Preface

Technical studies were initiated in 2014 to support both ongoing project planning and future permitting and approval requirements. Since the technical studies were initiated prior to finalizing the scope of the proposed Project, the scope of some studies consider physical activities and spatial areas that are beyond the scope of the Project assessed under the B.C. Environmental Assessment Act. The results of future studies will be presented in the Environmental Assessment Certificate Application that will be prepared for the Project.
Executive Summary

The B.C. Ministry of Transportation and Infrastructure (Ministry) is proposing the George Massey Tunnel Replacement Project (Project) to meet regional, provincial, and national transportation management goals. The proposed Project involves replacing the George Massey Tunnel (Tunnel) with a new bridge spanning the Fraser River South Arm and Deas Island, decommissioning the Tunnel, and improving Highway 99 between Bridgeport Road in Richmond and Highway 91 in Delta.

To support project planning and future permitting and approval requirements, the Ministry initiated studies to document existing environmental and socio-economic conditions that could potentially be affected by the Project. A hydrogeology study to review and document existing groundwater information along the Highway 99 corridor was conducted as part of the environmental program for the Project.

The spatial extent of the study was a 250-m wide corridor centred on the Highway 99 centreline, extending from Westminster Highway in Richmond to the Highway 10 interchange in Delta. This study area was selected based on hydraulic connectivity considerations.

The hydrogeology study was compiled based on a review of all available data and information pertaining to the study area. Although no site-specific groundwater data were collected, the data reviewed are considered to be representative of the regional hydrogeology.

Although groundwater data from the Richmond portion of the study area are limited or absent, regional hydrogeology data were extrapolated from the comprehensive set of studies of the well-understood depositional history and geology of the entire Fraser River delta, and were used to describe existing hydrogeological conditions in Richmond.

Shallow groundwater recharge in the study area originates as direct infiltration of precipitation in up-gradient areas, generally the raised bog systems of Burns Bog (in Delta) and Lulu Island Bog (in Richmond). The ultimate receptor for shallow groundwater from the study area in Delta is Boundary Bay and the Fraser River. In Richmond, the shallow groundwater receptor is the Fraser River. Some portion of the shallow groundwater is also expected to recharge the unconfined South Fraser River delta and Lulu Island aquifers.

Two groundwater and surface water interactions are expected in the study area: groundwater discharge to watercourses during low water-level summer months, and surface water discharge to groundwater during high water-level winter months. In both cases, shallow groundwater within the study area interacts with creeks, ditches, and other watercourses, and can represent a significant portion (up to 80 per cent) of the surface water baseflow.
### Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>μg/L</td>
<td>micrograms per litre</td>
</tr>
<tr>
<td>ASL</td>
<td>above sea level</td>
</tr>
<tr>
<td>L/s</td>
<td>litres per second</td>
</tr>
<tr>
<td>m/s</td>
<td>metres per second</td>
</tr>
<tr>
<td>Ministry</td>
<td>Ministry of Transportation and Infrastructure</td>
</tr>
<tr>
<td>Tunnel</td>
<td>George Massey Tunnel</td>
</tr>
</tbody>
</table>

### Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>acrotelm</td>
<td>Upper portion of the two distinct layers in undisturbed peat bogs; consists of living plant material.</td>
</tr>
<tr>
<td>anthropogenic</td>
<td>Relating to an effect or object caused by humans.</td>
</tr>
<tr>
<td>catotelm</td>
<td>Lower portion of the two distinct layers in undisturbed peat bogs; consists of dead plant material.</td>
</tr>
<tr>
<td>Highway 99 corridor</td>
<td>The right-of-way owned by the Province of B.C. for Highway 99 from the Peace Arch Canada–U.S. border crossing in Surrey to the Oak Street Bridge in Richmond.</td>
</tr>
<tr>
<td>hydraulic conductivity</td>
<td>A property that numerically describes water movement through soil; it is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient.</td>
</tr>
<tr>
<td>hydraulic gradient</td>
<td>Slope of the hydraulic head between two points. Hydraulic head is the elevation to which water will naturally rise in a well, and is the same as the water table for unconfined aquifers.</td>
</tr>
<tr>
<td>peat mound</td>
<td>Domed deposits of peat; associated with raised bogs with a central mound.</td>
</tr>
<tr>
<td>Project disturbance area</td>
<td>All lands and lands under water, except the Project footprint, which are subject to disturbance during Project construction and required for maintenance activities during Project operation.</td>
</tr>
<tr>
<td>water mound</td>
<td>Water table that closely follows the topography of a peat mound.</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS

Preface ................................................................................................................................. i
Executive Summary ................................................................................................................ ii
Abbreviations and Acronyms .............................................................................................. iii
Glossary ................................................................................................................................. iii

1.0 Introduction and Background ......................................................................................... 1
   1.1 Study Background .......................................................................................................... 1
   1.2 Objectives ..................................................................................................................... 1
   1.3 Study Area ..................................................................................................................... 1

2.0 Methodology .................................................................................................................... 2
   2.1 Burns Bog and Lulu Island Bog .................................................................................... 2
   2.2 Agricultural Areas ......................................................................................................... 3
   2.3 Domestic Water Supply Wells ....................................................................................... 3
   2.4 Groundwater Model ....................................................................................................... 3

3.0 Hydrogeological Setting .................................................................................................. 5
   3.1 Geological Setting .......................................................................................................... 5
   3.2 Aquifer Classification .................................................................................................... 6
   3.3 Bog Hydrogeology ......................................................................................................... 6
   3.4 Agricultural Land Hydrogeology ................................................................................... 9

4.0 Conceptual Groundwater Model ..................................................................................... 10
   4.1 Regional Groundwater Recharge and Discharge .......................................................... 10
   4.2 Local Groundwater Flow to the Study Area ................................................................. 10
      4.2.1 Eastern Portion of Study Area (South of Burns Bog) ............................................. 14
      4.2.2 Western Portion of Study Area (Crescent Slough) ............................................... 14
   4.3 Groundwater Flow to Study Area in Richmond ............................................................. 15
   4.4 Groundwater Interactions and Groundwater Receptors .............................................. 16

5.0 Conclusions ..................................................................................................................... 16

6.0 Closing ............................................................................................................................. 17

7.0 Statement of Limitations ................................................................................................. 18

8.0 References ....................................................................................................................... 19
LIST OF TABLES

Table 1  Study Area Estimated Groundwater Velocities..............................................................11

LIST OF FIGURES

Figure 1  Municipal Boundaries and Select Land Uses in the Vicinity of the Project ..........4
Figure 2  Idealized Schematic Hydrogeology Cross-section of the Study Area and Vicinity 8
Figure 3  Groundwater Elevation Contours near Burns Bog for September 2012 (Dry Season) ........................................................................................................................................12
Figure 4  Groundwater Elevation Contours near Burns Bog for March 2012 (Wet Season) ........................................................................................................................................13
1.0 Introduction and Background

This report presents the objectives, methods, and findings of the hydrogeology study undertaken to support project planning as well as future environmental permitting and approval requirements associated with the George Massey Tunnel Replacement Project (Project).

1.1 Study Background

The B.C. Ministry of Transportation and Infrastructure (Ministry) is proposing the Project to meet regional, provincial, and national transportation management goals. To support Project planning and future environmental permitting and approval requirements, the Ministry initiated studies in early 2014 to understand and document existing conditions of environmental components that could potentially be affected by the Project.

Because the studies were conducted prior to the Project scope being finalized, a broader spatial area was considered to accommodate potential refinements in the Project design. This broader scope was established based on a general understanding that the Project would involve modifications of the Highway 99 corridor, including replacement of the George Massey Tunnel (Tunnel) with a clear-span bridge, removal of all or part of the Tunnel, and replacement or upgrade of interchanges and widening of the highway as required.

1.2 Objectives

The objectives of this study were to review and document existing groundwater-related information in and around the study area. Available data are considered to be representative of the regional hydrogeology; site-specific groundwater data were therefore not collected or analyzed.

1.3 Study Area

The spatial extent of the study was a 250-m wide corridor centred on the Highway 99 centreline, extending from Westminster Highway in Richmond to the Highway 10 interchange in Delta, and was selected based on hydraulic connectivity considerations. This study area reflects the 100-m criterion of direct influence of surface water specified in other provinces such as Ontario and Saskatchewan, since B.C. does not as yet have any formal protocol for evaluating groundwater under direct influence of surface water. The 250 m study area width captures the Project footprint (50 m wide on average) plus the area 100 m on either side of it.
2.0 Methodology

The study involved a desktop review of groundwater-related information available at the time of the study that pertain to areas in and around the study area, specifically:

- Existing groundwater information
- Existing constructed features
- Recent and similar EAs for projects in the vicinity of the study area
- Studies pertaining to bogs in the vicinity of the study area

Four areas of potential environmental sensitivity, or receptors, in the vicinity of the study area were given particular consideration in this study (see Figure 1):

- Burns Bog (Delta)
- Lulu Island Bog (Richmond Nature Park)
- Agricultural areas near the study area in Delta and Richmond
- Domestic water supply wells in Delta and Richmond

Available groundwater data were largely limited to areas surrounding Burns Bog. Because there is little available groundwater information for Richmond (agriculture areas and Lulu Island Bog), hydrogeological understanding of the Delta portion of the Project was extrapolated to describe hydrogeology in Richmond. The rationale and method for the data extrapolation are described below.

2.1 Burns Bog and Lulu Island Bog

Burns Bog and Lulu Island Bog are in the vicinity of but not within the study area. Lulu Island Bog is situated in Richmond Nature Park, along Highway 99 between Alderbridge Way and Westminster Highway; Burns Bog is situated north of Highway 99, adjacent to Highway 17 in Delta (Figure 1).

Existing studies conducted by Golder Associates for the South Fraser Perimeter Road project (Golder 2009, 2013) were used to characterize existing groundwater conditions of Burns Bog in relation to the Project. Biophysical conditions of Lulu Island Bog were provided in a report conducted on behalf of the Richmond Nature Park Society (Davis and Klinkenberg 2008). Groundwater information from Burns Bog was used to extrapolate groundwater information and describe hydrogeological conditions at Lulu Island Bog. This is considered appropriate since both are raised bogs (i.e., bogs with a central mound) and have a common depositional history and ecological evolution.
Although similar in composition and historical development, each bog has a unique anthropogenic setting. Burns Bog and Lulu Island Bog are both surrounded by drainage ditches that separate them from the surrounding developments, which include highway corridors and agricultural areas. Lulu Island Bog is approximately one-tenth the size of Burns Bog and is transected by roads (Highway 99, Shell Road, and No. 4 Road). Historical developments in the vicinity of Lulu Island Bog likely affected the regional groundwater regime and encouraged dewatering through changes to surface and groundwater drainage and disturbances of the underlying geology. The main anthropogenic groundwater effects on bogs are typically associated with unintentional lowering of the water table and introduction of nutrients.

### 2.2 Agricultural Areas

Agricultural areas within and adjacent to the study area are surrounded by a system of drainage ditches. Groundwater data from within the agricultural lands along the Project footprint are limited to areas south of Burns Bog and the Vancouver Landfill. These data were used to extrapolate and describe hydrogeology for all agricultural areas within the study area. This extrapolation is considered appropriate based on the well-understood depositional history and geology of the Fraser River delta. Thus, agricultural areas in and adjacent to the study area are assumed to have generally uniform physical and chemical groundwater characteristics. Anthropogenic groundwater effects on the agricultural areas are generally associated with lowering of the water table and introduction of nutrients.

### 2.3 Domestic Water Supply Wells

A search of the BC Water Resource Atlas (B.C. MOE 2015) indicated the presence of two water supply wells in Delta, within 600 m of the study area, and two water supply wells in Richmond, more than 1,000 m from the study area. Domestic groundwater use is limited to agricultural operations (e.g., irrigation), since the drinking water supplies within Richmond and Delta are provided via the municipal water supply network. Potential anthropogenic groundwater effects on the aquifers that host the water supply wells are generally associated with a drop in water levels and reduction of groundwater quality.

### 2.4 Groundwater Model

A conceptual groundwater model was prepared to assist in describing hydrogeological conditions in the study area. The model was constructed based on the review of the available hydrogeological data and information as described above and in Section 3.0. The model outlines two general groundwater flow paths from Burns Bog to either Boundary Bay or to the Fraser River. As previously noted, in the absence of groundwater data from Lulu Island Bog, the hydrogeology information was extrapolated from the Delta portion of the Project. Section 4.0 provides the details of the conceptual model of groundwater flow.
SOURCES

Variation in polygon size represents differences in mapping accuracy associated with source data for each B.C. CDC element occurrence record.
3.0 Hydrogeological Setting

Background information on the hydrogeological setting of the study area used for the conceptual groundwater model is presented in this section.

3.1 Geological Setting

Surficial geology of the Vancouver area consists of unconsolidated deltaic sediments of the Fraser River delta. The deltaic sediments generally comprise an upward coarsening succession and are up to several hundred metres thick (Clague et al. 1998). The succession comprises sediments deposited during the recent glaciations and consists of thick complexes of till and stratified drift at depth and are overlain by marine clays and silts. These deposits were eroded by glaciers and streams (Clague et al. 1998).

Quadra Sand and Vashon Till are visible in upland areas to the east of Burns Bog in the Newton area of Surrey, and were deposited 10,000 to 30,000 years ago. Marine clays and Fraser River sand were deposited over the till.

The following summarizes the soil stratigraphy of the study area, based on data previously collected by the Ministry:

- 0.5 to 1.0 m: post-glacial topsoil and fill present outside the existing roadways
- 1.0 to 4.5 m: clayey silt and silty clay, firm to stiff near the surface, becoming soft with increasing depth
- 4.5 to 28 m: sand and silty sand (Fraser River sand), loose to compact, occasionally intersected by clayey silt lenses
- 28 to 320 m: clayey silt to silty clay interlayered with sand
- >320m - till
- the depth of bedrock is unknown

Golder (2006) reports that peat was observed at or near the ground surface in the vicinity of Burns Bog. The peat layers range in thickness from 0.5 to 1.5 m outside of the bog, and up to 9 m thick within the bog, where peat materials are characterized by a surficial, fibrous acrotelm underlain by a fine-textured catotelm. The peat was reported to be underlain by an organic-rich silt and clay, over silty sand and clean sand (Fraser Delta sediments) to depths of up to 30 m (Golder 2006).
3.2 Aquifer Classification

Two sand and gravel aquifers underlie the study area (South Fraser River delta and Lulu Island aquifers) and are listed as non-drinking-water type aquifers, and both have an aquifer classification IIIA, defined by low demand and high vulnerability to contamination from surface sources (B.C. MOE 2015). One report (Neilson-Welch and Smith 2001) describes saltwater intrusion below the Fraser River channel that can produce a wedge of saline water within permeable deposits adjacent to the river.

3.3 Bog Hydrogeology

Both Lulu Island Bog and Burns Bog are characterized as raised bogs due to their central peat mounds and water tables that closely follow their unique topographies. In winter, the Burns Bog water mound is situated about 500 m north of the Highway 99 centreline, at the eastern extent of the study area; in summer the mound moves to about 1,000 m north of the highway centreline\(^1\) (Golder 2013; Howie 2013; Vancouver Landfill, personal communication, 2014).

The peat texture within both bogs becomes less fibrous and hydraulically conductive with depth. Moderately conductive \((K = 10^{-5} \text{ m/s})\) and fibrous acrotelm at the surface is underlain by low-conductive \((K = 10^{-9} \text{ m/s})\) and finer-textured amorphous catotelm, and silt/clay stratum that effectively isolate the bog water mounds from the deeper groundwater (Golder 2006) (Figure 2).

Infiltration of precipitation is the main groundwater recharge mechanism within both bogs. The water table in Burns Bog is above the regional water table; a similar water table regime is expected at the Lulu Island Bog. Groundwater flows radially outward from the bogs, under a gentle gradient, into the surrounding surface water bodies that may potentially recharge the regional aquifer used by private water supply wells (Golder 2006). Water recharge for the bog areas is predominantly from precipitation and groundwater recharge from Surrey Uplands.

Historical data from the southern boundary of Burns Bog, collected from nested monitoring wells, generally indicate downward vertical gradients in the eastern portion of Vancouver Landfill, with the notable exception of an upward gradient in the vicinity of the north-south ditch along 88\(^{th}\) Street (at the eastern edge of Lot 9, located approximately 450 m east of the

\(^1\) The bog water mound is defined by Hebda et al. (2000) as the 1.0 m groundwater contour line (m above sea level). Distance from the +1.0 m contour to the Highway 99 centreline is based on seasonal monitoring as follows: 2007/2008 (Golder 2009), 2009 (Golder 2013), 2012 and 2013 (Vancouver Landfill, personal communication, 2014)
southeast corner of the landfill). Upward gradients are generally present in the western portion of the landfill and west of 72nd Street (Vancouver Landfill, personal communication, 2014). The upward hydraulic gradients are potentially associated with the regional groundwater discharge zones.

Groundwater elevation in the centre of Burns Bog ranges from 2 to 3.5 m above sea level (ASL). Water level variation between the wet seasons (November to April) and dry seasons (May to September) ranges from approximately 0.5 to 0.7 m. Because the water table below both bogs is near the ground surface, shallow groundwater is intercepted and controlled by ditches, drainage features, and control structures that surround the Project footprint. The ditch water (i.e., surface water) and groundwater interactions are further described in Section 4.0.

Subsurface utilities also have the potential to affect water levels and groundwater flow by providing groundwater conduits. The following utilities are located upgradient of the study area:

- An east-west sanitary sewer line north of Burns Drive
- A north-south gas line north of the Project located approximately 150 m east of 80th Street
- A north-south gas pipeline along 72nd Street
- A north-south sanitary sewer along Crescent Slough near Highway 17

Burns Bog groundwater is characterized by an overall low dissolved mineral load (calcium less than 3 mg/L), high concentration of organic compounds, and low pH (between 3.5 and 5.5). Naturally occurring cadmium and zinc in groundwater were detected at concentrations above the applicable provincial standards in some areas within the bog. Groundwater associated with the study area is mapped as non-bog water (Type III; calcium >10 μg/L, pH 5 to 8), except in the vicinity of 80th Street, Delta, where Type II (transitional; calcium 3 to 10 mg/L, pH 4.5 to 5.5) water is mapped north of and adjacent to Highway 99. The Type II water extends 200 m west and 800 m east of 80th Street, Delta (Golder 2006). Information about groundwater quality at Lulu Island Bog was not found. A generalized hydrogeology cross-section from Burns Bog in a southerly direction towards Boundary Bay is shown in Figure 2.
Legend

- Cross-Section A-A'
- Groundwater Flow Direction
- Water Table

Strata Layer
- Acrotelm
- Catotelm
- Silt/Clay/Peat
- Fraser River Sands

Sources
3.4 Agricultural Land Hydrogeology

There are three major surficial soil types within the upper stratigraphy below the agricultural land along the study area in both Richmond and Delta: discontinuous peat, silts and clays up to depth of approximately five metres, and Fraser River sands.

The hydraulic conductivity of silt and clay soils varies from $10^{-8}$ to $10^{-6}$ m/s. These soil types are generally associated with relatively poor drainage and can reduce water quality through stagnation. The high hydraulic conductivity of Fraser River sands ranges from $10^{-4}$ to $10^{-3}$ m/s. Groundwater elevation within the agricultural areas ranges from -0.5 to 1 m ASL, and water level variation between the wet and dry seasons ranges from 0.4 to 0.8 m.

Due to the shallow water table, creeks and discharge ditches control the majority of the groundwater flow towards Boundary Bay and the Fraser River in Delta, or the Fraser River in Richmond, while some of the groundwater is expected to reach the deeper unconfined aquifer. Baseflow studies conducted near the study area (Golder 2006) estimated the summer and winter runoff at about 20 and 80 per cent of the total annual discharge respectively, with baseflow rates from 0.1 to 117 L/s.

Water levels in Crescent Slough are kept low during the spring to help drain surrounding agricultural areas. In early summer, water from the Fraser River is pumped into Crescent Slough to provide farmers with a source of irrigation water (Jeglum et al. 2007).

Groundwater in the agricultural area is characterized by a pH of between five and eight, as well as by higher calcium concentrations, Ca-Mg-Na-HCO$_3$ water type, and slightly reducing conditions. Studies completed in 2006 identified chlorine, boron, nitrate, aluminum, iron, magnesium, manganese, and some hydrocarbon at concentrations above the provincial water quality standards. While some of the groundwater parameters are found naturally at elevated concentrations, others such as nitrates and hydrocarbons may be associated with the use of fertilizers and leaks from farm machinery (Golder 2006).
4.0 Conceptual Groundwater Model

4.1 Regional Groundwater Recharge and Discharge

Regional groundwater recharge and discharge are characterized as follows:

- Shallow groundwater recharge in the study area originates as direct infiltration of precipitation in upgradient areas—generally Burns Bog and Lulu Island Bog. Most groundwater flow within the raised bogs occurs at the hydraulically conductive top layer (acrotelm) while the bottom layers of the bogs are tight and relatively confining to vertical groundwater flow.

- Ditches and creeks within the study area control the level of the water table by either surface water discharge to groundwater (wet season) or groundwater discharge to surface water (dry season).

- Downward recharge of sands underlying the bogs is likely limited by amorphous peat and fine-grained mineral soil that underlies the acrotelm.

- Downward vertical gradients likely predominate over upward gradients in Burns Bog because the saturated peat is raised above the surrounding flat landscape and forms a groundwater mound. The flat deltaic depositional environment does not provide for an upland source of recharge to the mineral soil beneath the peat. Thus the peat generally recharges the underlying soil.

- At locations where the saturated peat drains (i.e., at the margin of the bog and in the vicinity of ditches), the local depression of water levels in the shallow peat could allow for local upward gradients to develop. Vertical gradients are generally downward in the eastern portion of Vancouver Landfill. Upward gradients are generally present in the western portion of the landfill and west of 72nd Street (Vancouver Landfill, personal communication, 2014).

4.2 Local Groundwater Flow to the Study Area

Due to the generally flat topography of the study area, the regional horizontal hydraulic gradient and estimated groundwater velocities are low. The calculated horizontal gradients around Burns Bog range from 0.0001 to 0.0106 (Golder 2009). For groundwater velocity estimates, the porosity of surficial soil types has been assumed to be between 0.2 and 0.4 (Domenico and Schwartz 1998). Table 1 summarizes the estimated groundwater velocities of various soil types within the study area.
**Table 1  Study Area Estimated Groundwater Velocities**

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Hydraulic Conductivity (m/s)</th>
<th>Porosity</th>
<th>Groundwater Velocity (m/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>$1 \times 10^{-4}$</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Acrotelm</td>
<td>$1 \times 10^{-5}$</td>
<td>0.4</td>
<td>0.01</td>
</tr>
<tr>
<td>Silt</td>
<td>$1 \times 10^{-6}$</td>
<td>0.3</td>
<td>0.001</td>
</tr>
<tr>
<td>Clay</td>
<td>$1 \times 10^{-8}$</td>
<td>0.2</td>
<td>$1 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

Dry season and wet season groundwater elevation contour maps downgradient from Burns Bog in Delta (Figure 3 and Figure 4, respectively) indicate two general horizontal groundwater flow paths from the bog toward the study area and beyond: the flow in the eastern portion (east of 72nd Street, Delta) is south-southwest toward Boundary Bay, while the flow in the western portion (west of 72nd Street, Delta) is west, toward the Fraser River.
Figure 3

SOURCES

Legend
- Baseline Groundwater Monitoring Well
- Inferred Groundwater Elevation Contours (m asl)
- Inferred Groundwater Flow Direction
- Burns Bog Ecological Conservancy Area

Source: Image
GEORGE MASSEY TUNNEL REPLACEMENT PROJECT
GROUNDWATER ELEVATION CONTOURS NEAR BURNS BOG FOR MARCH 2012 (WET SEASON)

Figure 4 15/04/2015

SOURCES
4.2.1 Eastern Portion of Study Area (South of Burns Bog)

Groundwater in the eastern portion of the study area originates as precipitation in any of the following areas along the generalized eastern groundwater flow path (to the south-southwest): Burns Bog → Vancouver Landfill → swamp north of Highway 99 → Burns Drive ditches → study area → agricultural area, Boundary Bay Airport, and associated ditches → Boundary Bay. Pump stations form a mechanical component of the flow between the agricultural and drainage ditches, and Boundary Bay.

Water levels in these areas are expected to be affected by ditches (within Burns Bog, surrounding Vancouver Landfill, and in the southern portion of the swamp north of Burns Road), subsurface utilities, and drainage associated with Burns Drive. These drainage features north of the study area are expected to intercept groundwater and therefore result in a lowering of the groundwater hydraulic gradient leading toward the study area. Groundwater flows more slowly under a lower gradient; thus, the effect of drainage features upgradient of the study area could be characterized as an impediment to groundwater flow reaching the study area.

The +1.0 m elevation contour associated with the bog groundwater mound is more than 500 m from the Highway 99 centreline in winter, and more than 1,000 m in summer. The groundwater hydraulic gradient is lower in the dry season compared with the wet season, represented as a larger spacing of groundwater elevation contours in the dry season (Figure 3), compared with the wet season (Figure 4). Thus, there is expected to be more groundwater flow upgradient of the study area in the wet season compared with the dry season.

The groundwater chemistry interface from transitional water type to non-bog water type is situated within the study area directly north of Highway 99. The southeast area of Vancouver Landfill directly north of Highway 99 is reported to contain transitional-type water (Golder 2009), while areas directly south of the highway are non-bog water types.

4.2.2 Western Portion of Study Area (Crescent Slough)

Groundwater in the western portion of the study area originates as precipitation in any of the following areas along the generalized western groundwater flow path (to the west): Burns Bog → Vancouver Landfill → 72nd Street → South Fraser Perimeter Road → Crescent Slough, associated ditches, and study area → Fraser River (main arm).

Water levels in any of these areas are expected to be affected by ditches (within Burns Bog and surrounding Vancouver Landfill), drainage associated with 72nd Avenue and Highway 17, subsurface utilities, and drainage associated with Crescent Slough. At the eastern margin of Crescent Slough (outside of the slough), the +1.0 m elevation contour associated with Burns Bog groundwater mound is more than 1,000 m from the Highway 99 centreline in summer and winter.
Groundwater chemistry in this area transitions from bog-type to non-bog-type water occur approximately 1,000 m north of Highway 99. Bog water is located north of Vancouver Landfill and east of Highway 17. Non-bog water is present in Vancouver Landfill and south and west of the landfill. Within Crescent Slough, and therefore also affecting the study area, water levels are controlled for agricultural purposes by ditches surrounding the slough.

4.3 **Groundwater Flow to Study Area in Richmond**

In the absence of physical groundwater data from within the Lulu Island Bog, groundwater flow direction can be inferred from the area’s topography, and from the geometry of the existing drainage system. Regional groundwater flow in Richmond is expected to be westward, in accordance with its delta setting. Shallow groundwater is expected to emerge at ditches and collect within north-south-oriented catchments. Localized radial shallow groundwater flow in Lulu Island Bog is evident based on the existence of bog habitat, which requires groundwater isolation, and the situation of the bog as a local elevation high point. The City of Richmond interactive map depicts drainage services within the north-south catchments that generally run parallel to roads (City of Richmond 2014).

Groundwater flows radially from the top of the bog mound and is expected to flow towards roadway drainage ditches and ultimately to north-south-oriented catchments. Lulu Island Bog is the drainage divide for several catchments (Davis and Klinkenberg 2008 as cited in City of Richmond 2004), and thus represents a relative high point of the flat landscape, and the origin of several flow paths, characterized as follows.

**Flowing South (relevant to study area):**

Lulu Island Bog (south part of Highway 99 within the bog) → roadway drainage ditches around the bog → Highway 99 drainage catchment → Fraser River Main Arm.

**Flowing North of study area:**

Lulu Island Bog (north part of Highway 99 within the bog) → roadway drainage ditches around the bog → Shell Road north drainage catchment → Fraser River Middle Arm.

Lulu Island Bog (north edge of Highway 99) → roadway drainage ditches around the bog → Bath Slough drainage catchment → Fraser River Middle Arm.

Lulu Island Bog (west part of the bog) → roadway drainage ditches around the bog → No. 4 Road north drainage catchment → Fraser River (middle arm).
Water levels in any of these areas are expected to be affected by ditches in Richmond Nature Park and surrounding existing roadways, as well as subsurface utilities. Due to the lack of groundwater information from Richmond, the extent of the Lulu Island Bog has not been defined based on an elevation contour, as has been done for Burns Bog.

The groundwater chemistry interface from transitional water type to non-bog water type is likely situated north of Westminster Highway, and is expected to be reflected by the area of fill imported to construct Highway 99 in 1958, and the Westminster Highway connector in 1975.

### 4.4 Groundwater Interactions and Groundwater Receptors

Two groundwater and surface water interactions are expected in the study area:

- Groundwater discharge to watercourses during low-water-level summer months
- Surface water discharge to groundwater during high-water-level winter months

In both cases, shallow groundwater within the study area interacts with creeks, ditches, and other watercourses, and can represent a significant portion (up to 80 per cent) of the surface water baseflow (Golder 2006).

The ultimate receptors for shallow groundwater from the study area in Delta are Boundary Bay and the Fraser River. In Richmond, the shallow groundwater receptor is the Fraser River. Some portion of the shallow groundwater is also expected to recharge the unconfined South Fraser River delta and Lulu Island aquifers.

### 5.0 Conclusions

The objectives of this hydrogeology study were to describe existing groundwater conditions in the study area.

This hydrogeology study was based on review of third-party data and information pertaining to the study area and surrounding areas. Site-specific groundwater data were not collected as part of this study; however, the data reviewed are considered to be representative of regional hydrogeology within the bogs and agricultural lands.
6.0 Closing

This technical data report was prepared and reviewed by the undersigned.

Report prepared by:     Report reviewed by:
Hemmera Envirochem Inc. Hemmera Envirochem Inc.

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7.0 Statement of Limitations

This report has been prepared for the sole benefit of the B.C. Ministry of Transportation and Infrastructure to describe existing hydrogeological conditions within a specific study area. This report is based on desktop studies including preparation of a conceptual model, and the data presented herein represent hydrogeological conditions at the time the desktop studies were undertaken.
8.0 References


