

Hydrogeology and Hydrology Characterization Report

Upland Landfill
Campbell River, British Columbia

Upland Excavating Ltd.



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1. Introduction

GHD Limited (GHD) was retained by Upland Excavating Ltd. (Upland) to prepare the following Hydrogeology and Hydrology Characterization Report (Report) for the future Upland Landfill (Landfill) located at 7295 Gold River Hwy, Campbell River, British Columbia (Site). The Report will form part of the Waste Discharge Application submitted to British Columbia (BC) Ministry of Environment (MOE) to obtain an Operational Certificate (OC) for the Landfill. This Report has been prepared in general accordance with the BC MOE's "Draft Second Edition Landfill Criteria for Municipal Solid Waste (2015)" and the "Guidelines for Environmental Monitoring at Municipal Solid Waste Landfills (1996)".

A waste Discharge Permit (Permit) was issued to the Site in 1992 for the discharge of waste. The Permit allows for landfilling (i.e. discharge) of municipal waste consisting of construction, demolition, and land clearing waste. Land clearing waste includes "stumps, trees, selected building demolition debris and residue of combustion from the open burning of wood waste". Upland is currently seeking to obtain an OC to replace the existing Permit. It is Upland's intention to develop the Site with an engineered Landfill that meets the requirements of the Comox Valley Regional District's solid waste management plan (SWMP) and satisfies the BC MOE standards for landfills as outlined in the Landfill Criteria for Municipal Solid Waste and the Guidelines for Environmental Monitoring at Municipal Solid Waste Landfills, 2015 (Landfill Criteria).

This Report has been prepared to satisfy the hydrogeology and hydrology characterization requirements of the Landfill Criteria. This Report is being submitted in conjunction with the Design, Operation and Closure Plan (DOCP). An assessment of the design, function, and predicted future performance of the engineered Landfill is described in the DOCP. The following sections of this Report provide information pertaining to the Site's background, the scope of characterization work completed, the physical setting of the Site, the environmental/hydrogeologic and hydrologic conditions at the Site, an assessment of existing water quality at the Site, and recommendations on future environmental monitoring at the Site.

In order to characterize the Site, GHD completed various investigative activities between August 2015 and February 2016 for the purpose of:

- Characterizing the geologic conditions underlying the future Landfill and the surrounding areas
- Investigating and characterizing the groundwater and surface water flows
- Investigating and defining groundwater and surface water quality within and in the vicinity of the future Landfill
- Characterizing groundwater quality upgradient and downgradient of the future Landfill footprint
- Developing recommendations for use in support of an application to the BC MOE to receive an OC for the Landfill

1.1 Site Location

The Site is located at 7295 Gold River Highway, Campbell River, British Columbia (BC) approximately 7 kilometres (km) southwest of the urban area of Campbell River and approximately 2 km southeast from the Ladore Falls Dam.

The Site's southern property coincides with the boundary between the City of Campbell River and the Strathcona Regional District. The Gold River Highway is located to the north and west of the Site. The legal description is Lot A, District Lot 85, Plan 30709, Sayward District. The total area of the Site is approximately 48.2 hectares (ha). A Site location map is presented in Figure 1.0.

1.2 Adjacent Properties

The Site is bound to the north by Gold River Highway (Highway 28), to the east by forested and industrial land parcels and to the west by Rico Lake, a construction storage yard, and an undeveloped industrial lot. Adjacent to the northeast corner of the Site is Argonaut Road and a utility tower. The Site is bound to the south by forested Upland Resource land located within the administrative boundaries of Strathcona Regional District.

Several residential properties are located on the north side of the Gold River Highway, along the shore line of Mclvor Lake. Four of the six residential properties are vacant. An additional vacant residential property is located just north of Rico Lake.

Adjacent properties and associated land uses are presented on Figure 1.2.

1.3 Off-Site Water Supply Wells

Based on information obtained through BC Water Resource Atlas (November 2015), eight private water supply wells are located within a 2 km radius of the Site and include commercial and industrial wells 74207, 39950, 84136 and 93413, private domestic wells 98020, 73577 and 103257, and well 74191 categorized as “other”. The locations of these wells are presented on Figure 1.3. The available well records for these wells are provided in Appendix B.

Groundwater contours generated as part of this assessment, as described in Section 3.4, indicate that these wells are located up-gradient or cross-gradient of the future Landfill footprint.

1.4 Site History

The Site is currently an active sand and gravel pit (Pit) that has been in operation since 1969 under Mines Act Permit G-8-114 issued December 1989 last amended in February 2014. Rock blasting and crushing is carried out in the southwestern portion of the Site. Aggregate washing takes place in the centre of the Pit.

As described in Section 1.0, a waste Discharge Permit was issued to the Site in 1992 for the discharge of municipal waste consisting of construction, demolition, and land clearing waste. Waste discharged at the Site historically has included clean wood wastes that are burned in the permitted burn area located in the southeastern corner of the Site. In addition, the Site has accepted demolition debris (specifically asphalt and concrete), which is stockpiled in the northern portion of the Site. The location of the asphalt and concrete stockpiles are indicated on Figure 1.1.

1.5 Characterization Approach

This hydrogeology and hydrology characterization was undertaken in order to characterize the geology, hydrogeology, and surface hydrology within and within the immediate vicinity of the Site.

The approach used for characterizing the hydrogeology and hydrology at the Site is as follows:

1. The physical setting of the Site was investigated in terms of subsurface geology and hydrogeology through advancement of boreholes and installation of groundwater monitoring wells.
2. Groundwater flow was characterized through surveying of groundwater monitoring wells and surface water features and measurement of static groundwater elevations.
3. Surface hydrology was evaluated to define the presence and movement of surface water within the Site area.
4. Groundwater and surface water quality was characterized by collecting and analysing water samples from on-Site monitoring wells, the on-Site wash plant, surface water bodies (McIvor Lake and Rico Lake), and a private residential water supply well north of the Site. This water quality sampling program included the collection of groundwater and surface water samples from background/upgradient and on-Site locations in order to characterize baseline or pre-landfilling water quality conditions.

1.6 Report Organization

This Report is organized into the following sections:

- Section 1.0 Introduction
- Section 2.0 GHD Field Investigations
- Section 3.0 Site Physical Setting
- Section 4.0 Baseline Water Quality Results
- Section 5.0 Conclusions and Recommendations

2. GHD Field Investigations

Hydrogeologic field investigations completed at the Site between August 2015 and February 2016, included borehole advancement, monitoring well installation, monitoring well development, single well response testing (SWRT), hydraulic monitoring, and water quality sampling. Field investigations were completed in accordance with the BC MOE “Field Sampling Manual for Continuous Monitoring Plus the Collection of Air, Air-Emission, Water, Wastewater, Soil, Sediment, and Biological Samples (2013)” and GHD’s standard operating procedures (SOPs). This Section presents an overview of completed activities and results.

2.1 Borehole Advancement

In 2014, prior to GHD beginning investigation activities at the Site, a series of boreholes and monitoring wells were completed by Red Williams Well Drilling Ltd. (Red Williams). Using air rotary drilling techniques, Red Williams advanced three boreholes on Site to depths ranging from 10.97 to

21.63 metres below ground surface (mBGS). Each of the boreholes was completed as monitoring wells (MW1-14, MW2-14, and MW3-14).

Blue Max Environmental Drilling Inc. of Vancouver, BC (Blue Max) and Drillwell of Vancouver Island, BC (Drillwell) provided drilling services during the GHD field investigations in 2015 and 2016, respectively.

Blue Max provided drilling services using a sonic drill rig for the advancement of five boreholes to depths ranging from 8.23 to 24.38 mBGS between August 5 and August 7, 2015. BH5-15 was abandoned prior to encountering groundwater or bedrock due to equipment limitations. The remaining four boreholes were completed as two monitoring well nests, MW4A/B-15 and MW5A/B-15.

Under the direction of GHD, advancement of three boreholes and installation of one monitoring well (BH1-16, BH2-16 and MW2A-16) was completed using rotary drilling techniques by Drillwell on January 27 and 28, 2016. Boreholes were advanced to depths ranging from 16.46 to 45.42 mBGS.

The locations of boreholes and monitoring wells advanced as part of the Site characterization are shown on Figure 2.0.

Soil samples from the 2015 and 2016 boreholes were collected using sonic sample tubes or split spoons. Samples were classified and described by a GHD geologist and were used to generate stratigraphic and instrumentation logs for each drill location.

During the 2016 borehole advancement work, five soil samples were collected between the three locations for grain size analysis. Three samples were collected from MW2A-16 and single samples were collected from BH1-16 and BH2-16. The results are discussed in the overburden geology Section of this report (Section 3.3.1).

Details of the stratigraphy encountered in 2014 to 2016 are presented on the Stratigraphic and Instrumentation Logs included as Appendix C.

2.2 Monitoring Well Installations

Monitoring wells (MW4A-15, MW4B-15, MW5A-15, MW5B-15 and MW2A-16) were constructed with No. 10 slot, 2-inch- (50-mm-) diameter PVC well screens and to 2-inch (50-mm) diameter, PVC riser pipe. A sand pack consisting of #2 silica filter sand was placed around each well screen to an average height of 0.30 m above the top of the well screen.

The annular space above the sand pack was backfilled with at least 1 m of hydrated granular bentonite to create an impermeable seal above the well screen. The remaining annular space was filled with cuttings to a depth of 1 to 2 mBGS where a surface seal of hydrated bentonite chips was placed to 0.5 mBGS. The monitoring wells were completed with above ground steel protective casings that were concreted in place.

2.3 Well Development

Monitoring well development was completed on September 11, 2015 at MW1-14, MW2-14, MW3-14, MW4A/B-15 and MW5A/B-15 and on January 28, 2016 at MW2A-16 using dedicated Waterra tubing, footvalves, and surge blocks. During well development, the footvalve and surge block was positioned within different intervals in the screen to ensure that the entire length of the screen was properly surged. Development continued until groundwater was considered stabilized (6

to 10 well volumes removed) and discharge was relatively clear. The monitoring wells that went dry during development (MW5A/B-15) were pumped dry for a second time prior to sample collection.

2.4 Single Well Response Tests

On September 18, 2015, GHD performed hydraulic conductivity testing in three monitoring wells to determine the characteristics of the sand and gravel overburden and fractured bedrock units (described in more detail in Section 3.0). GHD completed single well response tests (SWRTs or slug tests) on monitoring wells MW4A/B-15 and MW5A-15. SWRTs were completed in accordance with GHD's standard operating procedures (SOPs), which are summarized below.

Each slug test was completed by inducing a sudden change in the water level and measuring the response of the aquifer within the individual monitoring well being tested (i.e. measuring the change in water level over time). The water level change was induced by introducing or removing a known volume or "slug" into and out of each well.

Prior to each SWRT, GHD measured and recorded static water levels, removed all dedicated sampling equipment (tubing etc.), and installed a Solinst Levellogger pressure transducer. GHD field staff then used a slug constructed from a solid cylinder of PVC to displace the static water level within the monitoring well. Following this near instantaneous change in static water level, measurements of the recovery of water levels to near static levels (at least 90 percent of the total initial displacement) were recorded by the pressure transducer. Manual water level measurements were also recorded with an electronic water level tape to validate the pressure transducer measurements.

GHD analyzed the results of the SWRTs using the computer based software, AQTESOLV® (v. 4.01) and the Bouwer-Rice rising head test solution (Bouwer-Rice, 1976). The Bouwer-Rice method provides a solution for determining the hydraulic conductivity of an unconfined aquifer. Analysis involves matching a straight line to water-level displacement data collected over time.

Based on the results of these tests, the hydraulic conductivity of the overburden sand and gravel unit is estimated to be 2.0×10^{-2} cm/sec (measured at MW4B-15) and the hydraulic conductivity of the fractured bedrock unit is estimated to be 2.2×10^{-2} cm/sec at MW4A-15. Hydraulic conductivity of the bedrock at MW5A-15 is estimated to be 1.4×10^{-5} cm/sec.

A large difference in hydraulic conductivity is noted when comparing the results of the SWRTs at MW4A-15 and MW5A-15. This difference is interpreted to be due to a difference in rock quality or the degree of fracturing in the rock at these locations.

Both wells were completed within the upper shallow bedrock; however, less fracturing was noted in the bedrock at MW5A-15 at the time of drilling. Several fractures and a low rock quality designation (RQD) were noted by GHD field staff in the bottom of MW4A-15 (see Appendix C). The increased fracturing at MW4A-15 results in a higher hydraulic conductivity in the shallow bedrock aquifer in the vicinity of MW4A-15.

The calculated hydraulic conductivities for each monitoring well are included in Table 2.0. Single well response plots generated by AQTESOLV are provided in Appendix D.

2.5 Hydraulic Monitoring

Hydraulic (water level) monitoring was conducted at all existing on-Site monitoring well locations on September 11, September 17, October 5, 2015 (this did not include MW2A-16 which was completed in 2016).

Between January 25 and 29, 2016, a hydraulic monitoring event took place which included all of the 2015 and 2016 on-Site monitoring wells as well as McIvor Lake (SW15-01) and Rico Lake (SW15-02). Static water levels were also measured at the residential well RW-98020 and the MW2 well nest on February 15, 2016.

The depth to water levels and calculated groundwater and surface water elevations are summarized in Table 2.1.

All depth to groundwater levels were measured using electronic water level tapes. The water elevations in McIvor and Rico Lakes, measured on January 29, 2016, were measured directly using laser level survey equipment (surveying discussed in Section 2.9).

The results of the hydraulic monitoring program were used to determine the groundwater flow direction, vertical and horizontal hydraulic gradients, and the hydraulic relationship between the groundwater and surface water in the vicinity of the Site (discussed in Section 3.0).

2.6 Groundwater Sampling

Groundwater samples were collected from the existing monitoring well network on September 17, 2015, October 5, 2015 and January 25, 2016. Monitoring wells MW2-14 and MW2A-16, as well as the private domestic well 98020 were sampled on February 15, 2016.

Monitoring wells MW4A-15, MW4B-15, and MW5B-15 were purged and sampled following low-flow sampling techniques using a peristaltic pump and dedicated tubing. Monitoring wells MW1-14, MW2-14, MW3-14, and MW5A-15 were purged and sampled using inertial sampling techniques using dedicated Waterra tubing and a footvalve. Prior to sample collection, GHD purged the monitoring wells until field parameters stabilized indicating that the groundwater in the monitoring well was representative of the groundwater in the aquifer. During the September 17, 2015 monitoring event, MW5B-15 contained an insufficient water column for sample collection. However, during the October 5, 2015 sampling event, MW5B-15 was sampled utilizing low-flow techniques.

Groundwater samples collected for dissolved metals analysis were field filtered using dedicated filters. All samples were collected using laboratory supplied bottles which were provided with the appropriate preservative(s) for each type of sample.

All samples were given unique sample identification, packaged in an ice-chilled cooler, and submitted under chain-of-custody protocol for analytical testing.

Surface water samples were collected from McIvor Lake, Rico Lake and the third settling pond of the on-Site wash plant (chosen to represent wash plant surface water quality). Surface water samples were collected by directly dipping laboratory supplied sampling containers approximately 0.15 m below the water surface with the sample bottles completely submerged when possible to eliminate the collection of floating debris.

Field parameter measurements were recorded using a Horiba water quality multi-meter. The meter was submerged directly in the surface water body and allowed to stabilize prior to recording the field parameters. In order to avoid disturbing any sediment, field readings were collected after water quality sample collection was complete.

Surface water samples designated for dissolved parameters that could not be field filtered were collected unfiltered and delivered to the laboratory as soon as possible for filtration prior to analysis.

All samples were given unique sample identification, packaged in an ice-chilled cooler, and submitted to the analytical laboratory under chain-of-custody protocol for analytical testing.

2.7 Sample Analysis

Analytical services were provided by Maxxam Analytics (Maxxam), a Canadian Association for Laboratory Accreditation (CALA) registered laboratory, located in Burnaby, BC. Analytical results were sent directly to GHD. Laboratory reports generated for each of the monitoring events are included in Appendix E.

2.8 Monitoring Well Surveying

Monitoring wells were surveyed on January 29, 2015, March 8, 2016 and April 6, 2016 by Upland, as indicated on Table 2.0.

The surveys noted above were conducted to a Site specific vertical datum. In order to compare the on-Site surface features to off-Site surface features surveyed by others, such as McIvor Lake and the Quinsam River, a datum adjustment was required. McElhanney was retained by Upland to complete a comparison survey of the Site specific datum to the Canadian Geodetic Vertical Datum of 1928. Using the McElhanney survey data, a vertical adjustment of 17.3 metres was applied to the Site specific datum. The updated elevation data which is included in this report is the Canadian Geodetic Vertical Datum of 1928. The horizontal datum used for all surveys is NAD83 (CRS) and the coordinates are UTM Zone 10 North

2.9 Quality Assurance/Quality Control

In order to ensure adequate quality control for water monitoring samples, the following quality assurance/quality control (QA/QC) practices were employed:

- Field QA/QC samples were collected and analyzed to facilitate data validation. A groundwater duplicate and surface water duplicate were collected per sampling event and analyzed as part of the sampling program.
- Data validation was completed by a GHD chemist to assess laboratory and field QA/QC and determine if the data exhibited acceptable levels of accuracy and precision.

Data Quality Assessment and Validation results are presented in Appendix F. Validation of the data was based on information obtained from the chain-of-custody forms, field sample keys, analytical data, field duplicate analytical data, and recovery data for laboratory control samples and surrogate spikes.

Overall the data have acceptable levels of accuracy and precision and are suitable for their intended use with the noted qualifiers.

3. Site Physical Setting

The physical setting of the Site and surrounding lands is described in the following sections.

3.1 Site Topography and Drainage

Topography

The Site is located on a terrace that is partially surrounded by mountainous terrain. The terrace gradually slopes toward the Quinsam River located 3.8 km to the southeast of the east Site boundary. The Quinsam River channel is at an elevation that is greater than 100 meters below the Site. Prominent topographic features at and in the vicinity of the Site include a small mountain near the southwestern Site boundary, a bedrock outcrop at the base of this mountain at the southwestern Site boundary, and a bedrock ridge west and northwest of the Site. The mountain is located off-Site and stands approximately 80 m above the surrounding land surface. To the west and northwest of the Site are two lakes (Mclvor Lake and Rico Lake). The bedrock ridge exists between the lakes and the Site and provides a hydraulic (watershed) divide.

Near the central portion of the western Site boundary, above the Pit wall where gravel extraction has not occurred, surface topography dips from the terrace towards Rico Lake. At the centre of the Site the Pit has been excavated to an approximate depth of 20 m below the surrounding land surface.

Figure 1.1 illustrates the topographic contours within the Pit as well as portions of the southern and western Site boundary.

Drainage

Based on watershed information provided by BC Water Resource Atlas and hydrogeologic and geologic investigative results, the area in the vicinity of the Site is divided between two watersheds: the Campbell River Watershed and the Quinsam River Watershed, as illustrated on Figure 3.0A and Figure 3.0B.

Campbell River Watershed

The Campbell River watershed covers an area of 182,000 ha and is intersected by three manmade dams which form Upper Campbell Lake, Campbell Lake and John Hart Lake. The two lakes that are in close proximity to the Site include Mclvor Lake and Rico Lake.

Mclvor Lake is contiguous with Campbell Lake and is located approximately 50 to 150 m north of northern boundary of the Site. Mclvor and Campbell Lakes drain into John Hart Lake located north of the Ladore Falls Dam. John Hart Lake drains into the Campbell River (Figure 3.1).

The most eastern edge of Rico Lake is located approximately 10 m west of the west Site boundary. It is likely that Rico Lake is within a bedrock depression and primarily drains west toward Mclvor Lake (discussed in Section 3.4).

These surface water bodies are part of the Campbell River watershed.

Quinsam River Watershed

The Quinsam River watershed is a subwatershed of the Campbell River watershed and covers an area of 20,900 ha. The Quinsam River watershed is bound to the north and west by a mountainous divide that isolates it from the Campbell River watershed (Blackmun, Lukyn, McLean & Ewart, 1985). The bedrock ridge, as described above, is part of this mountainous divide and forms the western boundary of the Quinsam River watershed, as illustrated on Figure 3.0A and Figure 3.0B. The confluence of Campbell and Quinsam Rivers is located approximately 6 km northeast of the Site.

The principle surface water feature of this watershed is the Quinsam River which is located 3.8 km to the southeast of the east Site boundary. As shown on Figure 3.1 several ephemeral creeks located approximately 1.0 km to the southeast of the Site provide drainage locally. Based on the local topography in this area which slopes toward the Quinsam River, it is assumed that at times these creeks discharge flow into the Quinsam River. Lost Lake (also known as Hidden Lake) located 1.8 km to the northeast of the south east corner of the Site and drains through Cold Creek which feeds the Quinsam Hatchery before discharging into the Quinsam River. These surface water bodies are part of the Quinsam River watershed.

There are no permanent surface water features on-Site. Instead, precipitation and runoff from the small mountain located to the southwest of the Site infiltrate into the overburden soil and the sand and gravel aquifer underlying the Site.

A drainage map illustrating surface water features and overburden aquifers is presented as Figure 3.1.

3.2 Regional Geology

The Site is located on the eastern portion of central Vancouver Island approximately 7 km southwest of Campbell River, BC. Vancouver Island is part of the Wrangellia Terrane, which includes most of Vancouver Island, the Queen Charlotte Islands and parts of central Alaska. The Wrangellia Terrane is composed mostly of widespread, late Triassic aged flood basalts, including the Karmutsen Formation. The Karmutsen Formation consists mostly of submarine flood basalts up to 6 km in thickness. Vancouver Island is extensively faulted with thrust faults associated with the subduction of the Juan de Fuca Plate under the North American Plate (Guthrie, 2005) (Greene, Scoates & Weis, 2005). The outcrop of rock on the southwestern portion of the Site and the bedrock encountered in boreholes advanced below the overburden is Karmutsen basalt.

At several time periods during the Pleistocene Epoch, Vancouver Island was glaciated with ice thicknesses to 2,000 m. During the recession of the last glaciation approximately 14,000 years ago, glacial and glacio-fluvial sediments were deposited, and in some cases reworked and redeposited, to make up many of the present surficial deposits of Vancouver Island. These deposits consist of till, which is deposited directly by glacial activity and consist of larger clasts supported in a matrix of fine grained sediment, and of glacial outwash, which consists primarily of poorly sorted, coarse grained (sand and gravel) sediments deposited by glacial melt water (Greene, Scoates & Weis, 2005). The overburden at the site consists of glacio-fluvial and outwash deposits of sand and gravel.

3.3 Site Geology

The understanding of the Site geology presented in the following sections is based on subsurface investigations and documents reviewed by GHD (2015 and 2016). Documents reviewed included regional mapping, previous reports, and well completion logs from private wells. Refer to the references included in Section 6 for a complete listing of documents reviewed.

3.3.1 Overburden Geology

The geologic conditions within the Site have been evaluated through an examination of the Pit sidewalls and soil samples collected during borehole advancement overseen by GHD.

To illustrate the geologic sequence interpreted from the on-Site borehole data, three geologic cross-sections have been prepared. The locations of the cross-sections are shown on Figure 3.2. The cross-sections are presented on Figures 3.3 to 3.5.

In general, Site stratigraphy can be characterized as follows (in order from shallowest to deepest):

1. A native interbedded sand and gravel unit is present throughout most of the Site. The thickness of this unit is variable and ranges from non-existent at the south-western portion of the Site, where bedrock outcrops are present, to greater than 24 m at the southern portion of the Site.
 - A sand unit underlies the native sand and gravel at MW2A-16 (in the east portion of the Site) and is greater than 33 m in thickness. Water well records from the north to northeast of the Site indicate the presence of additional layers of sand and gravel; likely underlying the sand unit encountered at MW2A-16.
2. Fractured bedrock composed of igneous rock (basalt).

The structure of the overburden unit is consistent with glacio-fluvial and outwash depositional sources.

Soil samples were collected for grain size analysis (sieve and hydrometer) from BH1-16, BH2-16 and MW2A-16. The following table summarizes the results of the analyses:

Sample location	Subsoil Unit	Sample Depth (mBGS)	Soil Samples				USCS Classification
			Particle Size Distribution				
			% Gravel	% Sand	% Silt	% < 0.002 mm (clay)	
BH1-16	SAND, trace gravel, trace silt	8.84-10.36	3.9	93.3	2.8	SW	
BH2-16	SAND, some silt, some gravel	11.89-13.41	28.3	39.4	32.3	SM	
MW2A-16	gravelly SAND, trace silt	14.94-16.46	41.7	55.5	2.8	SW	

MW2A-16	SAND, some silt and clay	24.38-24.69	0.4	65.8	33.8	SM
MW2A-16	SAND, trace silt	38.10-38.7	0.0	91.9	8.1	SP

The particle size analysis sheets and a complete discussion on grain size analysis are provided in the 2015 Geotechnical Investigation, Upland Landfill (GHD, 2016).

The stratigraphy in the southwestern area of the Site (i.e. in the vicinity of MW5A/B-15), where a topographic high exists, differs from the rest of the Site and can be characterized as follows (in order from shallowest to deepest):

1. Granular fill consisting primarily of sand and gravel. The sand and gravel thickness is approximately 3 m as observed in MW5A-15 and MW5B-15. The fill unit is not present within the investigation locations in the Pit.
2. An interbedded silt unit consisting of layers of silty sand or silt with clay was observed underlying the sand and gravel fill unit. The thickness of the interbedded layers in the vicinity of these monitoring wells is approximately 2 m. Stratigraphic data from BH5-15, which is located approximately 85 m east of MW5A-15 and MW5B-15, indicates that the silt layer is discontinuous as it is not present at this location.
3. Bedrock composed of igneous rock.

As previously mentioned, bedrock is observed at surface near the southwestern corner of the Site.

Cross-Section A-A' (Figure 3.3), cross-Section B-B' (Figure 3.4) and cross-Section C-C' (Figure 3.5) illustrate the interpreted stratigraphy of the Site from southwest to northeast, west to east, and northwest to southeast respectively, based on the available borehole stratigraphic data.

3.3.2 Bedrock Geology

Bedrock at the Site consists of fine textured massive igneous rock of the Karmutsen Formation which varies in colour from blueish black to dark grey and green to dark brown (Golder 2014). Fractures of various sizes, densities and orientations (vertical, horizontal and oblique) were observed in bedrock from samples collected at borings and in exposures at the southwestern boundary of the Site. More significant fracturing was noted in the boring advanced within the Pit (MW4A-15). Evidence of weathering (i.e. iron staining) and secondary mineralization was observed in some fractures. According to laboratory tests completed by Golder in 2014, calcite is present in fractures and amygdulites.

The bedrock has been described as either basalt or granite. The water well record for RW-98020 as well as Red Williams' stratigraphic log for MW3-14 describe the rock as granite; however, the BC MOE identifies rock in the Karmutsen Formation as a basalt.

Residential well RW-98020 was completed at a depth of 60.96 mBGS (200 feet BGS). The stratigraphic log, included in Appendix B, indicates that bedrock was encountered at 1.8 mBGS (6 ftBGS). The log also shows that the bedrock unit was relatively competent with few water bearing fractures which is important in understanding the Site area hydrogeology discussed below.

Based on the presence of bedrock outcrops at the southwestern boundary of the Site, and direct evidence of more than 45 m of overburden at MW2A-16 on-Site, the bedrock surface is interpreted to be highly variable at and in the vicinity of the Site.

3.4 Site Hydrogeology

In general, the geologic units identified in the previous Section may be grouped into the following hydrogeologic units:

1. An overburden sand and gravel aquifer
2. A shallow fractured bedrock unit
3. Perched overburden and bedrock aquifers (located in the south-western undisturbed area of the Site)

The hydrogeologic properties of these units are discussed in the following sections.

3.4.1 Overburden Sand and Gravel Aquifer

An unconfined, shallow sand and gravel aquifer was identified within the overburden unit in boreholes advanced across the Site. Based on the consistency and spatial distribution of borehole locations, this aquifer is interpreted to be continuous across much of the Site (with the exception of the southwest undisturbed area of the Site).

The sand and gravel aquifer unit identified at the Site is a major aquifer in the region, and is identified in the BC Water Resource Atlas as aquifer 975 IIA (10)). This aquifer is interpreted to be the principal groundwater flow zone on-Site. In the context of the future Landfill, this aquifer represents the main receptor to potential Landfill-related groundwater quality impairments. As such this aquifer is of particular importance to this hydrogeologic characterization.

The sand and gravel aquifer unit does not exist in the southwestern portion of the Site. As previously discussed, bedrock outcrops are present at the southwestern property boundary of the Site and adjoining property and there is a large topographic difference between this area and the remainder of the Site. Significant hydraulic (water level) differences also exist when comparing the southwestern corner monitoring wells (i.e. MW5A/B-15) to water levels measured across the remainder of the Site. Based on the stratigraphic elevation differences and hydraulic water level differences it is interpreted that the sand and gravel aquifer does not extend to the southwest corner of the Site.

During the 2015 and 2016 field events, static groundwater elevations at monitoring wells installed in the overburden sand and gravel aquifer were calculated at elevations ranging between 155.8 mAMS (MW3-15 on September 11, 2015) and 167.3 mAMS (MW1-14 on September 11, 2015).

Figure 3.6 presents groundwater contours for water levels collected on January 25, 2016. The contours depicted on this Figure represent lines of inferred equipotential hydraulic head within the overburden sand and gravel aquifer.

As illustrated on Figure 3.6, groundwater flow at the Site within the sand and gravel aquifer is directed from the northwest to the southeast.

Figure 3.7 presents a conceptual depiction of groundwater flow at the Site. This Figure illustrates the movement of groundwater in the vicinity of and across the Site. The various directions of flow depicted on this Figure are based on the horizontal hydraulic gradients measured as part of the field program completed during this characterization. As illustrated on Figure 3.7, the bulk of flow in the sand and gravel aquifer unit is directed to the southeast. This is consistent with the flow direction interpreted from the groundwater contours presented on Figure 3.6.

Figure 3.7 also shows that a component of flow from the vicinity of Rico Lake is directed towards Mclvor Lake. The paragraphs below describe water flow in more detail.

The following table summarizes the surface water elevations within Mclvor and Rico Lakes as compared to static groundwater elevations within the overburden sand and gravel aquifer recorded on January 25 and 29, 2016. Measurements are presented in order of upgradient to downgradient.

Monitoring Location	Water Level	Water Elevation
	(mBTOR)	(mAMSL)
Rico Lake	-	181.2
Mclvor Lake	-	177.9
MW1-14	6.0	166.9
MW4B-15	4.2	165.0
MW2-14	14.7	159.1
MW3-14	11.3	157.2

As indicated in the above table, the static water elevations within Mclvor and Rico Lakes are much higher (>11 m higher) than the static groundwater elevations within the principal groundwater flow system on-Site (overburden sand and gravel aquifer). The substantial difference between the static elevations in these surface water bodies and the groundwater elevations presented supports the following interpretations:

- Based on the elevation differences between the lakes and the overburden sand and gravel flow zone, and the large difference in static water elevations between these two water bearing zones, it is likely that any hydraulic connection between the lakes and the overburden sand and gravel aquifer is a muted connection (weak connection). The weak connection is likely the result of a bedrock ridge between the Site and the lakes. The bedrock elevations at RW-98020 and MW5A-15 are consistent with this interpretation.
- If there is a vertical hydraulic connection between these water bearing units, the vertical gradient would be downward, from the lakes to the overburden sand and gravel aquifer.
- If there is a horizontal hydraulic connection between these water bearing units, then the direction of flow between these units would be from the lakes to the overburden sand and gravel aquifer and not vice versa.

These interpretations are of particular significance to the Site's hydrogeology due to the sensitivity of Mclvor and Rico Lakes as potential receptors to Landfill-related water quality impairments. Based on the hydraulic relationship described above, it is not possible for Mclvor or Rico Lakes to be potential receptors of Landfill-related water quality impacts under the scenario of Landfill development at the Site.

3.4.2 Bedrock Aquifer Unit

Currently, the bedrock aquifer at the Site is only monitored at MW4A-15, located in the central portion of the Site. MW3-14, located in the south-central portion of the Site (see Figure 2.0) is partially screened in the bedrock aquifer; however, is predominantly completed in the sand and gravel aquifer and is more representative of overburden groundwater conditions.

GHD attempted to install an additional bedrock monitoring well nested with MW2-15; however, bedrock was not encountered at the maximum depth possible with the available equipment. MW2A-16 was advanced at a final depth of 45.42 mBGS and screened in a sand unit. This provides additional evidence that the bedrock surface is variable at the Site. It follows that the presence and elevation of the bedrock aquifer is also variable across the Site.

In addition to MW4A-15, the residential well, RW-98020, is completed at 60.96 mBGS deep within the bedrock unit (bedrock was encountered at approximately 1.8 mBGS or 193.8 mAMSL). The well was constructed as an open borehole from approximately 4.8 mBGS to 61 mBGS.

Groundwater elevations at bedrock monitoring well MW4A-15 were on average 0.2 m higher than at nested well MW4B-15 which is screened within the shallow overburden sand and gravel aquifer. This indicates the presence of an upward vertical hydraulic gradient between the shallow bedrock aquifer and the overlying sand and gravel aquifer. Therefore, groundwater from the bedrock aquifer unit is recharging the overburden sand and gravel aquifer. In the scenario of Landfill development, the natural upward gradient between the bedrock and sand and gravel aquifer would mitigate potential Landfill-related water quality impacts to the bedrock aquifer.

As previously discussed the SWRT results for MW4A-15 indicated a hydraulic conductivity of approximately 2.2×10^{-2} cm/sec. This value is similar to the calculated conductivity in the sand and gravel aquifer (2.0×10^{-2} cm/sec). In comparison, the stratigraphic log for RW-98020 shows limited fractures and limited water availability (the estimated yield of the well is 6 gallons/minute or 27 litres/minute). This yield corresponds to a hydraulic conductivity much lower than what was calculated at MW4A-15.

There are insufficient monitoring points to accurately map the groundwater flow direction within the fractured bedrock aquifer unit; however, it is expected that flow direction will be similar to regional flow which is expected to be to the southeast towards the Quinsam River.

3.4.3 Horizontal Hydraulic Gradients and Groundwater Velocity

An average hydraulic gradient of 0.037 m/m is calculated for the overburden sand and gravel aquifer on-Site (an average of the gradients calculated between MW1-14 and MW2-14 and MW4B-15 and MW3-14). As previously mentioned, the hydraulic conductivities for the sand and gravel aquifer is approximately 2.2×10^{-2} cm/sec and 2.0×10^{-2} cm/s. Using a porosity estimate of 30 percent, an average linear groundwater velocity in the sand and gravel aquifer of 2.1 m/day can be calculated using Darcy's equation. For reference, Darcy's equation is provided below.

$$V_x = K i / n$$

Where:

V_x = average linear groundwater velocity

K = hydraulic conductivity

i = horizontal hydraulic gradient in the direction of groundwater flow

n = porosity

3.4.4 Perched Aquifers – MW5A/B-15

Two water bearing units were identified above the Pit in the southwest portion of the Site. These aquifers are interpreted to be disconnected from the primary flow zone within the sand and gravel and bedrock aquifer units described above.

A perched overburden and separate bedrock water bearing zones were identified at MW5A/B-15. Groundwater was found perched within the overburden overlying interbedded silt with clay layers. The interbedded silt with clay unit is approximately 2 m in thickness (noted between approximately 6.5 and 8.2 mBGS) and overlies water bearing bedrock. MW5A-15 was completed within the bedrock in this area. MW5B-15 was completed in the perched overburden water bearing zone.

Groundwater was encountered within the perched overburden monitoring well (MW5B-15) at an average elevation of 185.4 mAMSL and at an elevation of 183.5 mAMSL in the bedrock aquifer well (MW5A-15).

As discussed above, groundwater elevations across the rest of the Site are at very different elevations (>10 m lower). As such, it is expected that the water bearing zones noted at MW5A/B-15 are not connected with the remaining groundwater units at the Site.

Single well response tests were completed in MW5A-15. Based on the results of these tests, the hydraulic conductivity of the bedrock in the southwest is approximately 1.4×10^{-5} cm/sec. This indicates bedrock is relatively competent in the vicinity of MW5A-15.

3.4.5 Conceptual Groundwater Flow Model

This Section describes the hydrogeologic functioning of the Site by providing a conceptual model of the movement of water through the subsurface at and in the vicinity of the Site. This understanding is of particular importance in light of the topographic complexity and presence of McIvor and Rico Lakes nearby.

As described above, the principal groundwater flow zone within the Site is within an overburden sand and gravel aquifer that immediately overlies bedrock in the majority of the Site. Groundwater flow in this high permeability aquifer is to the southeast. Recharge to this aquifer is primarily through infiltration of precipitation through shallow high permeability soils within and upgradient of the Site. Groundwater that flows off-Site in this aquifer likely travels through coarse-grained overburden materials to the east or southeast towards the Quinsam River. Based on the elevation of the Quinsam River, it is likely that shallow groundwater ultimately discharges to the Quinsam River or one of its tributaries.

In order to better understand groundwater quality and flow as it leaves the Site, it is recommended that a monitoring well is installed within the overburden sand and gravel aquifer near the downgradient Site boundary (MW6-16). This monitoring well should be installed prior to Landfill development so that baseline water quality can be established.

To the west and northwest of the Site are two significant permanent natural standing water bodies; Mclvor Lake and Rico Lake. The existence of these lakes is necessarily dependent on a natural low permeability barrier which restricts the downward infiltration of the lake water into the subsurface. Based on the available stratigraphic record, the low permeability barrier appears to be competent bedrock. The elevation of bedrock at MW5A-15, RW-98020 and bedrock outcrops at the southwest corner of the Site provide evidence of a bedrock ridge between the Pit and these lakes.

Although the existence of a low permeability barrier between the Pit and the lakes restricts the movement of groundwater, water will still move through the barrier in the direction of the horizontal hydraulic gradient, albeit at a very low velocity. Based on the static groundwater elevations at the Site and the lake levels, the movement of water will be from Mclvor Lake toward the Site and from Rico Lake toward Mclvor Lake.

In order to further investigate the nature of this bedrock ridge and further validate the direction and magnitude of groundwater flow between the Site and Mclvor and Rico Lakes, an investigation of the bedrock ridge and bedrock between Rico and Mclvor Lakes should be undertaken through installation of three bedrock groundwater monitoring wells (MW7-16 MW8-16 and MW9-16).

The existence of a perched groundwater system in the southwest corner of the Site appears to have little influence on the hydraulic characteristics of the overburden sand and gravel. It is likely that this perched system is recharged by infiltration and runoff from the small mountain located to the southwest of this area.

Precipitation that infiltrates within the Pit infiltrates into the subsurface through the coarse-grained overburden soils, and is thus a source of recharge to the overburden sand and gravel aquifer. Precipitation that infiltrates within the upper terrace west of the Pit likely flows toward Rico Lake. Precipitation that infiltrates within the upper terrace east of the Pit flows toward the tributaries of the Quinsam River.

4. Baseline Water Quality Results

The purpose of the water quality sampling program was to characterize baseline groundwater quality prior to Landfilling activities. Understanding pre-landfilling water quality is important for several reasons, including:

1. Pre-landfilling water quality needs to be taken into account in predictive modelling used to assess future Landfill performance.
2. Pre-landfilling water quality is useful for comparing water quality results during and post Landfill development in order to quantify and assess the effects of landfilling to on-Site water quality.

Groundwater, residential, surface water, and wash plant samples were collected by GHD between September 2015 and January 2016. Groundwater samples were collected from monitoring wells MW1-14, MW2-14, MW3-14, MW4A/B-15 and RW-98020. Surface water samples were collected from Mclvor Lake (SW15-01), Rico Lake (SW15-02) and the on-Site wash plant (SW16-03).

Samples were analyzed for a full or partial list of field parameters, general chemistry, nutrients, metals, hydrogen sulfide, polycyclic aromatic hydrocarbons (PAHs), extractable petroleum hydrocarbons (EPH), volatile organic compounds (VOCs), and total oil and grease. These

parameters were selected to characterize baseline water quality at and in the vicinity of the future Landfill footprint. The analytical results along with the selected comparative criteria are summarized in Table 4.0 (groundwater), Table 4.1 (surface water), and Table 4.2 (wash plant water).

4.1 Applicable Water Quality Standards

The groundwater and surface water sample analytical results have been compared to the BC Contaminated Sites Regulation (CSR) (BC Reg. 375/96) standards and BC MOE Working and Approved Water Quality Guidelines (WQGs). These standards are appropriate for evaluating groundwater and surface water quality at permitted landfills as stated in the BC MOE Landfill Criteria for Municipal Solid Waste (Draft Second Edition 2015).

Rationale

Generic groundwater standards are provided in the CSR in Schedules 6 and 10. The applicability of the standards depends on current and future groundwater and surface water uses, and the potential for groundwater or surface water at the Site to flow to surface water bodies that support aquatic life.

BC MOE document *Technical Guidance 6: Water Use Determination* (TG6) states that aquatic life standards generally apply to all groundwater located within 500 m of a surface water body containing aquatic life, and also considering preferential pathways. The Schedule 6 standard for aquatic life standards (AW) is applied to groundwater greater than 10 m inland from the high water mark of an aquatic receiving environment, as outlined in *Technical Guidance 15: Concentration Limits for the Protection of Aquatic Receiving Environments* (TG15). For groundwater within 10 m of an aquatic receiving environment, BC Water Quality Guidelines (WQGs) apply. For the Site, standards protective of fresh water receptors and WQGs apply along the western Site boundary due to the proximity of Rico Lake to the west of the Site.

TG6 states that both current and future drinking water use must be considered when determining whether drinking water (DW) standards apply to a site. TG6 also provides several exemptions for DW standards applicability based on factors including the underlying aquifers' hydraulic conductivity and yield, natural total dissolved solids concentrations, where groundwater is contained within organic soils or muskeg, or where groundwater is protected by a confining geological unit.

Future land use in the vicinity of the Site may include potable water supply thus; the drinking water exposure pathway cannot be excluded for the Site. As a result, DW standards identified in Schedules 6 and 10 apply at the property boundary of the Site.

In summary, the applicable CSR standards and WQGs that apply at the boundary of the Site are as follows:

- Schedule 6 numerical Drinking Water (DW) standards
- Schedule 10 numerical DW standards
- BC WQGs for DW and freshwater aquatic life (FWAL) along the western property boundary

4.2 Groundwater and Surface Water Analytical Results

Water Quality Characteristics

Water quality in the overburden sand and gravel aquifer can be generally characterized as relatively fresh with low concentrations of alkalinity, hardness (soft to moderately hard), chloride and TDS. The bedrock aquifer has similar water quality characteristics as the overburden sand and gravel aquifer with slightly more elevated TDS, sodium, and specific conductivity.

Surface water quality in McIvor and Rico Lakes is similar to that observed in the overburden sand and gravel aquifer and is characterized as being low in alkalinity, hardness, conductivity, and TDS and with low concentrations of nutrients and major ions.

Water quality of the wash plant is similar to the overburden sand and gravel aquifer as indicated by low concentrations of alkalinity, hardness, chloride and TDS.

Water Quality related to Typical Indicator Parameters

A list of typical indicator parameters has been selected for characterizing baseline water quality. The selected indicator parameters have been selected as these parameters are typically elevated in landfill leachate from landfills containing construction and demolition wastes and contaminated soils. In order to best understand baseline water quality, it is important to establish the baseline concentrations of this list of indicator parameters in existing on-Site groundwater.

The list of selected indicator parameters for the Upland Landfill is as follows:

- Hardness
- Alkalinity
- Chloride
- Specific Conductance
- Hydrogen Sulphide
- Phenols
- Sulphate and Suphide
- Boron
- Iron
- Manganese
- Total Dissolved Solids (TDS)
- Ammonia
- Hydrocarbons

Alkalinity	Alkalinity increases downgradient of landfills primarily due to elevated levels of dissolved carbon dioxide in affected water (produced by the biological breakdown of organic material) causing the dissolution of carbonate from natural geologic materials within the aquifer.
Conductivity	Electrical or specific conductivity increases in leachate-affected groundwater as increases in dissolved ions result in increases in the conductive capacity of water.
Chloride	Chloride is generally abundant in waste and is formed in part by the degradation of various wastes. Chloride is a very useful leachate indicator parameter as it is not subject to retardation processes and thus migrates at essentially the same rate as groundwater flow.
Sulphide and Hydrogen Sulphide	Under anaerobic conditions, sulphide (as H ₂ S) is observed in the natural environment through the reduction of sulphur species. The reducing conditions resulting from the presence of buried waste thus favour the development of sulphide in leachate-affected waters.
Sulphate	Construction and demolition waste landfills often generate elevated concentrations of sulphate in leachate affected waters due to the abundance of sulphate available from drywall in the waste stream.

Hardness	Caused by the increased concentrations of calcium and magnesium ions due to the waste materials and more acidic pH breaking down the native lime-rich soils
Phenols	Sources of phenols in groundwater include ash and combustion waste as well as tar (roofing materials). Phenols are also a byproduct of the natural degradation of benzene.
TDS	Caused by the increased amount of cations and anions in solution due to the waste materials and dissolution of salts
Ammonia	High concentrations of ammonia are observed when the landfill enters its anaerobic stage. In the anaerobic stage, anaerobic decomposition dominates and the entire landfill is in a chemically reducing state that results in more ammonia than nitrate or nitrite.
Iron and Manganese	Concentrations typically increase in landfill-affected groundwater due to the alteration of redox conditions within the groundwater. The breakdown of dissolved organic matter within leachate consumes dissolved oxygen and related oxygen sources in groundwater and creates reducing conditions. Where conditions are reducing, naturally-occurring iron and manganese oxides within the geologic material are reduced to more soluble forms, which results in an increase in dissolved iron and manganese concentrations.
Hydrocarbons	Hydrocarbons are not typically naturally present at detectable concentrations in shallow groundwater. As construction and demolition wastes can be a source of hydrocarbons, they can be an effective indicator of landfill-related water quality impacts.

It should be noted that PAHs and VOCs were also analyzed from groundwater collected from MW4A/B-15 MW5A/B-15, and surface water monitoring locations SW15-01 and SW15-02.

Water Quality compared to BC WQGs and CSR Standards

Groundwater

Groundwater samples were collected from monitoring wells MW1-14, MW2-14, MW3-14 and MW4A/B-15 between September and October 2015. Groundwater samples collected from the above listed monitoring wells contained concentrations of several parameters above their respective DW and/or FWAL criteria and CSR standards. Exceedance summary figures for groundwater parameters above applicable WQGs and CSR standards are presented on Figures 4.0 and 4.1, respectively. The analytical tables (Table 4.0) highlight each exceedance of the applicable WQGs and CSR standards.

As shown on Figure 4.0, concentrations of aluminum, zinc, sulfide, cadmium, ammonia and nitrite were above FWAL criteria within the sand and gravel aquifer. And concentrations of aluminum, cadmium and zinc (MW5A-15 only) were above FWAL criteria in the bedrock unit. Manganese concentrations were above DW criteria within the sand and gravel aquifer and the bedrock unit (MW5A-15 only).

As shown on Figure 4.1, only hydrogen sulfide was above the CSR standard for FWAL in the sand and gravel aquifer (at MW3-14).

In comparison to WQGs and CSR standards, groundwater quality within the overburden sand and gravel aquifer is characterized as having slightly elevated concentrations of sulphide, hydrogen sulphide, aluminum, nitrite, and zinc. The following table summarizes the ranges of selected parameter concentrations from the overburden sand and gravel aquifer unit:

Hydrogeologic Unit:	Units	Overburden Sand and Gravel Aquifer	
Selected Indicator Parameters:		Minimum Concentration	Maximum Concentration
Conductivity, field	mS/cm	0.092	0.283
Total dissolved solids, field (TDS)	g/L	0.061	0.184
Alkalinity, total (as CaCO ₃)	mg/L	15.40	77.90
Chloride (dissolved)	mg/L	0.83	24.00
Conductivity	uS/cm	55.50	240.00
Hardness (dissolved)	mg/L	16.80	81.10
Hydrogen sulfide	mg/L	ND (0.0019)	0.029 ^c
Sulfate (dissolved)	mg/L	ND (0.50)	8.22
Sulfide	mg/L	ND (0.0019)	0.027 ^a
Phenols (total)	mg/L	ND (0.0010)	ND (0.0010)
Total dissolved solids (TDS)	mg/L	52 J	162.00
Ammonia-N	mg/L	ND (0.0050)	0.2
Boron (dissolved)	ug/L	ND (50)	ND (50)
Iron (dissolved)	ug/L	ND (5.0)	305.00
Manganese (dissolved)	ug/L	ND (1.0)	24.00

Notes:

- ^a Exceeds BC WQG Freshwater Aquatic Life (FWAL) Working Guideline of 0.002 mg/L.
^c Exceeds BC CSR Schedule 6 Freshwater Aquatic Life (FWAL) Guideline of 0.02 mg/L.
J Estimated concentration
ND Concentration below detection limit

The following table summarizes the ranges of selected parameter concentrations from the bedrock aquifer unit:

Hydrogeologic Unit:	Units	Bedrock Unit*	
Selected Indicator Parameters:		Minimum Concentration	Maximum Concentration
Conductivity, field	mS/cm	0.135	0.323
Total dissolved solids, field (TDS)	g/L	0.088	0.21
Alkalinity, total (as CaCO ₃)	mg/L	58.6	102 J
Chloride (dissolved)	mg/L	2.4	27.00
Conductivity	uS/cm	124	309 J
Hardness (dissolved)	mg/L	53.3	53.3
Hydrogen sulfide	mg/L	ND (0.0019)	ND (0.0019)
Sulfate (dissolved)	mg/L	3.72	6.84
Sulfide	mg/L	ND (0.0019)	ND (0.0078)
Phenols (total)	mg/L	ND (0.0010)	ND (0.0010)
Total dissolved solids (TDS)	mg/L	58.00	204 J
Ammonia-N	mg/L	ND (0.0050)	0.02
Boron (dissolved)	ug/L	5.9	ND (50)
Iron (dissolved)	ug/L	ND (5.0)	20.1
Manganese (dissolved)	ug/L	8.5	42.4

Notes:

- ND Concentration below detection limit
J Estimated concentration
* The analytical results of samples collected at MW5A-15 are not included in the above table

The concentration ranges summarized above are representative of baseline water quality for assessing potential on-Site Landfill-related water quality alterations should they occur.

EPH, PAHs and VOCs were not detected at concentrations above their respective reporting limits in the groundwater samples (MW4A/B-15 and MW5A/B-15) analyzed for those parameters.

Surface Water- Mclvor and Rico Lakes

Surface water samples were collected from Mclvor and Rico Lakes at SW15-01 and SW15-02, respectively, between September and October 2015. At both surface water sample locations, temperature (field) and sulphide concentrations were above the applicable BC WQGs for FWAL and/or DW protection. At Rico Lake (SW15-02), dissolved oxygen (field) was also above the WQG for FWAL. Surface water analyte concentrations were not reported above CSR standards. These results are presented on Table 4.1. Analytical summary figures for surface water parameters as compared to applicable WQGs and CSR standards are presented on Figures 4.0 and 4.1, respectively.

As shown on Figure 4.0, concentrations of temperature (field), dissolved oxygen (field), and sulfide are above their respective WQG criteria (exceedances are highlighted yellow).

As shown on Figure 4.1, water quality parameter concentrations did not exceed CSR standards.

The following table summarizes the ranges of selected parameter concentrations in surface water:

Selected Indicator Parameters:	Units	Minimum Concentration	Maximum Concentration
Total dissolved solids, field (TDS)	g/L	0.04	0.05
Alkalinity, total (as CaCO ₃)	mg/L	14.70	105.00
Chloride (dissolved)	mg/L	0.90	25.00
Hardness	mg/L	16.30	51.60
Hardness (dissolved)	mg/L	22.40	48.30
Hydrogen sulfide	mg/L	ND (0.0019)	ND (0.0019)
Phenols (total)	mg/L	ND (0.0010)	ND (0.0010)
Sulphate (dissolved)	mg/L	0.75	8.51
Sulphide	mg/L	ND (0.0019)	0.0085^a
Total dissolved solids (TDS)	mg/L	ND (51)	192.00
Ammonia-N	mg/L	0.02	0.02
Boron	ug/L	ND (50)	ND (50)
Iron	ug/L	ND (10)	86.00
Manganese	ug/L	2.50	25.10

Notes:

- ^a Exceeds BC WQG Freshwater Aquatic Life (FWAL) Working Guideline of 0.002 mg/L.
 ND Concentration below detection limit

Mclvor and Rico Lakes are not interpreted to be potential receptors of Landfill-related water quality impairments based on the documented flow direction (Figure 3.6). As such, the concentration ranges summarized above should be used to characterize surface quality at Mclvor and Rico Lakes.

EPH, PAHs and VOCs were not detected at concentrations above their respective reporting limits in the surface water samples (Rico and Mclvor Lakes) analyzed for those parameters.

Surface Water - Wash Plant

In order to determine if the wash plant is a source of impact to the overburden sand and gravel aquifer, samples were collected from the third settling pond of the on-Site wash plant (SW16-03) on January 29, 2016. Based on the wash plant analytical results, which are presented on Table 4.2, surface water concentrations from samples collected at the wash plant are similar to groundwater quality within the sand and gravel overburden aquifer.

Concentrations of sulphide and aluminum were above the applicable WQGs for FWAL. However, were below the maximum concentrations reported from groundwater samples collected within the sand and gravel overburden aquifer. Surface water samples collected from the wash plant were not reported above the applicable WQGs for DW protection or CSR standards. Analytical summary figures for surface water parameters as compared to applicable WQGs and CSR standards are presented on Figures 4.0 and 4.1, respectively. Exceedances are highlighted yellow.

Based on these results surface water from the wash plant is not a source of impact to the overburden aquifer. Additional investigation or monitoring of the wash plant is not necessary.

4.3 MW5A/B-15 Water Quality

As discussed in Section 3.4 (Site Hydrogeology), the aquifer units in which MW5A/B-15 are completed are not connected to the overburden sand and gravel aquifer unit or the bedrock unit noted across the rest of the Site. This conclusion is based on differences in stratigraphic elevation and hydraulic elevation differences. The water quality results from MW5A-15 and MW5B-15 provide additional evidence of the disconnection as water quality is dissimilar between the two wells and the rest of the Site. Concentrations of many general chemistry parameters are notably higher in the samples collected from MW5A/B-15.

As previously discussed, as MW5A/B-15 are located at an elevation much greater than the future Landfill base and that the aquifer units are not connected to the sand and gravel aquifer (the receiving water body for any potential Landfill-related impacts), water quality will not be subject to potential Landfill-related water quality alterations. As such, additional investigation or monitoring of this unit is not necessary in the scenario of Landfill development.

4.4 Downgradient Groundwater Quality

In order to determine and assess future groundwater quality downgradient of the future Landfill and to verify the interpreted groundwater flow direction downgradient of the Pit, installation of an additional monitoring well (MW6-16) is recommended. MW6-16 should be installed near the downgradient Site boundary so that water quality results from this location can be used for assessing Site groundwater compliance with the applicable water quality standards and guidelines identified for the Site. The future location of monitoring well MW6-16 is depicted on Figure 2.0.

It is recommended that installation and sampling of MW6-16 is completed prior to Landfill development activities so that baseline water quality data can be obtained from this well.

4.5 Residential Groundwater Quality

In order to determine baseline residential groundwater quality prior to Landfilling activities, permission to sample Residential Well 98020 was obtained.

The results from RW-98020 are summarized in Table 4.0 and indicate that water quality is similar to the water quality of the on-Site bedrock aquifer unit. Results indicate fresh groundwater with slightly elevated TDS, sodium, and specific conductivity.

5. Conclusions and Recommendations

This hydrogeology and hydrology characterization was undertaken in support of Upland's Waste Discharge Application. This Report has been prepared to satisfy the hydrogeology and hydrology characterization requirements of the Landfill Criteria. This Report provides information pertaining to the Site's background, the scope of characterization work completed, the physical setting of the Site, the environmental / hydrogeologic and hydrologic conditions at the Site and an assessment of existing water quality at the Site. The pertinent conclusions and recommendations resulting from the characterization are as follows:

1. Site geology consists of granular overburden deposits (primarily sand and gravel) overlying basaltic bedrock.
2. The top of bedrock is highly variable at and in the vicinity of the Site. Bedrock outcrops are present in the southwest corner of the Site.
3. There are two primary groundwater bearing zones at the Site:
 - An overburden sand and gravel aquifer
 - A shallow bedrock aquifer
4. The overburden sand and gravel aquifer is the principal groundwater flow system at the Site. Interpreted groundwater flow within the overburden sand and gravel aquifer on-Site is to the southeast.
5. With the exception of Rico Lake and McIvor Lake, there are no natural surface water bodies within 500 m of the Site.
6. Any hydraulic connection between Rico Lake or McIvor Lake and the overburden sand and gravel aquifer is a muted connection. Hydraulic separation of these lakes and the overburden sand and gravel aquifer is likely due to a competent bedrock ridge located to the west and southwest of the Site.
7. Based on the steep hydraulic gradients between McIvor Lake and Rico Lake and the overburden sand and gravel aquifer, flow between these water bearing units would be from the lakes to the Site.
8. The vertical gradient between the sand and gravel aquifer and the bedrock aquifer beneath the base of the Pit is upward.
9. Groundwater quality in the overburden sand and gravel aquifer can be generally characterized as relatively fresh with low concentrations of alkalinity, hardness (soft to moderately hard), chloride, and TDS. The bedrock aquifer has similar water quality characteristics with slightly more elevated TDS, sodium, and electrical conductivity.
10. Surface water quality in McIvor and Rico Lakes is similar to that observed in the overburden sand and gravel aquifer and is characterized as being low in alkalinity, hardness, conductivity, and TDS and with low concentrations of nutrients and major ions.
11. The applicable CSR standards and WQGs that apply at the boundary of the Site are as follows:
 - Schedule 6 numerical Drinking Water (DW) standards
 - Schedule 10 numerical DW standards

- BC WQGs for DW and freshwater aquatic life (FWAL) along the western property boundary

Based on the results of the information summarized in the previous sections, the following recommendations are made:

1. A groundwater monitoring well (MW6-16) should be installed downgradient of the future Landfill footprint in close proximity to the Site boundary so that Site compliance with respect to groundwater quality can be assessed during and post Landfill development.
2. The nature of the bedrock ridge extending from the southwest to northwest of the Site and the direction and magnitude of groundwater flow between the Site and Mclvor and Rico Lakes should be further investigated with three bedrock monitoring wells (MW7-16, MW8-16 and MW9-16).

All of which is Respectfully Submitted,

GHD

A handwritten signature in black ink, appearing to read "Rose Marie Rocca".

Rose Marie Rocca, B.Sc.

A handwritten signature in black ink, appearing to read "Simon Foster".

Simon Foster, M.Sc.



Gregory D. Ferraro, P. Eng.

6. References

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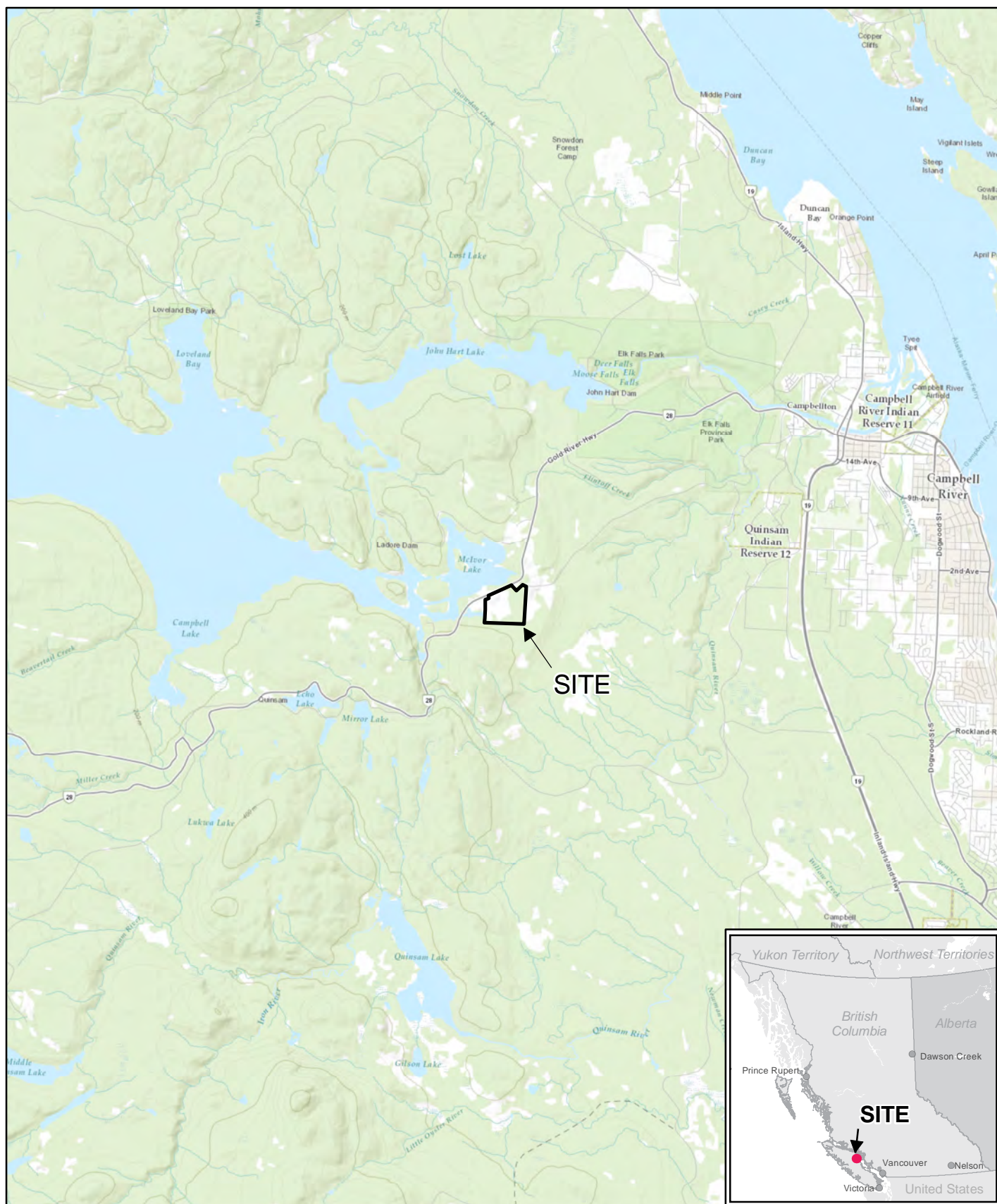
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Source: ESRI Topographic Basemap, Accessed 2016
 Inset Map: ESRI Data & Maps 2008 Data Distribution Application (DDA)

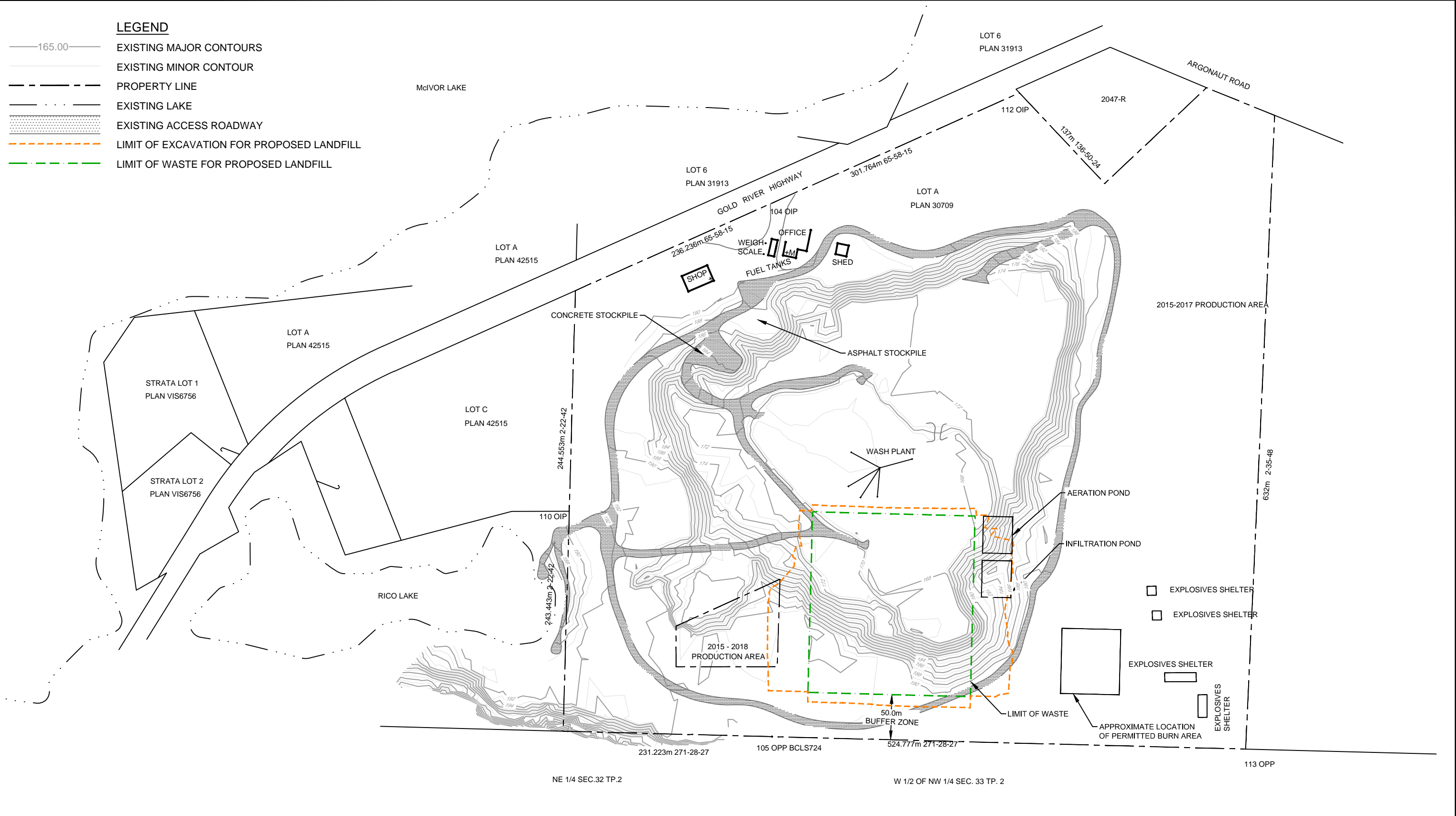
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 Coordinate System:
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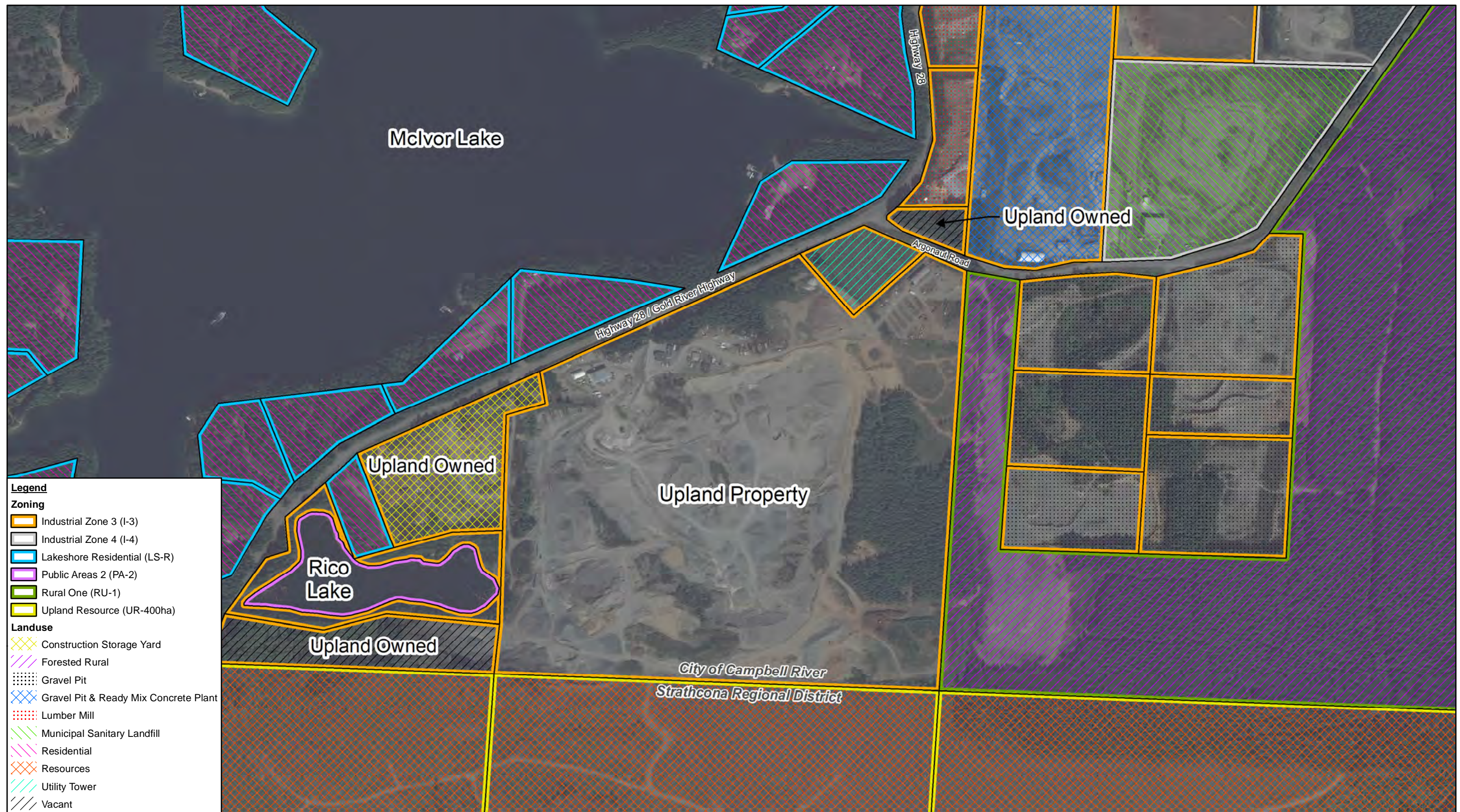


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FIGURE 1.0





Sources: CanVec Edition 1.1 © Department of Natural Resources Canada, all rights reserved; National Road Network 2.0 GeoBase; Property Parcels - City of Campbell River; Microsoft product screen shot(s) reprinted with permission from Microsoft Corporation.

0 60 120 180
Meters
Coordinate System:
NAD 1983 UTM Zone 10N

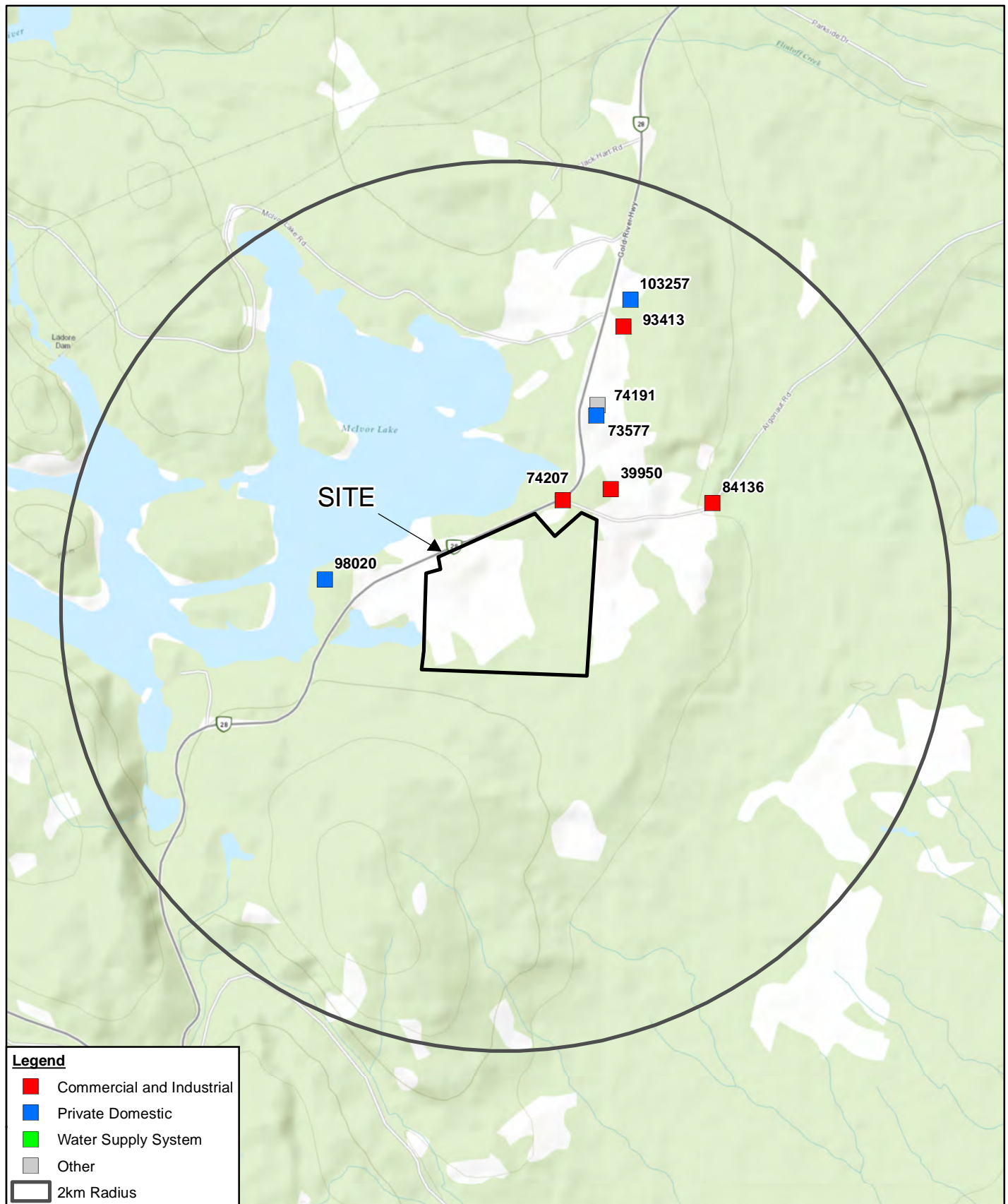


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FIGURE 1.2



Source: ESRI Topographic Basemap, Accessed 2016;
British Columbia Ministry of Environment, Water Protection and Sustainability Branch, September 11, 2014

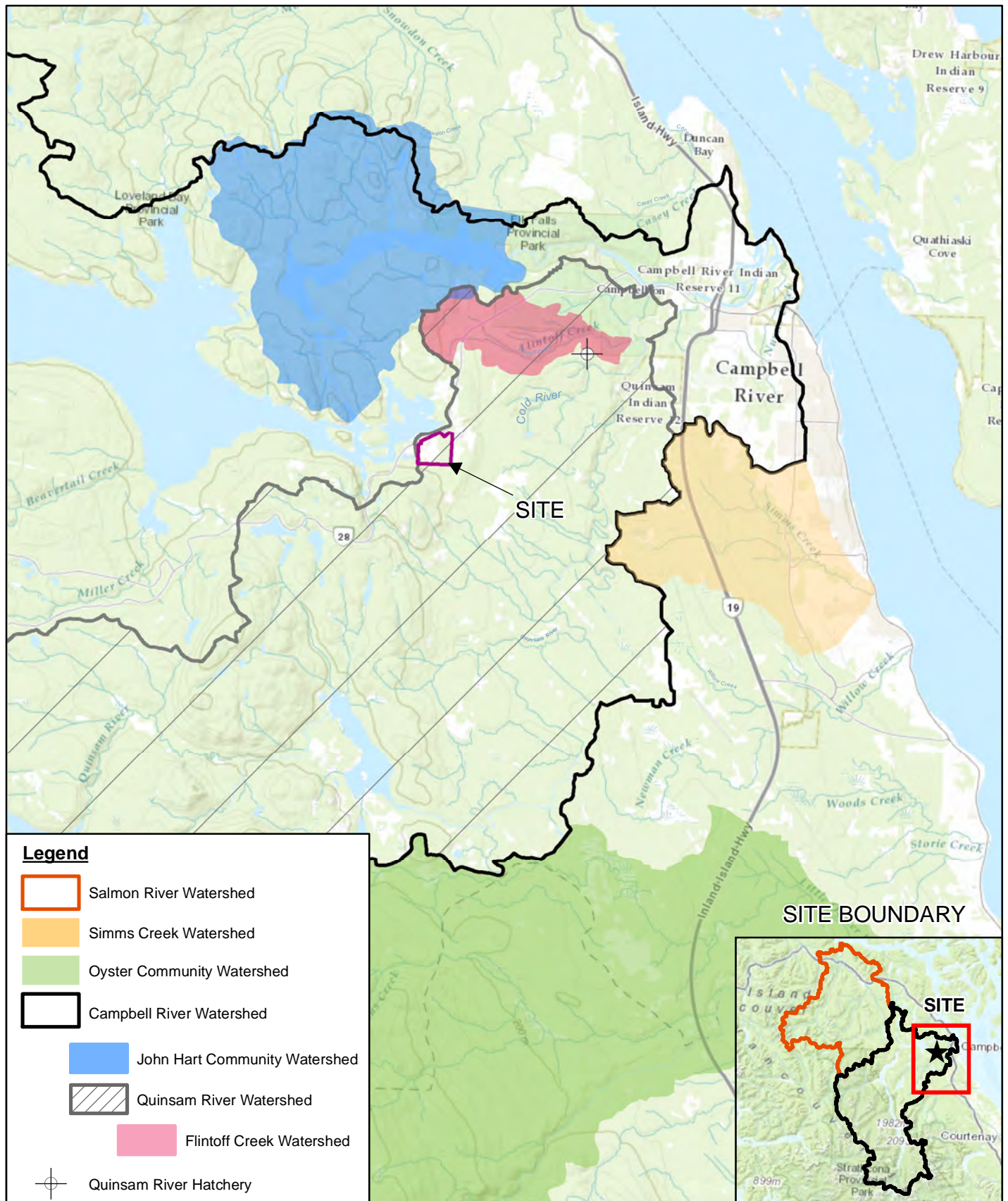
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NAD 1983 UTM Zone 10N



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FIGURE 1.3



Source: ESRI Topographic Basemap, Accessed 2016 Canada.
The watershed divide is approximate and based on site specific geologic, hydrogeologic, and BC Water Resource Atlas information

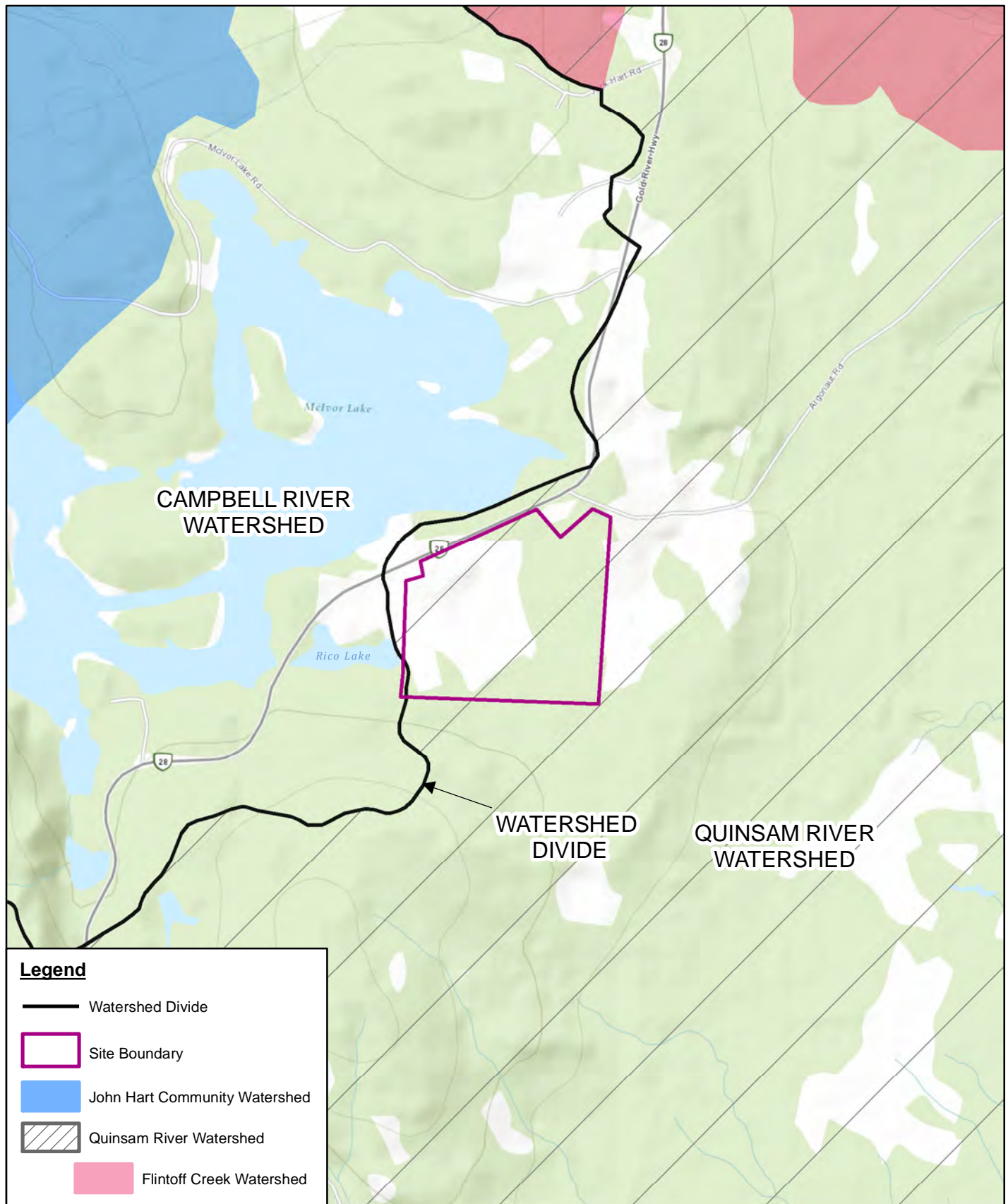
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Coordinate System:
NAD 1983 UTM Zone 10N



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REGIONAL WATERSHED MAP FIGURE 3.0A



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Coordinate System:
NAD 1983 UTM Zone 10N

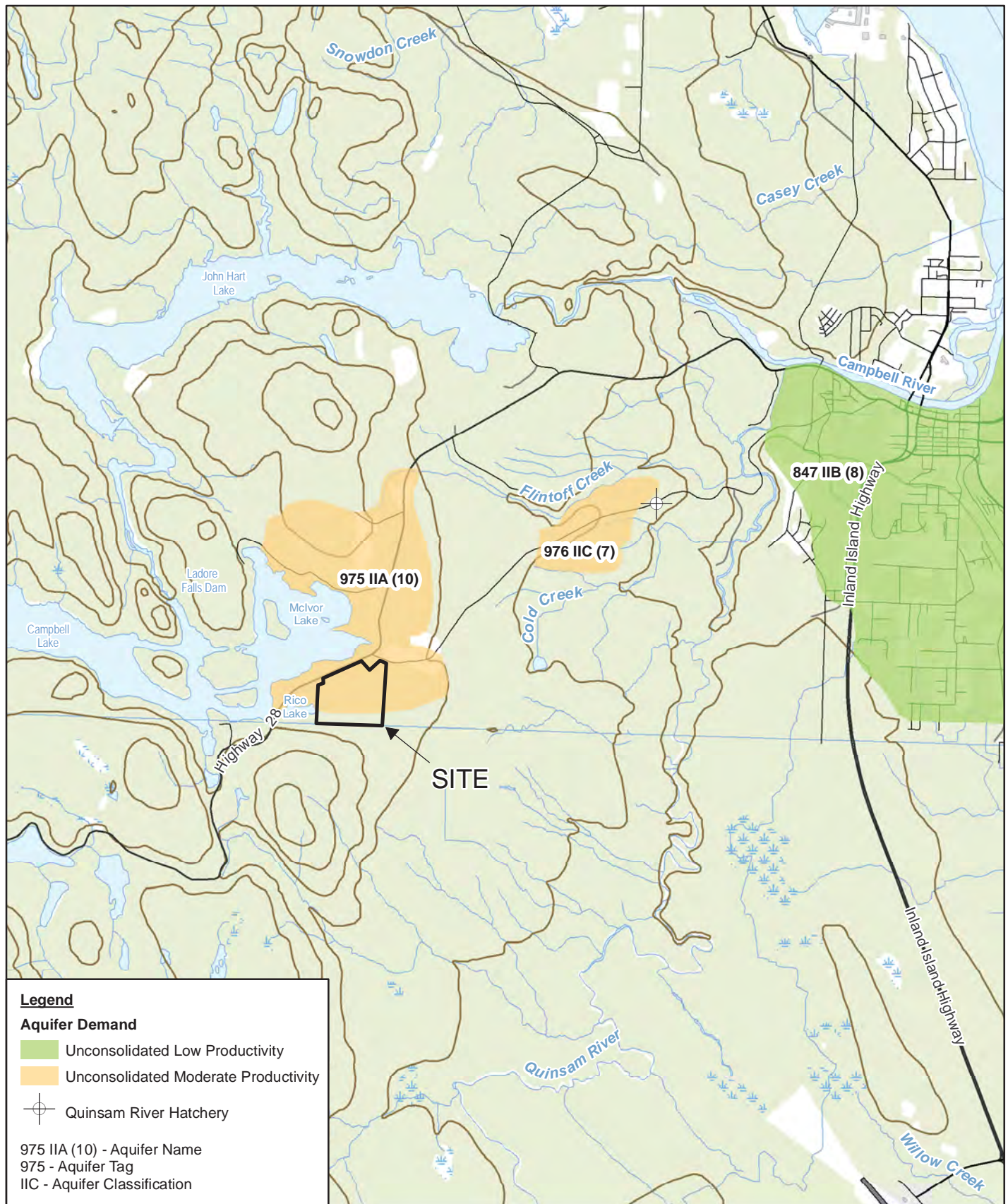


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LOCAL WATERSHED MAP

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FIGURE 3.0B



Source: CanVec Edition 1.1 © Department of Natural Resources Canada. All rights reserved. National Road Network 2.0 GeoBase

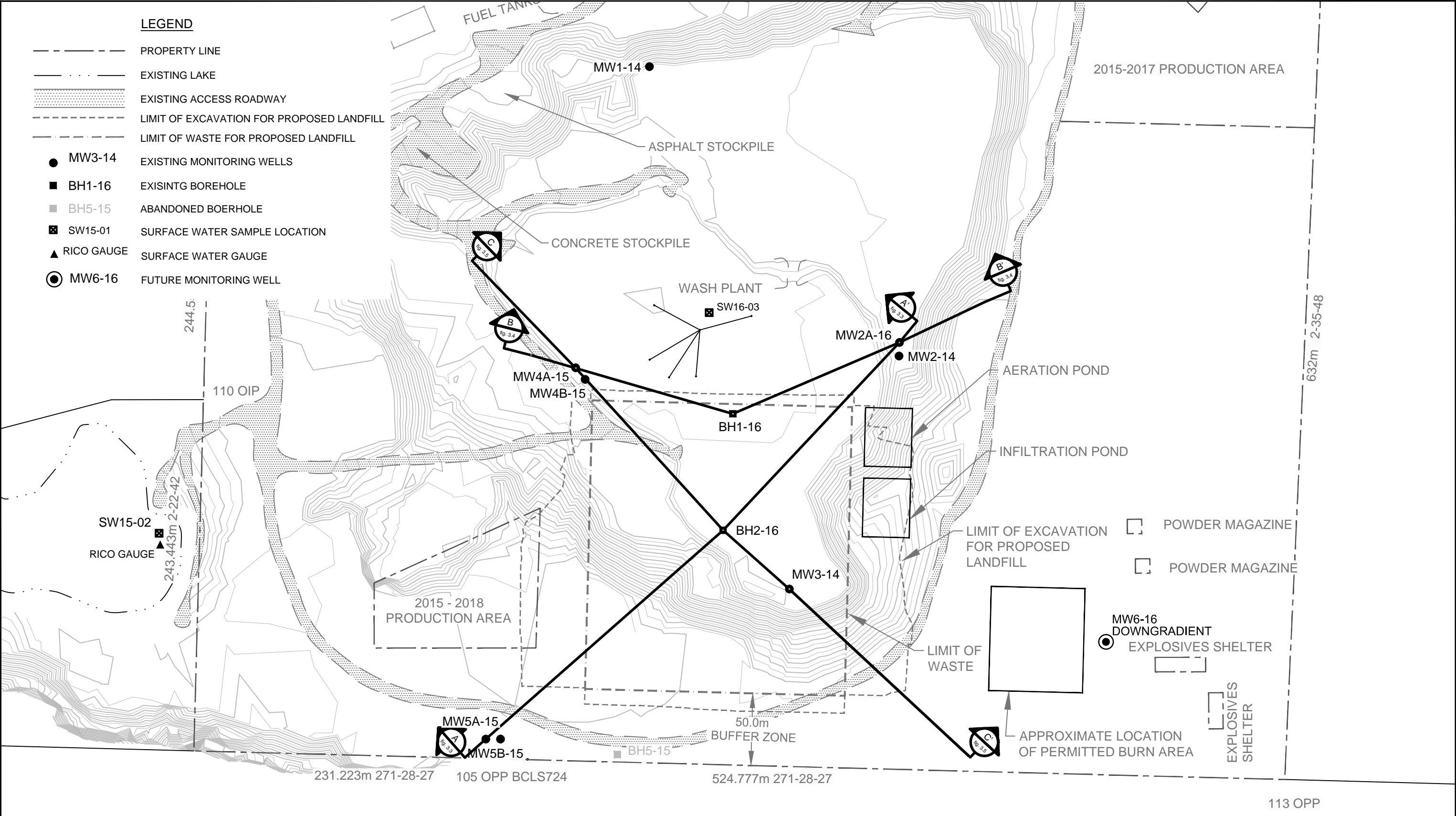
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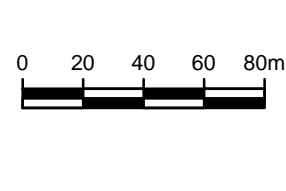
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DRAINAGE MAP

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FIGURE 3.1



Source: TOPOGRAPHICAL SURVEY CONDUCTED BY UPLAND CONTRACTING LTD., JANUARY 29 2015

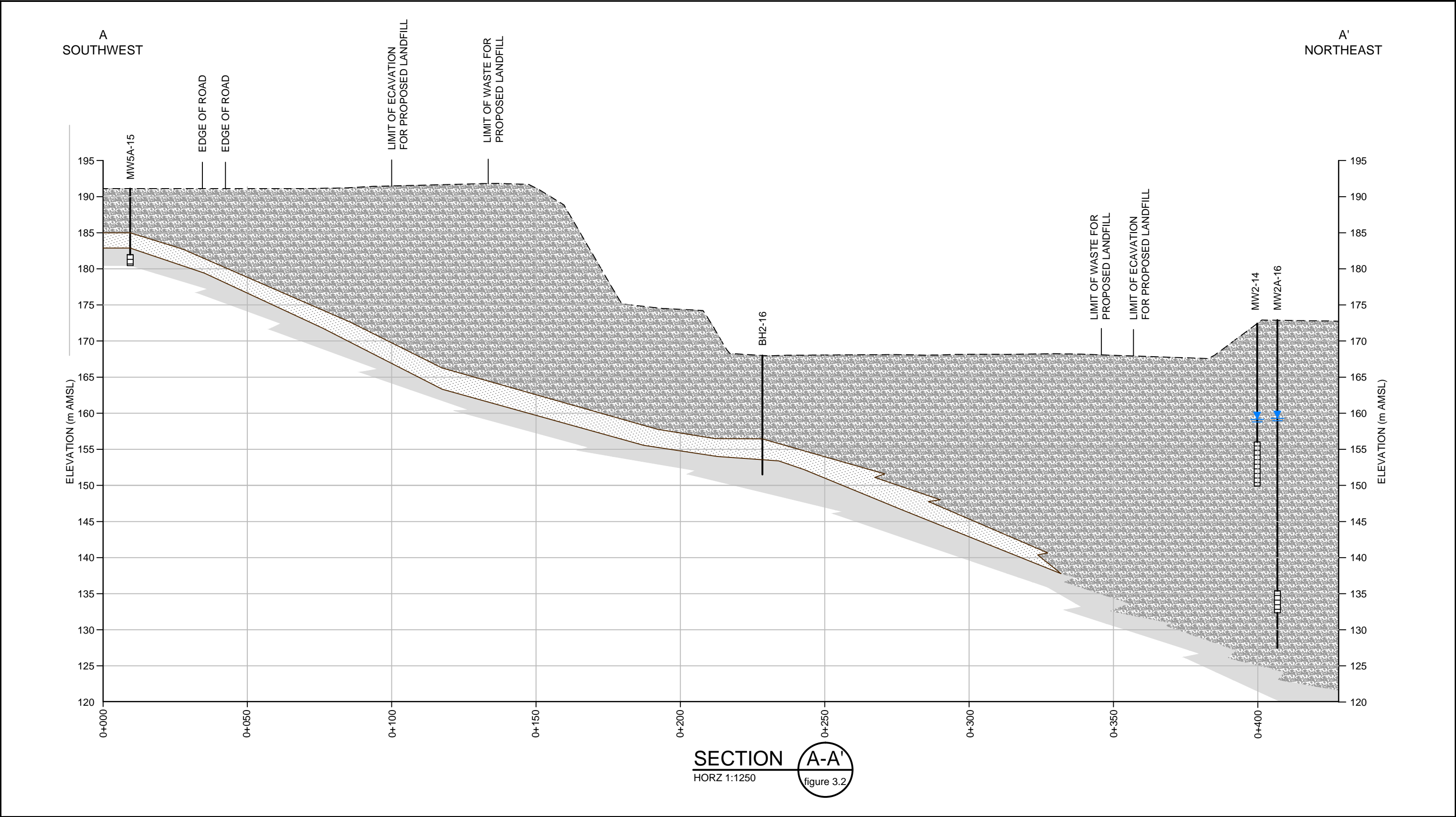


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CROSS-SECTION PLAN

FIGURE 3.2



LEGEND

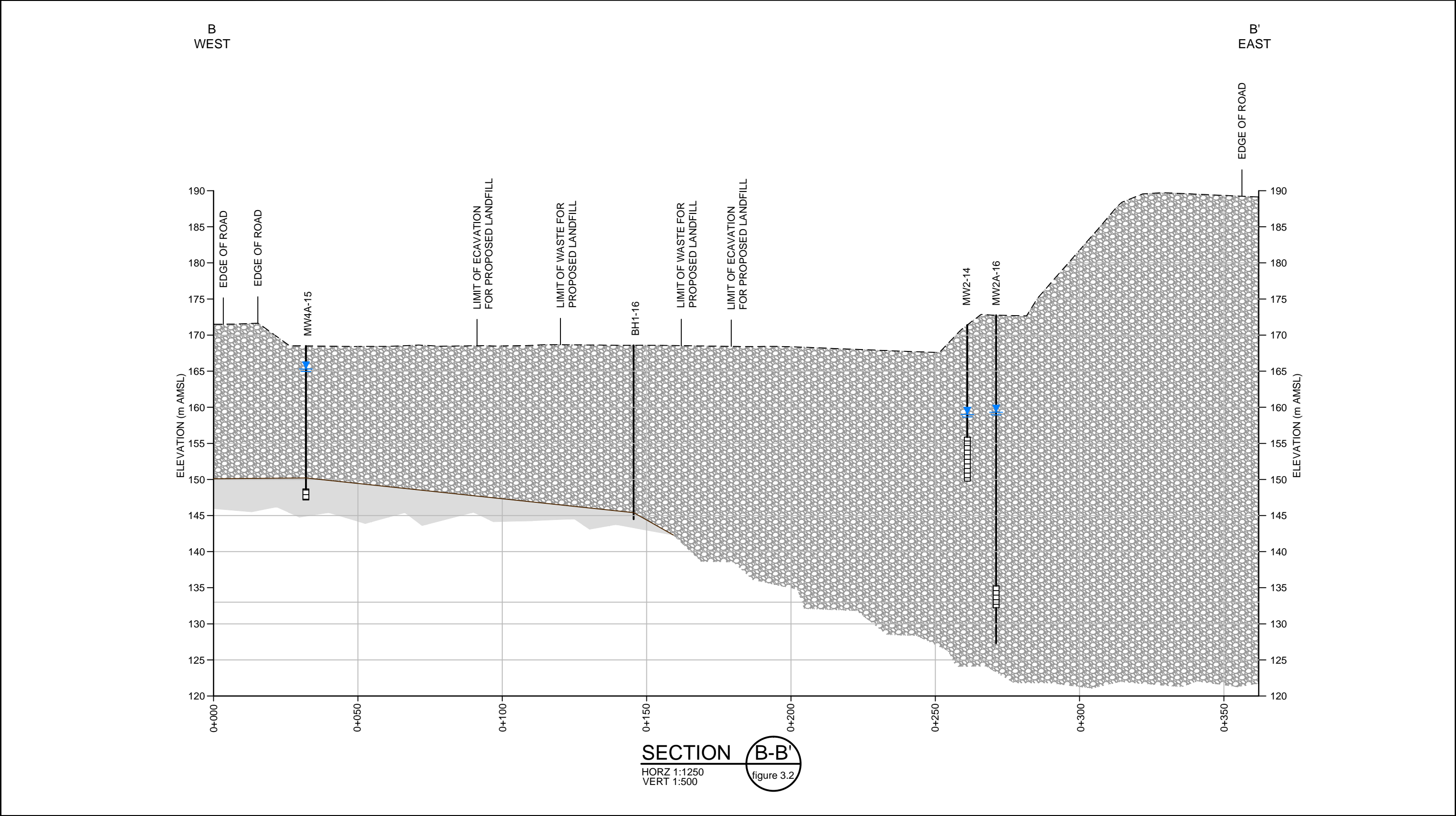
	SAND AND GRAVEL		SCREEN INTERVAL
	SANDY SILT		WATER LEVEL (m AMSL) (JANUARY 25, 2016)
	BEDROCK (BASALT)		

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CROSS-SECTION A-A'

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FIGURE 3.3



LEGEND

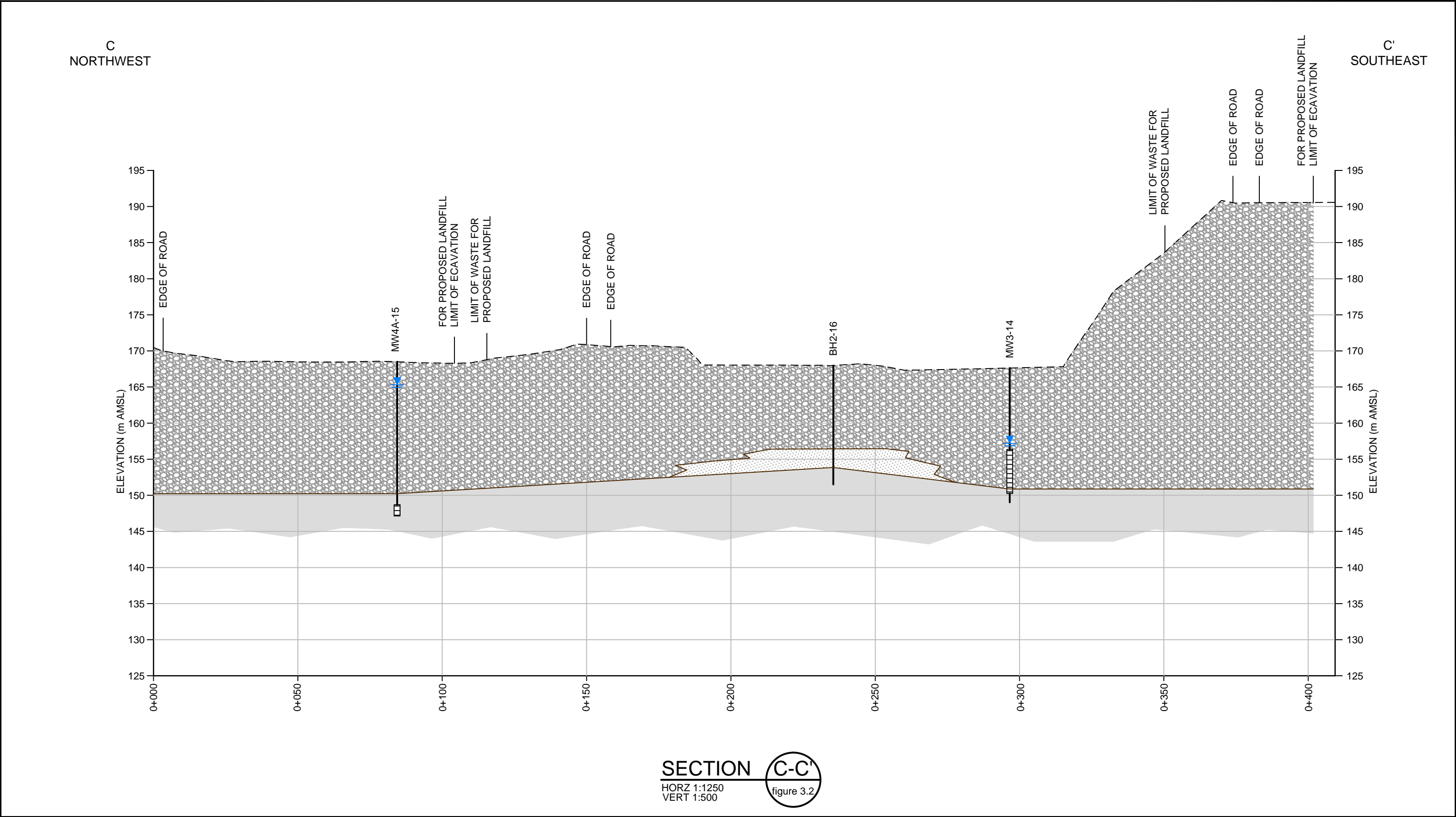
	SAND AND GRAVEL		SCREEN INTERVAL
	SANDY SILT		WATER LEVEL (m AMSL) (JANUARY 25, 2016)
	BEDROCK (BASALT)		

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CROSS-SECTION B-B'

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FIGURE 3.4



LEGEND

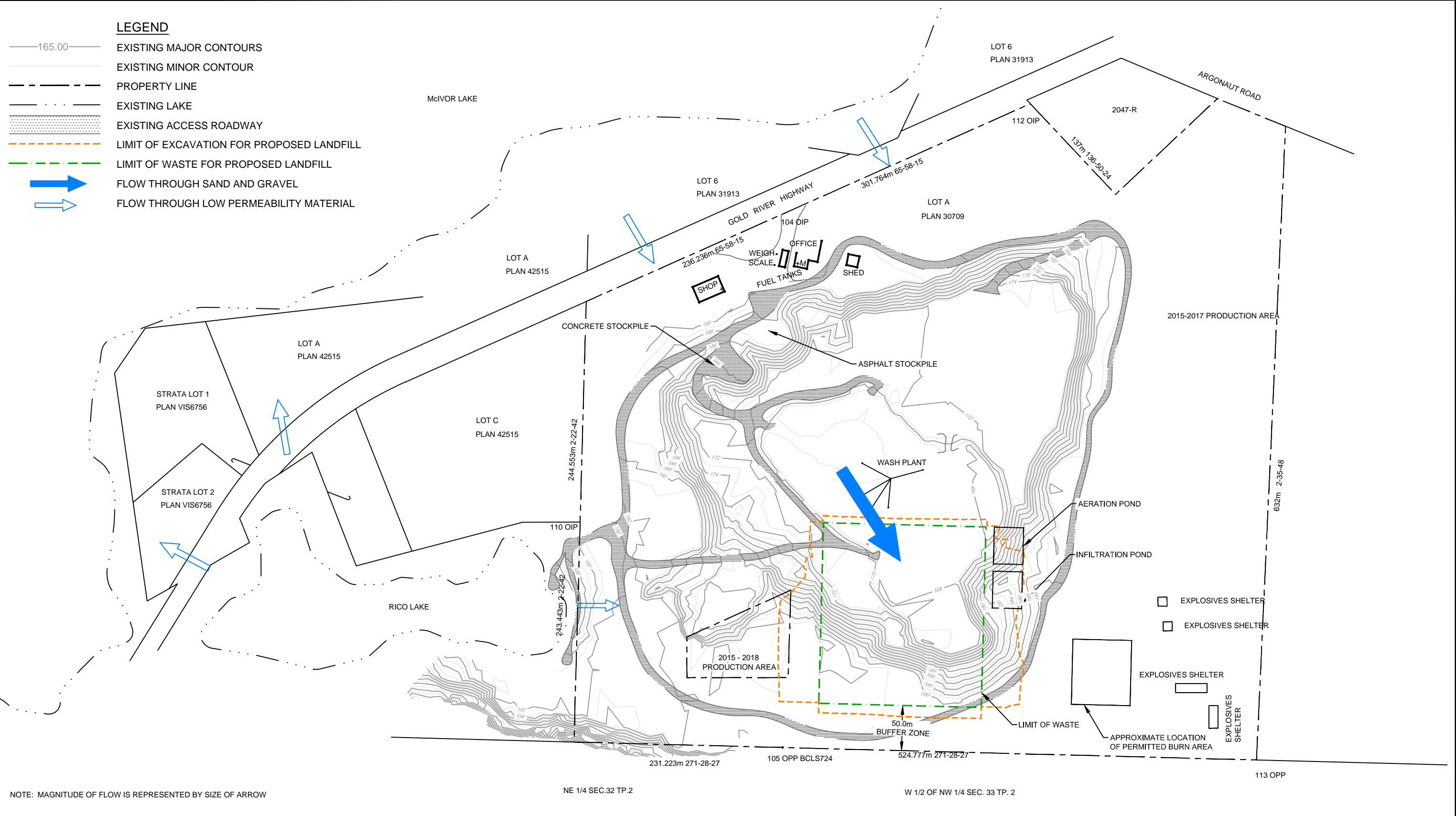
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	SANDY SILT		WATER LEVEL (m AMSL) (JANUARY 25, 2016)
	BEDROCK (BASALT)		

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CROSS-SECTION C-C'

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FIGURE 3.5



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