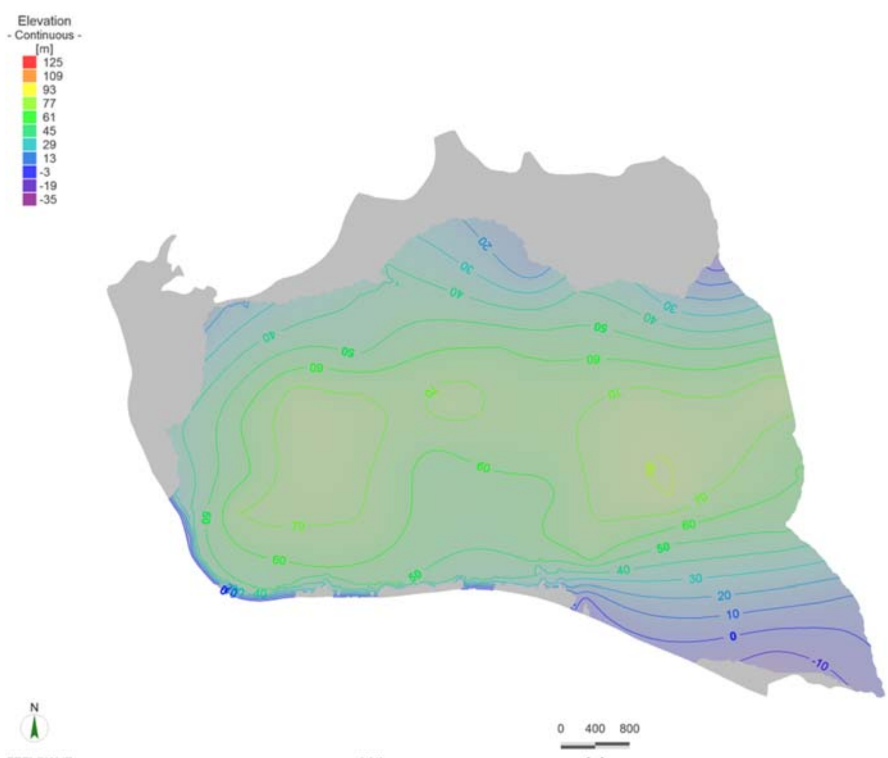

Figure 4 Layer 3 Surface Elevation

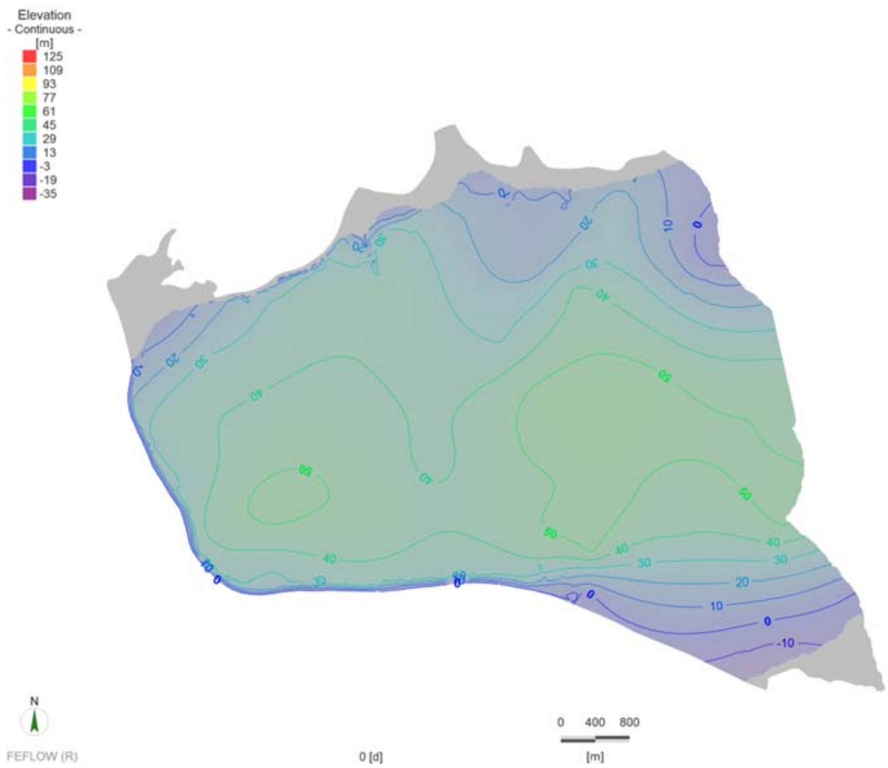

Figure 5 Layer 4 Surface Elevation

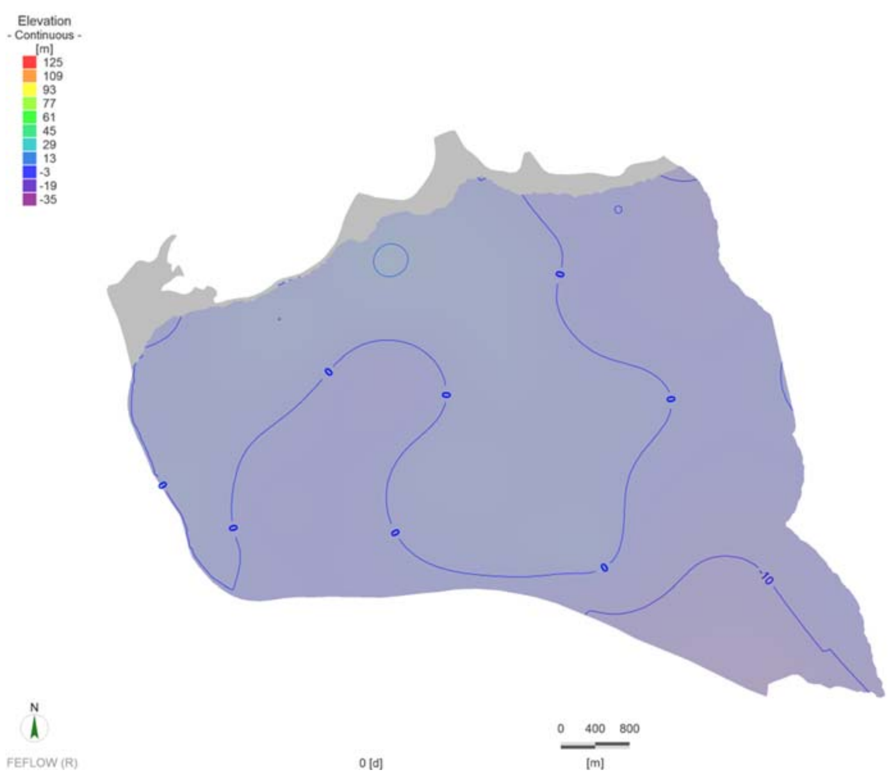

Figure 6 Layer 5 Surface Elevation

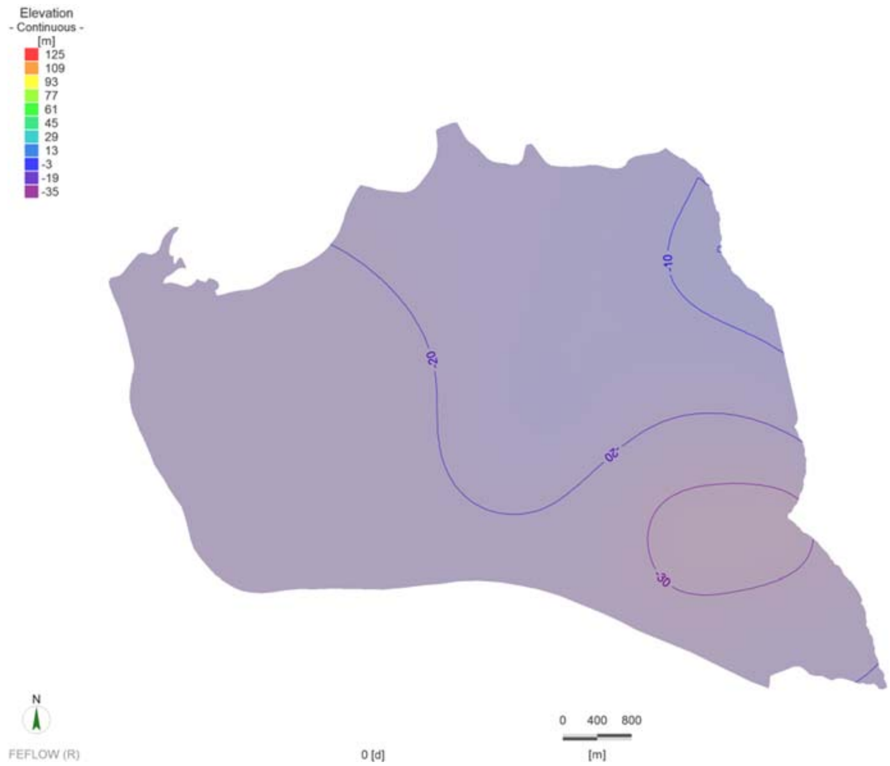

Figure 7 Model Bottom Elevation

3.5 Hydraulic Conductivity Distribution

Pumping test results from the CoWR were reviewed to provide estimates of hydraulic conductivity (K) and specific storage (Ss). Armstrong (1984) and Freeze & Cherry (1979) were used to define hydraulic properties in the absence of site-specific information. A summary of the material properties for each model layer is provided in Table 3. Hydraulic conductivities applied to the model layers are shown in Figure 8 to Figure 12. All layers were assumed to have a vertical hydraulic conductivity one order of magnitude lower than the respective lateral hydraulic conductivity. A porosity of 0.3 was assumed for all layers.

Table 3 Hydraulic Properties and Data Sources

HGU No.	Lithology	K (m/s)	Ss (1/m)	Reference
L1	SAb – lowland peat, in part overlying sandy to clay loam	$1x10^{-9}$ to $1x10^{-5}$	-	Freeze and Cherry 1979, range for silt
	SAg – medium to coarse sand and gravel	$1x10^{-5}$ to 1	-	Freeze and Cherry 1979, range for clean sand and gravel
	Ca - poorly sorted sand and gravel	$1x10^{-5}$ to 1	-	Freeze and Cherry 1979, range for clean sand and gravel
	Cb - medium to coarse sand	$1x10^{-5}$ to $1x10^{-2}$	-	Freeze and Cherry 1979, range for clean sand
	Cd - silt loam, clay loam, till-like	$1x10^{-9}$ to $1x10^{-5}$	-	Freeze and Cherry 1979, range for silt/loess, also within upper range of glacial till
L2	Hardpan, till, clay	$1x10^{-12}$ to $1x10^{-5}$	-	Freeze and Cherry 1979, range for glacial till
L3	Fine sand, silty sand, fine sands, and sand with clay	$1x10^{-7}$ to $1x10^{-3}$	-	Freeze and Cherry 1979, range for silty sand
L4	Till and clay	$1x10^{-12}$ to $1x10^{-5}$	-	Freeze and Cherry 1979, range for glacial till
L5	Sand and gravel, silty sand and gravel, silt and gravel, sand with gravel	$9x10^{-4}$ to $3x10^{-2}$, geomean ($3x10^{-3}$)	$5x10^{-6}$ to $3x10^{-2}$	Pumping test data for MW#7 (Piteau 2012) and MW#8 (Piteau 2017)

Homogeneous properties were assumed for each layer given the available data and the current level of understanding in the CSM with the following exceptions:

- The Capilano Aquitard (Layer 1, Figure 8), surficial geology mapping (GSC Map 1484A) was used to delineate areas having different hydraulic properties;
- Semiamhoo Aquitard (Layer 4, Figure 11), two higher K windows based on interpretation of well logs to represent hydraulic connection to the Quadra Sand Aquifer (Layer 3); and
- Sunnyside Aquifer (Layer 5, includes 5a, 5b, and 5c, Figure 12), two parameter zones used to better calibrate to the observed hydraulic gradients (steeper to the east and shallower to the west).

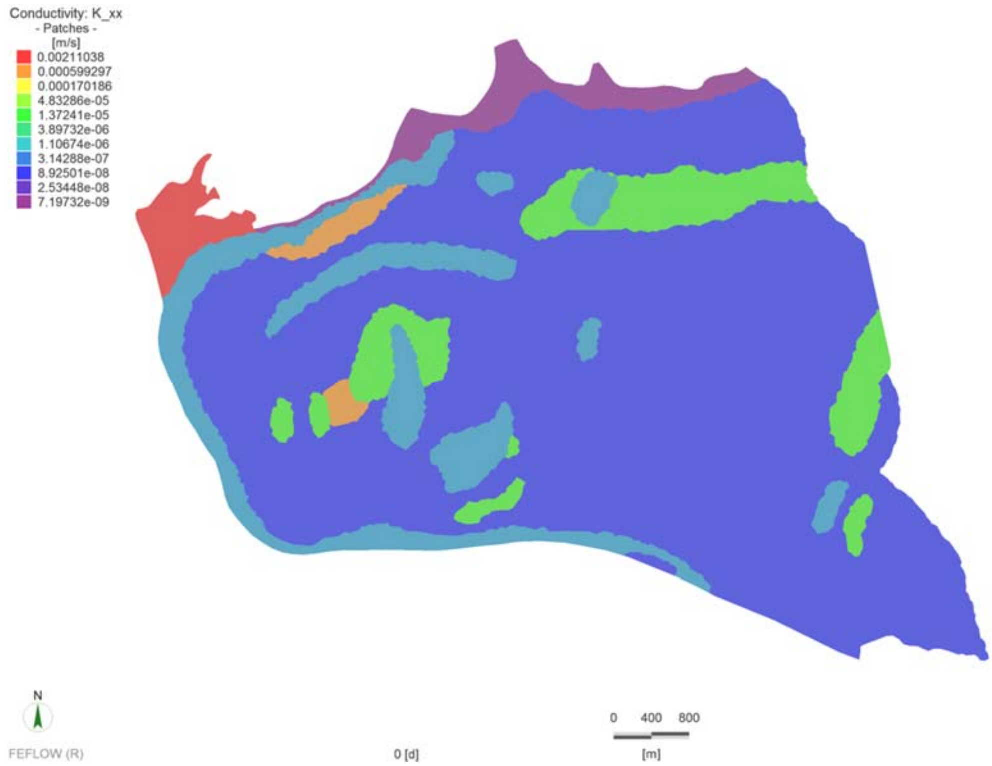

Figure 8 Layer 1 Hydraulic Conductivity Distributions

Figure 9 Layer 2 Hydraulic Conductivity Distributions

Figure 10 Layer 3 Hydraulic Conductivity Distributions

Figure 11 Layer 4 Hydraulic Conductivity Distributions

Figure 12 Layer 5 Hydraulic Conductivity Distributions

3.6 Boundary Conditions

3.6.1 Recharge

Monthly recharge rates were calculated based on a percentage of precipitation. An annual recharge rate of 258.5 mm/year was estimated for the South Surrey Uplands based on land use, slope, and soil characteristics (Gartner Lee 1999). Assuming annual precipitation of 1,100 mm from 1981-2010 climate normals for the White Rock STP climate station (WMO ID 1108914), this corresponds to approximately 23% of precipitation infiltrating into the subsurface.

The 23% recharge rate was applied to monthly precipitation normals for the White Rock STP climate station for the steady state model and under baseline conditions for transient model predictions. Predictive modeling runs that accounted for climate change conditions used projected monthly precipitation based on the Representative Concentration Pathway (RCP) 8.5 emission scenario for the 2025s (2011-2040) timeslice. The methodology used to project future precipitation conditions is outlined in the Plan. A summary of monthly recharge values for baseline and climate change conditions is provided in Figure 13.

For the steady state model, monthly recharge rates were calculated and applied to the entire model domain with the exception of the very low K region along the Nicomekl River (SAb, see Table 3). Low recharge values were used in areas with low K to reduce numerical instability. This is a reasonable approach since the recharge occurring in these location is likely very low, and would have negligible impact on the area of interest in the model.

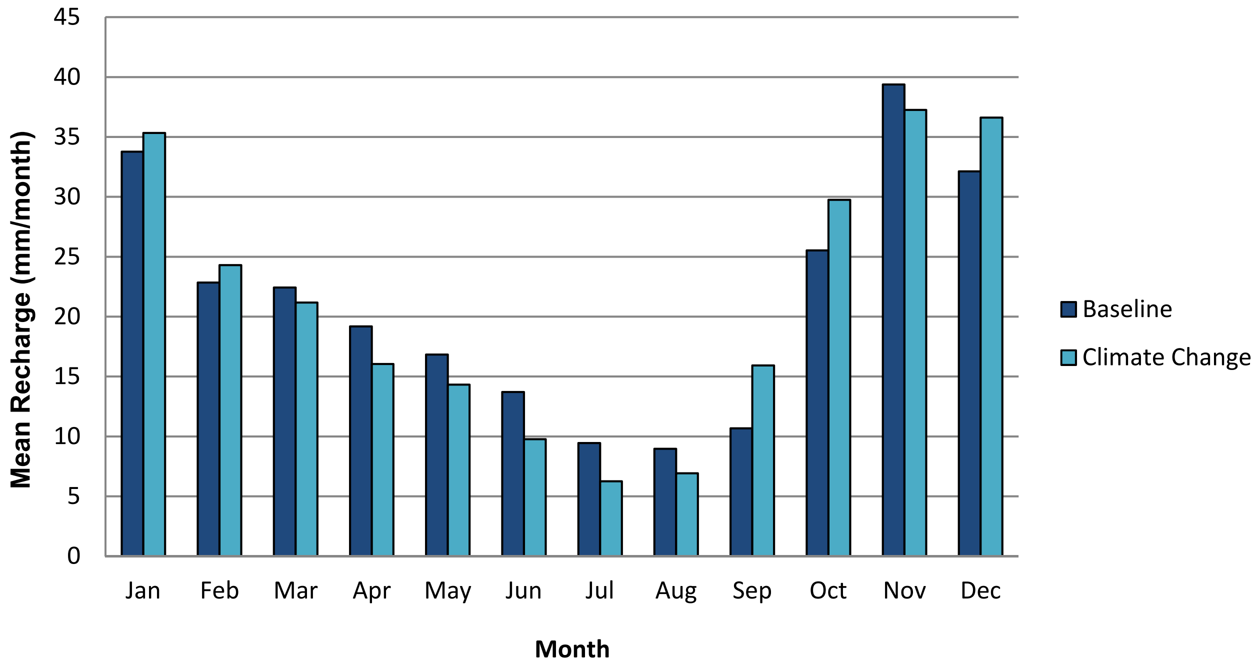

Figure 13 Monthly Recharge for Baseline and Climate Change Conditions

3.6.2 Surface Water Features

The Nicomekl River, Campbell River, and sea level along the coastline were represented as transfer boundary conditions (Figure 14). Transfer boundaries allow specification of groundwater-surface water interaction on the basis of user-defined river stage and river bed conductance, simulated hydraulic head and using Darcy's Law.

Transfer boundary conditions for the rivers were applied to the top layer of the model. FEFLOW allows specification of both an outflow (base flow) and inflow (stream losses to groundwater) conductance for surface water reaches (Diersch 2014). The inflow conductance (C_{out}) for rivers was set to 5.2 x 10^{-8} s^{-1}, assuming 1 m thickness (b) of river bed material and a hydraulic conductivity (K) of 5.2 x 10^{-8} m/s (C_{out} = Kh/b). The rivers are almost entirely gaining within the reaches modelled, so C_{in} has negligible effect on the modelling and was assigned the same value as C_{out}.

Coastal geometry has not been explicitly modelled (i.e. bathymetry data was not used to represent the sea bed elevations beyond the coast). It was assumed that inflow and outflow to the ocean are likely mediated by coastal sediments. The ocean boundary condition was applied as a transfer boundary condition (0 m elevation) to all layers above the Sunnyside Aquifer. The observed static water level dataset suggests a lower connectivity between the Sunnyside Aquifer and the ocean in the west half of the model; therefore, two conductance values were use: 1.2 x 10^{-4} s^{-1} to the west of Coldicutt Park (towards the western edge of the City of White Rock Municipal Boundary) continuing along the coast to the mouth of the Nikomekl River, and 2.27 x 10^{-4} s^{-1} to the east Coldicutt Park to the southern edge of the model boundary.

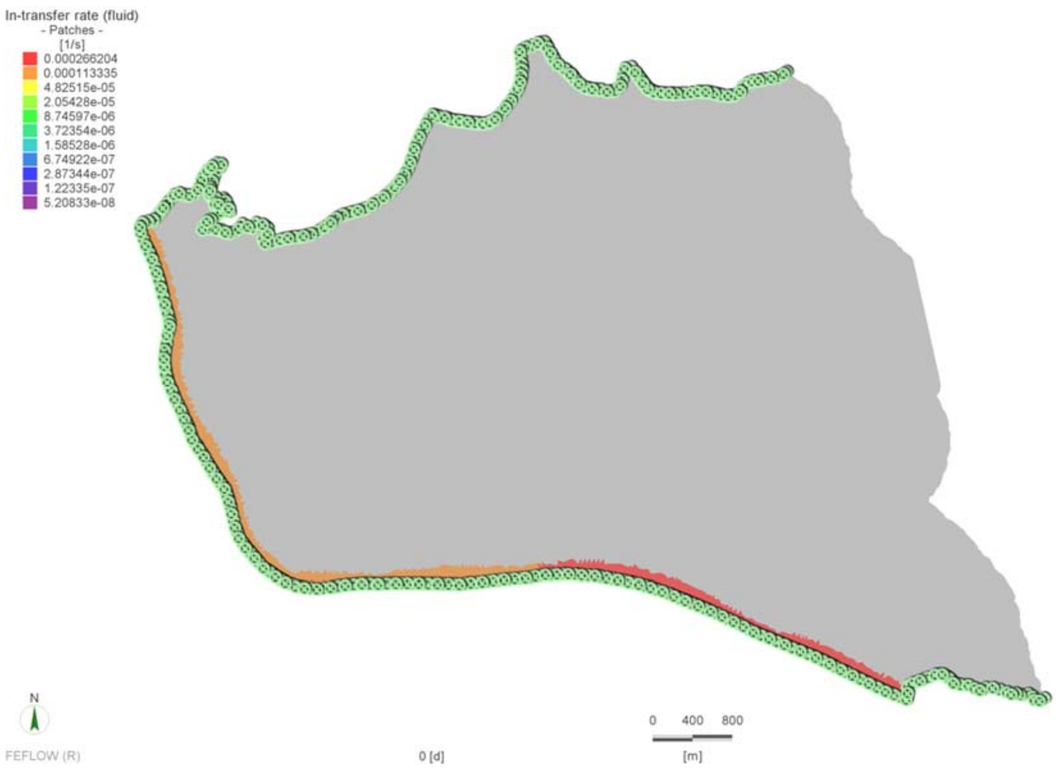

Figure 14 Surface Water Transfer Boundary Condition (green circles)

3.6.3 Sunnyside Aquifer Lateral Inflow

The lateral inflow from the east to the Sunnyside Aquifer was introduced as a result of the initial stages of calibration that indicated that the required volume of recharge for reasonable calibration was not possible from the infiltration of precipitation alone. Inspection of geological logs indicated that there were two areas which were potentially connected to aquifers to the east. A transfer boundary condition was applied at these locations to Layer 5 and a small portion of Layer 4 where the till pinched out (Figure 15).

Water levels observed at Well 28 (Table 6), which was approximately 4.2 km beyond the model boundary, was used to set the eastern transfer boundary condition. The eastern transfer boundary condition represents a hydraulic head at that distance outside the model boundary, flowing through a porous media with initial hydraulic conductivity equal to that of the Sunnyside Aquifer. This conductivity value was later adjusted during calibration.

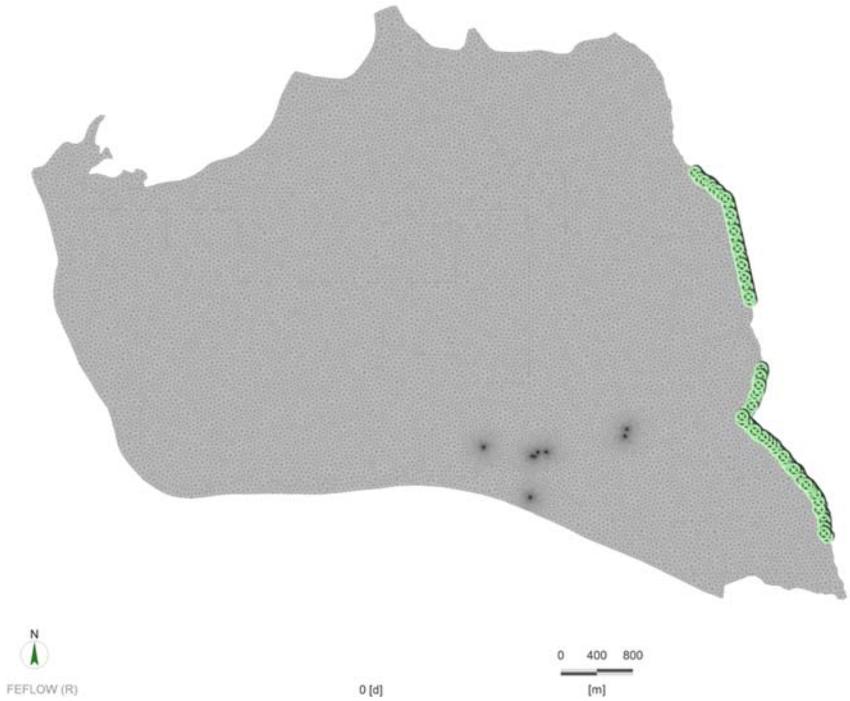

Figure 15 **Eastern Transfer Boundary Condition**

3.7 Model Settings

3.7.1 Flow System Configuration

The model was set as fully confined in order to achieve a satisfactory degree of convergence. Given that the aquifer of interest behaves mostly as confined and all calibration data as well as pumping stresses are within the Sunnyside Aquifer, this was deemed to be a reasonable assumption worth the benefits of greater model stability.

3.7.2 Time Stepping and Initial Conditions

Three types of simulations were performed. The time-step, initial water level conditions, and simulation period for each simulation type is summarized in Table 4. Steady-state calibration represents pre-pumping conditions and provides the initial conditions for the transient calibration. The transient calibration results provide the initial conditions for the forward-looking scenarios.

The transient calibration used a fully automated time-stepping procedure which employed a predictor-corrector method by which FEFLOW reduces the length of the time step as necessary in order to meet the user specified solver criteria. The maximum time-step of the adaptive algorithm was also controlled by the chosen interval for representing the time-variant production well withdrawal rates.

Table 4 Temporal Simulation Details Summary

Simulation Type	Time Step	Initial Conditions	Simulation Period
Steady-State Calibration	n/a	n/a	n/a
Transient Calibration	Daily	Steady-State Calibration	Jan 1, 2011 to Jan 1, 2017
Predictive Scenarios	Monthly	Transient Calibration	Jan 1, 2017 to Dec 31, 2045

3.7.3 Solver Parameters

The FEFLOW SAMG (Algebraic Multigrid method) solver was employed with settings as specified in Table 5.

Table 5 Solver Parameter Summary

Property	Value/Selection
Equation-System Solver	SAMG
Termination Criterion	1.00E-8
Maximum number of PCG Iterations	200
Euclidian Integral (RMS) Norm	1.00E-03
Maximum number of AMG Cycles	50

4. Model Calibration

4.1 Approach

As noted in section 3.7.2, two types of calibration were performed: (1) steady-state calibration representing predevelopment conditions, and (2) transient calibration representing the 1 Jan 2011 to 1 Jan 2017 period.

For the steady-state calibration, manual calibration was achieved by trial-and-error. An initial model run was completed using best estimates of input parameters based on the existing CSM. Water balance estimates were not formally incorporated in the calibration due to inadequate data to assess outflows to the rivers and ocean.

Trial solutions were then generated by changing model input parameters and comparing simulated water levels to observed water levels from the WELLS database. Model input parameters were varied within the range of uncertainty identified for input parameters. Only one parameter was varied for each trial solution. Trial solution results were evaluated by comparing simulated results to observed conditions for hydraulic heads, groundwater flow (gradients and direction), and qualitatively for components of the water balance.

The transient calibration was informed by observed water levels from the CoWR pumping wells in the Sunnyside Aquifer; however, calibration to pumping well water levels is problematic due to the well-loss component of drawdown, which is not explicitly represented in the model. Well losses vary between wells, and over time and by pumping rate at each individual well. For this reason, the transient portion of the calibration was focussed on seasonal trends, and longer-term trends visible in the data. In addition to this, as a general guide, the drawdown in the aquifer should be less than that observed in the pumping well itself.

Model water balance calculations were monitored during the calibration process. A model with a poor mass balance can indicate that improvements may be needed and that the quality of the calibration could be suspect (Jones and Mendoza 2013). Water balance closure (achieving a water balance error less than 1%) was a key aspect considered in determining a numerical solution strategy for modelling.

4.2 Results

4.2.1 Steady State

The water level dataset used for steady state calibration is provided in Table 6. The well tag number (WTN) corresponds to the well identification in the WELLS database. These wells were interpreted as screened within the Sunnyside Aquifer based on well depth and the top of the model layer for the Semiahmoo sand and gravel unit. Water level measurement dates were assumed to be the same as the construction date provided in the WELLS database. As shown in Table 6, the year and season the water level measurements were recorded varies from well to well. The water levels provide an indication of groundwater direction; however, a better dataset is required to provide greater certainty in interpretation.

Table 6 Water Level Calibration Dataset from WELLS Database

No.	WTN	Easting	Northing	Date	Observed (masl)	Simulated (masl)	Residual (m)
1	2658	508909	5432461	1-Jan-46	1.38	0.93	0.45
2	3007	510449	5433937	1-Jan-48	1.6	2.16	-0.56
3	3329	508890	5433565	1-Jan-49	0.14	0.62	-0.48
4	14707	508857	5432626	1-Jan-56	4.6	0.84	3.76
5	15720	513661	5433717	1-Jan-59	9.84	7.52	2.32
6	16126	514734	5431362	1-Oct-59	9.77	7.81	1.96

No.	WTN	Easting	Northing	Date	Observed (masl)	Simulated (masl)	Residual (m)
7	20099	509664	5430727	11-Aug-66	5.58	0.77	4.81
8	21583	510218	5433432	26-Jun-68	2.15	2.53	-0.38
9	23974	513623	5434824	9-Sep-70	8.63	8.57	0.06
10	25764	513219	5430705	1-Jan-72	3.49	4.02	-0.53
11	27191	514199	5434671	1-Nov-72	9.57	10.05	-0.48
12	30303	513299	5431404	9-May-74	6.6	5.30	1.30
13	32460	513474	5433420	6-May-75	5.91	6.81	-0.90
14	33875	513669	5433456	23-Nov-75	2.67	7.23	-4.56
15	34041	513409	5434219	1-Jan-76	7.8	7.56	0.24
16	36239	509015	5431450	1-Jan-77	1.12	0.76	0.36
17	37780	514140	5434840	29-Jul-77	9.99	10.05	-0.06
18	45419	510123	5431180	26-Jun-80	2.42	1.36	1.06
19	46780	512769	5433113	17-Dec-80	1.87	5.47	-3.60
20	81630	514788	5430842	26-Apr-91	4.78	7.38	-2.60
21	72333	511501	5432647	23-May-96	3.52	3.26	0.26
22	34039	513251	5432311	1-Jan-76	4.21	5.96	-1.75
23	36241	513210	5432367	1-Jan-77	2.83	5.92	-3.09
24	49573	514155	5434680	19-Nov-81	11.79	9.97	1.82
25	27190	514161	5434725	1-Nov-72	8.19	10.02	-1.83
26	23109	513758	5430619	2012	2.89	4.88	-1.99
27	112567	513787	5430615	4-Jul-05	2.47	4.93	-2.46
28	74126	519142	5431022	15-Dec-88	23.26		

Note: masl: metres above sea level.

Table 7 shows the calibration statistics for the steady state calibrated model. The scaled residual mean (which takes into account the range of observed heads, i.e. 11.65 m) of 2.2% and scaled residual deviation of 18.1% satisfy the targets of less than 10% and 20% respectively for moderate quality data sets (Anderson and Woessner 1992).

Table 7 Calibrated Model Steady State Statistics

Calibration Statistic	Value
Residual Mean	-0.25
Absolute Residual Mean	1.62
Residual Std. Deviation	2.11
Sum of Squares	121.61
Root Mean Squared (RMS) Error	2.12
Min. Residual	-4.56
Max. Residual	4.81
Number of Observations	27
Range in Observations	11.65
Scaled Residual Std. Deviation	18.1%
Scaled Absolute Residual Mean	13.9%
Scaled RMS Error	18.2%
Scaled Residual Mean	-2.2%

The general flow pattern of inflow from the east and outflow to the north, west and south, as seen in the contoured steady state data set (Figure 4-4 of Plan), is reasonably represented in the calibrated simulated head contours (Figure 16). A second zone of higher hydraulic conductivity was added to the Sunnyside Aquifer in order to address the observed discrepancy in hydraulic gradients in the eastern half of the model compared to the western half. Alternatives for this flow behaviour may include changes to aquifer thickness, connectivity of aquifers above, or variation in the spatial distribution of recharge.

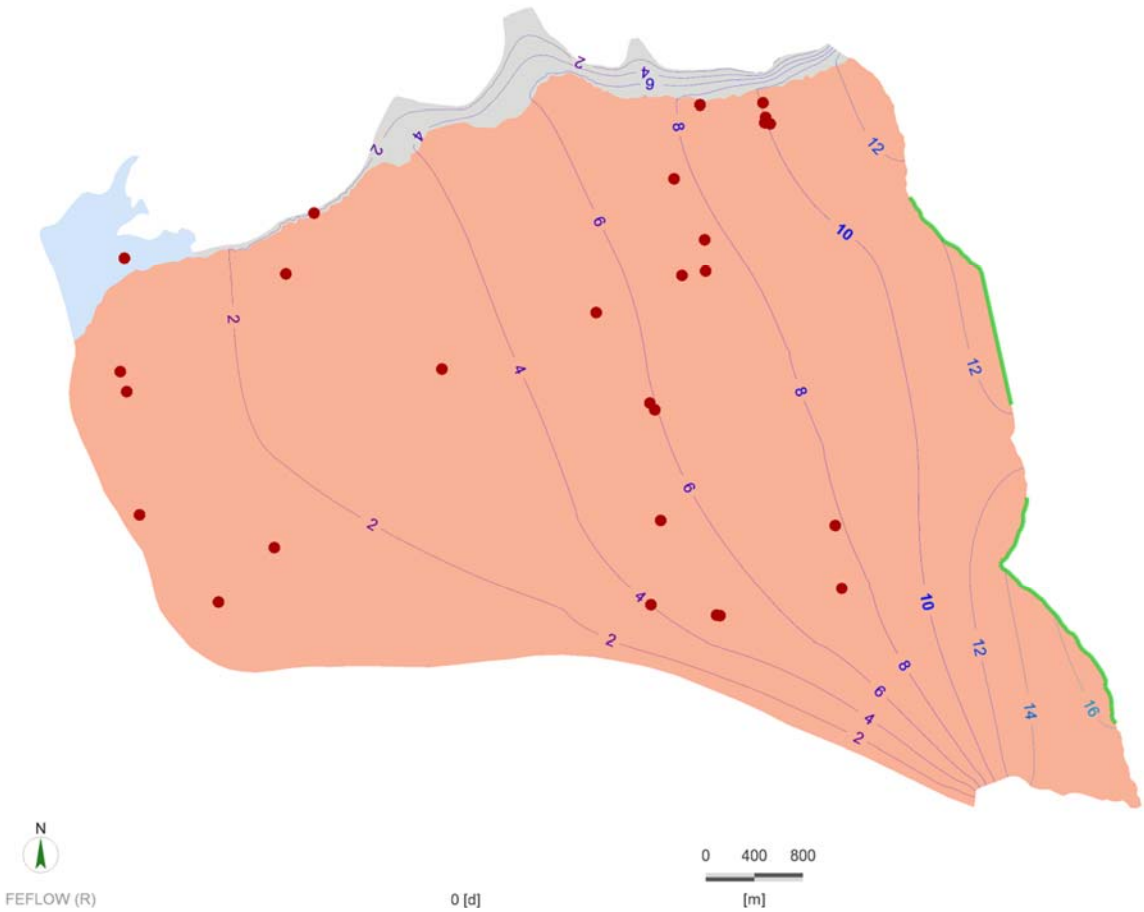

Figure 16 Simulated Hydraulic Head Contours

Table 8 lists the mass balance components for the steady state model. For the calibrated model, the key components of the flow are inflow from vertical drainage (24,390 m^3/d) and inflow from the east (9,460 m^3/d), which constitute 70% and 27% of total recharge respectively. Given the lack of major surface water feature within the model domain, the balance and magnitude of these two inflows is the main driving force behind the mass balance. The vast majority of the inflow eventually exits the model at the ocean boundary. The small quantities exiting at both rivers may be an underestimation, but there are no data available within the model domain upon which baseflow to these rivers can be readily estimated. Higher conductance values for the river beds were tested and had a negligible effect on the groundwater contours, particularly near the CoWR wells.

Table 8 Calibrated Steady State Mass Balance

Component	Out (m^3/d)	In (m^3/d)
Recharge from Precipitation	-	24,390
Eastern Inflow to Sunnyside Aquifer	-	9,460
North River	30	-
South River	180	-
Ocean	34,220	690
Error	0.3%	

Calibrated Parameter Values

Table 9 lists the calibrated hydraulic conductivity values for all differentiated hydrogeological units. Vertical hydraulic conductivity was maintained at one order of magnitude lower than corresponding lateral hydraulic conductivity. Specific storage was maintained at the uniform initial parameter value of 1.0E-04 for all layers.

Table 9 Calibrated Hydraulic Conductivity Values

Layer	Hydrogeological Unit (HGU)	Expected Range (m/s) [1]	Calibrated Value (m/s)
1	Surficial Geology (SAb)	$1x10^{-9}$ to $1x10^{-5}$	7.2E-09
1	Surficial Geology (SAg)	$1x10^{-5}$ to 1	2.1E-03
1	Surficial Geology (Ca)	$1x10^{-5}$ to 1	5.7E-04
1	Surficial Geology (Cb)	$1x10^{-5}$ to $1x10^{-2}$	1.9E-05
1	Surficial Geology (Cd)	$1x10^{-9}$ to $1x10^{-5}$	1.0E-07
2	Vashon Aquitard	$1x10^{-12}$ to $1x10^{-5}$	6.3E-07
3	Quadra Sand Aquifer	$1x10^{-7}$ to $1x10^{-3}$	5.7E-04
4	Semiahmoo Aquitard	$1x10^{-12}$ to $1x10^{-5}$	2.0E-06
4	Semiahmoo Aquitard (High K Window)	$1x10^{-7}$ to $1x10^{-3}$	1.3E-04
5	Sunnyside Aquifer (East)	$9x10^{-4}$ to $3x10^{-2}$	2.7E-04

Layer	Hydrogeological Unit (HGU)	Expected Range (m/s) (1)	Calibrated Value (m/s)
5	Sunnyside Aquifer (West)	$9x10^{-4}$ to $3x10^{-2}$	1.1E-03

Notes: 1 See Table 2 for details on expected range.

4.2.2 Transient

As mentioned in Section 4.1, the transient calibration took an informal approach owing to the absence of monitoring well data from non-pumped wells. Simulated long term trends and seasonal variability were reasonably represented in the model when compared to the water levels observed in the pumping wells. It was important not to over-calibrate to these data due to the uncertainty inherent in water levels in pumped wells, which consist of a currently unknown proportion between aquifer drawdown and the drawdown component from well loss.

The drawdown in the aquifer will typically be less than the drawdown in a pumped well; therefore, the target drawdown at the well should be less than observed data. However, the model is configured as fully confined for numerical stability reasons, but pumping test responses suggest a more leaky confined behaviour.

The model configuration as fully confined will result in greater simulated drawdown at the well than if it were modelled as unconfined and the water table allowed to drop below the top of the Sunnyside Aquifer. Calibration efforts tried to ensure drawdown at the well was less than seen in the observed data to avoid the risk of overcompensating with increased hydraulic conductivity values. Due to transient data quality concerns, it was preferred to weight calibration efforts towards steady state and to use pumping test results to provide some constraints on the parameter values of the Sunnyside Aquifer.

Following updates to the steady state model, the transient model was ran as check on long-term trends and seasonal variability. In general, these were deemed to be acceptable given the confidence in the transient data set. Graphs of the simulated and observed water levels at the pumping wells are provided in Attachment.

5. Sensitivity Analysis

5.1 Steady State

Model-independent parameter estimation and uncertainty analysis (PEST) was used to assess the sensitivity of the steady state parameterisation. The sensitivities of the calibrated model are shown in Table 10. The steady state model simulation is most sensitive to recharge applied to the top of the model. Gartner Lee (1999) provided an estimate for recharge within the model domain and it was decided to constrain this value to the data available. The model is also sensitive to horizontal hydraulic conductivity of the aquifers, high K windows of the Semiahmoo Aquitard, and inflow rates to the Sunnyside Aquifer (from the east, outside the model domain).

Based on the sensitivity analysis, future data collection efforts should focus on recharge studies, hydraulic conductivity/pumping tests that are spatially distributed throughout the model domain, and investigating the hydraulic connection of the Sunnyside Aquifer to the Quadra Sands and to aquifer systems in the east.

Table 10 Calibrated Steady State Parameter Sensitivities (PEST)

Layer	Zone	Parameter	Sensitivity
1	Model Top	Recharge	1.14E+03
5	Sunnyside Aquifer (East)	Kh	1.04E+00
3	Quadra Sand Aquifer	Kh	4.51E-01
5	Sunnyside Aquifer (West)	Kh	4.38E-01
-	Transfer Rate (Inflow to Sunnyside Aquifer)	In Transfer Rate	4.27E-01
4	Semiahmoo Aquitard (High K Windows)	Kh	1.22E-01
-	Outflow to Ocean (Western Section)	Out Transfer Rate	7.29E-02
5	Sunnyside Aquifer (East)	Kv	4.65E-02
4	Semiahmoo Aquitard	Kv	3.17E-02
-	Outflow to Ocean (Eastern Section)	Out Transfer Rate	2.85E-02
3	Quadra Sand Aquifer	Kv	2.57E-02
-	Inflow from Ocean (Western Section)	In Transfer Rate	1.97E-02
4	Semiahmoo Aquitard	Kh	1.83E-02
4	Semiahmoo Aquitard (High K Windows)	Kv	1.52E-02
1	Surficial Geology (Cb)	Kh	1.17E-02
1	Surficial Geology (Sag)	Kh	1.10E-02
1	Surficial Geology (Sab)	Kh	1.05E-02
5	Sunnyside Aquifer (West)	Kv	9.61E-03
-	Inflow from Ocean (Eastern Section)	In Transfer Rate	9.04E-03
1	Surficial Geology (Sab)	Kv	7.29E-03

Layer	Zone	Parameter	Sensitivity
2	Vashon Aquitard	Kv	3.95E-03
-	Outflow to Nikomekl River	Out Transfer Rate	3.15E-03
1	Surficial Geology (Cd)	Kh	2.98E-03
1	Surficial Geology (Cd)	Kv	2.58E-03
2	Vashon Aquitard	Kh	2.38E-03
-	Outflow to Campbell River	Out Transfer Rate	1.83E-03
1	Surficial Geology (Sag)	Kv	5.56E-04
1	Surficial Geology (Cb)	Kv	2.61E-04
-	Inflow from Campbell River	In Transfer Rate	2.14E-04
1	Surficial Geology (Ca)	Kh	1.07E-04
-	Inflow from Nikomekl River	In Transfer Rate	7.82E-05
1	Surficial Geology (Ca)	Kv	4.02E-06
-	Outflow from Sunnyside Aquifer	Out Transfer Rate	0

5.2 Transient

As with the transient calibration, assessment of transient sensitives was simply a high-level review. This included inspection of the deviation from general long term and seasonal trends as well as changes in short-term responses to pumping.

In contrast to the steady state model simulation, the transient model was not sensitive to changes in recharge. This difference likely reflects the relatively short time duration of the transient model which does not allow sufficient time for the hydraulic head distribution to adjust to the change in inflow. Sensitivity to specific storage of the Sunnyside Aquifer was very low and within the range of literature values in Batu (1998).

As would be expected, the transient model was sensitive to hydraulic conductivity changes in the Sunnyside Aquifer, with changes of a factor of +/-25% resulting in maximum drawdown at the well increasing by 4 m between the +25% and -25% simulations. This suggests that the calibrated model is likely in a representative range of hydraulic conductivity values, since changes much beyond that would result in more drastic changes in model behaviour that no longer adequately represent the observed data.

6. Model Limitations

The groundwater flow model developed herein is subject to the following main assumptions and limitations:

- The FEFLOW model is designed to simulate groundwater flow in which: (a) saturated matrix flow conditions exist; (b) Darcy's Law applies; (c) the density of groundwater is constant; and (d) the principal directions of anisotropy do not vary within the system.
- Due to a lack of data and the assumption that pumping wells were reasonably far from the coast, density dependent flow was not simulated for the seawater boundaries. The prediction of capture zones, which are predominantly further inland than the pumping wells, should be minimally impacted by this interpretation. However, the application of simulated model results within a few hundred metres of the coast should take this limitation into account.
- Due to limited transient monitoring well data availability, transient calibration of the site-specific behaviour of each individual well was not possible, and thus the model should not be used for precise well behaviour predictions without further data collection in order to perform a full formal calibration.
- The CSM forms the basis for model development and provides a simplified representation of the hydrogeological conditions. In reality, there may be heterogeneity in hydraulic parameters within and between the aquifers and aquitards that has not been considered.
- The model has been configured as fully confined; however, pumping test results suggest that the Sunnyside Aquifer exhibits a leaky confined aquifer behaviour. The model configuration as fully confined will result in slightly greater simulated drawdown at a well than if it were modelled as unconfined and the water table allowed to drop below the top of the Sunnyside Aquifer. However, this flow model configuration was considered reasonable given that it will result in a more conservative estimate of capture zones for aquifer protection planning.
- Coastal geometry has not been explicitly modelled (i.e. bathymetry was not used to represent the sea bed elevations beyond the coast as described in Section 3.6.2). This assumption typically results in slightly underestimated heads in the vicinity of a coast when the ocean boundary condition is represented as a vertical column over the full model thickness. Consequently, heads can be overestimated in the vicinity of a coast when the ocean boundary condition is represented only in the upper layers. The latter assumption has been used here due to the suggested limited connectivity between the ocean and Sunnyside Aquifer; hence, calibrated recharge and hydraulic conductivity may account for some of this error (decreased and/or increased respectively). Given that the pumping wells are reasonably far from the coast, it is unlikely that the choice of coastal boundary condition will unduly affect capture zone results, but this limitation will affect the model predications in the immediate vicinity of the coastal area.
- The emphasis of the model calibration has been on general groundwater flow patterns and responses to seasonal and multi-year stresses. The model is therefore not necessarily suitable to simulate responses to stresses over shorter time scales.
- Additional field data are required to address model non-uniqueness and refine the CSM. This could include a greater understanding of the hydraulic connection with aquifer systems to the east, an expanded hydraulic conductivity dataset to inform variation both vertically and laterally, improved estimates of the spatial distribution of recharge, and a greater understanding of connection with seawater.

7. References

ASTM (American Society for Testing and Materials) D 5447-93. Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem.

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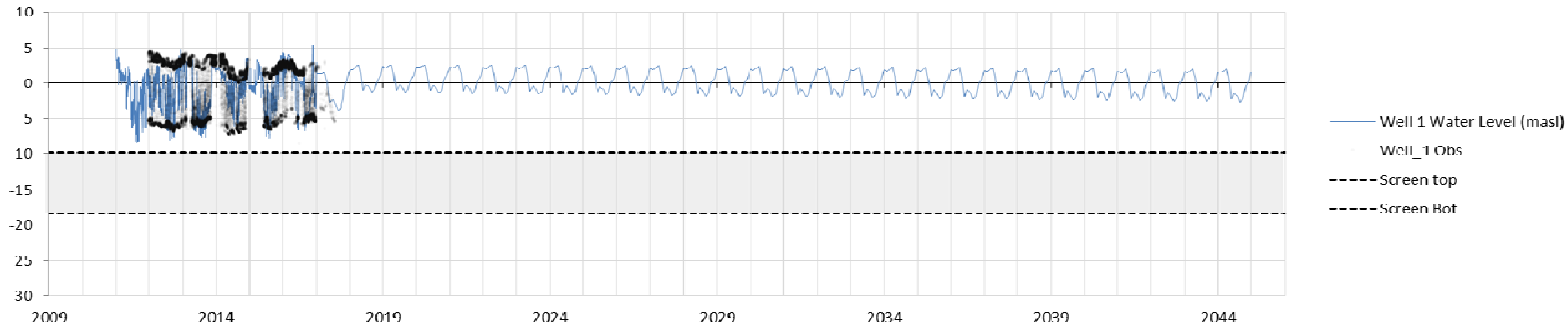
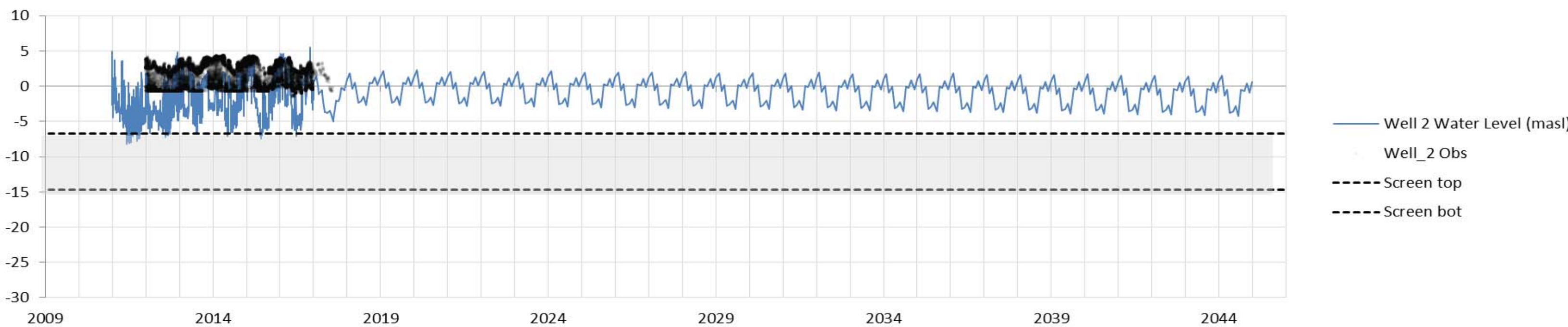
Attachment





CITY OF WHITE ROCK
GROUNDWATER MODEL DEVELOPMENT

HYDROGRAPHS

WELL NO. 1 AND WELL NO. 2

Date: 25-MAY-2018	Drawn by: MW	Edited by: ZH	App'd by: MES

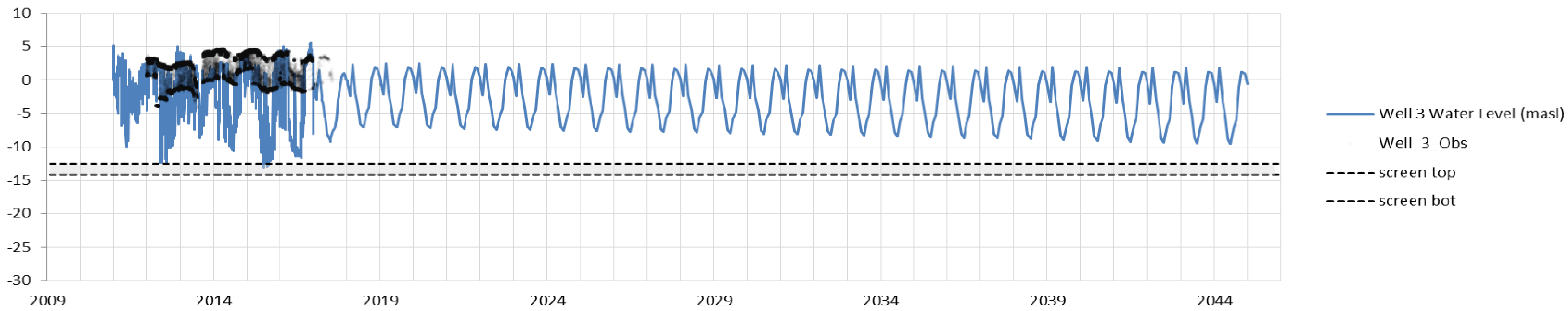
OneWay to zero harm

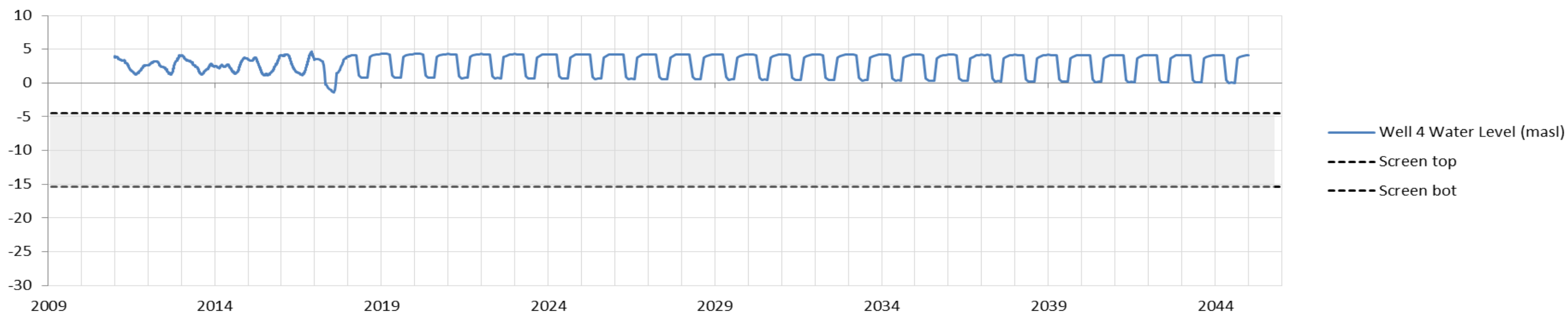
Advisian WorleyParsons Group

WorleyParsons Project No. 307071-01216

FIGURE: A1

REV 0





CITY OF WHITE ROCK
GROUNDWATER MODEL DEVELOPMENT

HYDROGRAPHS
WELL NO. 3 AND WELL NO.4

Date:	25-MAY-2018	Drawn by:	MW	Edited by:	ZH	App'd by:	MES

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WorleyParsons Project No. 307071-01216

FIGURE: A2

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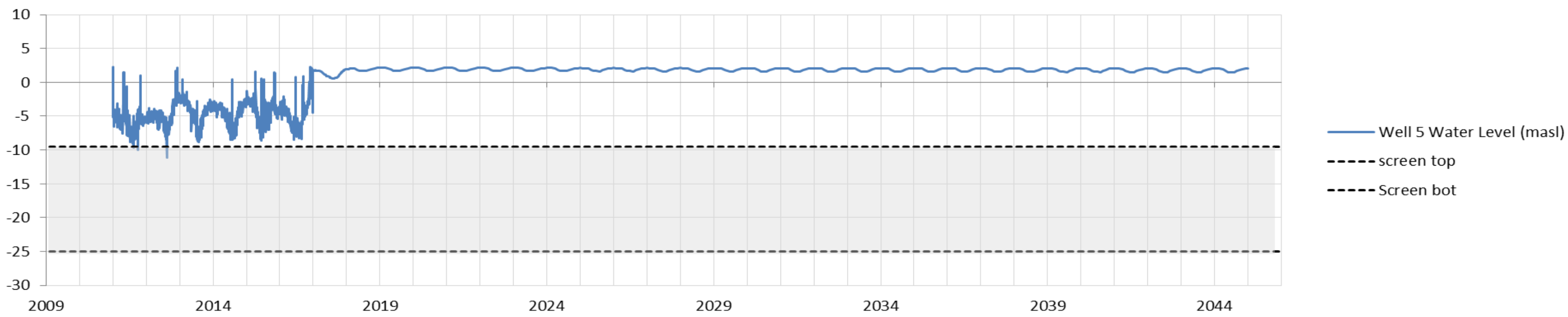

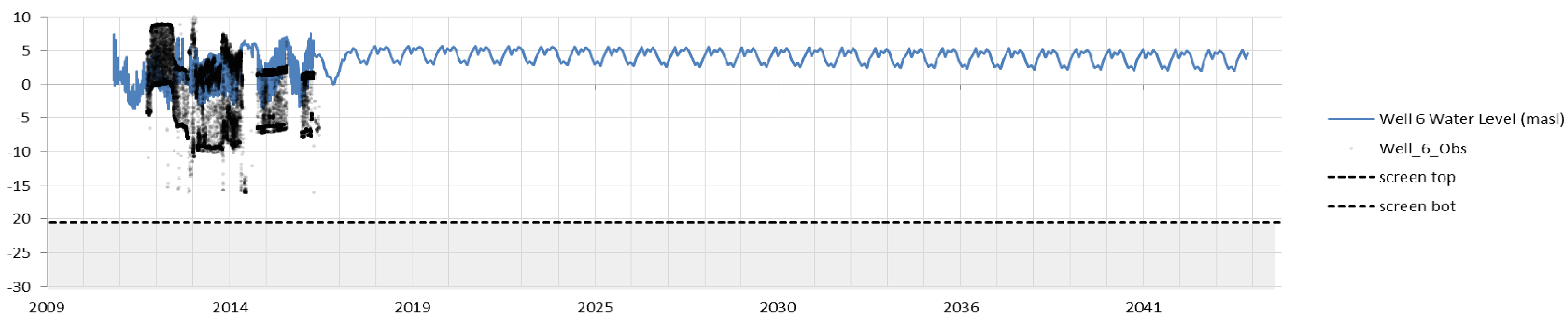

CITY OF WHITE ROCK
GROUNDWATER MODEL DEVELOPMENT

HYDROGRAPHS
WELL NO. 5 AND WELL NO. 6

Date:	25-MAY-2018	Drawn by:	MW	Edited by:	ZH	App'd by:	MES

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WorleyParsons Project No. 307071-01216

FIGURE: A3

REV 0

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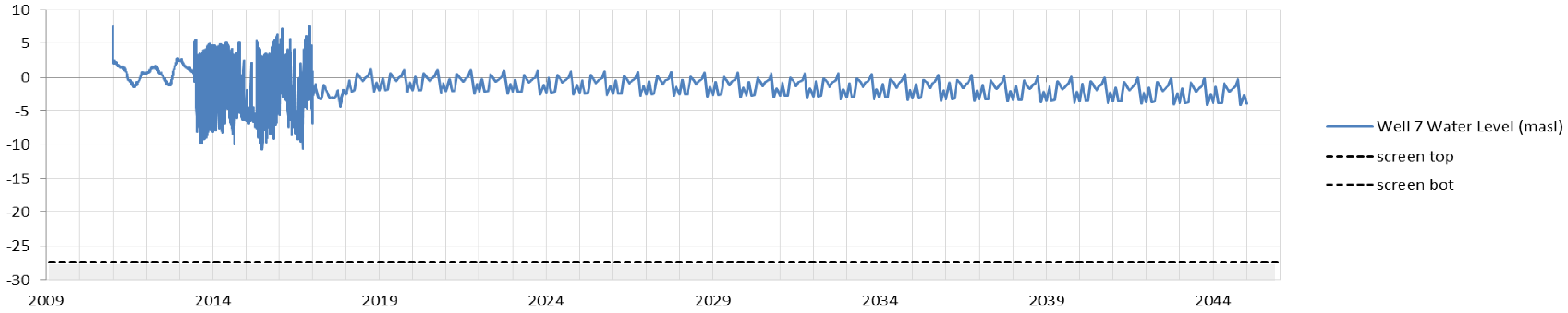

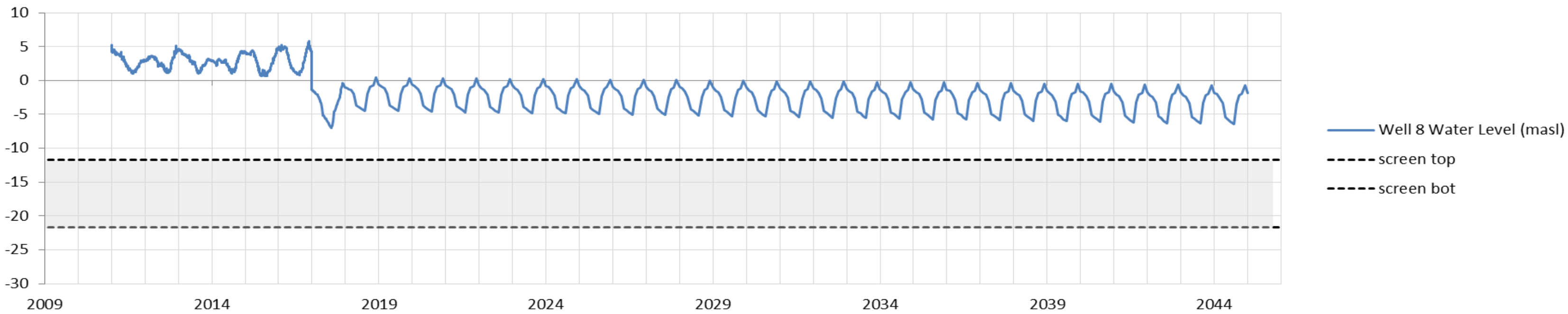

CITY OF WHITE ROCK
GROUNDWATER MODEL DEVELOPMENT

HYDROGRAPHS
WELL NO. 7 AND WELL NO. 8

Date: 25-MAY-2018	Drawn by: MW	Edited by: ZH	App'd by: MES

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WorleyParsons Project No. 307071-01216

FIGURE: A4 | REV 0

Appendix 4 Groundwater Supply Risk Characterization Table

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City of White Rock Aquifer Protection Plan
Groundwater Supply Risk Characterization Table

CITY OF WHITE ROCK

Risk No.	Groundwater Hazard	Distance from CoWR Wells	Possible Effects	Category	Scale	Current CoWR Mitigation Measures	Likelihood Level		Consequence Level		Risk Classification		New Mitigation Action
1	Future groundwater withdrawals by the City of Surrey	Outside of well capture zone, approximately 3 km northwest of the Oxford Site	Decrease in groundwater quantity	Quantity	CoWR/ Regional/ Provincial	*Water Sustainability Act* (2016) *Environmental Assessment Act* (2002)	Municipality of Surrey has plans to supplement water supplied from Greater Vancouver Water District with groundwater from two wells at Sunnyside Acres Urban Forest Park, annual extraction volumes of 800,000 m^3 and 1.3 million m^3 starting within the next 10 years (2023).	A	Groundwater modeling of City of Surrey and CoWR extraction suggests modifications to groundwater flow patterns; however, hydrostratigraphy review indicates minimal impact to operations.	1	Moderate	4	1) Regional study: development of a regional groundwater model to better understand connectivity of Sunnyside Aquifer to adjacent aquifers and to support boundary conditions for local models. 2) Regional Groundwater Committee, goal includes sustainable groundwater resources development 3) CoWR needs to be recognized as a stakeholder for any proposal that involves the Sunnyside Aquifer, working collaboratively with regulatory agencies and project proponents
2	Future groundwater withdrawals by the City of Surrey	Outside of well capture zone, approximately 3 km northwest of the Oxford Site	Pumping in other locations of the aquifer could result in changes to well capture zone that would impact groundwater management approach	Quality	CoWR/ Regional/ Provincial	*Water Sustainability Act* (2016) *Environmental Assessment Act* (2002)	Municipality of Surrey has plans to supplement water supplied from Greater Vancouver Water District with groundwater from two wells at Sunnyside Acres Urban Forest Park, annual extraction volumes of 800,000 m^3 and 1.3 million m^3 starting within the next 10 years (2023).	A	Capture zones delineated following the simulation of Scenario 2 indicates that pumping conducted by the City of Surrey has a very minor effect to the well protection zone.	1	Moderate	4	1) Regional study: development of a regional groundwater model to better understand connectivity of Sunnyside Aquifer to adjacent aquifers and to support boundary conditions for local models. 2) Regional Groundwater Committee, goal includes sustainable groundwater resources development 3) CoWR needs to be recognized as a stakeholder for any proposal that involves the Sunnyside Aquifer, working collaboratively with regulatory agencies and project proponents
3	Agricultural land use east of model boundary	Outside of well capture zone, approximately 3km east of Merklin Site	Groundwater contamination - nutrients, fertilizer/pesticide, microbiological as a result of agricultural land use east of the model boundary	Quality	CoWR/ Regional/ Provincial	APP (2018) CoWR Source Water Monitoring Program (includes nitrate-N and nitrite-N)	Groundwater contamination from agricultural land use (nutrients, fertilizer/pesticide, microbiological) could occur at some time given inflows to the aquifer from the east based on current conceptual model and that the Merklin Site 10-yr capture zone extends to the eastern extents of the Sunnyside aquifer. The full extent of this capture zone is uncertain given the limited understanding of the Sunnyside aquifer's connectivity to adjacent aquifers.	B	Annual sampling of Nitrate-N and Nitrite-N already included in monitoring program with concentrations below drinking water guidelines or non-detect based on 2016 CoWR Annual Water Report.	2	Moderate	5	1) Regional study: development of a regional groundwater model to better understand connectivity of Sunnyside Aquifer to adjacent aquifers and to support boundary conditions for local models. 2) Regional Groundwater Committee, goal includes integrated water resource and land use planning. 3) Periodic monitoring of a comprehensive list of PCOC in raw groundwater.
4	Uncertainty in groundwater flow into the aquifer from the east	Outside of well capture zone, approximately 3km east of Merklin Site	Decrease in groundwater levels, larger 10-yr capture zone, and conflicts with minor water users (seasonal groundwater extraction for irrigation)	Quantity	CoWR/ Regional/ Provincial	APP (2018)	Groundwater from the east estimated to provide approximately 45% of inflows to aquifer system, the groundwater model is sensitive to regional flow estimates, decrease in regional inflows possible due to increase in groundwater demand by municipalities to the east or minor groundwater users for agricultural purposes, and the Merklin Site 10-yr capture zone extends to the eastern extents of the Sunnyside aquifer. The full extent of this capture zone is uncertain given the limited understanding of the Sunnyside aquifer's connectivity to adjacent aquifers.	B	Some impacts to groundwater availability. Well capture zone may expand further to the east, resulting in some conflicts with minor groundwater users.	2	Moderate	5	1) Regional study: development of a regional groundwater model to better understand connectivity of Sunnyside Aquifer to adjacent aquifers and to support boundary conditions for local models. 2) Regional Groundwater Committee, goal includes sustainable groundwater resources development 3) CoWR needs to be recognized as a stakeholder for any proposal that involves the Sunnyside Aquifer, working collaboratively with regulatory agencies and project proponents
5	Potential water use inefficiencies by local users	CoWR municipal boundaries	Seasonal decrease in groundwater quantity	Quantity	CoWR	APP (2018) Water Restrictions Water Conservation Plan	Seasonal water restrictions not followed by some CoWR residents, inefficient toilets, inefficient irrigation systems, high water demand landscaping	B	Some water availability impacts within the next 10 years, particularly during summer season when water demand is highest	2	Moderate	5	1) Public awareness based on public opinion poles to target communication efforts (e.g., public open house, pop-up displays, school programs, library groundwater resource center, etc.). 2) Development of rebate program targeting toilets, laundry machines, and landscaping/irrigation systems. 3) Better enforcement of water restrictions.
6	Agricultural land use east of model boundary/ inter-aquifer flow from the east	Outside of well capture zone, approximately 3km east of Merklin Site	Decrease in groundwater quantity, user conflicts	Quantity	CoWR/ Regional/ Provincial	*Water Sustainability Act* (2016) *Environmental Assessment Act* (2002)	Groundwater modeling suggests connection to adjacent aquifers to the east. Irrigation wells and water supply systems have been identified to the east. It is possible that groundwater demands may increase in the future, resulting in a lower water table and less water inputs into the Sunnyside Aquifer.	B	Some impact to water availability and some water use conflicts, regional water use contributes to cumulative effects	2	Moderate	5	1) Regional study: development of a regional groundwater model to better understand connectivity of Sunnyside Aquifer to adjacent aquifers and to support boundary conditions for local models. 2) Regional Groundwater Committee, goal includes sustainable groundwater resources development

Risk No.	Groundwater Hazard	Distance from CoWR Wells	Possible Effects	Category	Scale	Current CoWR Mitigation Measures	Likelihood Level		Consequence Level		Risk Classification		New Mitigation Action
7	Saltwater intrusion/upconing of coastal aquifer based on existing well network	Outside of groundwater capture zone	Groundwater contamination - natural source of chloride and sodium	Quality	CoWR/ Regional/ Provincial	CoWR monitoring program Well#5 no longer in use	Current CoWR well network is located more than 600 m from coastline at elevations above 80 masl, low chloride concentrations based on 2016 CoWR Annual Water Report, Well#5 no longer in use. Simplified analytical solution suggests saltwater interface is downgradient of well capture zone using projected pumping rates at the Oxford site.	C	Concentration of potential contaminants of concern expected below DW guideline, aesthetic objective. Long-term corrective actions required if saltwater impacts occur. Salt concentrations could impact operations.	3	Moderate	6	1) Regional study: Modeling of freshwater/saltwater interface and potential impacts of saltwater intrusion/upconing under various pumping scenarios. 2) Continued monitoring of chloride and sodium. Include boron analysis to identify salt from seawater. 3) Installation of a monitoring well between the CoWR well network and the coastline to monitor for potential saltwater intrusion.
8	Changes to recharge due to climate change impacts	Within 10-yr capture zone and aquifer recharge zones east of the model domain	Changes in groundwater quantity	Quantity	CoWR/ Regional	CCAP (2010) ISMP (2010)	Large body of evidence to support climate change is occurring. Changes in recharge assumed to be proportional to changes in precipitation but further study on climate change impacts to the hydrologic cycle is required.	B	Some impact, potential for seasonal impacts to water availability.	1	Low	7	1) Regional study: Detailed assessment of climate change and land use impacts to hydrologic cycle (e.g. HELP model) to better understand effects on recharge. 2) Regional Groundwater Committee, goal to develop a regional climate change strategy and regional monitoring network that includes climate stations, stream gauge stations, and dedicated groundwater monitoring wells. 3) A request should be made to the Provincial government to install an observation well in the Sunnyside aquifer.
9	Chevron Service, 1776 Martin Dr, Surrey, BC V4A 6E7 Station	Outside CoWR boundaries, approximately 800m northeast of Oxford Site	Groundwater contamination - BTEX, LEPH, VPH, VOCs, MTBE, PAHs	Quality	CoWR/ Regional/ Provincial		Contamination can result from spills/leakage, age of service station unknown, potential for attenuation and chemical biodegradation, natural barrier to vertical migration provided by confining layer.	C	Concentrations of potential contaminants of concern expected below DW guideline, human-health based.	2	Low	8	1) Regional Groundwater Committee, goal includes integrated water resource and land use planning 2) Follow-up with business to provide well protection information and ensure best management practices and environmental performance program is in place 3) Request City of Surrey review zoning in the area of the well capture zone to determine if other commercial/industrial activities with the potential to pollute have been permitted 4) Signage in well capture zone and recharge areas. 5) Periodic analysis of a comprehensive list of PCOC in raw groundwater.
10	Courtesy Cleaners, 1959 152 St, Surrey	Outside of CoWR boundaries, approximately 1 km northeast of Oxford Site	Groundwater contamination - VPH, LEPH, PCE and degradation products (TCE, DCE, vinyl chloride)	Quality	CoWR/ Regional/ Provincial		Contamination can result from spills/leakage, potential for attenuation and chemical biodegradation, natural barrier to vertical migration provided by confining layer.	C	Concentrations of potential contaminants of concern (TCE) expected below DW guideline, human-health based.	2	Low	8	1) Regional Groundwater Committee, goal includes integrated water resource and land use planning 2) Follow-up with business to provide well protection information and ensure best management practices and environmental performance program is in place 3) Request City of Surrey review zoning in the area of the well capture zone to determine if other commercial/industrial activities with the potential to pollute have been permitted 4) Signage in well capture zone and recharge areas. 5) Periodic analysis of a comprehensive list of PCOC in raw groundwater.
11	Surrey Winter Maintenance Routes (1st Priority)	Outside of CoWR boundaries, approximately 300 m from both Merklin and Oxford sites	Groundwater contamination - chloride, sodium	Quality	CoWR/ Regional/ Provincial	Monitoring Program (includes sampling for chloride and sodium)	Seasonal application of brine, occurs intermittently and generally for relatively short duration during winter months, natural barrier to vertical migration provided by confining layer.	C	Concentrations of potential contaminants of concern (chloride, sodium) expected below DW guideline, aesthetic based. Sodium-restricted diets would require concentration in drinking water no higher than 20 mg/L (Guidelines for Canadian DW Quality: Technical Document-Sodium 1992).	2	Low	8	1) Review of winter maintenance practices by Surrey 2) CoWR may want to highlight sodium guideline for those on sodium-restricted diets as part of water quality reporting
12	Trucking route (152 St)	Outside of CoWR boundaries, 800m northeast of Oxford Site.	Spills	Quality	CoWR/ Regional/ Provincial		Transportation arteries represent greater risk of spills. Small quantities expected with spill response and remediation as needed. Natural barrier to vertical migration provided by confining layer.	C	Various parameters depending on nature of spills, expected below DW guidelines.	2	Low	8	1) Request notification from Province when spill reporting occurs in the area of the well capture zone. 2) Develop contingency planning in the event a spill occurs in the well capture zone.

City of White Rock Aquifer Protection Plan
Groundwater Supply Risk Characterization Table

Risk No.	Groundwater Hazard	Distance from CoWR Wells	Possible Effects	Category	Scale	Current CoWR Mitigation Measures	Likelihood Level		Consequence Level		Risk Classification		New Mitigation Action
13	King George Blvd	Outside of CoWR boundaries, 1.4km northeast of Merklin Site	Spills	Quality	CoWR/ Regional/ Provincial		Transportation arteries represent greater risk of spills. Small quantities expected with spill response and remediation as needed. Natural barrier to vertical migration provided by confining layer.	C	Various parameters depending on nature of spills, expected below DW guidelines.	2	Low	8	1) Request notification from Province when spill reporting occurs in the area of the well capture zone. 2) Develop contingency planning in the event a spill occurs in the well capture zone.
14	Site Registry ID 6184	Located 700m northeast of Oxford Site	Groundwater contamination - LEPH, HEPH, PAHs, metals, VPH, VOCs, MTBE	Quality	CoWR		Included in Site Registry database. Commercial/industrial activities under Schedule 2 of the CSR listed in synopsis report include F5 (PETRO. PROD., DISPENSE FACILITY, INC. SERV STA./CARDLOT) and G2 (AUTO/TRUCK/BUS/SUBWAY/OTHER VEHICLE REPAIR/SALVAGE/WRECKING). Areas of potential concern include underground fuel or chemical storage tanks.	C	Concentration of potential contaminants of concern expected below drinking water guideline, human-health based.	2	Low	8	1) Update OCP to incorporate groundwater protection into policies 2) Review of CoWR zoning in the area of the well capture zone to ensure that no polluting land uses are permitted 3) Development Permit Areas (DPAs) specific to groundwater protection 4) Follow-up with Province on status of Site IDs with site profiles. 5) Periodic monitoring of a comprehensive list of PCOC in raw groundwater. 6) Signage in well capture zone and recharge areas.
15	Site Registry ID 14507	Located on adjacent property north of Oxford Site	Groundwater contamination - BTEX, LEPH, VPH, VOCs, metals, MTBE, PAHs	Quality	CoWR		Included in Site Registry database. Commercial/industrial activities under Schedule 2 of the CSR listed in synopsis report include F7 (PETRO. PROD., /PRODUCE WATER STRG ABVEGRND/UNDERGRND TANK). Areas of potential concern include above ground fuel or chemical storage tanks other than storage tanks for compressed gases based on synopsis report.	C	Concentration of potential contaminants of concern expected below drinking water guideline, human-health based.	2	Low	8	1) Update OCP to incorporate groundwater protection into policies 2) Review of CoWR zoning in the area of the well capture zone to ensure that no polluting land uses are permitted 3) Development Permit Areas (DPAs) specific to groundwater protection 4) Follow-up with Province on status of Site IDs with site profiles. 5) Periodic monitoring of a comprehensive list of PCOC in raw groundwater. 6) Signage in well capture zone and recharge areas.
16	Changes to recharge due to urbanization or land use changes outside of the CoWR.	Within 10-yr capture zone and aquifer recharge zones east of the model domain	Decrease in groundwater quantity, user conflicts	Quantity	CoWR/ Regional		Large areas of rural/suburban and recreational land use outside of the CoWR. More urbanization could occur at some time given population growth.	C	Consequence depends on spatial extent and type of land use change. Some impact to groundwater availability assumed.	2	Low	8	1) Regional Groundwater Committee, goal includes integrated water resource management and land use planning 2) Regional Study: Recharge study, improve understanding of inputs to water system, could include assessment of historical and future land use on recharge
17	Site Registry ID 18637	Located 200m north of Oxford Site	Groundwater contamination - benzo(a)pyrene	Quality	CoWR		Included in Site Registry database. Commercial/industrial activities under Schedule 2 of the CSR listed in synopsis report include H7 (CONTAMINATED SOIL STORAGE, TREATMENT OR DISPOSAL). Investigation reports indicate contaminated fill material was used to decommission a below ground concrete reservoir (as referenced in Piteau 2016). Soil samples of the fill material contained concentrations of chromium and copper above CSR standards for residential and parkland land use. In addition, samples of water collected in January 2016 from the saturated sediments at the base of the reservoir had concentrations of benzo(a)pyrene that exceeded drinking water standards in the CSR. Plans for future development of 1454 Oxford Street include removal and off-site disposal of the former reservoir	C	Concentration of potential contaminants of concern expected below DW guideline, human-health based.	1	Low	9	1) Update OCP to incorporate groundwater protection into policies 2) Review of CoWR zoning in the area of the well capture zone to ensure that no polluting land uses are permitted 3) Development Permit Areas (DPAs) specific to groundwater protection 4) Follow-up with Province on status of Site IDs with site profiles. 5) Periodic monitoring of a comprehensive list of PCOC in raw groundwater. 6) Signage in well capture zone and recharge areas.
18	Site Registry IDs 1796, 7341, 13850, 16271, 17396, 19103	Greater than 300m	Groundwater contamination	Quality	CoWR		Included in Site Registry database. No site profile has been submitted. This suggests commercial/industrial activities under Schedule 2 of the CSR have likely not occurred at the site.	C	Low impact assumed given that no site profile was required.	1	Low	9	1) Update OCP to incorporate groundwater protection into policies 2) Review of CoWR zoning in the area of the well capture zone to ensure that no polluting land uses are permitted 3) Development Permit Areas (DPAs) specific to groundwater protection 4) Follow-up with Province on status of Site IDs with site profiles. 5) Periodic monitoring of a comprehensive list of PCOC in raw groundwater. 6) Signage in well capture zone and recharge areas.

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City of White Rock Aquifer Protection Plan
Groundwater Supply Risk Characterization Table

CITY OF WHITE ROCK

Risk No.	Groundwater Hazard	Distance from CoWR Wells	Possible Effects	Category	Scale	Current CoWR Mitigation Measures	Likelihood Level		Consequence Level		Risk Classification		New Mitigation Action
19	Sanitary/Storm Sewer	In close proximity to all CoWR wells.	Groundwater contamination by sanitary waste or potential contaminated stormwater	Quality	CoWR	Sanitary sewer maintenance, including leak detection programs	Included in Site Registry database. No site profile has been submitted. This suggests commercial/industrial activities under Schedule 2 of the CSR have likely not occurred at the site.	C	Low impact assumed given that no site profile was required.	1	Low	9	1) Periodic analysis of a comprehensive list of PCOC in raw groundwater.
20	Potential contamination from residential land use	In close proximity to all CoWR wells.	Localized groundwater contamination	Quality	CoWR		Could occur, likely to be localized and minor volumes, natural barrier to vertical migration provided by confining layer.	C	Consequence dependent on contaminant, concentration expected below DW guideline	1	Low	9	1) Community hazardous waste collection programs 2) Signage in well capture zone and recharge areas 3) Public awareness based on public opinion poles to target communication efforts (e.g., public open house, pop-up displays, school programs, library groundwater resource center, etc.).
21	Wells constructed prior to 2005	Approximately 1km northeast of Oxford Site, includes WTN 3557, 16126, and 19231 with unknown well use. WTN 25764 located near High Street, potential duplicate of Well#4.	Localized groundwater contamination from surface.	Quality	CoWR		Wells may not be constructed to current regulatory standards, thereby providing potential vertical migration of contaminants that may result in localized impacts to aquifer.	C	Consequence dependent on contaminant, concentration expected below DW guideline	1	Low	9	1) Regional Groundwater Committee, well closure bylaw considerations 2) Confirmation if identified WTN exist within well capture zone through completion of a well inventory 3) Educate domestic well owners on the appropriate methods for well closure and abandonement
22	Presence of naturally occurring arsenic	Within 10-yr capture zone	Arsenic	Quality	CoWR	REAS'EAU Water-NET partnership Treatment Plant Water quality monitoring program	Naturally occurring levels of arsenic, groundwater from Well#6 and Well#7 have the highest levels at or near drinking water guideline based on CoWR monitoring program.	C	Human-health based drinking water guideline of 10 ug/L, as low as reasonably achievable. Water treatment is proposed to address concentrations.	1	Low	9	1) Regional study: build-on existing studies, geochemistry evaluation to better understanding groundwater inflows into the system as well as the source and mobility of arsenic and manganese 2)CoWR monitoring to determine if well operations impact raw groundwater quality (e.g. introduction of oxidizing conditions due to drawdown)
23	Presence of naturally occurring manganese	Within 10-yr capture zone	Manganese	Quality	CoWR	REAS'EAU Water-NET partnership Water treatment plant construction Water quality monitoring program	Naturally occurring levels of manganese, above drinking water guideline in groundwater from a majority of CoWR wells based on CoWR monitoring program. Construction of water treatment plant to removed manganese planned by CoWR.	C	Aesthetic objective based on taste and staining of laundry and plumbing fixtures. Water treatment is proposed to address concentrations.	1	Low	9	1) Regional study: build-on existing studies, geochemistry evaluation to better understanding groundwater inflows into the system as well as the source and mobility of arsenic and manganese 2)CoWR monitoring to determine if well operations impact raw groundwater quality (e.g. introduction of oxidizing conditions due to drawdown)
24	Tsunami hazard	Within 10-yr capture zone	Vertical migration of contamination (saltwater, contaminated waters due to spills, etc.), resulting from a tsunami	Quality	CoWR	Delineation of tsunami area	Existing well network located outside of tsunami hazard area, therefore potential for localized contamination and well damage during tsunami is unlikely. Well #5 located in tsunamic hazard area but no longer in use.	C	Concentration of potential contaminants of concern expected below DW guideline.	1	Low	9	1) Closure of Well #5 in accordance with the Groundwater Protection Regulation