REPORT ON

PHASE 1:
GROUNDWATER PROTECTION STUDY
DISTRICT OF HIGHLANDS

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EXECUTIVE SUMMARY

This report presents the results of the first year (Phase 1) of a three-year Groundwater Protection Study conducted by Golder Associates Ltd. (Golder) on behalf of the District of Highlands (Highlands). The objectives of the Groundwater Protection Study are to assess groundwater conditions throughout the District, to provide the Highlands with information and tools to support the protection and conservation of groundwater quality and quantity and to guide future land-use decisions within the Highlands in light of potential climate change impacts.

The scope of work of Phase 1 of the Groundwater Protection Study consisted of compiling and reviewing available data and information to develop a conceptual model of groundwater flow in the Highlands, compiling an inventory of unused water wells, developing a numerical model of groundwater flow in the Highlands and developing a preliminary groundwater monitoring program for groundwater quality and water level measurements. The numerical groundwater model was used to conduct a water balance analysis for the bedrock aquifer within the District of Highlands and to assess the sustainability of current and future groundwater withdrawals. The model was also used to delineate capture zones for select communal/commercial wells within the Highlands, including those operated by the Bear Mountain Golf Course and the well that services the River's Crossing Retreat Centre and the Hannington Estates Subdivision.

Data Compilation and Review

Data and information were collected through on-line searches, telephone enquiries and a search of files maintained by the Highlands and Golder. The information included published maps and papers, data from federal, provincial and municipal government sources, reports prepared by consultants, and information collected from property owners and operators.

Key geological and hydrogeological data were collected from water well records maintained in the on-line Water Resources Atlas by the BC Ministry of Environment (MoE) and information presented in hydrogeological reports and studies. This information was compiled into a project database (Highlands database). The Highlands database consists of detailed information on a total of 654 water wells; of these, 635 wells are located in the Highlands and 19 wells are located in Langford, immediately south of the Highlands. These data were reviewed to characterise the hydrostratigraphy of the Highlands, assess groundwater levels, determine representative hydrogeologic parameters, and estimate rates of groundwater recharge, surface water use and groundwater use.

Information was also collected to characterize the hydrology in the Highlands, including climate data (precipitation and temperature) and information on topography, watershed characteristics and streamflow in major streams and rivers. Golder conducted a limited streamflow monitoring program at key locations in the Highlands to assess baseflow at the end of the dry season.

Conceptual Model

Information gathered during the data compilation and review task was used to develop a conceptual model of groundwater flow in the Highlands. The Highlands study area is characterized as a fractured, metamorphic bedrock aquifer system. Groundwater flow within the Highlands is governed by the rate of recharge by precipitation, the hydraulic properties of the bedrock, and the presence of lineaments, some of which act as permeable features. The water table within the bedrock aquifer is inferred to be a subdued impression of the local topography; groundwater flows from higher elevations into the valleys and numerous surface water courses throughout the Highlands.

A total of 674 residential properties in the Highlands are estimated to obtain water for domestic purposes from private water wells. In addition, five communal/commercial users with one or more wells were identified in the southern portion of the District of Highlands and the northern portion of Langford.

Inventory of Unused Water Wells

During the data compilation and review task, Golder compiled a preliminary inventory of unused wells. The inventory of unused wells was compiled by means of a search of existing reports and data sources, together with telephone enquiries to groundwater consultants, water well drillers and pumping test operators involved in groundwater supply projects in the Highlands. In addition, the District office provided Golder with information on wells that was provided by residents in the Highlands. The results of the unused well survey were compiled in the Highlands database. A total of 32 unused wells were identified in the Highlands. Golder will continue to update the inventory of unused water wells during Phases 2 and 3 if additional information becomes available.

Numerical Groundwater Model

A numerical model of groundwater flow in the Highlands was developed and calibrated. The numerical model was constructed using FEFLOW, a three-dimensional finite numerical code (Diersch, 2003). The model domain covers an area of approximately 60 km^2, encompasses the entire District of Highlands and extends into adjacent jurisdictions, including the District of Saanich to the east and the Districts of Langford and View Royal to the south. Vertically, the model is divided into three layers with the top of the model set to ground surface and the base of the model set to an elevation of 400 m below sea level.

Specified head boundaries were used to represent the eastern boundary of the model (Finlayson Arm) and lakes, wetlands, streams and drainage courses within the model domain. No-flow (zero flux) boundaries were used to simulate inferred groundwater flow divides along the perimeter and base of the model. Specified fluxes were applied to the top of the model to simulate aerially distributed recharge from precipitation and human sources, and to simulate residential water consumption. Major groundwater users were simulated using specified flux boundaries assigned to element nodes representing the location of the well screen.

The hydrogeologic model was calibrated to static hydraulic head data contained within the water well database, water levels recorded in specific wells during pumping tests and the stream flow measurements recorded by Golder in September 2007. During model calibration, some model parameters, including hydraulic conductivity and storage properties, were adjusted to improve the match between model predictions and calibration targets.

The hydrogeologic model developed for the Highlands is a regional-scale model capable of assessing average groundwater conditions over large areas. Although the model is capable of simulating transient conditions, running these simulations with the model are not recommended at this time as seasonal water level data are required to calibrate the model. The model should be considered as a “working tool”, which can be refined to simulate transient conditions when seasonal water level data become available. Currently, the model is also not suitable for local-scale applications such as well field design and optimization.

Water Balance Analysis

Water balance analyses were conducted to assess the sustainability of current and future groundwater withdrawals. The results of this analysis provides a basis for the Highlands to address some of its concerns related to maintaining sustainable groundwater withdrawals and understanding how climate change may impact groundwater supply.

Steady-state model simulations were conducted to determine the water balance under current conditions and four future scenarios that assess the influence of increased development in the Highlands (full build-out) and potential impacts from climate change. Simulation of the four future scenarios indicates that climate change will likely have the most significant impact on groundwater conditions within the District of Highlands. The simulation that included full build-out and potential impacts associated with climate change predicted a average annual decline in groundwater levels of up to 16 m in the higher elevations of the Highlands, with less effect observed in groundwater discharge areas (i.e., in the valleys present within the Highlands). Although the simulation results do not indicate a significant effect related to increased residential development, water conservation programs would help offset the impacts of climate change in the Highlands.

Capture Zone Analysis

A capture zone is defined as the portion of an aquifer from which groundwater is derived by a pumping well. Time of travel zones are sub-regions of the capture zone from which groundwater is derived in a fixed period of time. The calibrated model was used to delineate capture zones and time of travel zones (250 days, 5-years, 20-years) for the wells operated by the Bear Mountain Golf Course and the well that services the River's Crossing Retreat Centre and the Hannington Estates Subdivision. Capture zones were defined assuming that all major users would operate simultaneously at their current estimated pumping rates.

In general, the size of the capture zones were influenced by the estimated pumping rates of the wells, the presence of lineaments, and well interference effects. The capture zones for the Bear Mountain Golf Course wells are relatively larger than that for the pumping well at the River's Crossing Retreat Center and Hannington Estates Subdivision. It is possible that the capture zones for the Bear Mountain wells could be larger than those predicted by the model, as the full extent of the lineament in the vicinity of the Bear Mountain wells could not be determined from the existing data. The upper-bound extent of each capture zone was calculated by adjusting the values of hydraulic conductivity of all bedrock units by a factor of +/- 2 from the calibrated values.

Preliminary Groundwater Quality and Water Level Monitoring

Based on the results of the numerical model and water balance analysis, three potential monitoring well locations were selected for establishing baseline chemistry data representative of general water quality in the Highlands and to facilitate long-term, continuous water-level monitoring. The monitoring well locations are spread across the Highlands to provide good spatial coverage of groundwater conditions.

The three potential well locations correspond to wells that are presently not being used by the property owner. The unused wells were selected based on a preliminary well inspection program conducted by Golder on September 8, 2008. During this program, Golder inspected the conditions of specific unused wells and assessed their suitability for use in the groundwater monitoring program. Although only three wells have presently been selected, the monitoring well network will be expanded during Phase 2 of the Groundwater Protection Study after reviewing the results of the Contaminant Inventory and Chemical Storage Inventory. These inventories may identify additional monitoring well locations needed to address potential water quality concerns in specific areas of the Highlands.

Recommendations

Additional data were identified that, if obtained, could assist with the refinement of the numerical model to reduce model uncertainty and support the assessment of seasonal variations. The data collected from these wells would support calibration of the model for transient groundwater conditions in the Highlands. Recommendations for additional data gathering include:

- Establishing a network of surveyed monitoring wells (ten to twenty) for manual water-level monitoring during the dry and wet seasons to assess groundwater gradients. This network can include the three unused wells selected for water quality and continuous water-level monitoring;

- Conducting regular baseflow monitoring in major fish-bearing creeks or water courses that are known to be used as a water supply source; and,

- Conducting further investigations of the northwest-trending lineament in the vicinity of the Bear Mountain Golf Course wells.

Golder recommends that the Groundwater Task Force and Golder review and refine the Tasks that are proposed for Phase 2 of the Groundwater Protection Study. These tasks include conducting a contaminant inventory and a comprehensive chemical storage inventory, establishing the foundation for groundwater protection planning and educating the public about groundwater protection, expanding the groundwater monitoring network in consideration of the results of the contaminant and chemical storage inventories, and continued monitoring of groundwater wells to collect water level and baseline chemistry data.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

This report presents the results of the first year (Phase 1) of a three-year Groundwater Protection Study conducted by Golder Associates Ltd. (Golder) on behalf of the District of Highlands (Highlands). The Phase 1 tasks were completed in accordance with the scope of work outlined in Golder's work plan entitled *"Proposal for a Groundwater Protection Study and the Development of a Groundwater Monitoring Program"*, dated September 20, 2007 (Golder file number P7-1414-0014, E/07/434).

This report should be interpreted and used in accordance with the limitations and considerations set out in the Golder Associates Ltd. *Limitations and Use of this Report*, which appears in Section 11.0.

1.1 Background and Objectives

The Highlands is one of 13 member municipalities of the Capital Regional District (CRD), encompassing approximately 37 square kilometers and located northwest of Victoria, B.C. (Figure 1). The majority of the residential population of approximately 1,900 obtains potable water from private, individual water wells. A small number of individual residences obtain potable water from local streams and lakes under surface water licenses. In addition, the River's Crossing Retreat Centre and an estimated six households currently associated with the Hannington Estates development; located along the southern portion of the Highlands, obtain water from a communal well. Sewage servicing within the Highlands is by individual septic systems.

Commercial groundwater use is limited to the southern portion of the Highlands and in the City of Langford, immediately south of the District. Irrigation water for the Bear Mountain Golf Course is sourced from groundwater wells located within the Highlands and businesses within the Millstream Industrial Park use groundwater. Commercial groundwater users located in the north part of neighbouring Langford include Topline Roofing and Independent Concrete Ltd. and the All Fun Recreation Centre.

Groundwater supplies within the Highlands are derived primarily from drilled wells completed in a bedrock aquifer, with one dug well deriving groundwater from shallow, overburden materials. Well yields are variable and dependent upon the presence of fractures encountered in the borehole. Concerns have been raised over groundwater quantity, particularly in relation to future development and land use, development of secondary suites in single-family zoning areas, reports of declining water levels in wells located within the Highlands boundaries, and the need to maintain baseflow to support local salmonid streams and wetlands.

The District of Highlands Official Community Plan (OCP) identifies the community objectives and outlines policies to guide Council’s decisions regarding land use, zoning, development and servicing (District of Highlands, 2007). The intent of the Highlands is to continue to supply water through groundwater sources and to provide sewage servicing through individual systems, other than in the area specified as the Proposed Highlands Servicing Area in the District of Highlands Official Community Plan (2007). Highlands Bylaw No. 154 outlines the standards for regulating the subdivision or development of land within the Highlands, including standards for sanitary sewage systems and standards for water service. Under Bylaw No. 154, each lot is required to have an individual well that has been evaluated by a qualified professional and meets the bylaw requirements, including a yield of at least 4,000 litres per day and compliance with minimum water quality guidelines. The resulting hydrogeological reports have typically provided site specific assessments, including yield estimates for one or more specific wells and estimated groundwater recharge as a function of precipitation and representative aquifer characteristics.

The objectives of the current Groundwater Protection Study are to assess groundwater conditions throughout the District, to provide the Highlands with information and tools to support the protection and conservation of groundwater quality and quantity, and to guide future land-use decisions within the Highlands in light of potential climate change impacts. The Groundwater Protection Study was designed to be delivered over a period of three years, in the following phases:

- Phase 1 – Data Compilation and Water Balance Analysis
- Phase 2 – Contaminant Inventory and Preliminary Groundwater Protection Planning
- Phase 3 – Groundwater Monitoring and Detailed Groundwater Protection Planning

This current report presents the results of Phase 1 of the Groundwater Protection Study. Details on the individual tasks proposed for Phases 2 and 3 of the Groundwater Protection Study are outlined in Golder’s work plan dated September 20, 2007 (Golder file number P7-1414-0014, E/07/434). Phase 1 of the Groundwater Protection Study was completed with input and direction from the Highlands Groundwater Task Force, a team comprising a staff member of the Highlands Municipal Office, a member of the Highlands Council and two volunteer residents. It is anticipated that the Groundwater Task Force will continue to guide the completion of Phases 2 and 3 of the Groundwater Protection Study.

1.2 Scope of Work

The scope of work that was defined for Phase 1 of the Groundwater Protection Study includes the following tasks:

- **Task 1** – Data Compilation and Review: Available information including groundwater studies, water well records, water use estimates and geological, hydrogeological and hydrological data was assembled and reviewed;

- **Task 2 –** Conceptual Groundwater Model: Information gathered during Task 1 was analysed and used to develop a conceptual model of groundwater flow within the Highlands;

- **Task 3 –** Inventory of Unused Water Wells: An inventory of unused water wells was compiled;

- **Task 4 –** Numerical Groundwater Model: Following completion of the conceptual model, a numerical model was developed to conduct the hydrogeological data analysis and water balance calculations;

- **Task 5 –** Water Balance Analysis: Once constructed and calibrated, the numerical model was used to assess the existing groundwater flow regime and predict future groundwater conditions based on potential groundwater usage and climate change scenarios;

- **Task 6 –** Capture Zone Analysis: The numerical model was used to delineate capture zones for key community wells to facilitate groundwater protection planning in Phase 2 of the Groundwater Protection Study;

- **Task 7 –** Preliminary Groundwater Quality Testing: The unused wells identified under Task 3 were reviewed and specific water wells were identified for the groundwater monitoring program;

- **Task 8 –** Draft Report: The results of Phase 1 of the Groundwater Protection Study were outlined in a draft report that was provided to the Groundwater Task Force for review;

- **Task 9 –** Final Report: Upon receiving comments from the Groundwater Task Force, Golder finalised the report for Phase 1 of the Groundwater Protection Study and provided hard copies and electronic copies of the final report to the Highlands; and,

- **Task 10 –** Meetings: Golder representatives participated in a meeting with the Groundwater Task Force at the outset of the Groundwater Protection Study to review the proposed Phase 1 tasks. Once the numerical groundwater model was constructed, and prior to finalising the water balance and capture zone analyses, a member of the Golder team presented the preliminary results to the Groundwater Task Force and participated in discussions to define the future groundwater use scenarios used in Task 5. It is expected that representatives from the Golder team will provide a presentation of the Phase 1 results in a District of Highlands Committee of the Whole Council Meeting to allow for public response and input.

The results of Tasks 1 to 7 are presented in Sections 2.0 through 8.0, of this report. A discussion is provided in Section 9.0 and recommendations are provided in Section 10.0.

2.0 DATA COMPILATION AND REVIEW

The objective of Task 1 was to compile and review the data and information required to develop a conceptual model of groundwater flow within the Highlands. The following sections describe the methodology employed to compile the data and present the results of the data review.

2.1 Methodology

The data and information were collected through on-line searches, telephone enquiries and a search of files maintained by the Highlands and Golder. The data compilation activities focused on the area within the boundaries of the Highlands. However, some information was also collected for adjacent jurisdictions, including the District of Saanich to the east, the Town of View Royal to the southeast and the City of Langford to the south (Figure 2).

The data compilation and review exercise was an iterative process where, based on the preliminary results of the conceptual model and numerical model, specific data searches were conducted to obtain the information required to refine the numerical model. A summary of the information that was collected for data review is presented in Table 1.

2.2 Results of Data Review

The data and information that were collected for review included published maps and papers, data from federal, provincial and municipal government sources, reports prepared by consultants, and information collected from property owners and operators.

Hydrogeological data were collected from water well records maintained in the digital, on-line Water Resources Atlas by the BC Ministry of Environment (MoE), information presented in hydrogeological reports, and data provided in a previous groundwater study that was conducted in the Highlands (Kenny, 2004). Information from these sources was compiled into a project database (Highlands database). The resulting database consists of detailed information on a total of 655 water wells; of these, 636 wells are located in the Highlands and 19 wells are located in Langford, immediately south of the Highlands.

The objective of the data review exercise was to identify key information required to develop the conceptual model. The data review did not include re-analysis of the original data provided in previous hydrogeological reports. However, where possible, data from separate sources were compared to assess the quality of the data prior to use in the numerical model.

A summary of the results of the data review exercise is provided in the following sections.

2.2.1 Geology

Bedrock Geology

The bedrock geology of the Highlands and locations of major lineaments are presented in Figure 3. The majority of the Highlands is underlain by the Wark-Colquitz Complex which comprises massive and gneissic metadiorite, metagabbro and amphibolite with some quartz-feldspar gneiss and localized limestone and crystalline marble (Muller, 1980; Yorath and Nasmith, 1995). The majority of the documented limestone deposits are located within the Wark gneiss, with minor lenses reported near Jocelyn Hill and south of Teanook Lake (Muller, 1980; Fischl, 1992). The Millstream Meadows site, located at 1965 Millstream Road, was operated as a limestone quarry prior to 1908. Limestone and crystalline marble were noted in some well logs; however, insufficient information is available to estimate the extent of these localised deposits.

The bedrock in the western portion of the Highlands includes the meta-sedimentary and meta-volcanic deposits of the Leech River Complex, including ribbon chert, cherty argillite, metarhyolite, metabasalt and chlorite schist, with bands of thinly bedded greywacke and argillite, slate, phylite, and quartz-biotite schist. Along the northern edge of the Highlands, the bedrock consists of volcanic units of the Bonanza Group, including basaltic to ryholitic tuff, breccia, flows, minor argillite and greywacke.

Lineaments, or large-scale linear features, have been identified at ground surface across the Highlands using combined Landsat Thematic Maper data and Terrain Resource Information Mapping Digital Elevation Model data sets (as reported in Kenny, 2004; Journeay, personal communication, 2008). These lineaments, which at surface may resemble a narrow valley or line of isolated hills, are an indication of an underlying structural feature, such as a fault zone. Lineaments are sometimes an area of locally higher hydraulic conductivity (relative to bulk permeability of the bedrock), and therefore an indication of where installed water wells may potentially exhibit higher yields.

Major lineaments in Highlands trend in a NNW-SSE direction, with secondary joints and fracture networks oriented in an ENE-WSW direction (Journeay, 2003). Lithology significantly influences the structural characteristics of the bedrock units. The meta-sedimentary units within the Leech River Complex are inferred to exhibit foliated textures and fracture patterns that result in higher secondary porosity (void spaces associated with the fracturing rather than the bulk bedrock) than the relatively more competent crystalline meta-igneous units of the Wark-Colquitz Complex. However, the limestone and crystalline marble units within the Wark-Colquitz Complex are inferred to be affected by dissolution processes, resulting in relatively higher secondary porosity in localised areas. Porosity refers the amount of void space present in the rock matrix.

Surficial Geology

Figure 4 presents depths of unconsolidated, overburden materials above the bedrock and identifies areas where these materials likely represent confining sediments (i.e. low permeability sediments such as clay and/or till), as reported on available well logs. The surficial sediments in the Highlands are generally thin (approximately 2 to 3 m on average) and discontinuous. The sediments range from highly permeable colluvium, sand and gravels, to relatively less permeable clay, till and organic soils (Blyth and Rutter, 1993). In particular, deposits of till and other low permeability materials are present in the western portion of the Highlands at relatively high elevations, in the vicinity of the contact between the Wark-Colquitz Complex and the Leech River Complex.

2.2.2 Hydrology

Climate and Precipitation

The Highlands is located in the Coastal Douglas-fir biogeoclimatic zone of BC, characterized by warm, dry summers and mild, wet winters (Ministry of Forests and Range, 2003). Four weather stations were recently established in the Highlands as part of the University of Victoria (UVIC) School-Based Weather Station Network. Limited precipitation data were available for these weather stations; data for the Cal Revelle Nature Sanctuary station were available for the period 2006 to 2008, and data from the East Highlands District Firehall, West Highlands District Firehall and District of Highlands Office weather stations were available for the period 2007 to 2008. Therefore, long-term climate data were obtained from the on-line Environment Canada National Climate Archive. Average monthly precipitation data (rainfall and snowfall) were available for the Victoria Highlands weather station for the period 1962 to 2003. Average monthly temperature data were obtained for the Victoria International Airport weather station for the period 1971 to 2000. The locations of the four UVIC weather stations and the Highlands weather station are presented in Figure 5. The precipitation and temperature data are presented in Figure 6.

Average annual precipitation at the Highlands station for the period 1962 to 2003 is approximately 1205 mm. The majority of the precipitation occurs from October through March, with some snow recorded between November and March. Average monthly temperatures recorded at the Victoria International Airport weather station range from approximately 3.8 ºC in January to 16.4 ºC in July and August, with an average annual temperature of approximately 9.7 ºC. The results of a watershed detention study indicated that within the Millstream Watershed, potential evapotranspiration or open water evaporation is estimated to exceed normal precipitation during the period from April or May to August or September, suggesting that a precipitation deficit occurs during the summer months (M. Miles and Assoc., 2002).

Topography and Watershed Characteristics

Topographic data and information on watershed boundaries were collected from the British Columbia Integrated Land Management Bureau and the Capital Regional District (CRD) on-line Natural Areas Atlas, respectively. The topography of the Highlands and major watershed boundaries are presented in Figure 5.

The topography of the Highlands is characterized by low to moderate relief, with relatively steeper slopes encountered on the western side of the Gowlland Range. Elevations range from sea level adjacent to Finlayson Arm to over 440 m at Lone Tree Hill and Mount Work.

The majority of the Highlands is located within three main watersheds; the Pease Creek watershed drains the northern portion of the Highlands into Saanich Inlet and the Millstream Creek and Craigflower Creek watersheds drain the central and eastern portions of the Highlands, respectively, towards the south. These watersheds include a number of ephemeral creeks that discharge into the lakes and wetlands that are located at lower elevations. A number of smaller watersheds drain into Saanich Inlet from the slopes along the western and northwestern extent of the Highlands.

Streamflow: Watershed Runoff and Baseflow

A search of Station Information for Environment Canada’s on-line monitoring networks indicated that there were currently no active hydrometric stations on Millstream Creek, Craigflower Creek or Pease Creek. A former hydrometric station was once located on Craigflower Creek (#08JA034); however, this station has been inactive since 1981. Records are available from this station from 1974 to 1981. Golder conducted a limited streamflow monitoring program on September 27 and 28, 2007 at key locations in the Highlands to assess baseflow at the end of the dry season (see Figure 5). The results of the streamflow monitoring program are summarized in Table I-1, Appendix I.

Storm water attenuation in the upland areas of the Highlands is limited by the shallow, discontinuous layer of surficial sediments and low rates of bedrock infiltration, resulting in the majority of the wet season precipitation contributing to stream flow as surface runoff (M. Miles and Assoc., 2002). The hydrometric responses of surface water bodies in the Highlands are strongly correlated to seasonal precipitation patterns. During the dry summer months, when stream flow in most water bodies throughout the Highlands is negligible, baseflow is minimal. At the time of the streamflow monitoring program on September 27 and 28, 2007, flowing conditions were observed in Millstream Creek at Site Locations 1 and 5 at discharge rates estimated to be approximately 5.5 litres per second (L/s) and 0.15 L/s, respectively. Pooled water and no flow were observed in Craigflower Creek at Site Locations 8 and 10. Dry conditions were observed at the other accessed site locations.

2.2.3 Hydrogeology

Hydrostratigraphy

A review of the MoE Water Resources Atlas indicated that the majority of the Highlands is underlain by the Wark-Colquitz Aquifer No. 680. This bedrock aquifer is categorized as class IIB under the BC Aquifer Classification System, indicating moderate demand relative to aquifer productivity and moderate vulnerability of the aquifer to contamination from surface sources (Kreye, *et al.*, 2002). The northern portion of the District of Highlands is underlain by Willis Point Aquifer no. 681. A search of the MoE database did not identify any registered wells completed in this aquifer within the Highlands.

Water Levels

The locations of water wells compiled into the Highlands database are presented on Figure 7. The Highlands database includes water levels reported on MoE water well records at the time of drilling, static water levels reported at the start of pumping tests in the hydrogeological reports, and water levels recorded in a previous hydrogeological study (Kenny, 2004).

Compiled water levels in the database were screened to remove water levels that were suspected to be erroneous. For example, in many of the MoE water well records, the reported static water level appeared to correspond to the pump elevation or to the depth of the fracture zone and not to the static water level. In general, the water level records indicate that the depth to water ranges from 0 to 38 m below ground surface and the water table elevation ranges between 65 m and 264 m elevation above sea level. The depth to water generally increased with elevation.

Well Yields

The water well records downloaded from the MoE database included information on estimated water well yield (rate at which the well was pumped), depth drilled, and static water levels measured at the time of drilling. This information was incorporated into the Highlands database and supplemented with well yields obtained from reviewed hydrogeological reports. The estimated well yields from the MoE water well records were generally estimated by injecting air into the well to lift the water to surface. Well yields estimated from this method are considered to be less accurate that those derived from pumping tests, where a well is pumped for a sustained period of time.

Figures 7 and 8 present a summary of water wells incorporated in the database together with the depth drilled and reported well yields, respectively. Overall, the depth drilled ranged from 5 m to 250 m and the reported well yields ranged from less than 0.01 liters per second (L/s; 0.2 US gallons per minute [US gpm]) to 19 L/s (300 US gpm). The typical or average well yield was 0.7 L/s (11 US gpm), which is considered relatively high for bedrock. Over 10 percent of the wells could be defined as having large yields, with reported yields being greater than 1.6 L/s (25 US gpm).

Reported yields for wells in the Highlands are generally estimated to be influenced by the permeability of the bedrock, the depth drilled, topographic slope location and the distance of the well from a lineament feature (Kenny, *et al.*, 2006). In general, well yields were lower at greater borehole depths. This observation is attributed to a general decrease in hydraulic conductivity with depth that is typically observed in bedrock. Well yields also tend to be higher in the vicinity of lineaments, which is attributed to the potential increased fracturing in the area of these features. The potential influence of lineaments is illustrated in the southern portion of the Highlands, where reported pumping test results indicate relatively higher yields at wells that intercept major lineaments.

Hydrogeologic Parameters

The hydraulic conductivity of an aquifer defines the ease at which it can transmit water, with higher values of hydraulic conductivity indicating a larger capability to transmit water. Bedrock hydraulic conductivity is primarily governed by fracture apertures, their length and their connectivity. Aquifer transmissivity is a product of its hydraulic conductivity and thickness.

In the Highlands, transmissivity estimates are influenced by the bulk hydraulic conductivity of the bedrock and the hydraulic conductivity of the lineaments, if present. For example, a well completed in bedrock that is not connected to a more permeable lineament feature would have a lower transmissivity and hydraulic conductivity estimate than a well completed in a lineament or hydraulically connected to a lineament.

In the reviewed reports for Highlands, transmissivity estimates were provided based on the results of 12 pumping tests. The geometric average of the estimated hydraulic conductivity values derived from the transmissivity estimates was approximately 6 x 10^{-7} m/s. Several of the tested wells are known to intersect delineated lineaments (such as near the Bear Mountain Golf Course); therefore, this estimate of hydraulic conductivity is likely influenced by both the bulk hydraulic conductivity of the bedrock and the hydraulic conductivity of the lineaments.

For 119 locations, pumping data (in the form of pumping rates, observed drawdowns and/or well yield estimates) were available; however, estimates of hydraulic conductivity and transmissivity were not provided. As a result, an approximate estimate of hydraulic conductivity was estimated by Golder from simplified analytical equations that relate the pumping rate and observed drawdown during a test to the transmissivity of the aquifer (Kasenow, 2006). The geometric average of estimated hydraulic conductivity values from this method was approximately 3 x 10^{-7} m/s. Given the wide distribution of the test locations (i.e. the wells do not appear to be clustered around lineaments), this estimate of hydraulic conductivity is considered to be a reasonable estimate of the bulk bedrock hydraulic conductivity.

To determine if there is any trend in hydraulic conductivity with depth for the 119 locations described above, the calculated values were plotted relative to well depth on Figure 9. This plot indicates that as well depth increases, the estimated hydraulic conductivity decreases. As discussed above, this reduction in hydraulic conductivity with depth is commonly observed in bedrock due to the increase in compressive stress and associated closing of fractures.

An additional assessment of bedrock hydraulic conductivity was completed by Golder based on estimated well yields for 619 wells provided by the Drillers in the MoE database, using the same simplified analytical equations referenced above. These well yield values were generally derived using the air lift method and likely over estimate the well yield. Because the drawdown associated with the estimated well yield is not reported on the logs, it was assumed that the drawdown was equal to the saturated depth of the well. Calculated values of hydraulic conductivity from the driller estimated well yields are plotted relative to well depth on Figure 9. Similar to the pumping test data, the estimated hydraulic conductivity decreases with depth. The geometric average of the estimated hydraulic conductivity values is 9 x 10^{-8} m/s. This estimate of hydraulic conductivity is considered to be less accurate than the estimate derived by the 119 pumping tests; however, the data provided was useful in confirming the decrease in hydraulic conductivity with depth.

Overall, the pumping test data indicates that the bulk hydraulic conductivity of the bedrock aquifer within the upper 150 m is approximately 3 x 10^{-7} m/s. Both the drilling data and the pumping test data indicate that the estimated hydraulic conductivity decreases with depth. For example, the geometric average of the hydraulic conductivity values for wells completed below a depth of 150 m below ground surface indicates a hydraulic conductivity of 5 x 10^{-8} m/s. As no tests were conducted below a depth of 200 m, the hydraulic conductivity below this depth is presently not known.

Groundwater Recharge

Precipitation during the wet season is the major source of groundwater recharge to the bedrock aquifer system in the Highlands. The amount of recharge is affected by the amount of precipitation lost by evapotranspiration and surface water runoff. Both of these factors vary on a seasonal basis. Overall, groundwater recharge is lower during the dry, summer months.

In addition to recharge from precipitation, groundwater can be recharged by anthropogenic sources. Communications with the Highlands and a private contractor, Westshore Environmental, indicates none of the properties within the Highlands is connected to a municipal sewer system. Westshore Environmental is a private contractor that maintains the sewer system within Langford. Because the Highlands is not connected to a common sewer system, water from private septic fields would contribute to groundwater recharge. Published rates of return indicate about 60 percent to 85 percent of per capita consumption of water becomes wastewater with the lower percentages applicable to semiarid regions of the southwestern United States (Tchobanoglous and Burton, 1991). For the Highlands, it was assumed that 70 percent of all groundwater withdrawals would recharge the aquifer system via septic water return. This is considered conservative given that the Highlands is located in a temperate rainforest climate. However, the value of 70 percent is an annual average that does not account for seasonal variation.

Surface Water and Groundwater Use

Most of the residences in the Highlands obtain domestic water supply from private groundwater wells and dispose of wastewater to individual septic fields. To a lesser degree, some surface water sources are also utilized for domestic use and other purposes.

A search of the MoE database identified a total of 51 registered active surface water licenses in the Highlands at the locations identified on Figure 5. The majority of the surface water licenses were designated for domestic use at quantities ranging from 500 to 2000 US gallons per day (US gpd) (1.90 to 7.58 m^3/day). Other purposes included storage, irrigation and watering, land improvement and fire protection; quantities for these licenses were less than 1 m^3/day. In our experience, actual surface water usage is usually significantly less than the licensed amount. A summary of the surface water license information is presented in Table II-1, Appendix II.

Based on cadastral information provided by Highlands, 674 developed properties were identified within the District boundaries. A total of 730 residences were identified from the 2006 census data, with a total population of 1903 people. Based on the relative difference in residences, it was assumed that approximately 8 percent of the developed properties contain secondary suites. However, this estimate assumes that the 2006 census data accounted for all residents and residences in the Highlands. Therefore, the actual percentage of secondary suites may be higher than 8 percent.

Domestic groundwater use for each of the primary and secondary residences was estimated using available on-line data, including survey statistics on municipal water use provided by Environment Canada. In general, secondary residences were assumed to have 1.5 people per residence for a total of 84 secondary residents. The remaining population, 1819, was assumed to occupy primary residences. The water use for a primary and secondary suite was estimated at 450 L/day/capita and 314 L/d/capita, respectively. Details on the assumptions, calculations and estimated groundwater usage are provided in Table II-2 in Appendix II.

Based on discussions with the Groundwater Task Force and the results of telephone enquiries, the following five communal/commercial groundwater users were identified in the southern portion of the Highlands and in the City of Langford, to the south:

- River’s Crossing Retreat Centre and the Hannington Estates subdivision located along Hannington Road and River Road;

- Bear Mountain Golf Course, sourced from wells located to the west of the Hannington Estates subdivision;

- Millstream Industrial Park, located at 2015 Millstream Road;

- Top Line Roofing and Independent Concrete Ltd., located at 2023 Millstream Road; and,

- All Fun Recreation Centre, located at 2207 Millstream Road.

Based on communications with the property operators, the total groundwater consumption and number of operating pumping wells for each property was estimated. In some cases the properties had more than one pumping well and the relative pumping rates for each of the wells was not known. In these cases, the reported well yield on the drilling logs was used to subdivide the usage rate between the wells (i.e., if a property had two wells and one well had a yield twice as much as the other, that well was assumed to pump two thirds of the total groundwater consumption and the well with the lower yield was assumed to pump one third of the total groundwater consumption). A summary of the estimated total groundwater usage for each of the communal/commercial users is provided in Table II-3, Appendix II and a summary of the individual wells and the assigned pumping rates is provided in Table 2. The estimated rates of groundwater withdrawal were averaged over the year. As discussed in Section 6, the results of the water balance analysis are representative of average annual conditions and do not account for seasonal variations.

Of the communal/commercial users, 70 percent of the water consumption at River’s Crossing Retreat Center and the Hannington Estates subdivision, Millstream Industrial Part and Top Line Roofing and Independent Concrete Ltd was assumed to recharge the aquifer as septic water return. At the Bear Mountain Golf Course, it was conservatively assumed that groundwater withdrawals matched irrigation requirements and that no aquifer recharge from irrigation water occurred. All Fun Recreation Centre was identified by Westshore Environmental to be connected to the Langford sewer system. Therefore, groundwater recharge from wastewater produced by the All Fun Recreation Center was not estimated for this property.

3.0 CONCEPTUAL GROUNDWATER MODEL

A conceptual model is a hypothesis that describes the geology of a defined area, the hydrogeological setting, water use patterns and the relationships between these parameters and the patterns of groundwater flow. The conceptual model provides the basis for the development of the numerical model that is presented in Section 4.0. The following sections discuss the methodology employed to develop the conceptual model and the results.

3.1 Methodology

The information that was gathered under Task 1 – Data Compilation and Review, was used to establish the geological framework for the Highlands. The published information and data from the Highlands database were analyzed to define major hydrostratigraphic units and outline the distribution of structural features. Data from the Highlands database, including pumping test results from various reports, were reviewed to estimate the hydraulic properties of the hydrostratigraphic units and to identify groundwater flow patterns. Data derived from published sources and collected during telephone enquiries were used to estimate groundwater use within the model area.

3.2 Results

The Highlands study area can be characterized as a fractured, metamorphic bedrock aquifer. Groundwater flow within the Highlands is governed by the rate of recharge by precipitation, the hydraulic properties of the bedrock, and the presence of lineaments, some of which act as permeable features. A schematic of the developed conceptual model that describes the groundwater flow system is presented on Figure 10. The components of the conceptual model are described in more detail below.

3.2.1 Hydrostratigraphy

The main hydrostratigraphic layer in the Highlands is the fractured, metamorphic bedrock. Although the bedrock is overlain by unconsolidated sediments, the sediments are relatively thin, discontinuous and occasionally unsaturated. Based on these observations, the sediments were not inferred to be a major hydrostratigraphic unit.

Lineaments, or large-scale linear features, have been identified at ground surface across the Highlands. Only lineaments with a significant number of water wells located in close proximity to the feature were included in the model. The cluster of water wells near the lineaments was taken as an indication the hydraulic conductivity of the lineament could potentially be higher than the bulk hydraulic conductivity of the bedrock. As a conservative assumption, lineaments without water wells nearby were not included in the model; because in the absence of water wells, there was no indication the lineaments could influence the groundwater flow system. Including these lineaments in the model may have given the false indication that an area of the Highlands is capable of yielding more water than it actually is. Excluded lineaments can be incorporated in the model in the future, should more information become available.

3.2.2 Groundwater Flow Directions

The reviewed water levels contained in the database were used to infer groundwater flow directions across the Highlands. Water levels or hydraulic heads included in this database were supplemented by surface water elevations of local wetlands, streams, creeks and drainage courses in order to produce the water level contours shown on Figure 10. Inclusion of these points assumes that the water table intersects the ground surface at these locations.

Overall, the water table within the bedrock aquifer is inferred to be a subdued impression of the local topography. Groundwater flows from higher elevations into the valleys and numerous surface water courses throughout the Highlands. Although a small portion of groundwater near the boundaries of the Highlands is inferred to flow from the neighbouring jurisdictions into the Highlands, a larger portion of groundwater flows from the Highlands into the neighbouring jurisdictions.

3.2.3 Hydrogeologic Boundaries

Finlayson Arm forms a hydrogeologic boundary to the west and north of the District of Highlands. To the east and south, the bedrock aquifer extends into the neighboring jurisdictions. Within these jurisdictions, hydrogeologic boundaries were delineated along inferred groundwater flow divides and locations of surface water bodies. The surface water bodies were assumed to be in direct hydraulic connection with the bedrock aquifer.

The water table within the bedrock aquifer is primarily controlled by recharge from precipitation and the local topography. Numerous streams, lakes, wetlands and drainage courses have formed where the water table meets the ground surface and where surface water runoff accumulates. These surface water courses form both recharge and discharge boundaries for the aquifer.

For a fractured bedrock aquifer, recharge is assumed to range between 5 percent and 15 percent of the annual precipitation (1205 mm/year). This assumption was assessed during the model calibration, as described in Section 5.1.6. Recharge from precipitation is also supplemented by recharge from anthropogenic sources associated with septic water return.

Water supply in the Highlands is predominantly derived from groundwater. Overall, 674 properties were identified in the District of Highlands that could potentially have a groundwater well for water supply. In addition, five communal/commercial users with one or more wells were identified in the southern portion of the District of Highlands and the northern portion of Langford. A summary of the estimated groundwater withdrawals from residents and communal/commercial users is presented in Table II-1 and Table II-2 in Appendix II.

3.2.4 Hydrogeologic Parameters

The hydraulic conductivity of the bedrock aquifer is estimated from the reported well yields and pumping test data to be approximately 3 x 10^{-7} m/s. At increasing depths, the hydraulic conductivity of the aquifer is inferred to decrease, with an average hydraulic conductivity of 5 x 10^{-8} m/s estimated at depths greater than 150 m below ground surface. No information is available on the hydraulic conductivity of the bedrock below 200 m.

Limited information is available on the hydraulic conductivity of the major lineaments. In the southern portion of the model and where numerous pumping tests have been conducted, the lineaments were inferred to have a hydraulic conductivity of approximately 1 x 10^{-6} m/s. In other portions of the study area, where less data exists but a high density of water wells are present, the lineaments were assumed to have a hydraulic conductivity of 5 x 10^{-7} m/s. In the absence of pumping test data, this slightly lower hydraulic conductivity relative to the southern lineaments is considered to be more conservative for developing the numerical model.

4.0 INVENTORY OF UNUSED WATER WELLS

The three main objectives for Task 3 were to:

- Identify and inventory unused or abandoned water wells in the Highlands;
- Identify candidate wells for water quality and water-level monitoring; and,
- Provide residents of Highlands with public information on groundwater protection issues.

When the Phase 1, Task 3 activities were initially developed at the outset of the project, Golder proposed to hire local residents (2) to undertake a door-to-door canvass of the community to gather information and compile a list of abandoned or unused wells. Golder also proposed to review DoH files and MoE records to supplement this information and suggested that during public consultations, presentations and meetings, a request be made of local residents to provide any additional information they have on abandoned or unused wells.

During the compilation and review of the background information under Task 1, Golder compiled a preliminary inventory of unused wells. Based on this information, Golder recommended refining the Task 3 activities. The door-to-door canvass was assigned to Phase 2 of the Groundwater Protection Study to incorporate those activities into the public education task. Golder also recommended that potential monitoring well locations be identified following the completion of the numerical modeling and water balance analysis to ensure the selection of optimal locations for water-level montioring.

4.1 Methodology

The inventory of unused wells was compiled by means of a search of existing reports and data sources maintained by the Highlands and Golder, together with telephone enquiries to groundwater consultants, water well drillers and pumping test operators involved in groundwater supply projects in the Highlands. Golder also provided support to the Highlands in composing the text for an article in the Highlands Community Newsletter. The article provided an update on the Groundwater Protection Study and requested residents to contact the District office with information on unused or abandoned wells. Responses received at the District office were forwarded to Golder for inclusion in the inventory of abandoned wells. The results of the unused well survey were compiled in the Highlands database.

4.2 Results

A total of 38 properties were identified in the Highlands where unused wells may be present. Of these, the locations of the unused wells were identified on 32 properties. For the remaining 6 properties, specific locations of the reported unused wells could not be identified. The locations of the unused wells in the Highlands are presented on Figure 11.

A portion of the effort under Task 3 was also directed towards reviewing the results of the inventory of unused wells and selecting candidate wells for the monitoring program. The inventory of unused wells and the preliminary results of the numerical model and water balance analysis, Tasks 4 and 5, respectively, were presented to the Groundwater Task Force by Golder in a meeting at the Highlands Municipal Office on June 18, 2008. Based on this information, potential monitoring well locations were discussed. Further recommendations on the groundwater monitoring program associated with these wells are provided in Section 9.0.

5.0 NUMERICAL GROUNDWATER MODEL

The objective of Task 4 was the development and calibration of a District-wide numerical hydrogeological model based on the conceptual model developed in Task 2. The calibrated model was then used to support the hydrogeological data analysis, water balance calculations and capture zone analysis. The following sections present a description of the model development, together with the results of the calibration.

5.1 Model Development

5.1.1 Model Code

The numerical hydrogeologic model was constructed using FEFLOW, a three-dimensional finite numerical code developed by WASY Institute in Germany (Diersch, 2003). FEFLOW is capable of simulating three-dimensional groundwater flow in complex geological settings under a variety of boundary conditions and hydrogeological conditions. Unlike other numerical codes, such as MODFLOW, FEFLOW can simulate discrete features of enhanced permeability, such as lineaments, using discrete feature elements. FEFLOW is widely used for hydrogeological modelling and is well recognized by regulators, the research community and professional hydrogeologists.

5.1.2 Finite Element Mesh

The general model layout and extent of the finite element mesh is presented on Figure 12. Horizontally, the model domain covers an area of approximately 60 km^2 and extends from 459250 m E to 5376100 m E and from 5368050 m N to 5378050 m N. The model generally encompasses the entire District of Highlands, and extends into the adjacent jurisdictions, including the District of Saanich to the east and the Districts of Langford and View Royal to the south. Vertically, the top of the model is set to ground surface, which ranges in elevation from 0 m near Finlayson Arm to over 440 m above sea level (asl) near Mount Work. The base of the model is horizontal and set to an elevation of 400 m below sea level. Based on estimated hydraulic conductivity data and the installation depth of water wells within the District, it is assumed that groundwater flow at depths greater than 400 m below sea level has a negligible influence on the portion of bedrock utilized by the District for water supply.

The finite element mesh consists of over 140,000 triangular elements. In the horizontal direction, the average size of the element edges varied from approximately 25 m near major lineaments and pumping well locations, to approximately 75 m along the perimeter of the model domain. Vertically, the model is divided into three layers to adequately represent the groundwater flow field in the bedrock aquifer. The upper two layers are each approximately 150 m thick. The third (bottom) layer ranges from 100 m to 550 m in thickness.

5.1.3 Initial Model Parameters

Table 3 presents the initial values of hydrogeological parameters used in the groundwater flow model. Initial values of hydraulic conductivity were assigned based on well yields and transmissivity values contained in reviewed reports and based on well yields reported in MoE water well records. Other values of hydrogeological parameters, including the ratio of horizontal to vertical hydraulic conductivity, specific storage, and effective porosity, for which field measurements were not available, were assigned based on the values published in the literature (Maidment, 1993). Specific storage describes the volume of water a unit volume of saturated aquifer would release under a 1 m decline in hydraulic head. Effective porosity describes the proportion of voids in a rock mass that are interconnected and allow the passage of water.

5.1.4 Boundary Conditions

Boundary conditions are an important component of the groundwater model because they provide a link between the groundwater system within the area of interest and other components of the hydrogeologic cycle. Three types of boundary conditions were used in the numerical model, as shown on Figure 13. These included specified head boundaries, specified flux boundaries, and no-flow (zero flux) boundaries. A specified head boundary is a boundary that assigns a specific hydraulic head to a node in the model. The model will allow water to exit or enter the model domain at this node in order to maintain the assigned hydraulic head. A specified flux boundary describes a node or element in the model that is assigned a specific flux, such as aerial recharge rate or pumping rate. The model will remove or introduce the assigned flux at the node or element during the model simulations. A no-flow (zero-flux) boundary is a special case of the specified flux boundary. These boundaries are assigned to nodes or elements across which the flux is set to zero. No-flow boundaries are commonly set along groundwater flow divides.

A specified head boundary was used to represent the Finlayson Arm on the western boundary of the model. This boundary was set equal to ground surface, which was approximately zero meters elevation. In addition to Finlayson Arm, specified head boundaries were also used to represent the lakes, wetlands, streams and drainage courses within the model domain. These boundaries were set equal to ground surface along each surface water feature. For wetlands, streams and drainage courses that were inferred to be intermittent, the specified head boundary was constrained to only allow water to leave the model domain (*i.e.*, discharge only). For permanent water bodies, both inflow (recharge) and outflow (discharge) of groundwater was allowed. The assumption that intermittent water bodies do not act as a source of groundwater recharge is considered to be conservative in terms of the objectives of the study (*i.e.*, it conservatively assumes less available groundwater recharge and therefore less available groundwater for water supply).

No-flow (zero flux) boundaries were used to simulate inferred groundwater flow divides along the perimeter of the model. These boundaries were assigned in all model layers based on the assumption that groundwater divides correspond to topographic divides. A no-flow boundary was also assigned at the base of the model under the assumption that groundwater flow at greater depth has a negligible influence on the portion of bedrock utilized by the District for water supply.

A specified flux boundary was used to simulate aerially distributed recharge from precipitation and human sources. This boundary was applied to the top of the model domain. Infiltration from precipitation was initially assumed to be approximately 10 percent of the average annual precipitation. This value was later adjusted during model calibration.

A specified flux boundary was also used to simulate groundwater use by minor users (*i.e.*, residential water consumption). This boundary was applied to the top of the model over each of the 674 properties identified in the Highlands under the assumption that minor groundwater withdrawals will generally occur within the first layer of the model (within 150 m of ground surface). Major groundwater users were simulated using specified flux boundaries assigned to element nodes representing the location of the well screen. The flux values assigned to these boundaries were varied according to the average annual water usage estimates (Table 2).

5.1.5 Discrete Feature Elements

The majority of permeable lineaments in the District of Highlands were simulated using two-dimensional discrete elements. Discrete feature elements are finite elements of lower dimension that can be inserted at faces and node connections of an existing mesh to represent a facture plane. These elements were arbitrarily assumed to extend to depths of 150 m and have a width of 10 m, with a hydraulic conductivity of 5 x 10^{-7} m/s. This hydraulic conductivity is slightly higher than the hydraulic conductivity of the bulk bedrock (3 x 10^{-7} m/s).

In the area of Bear Mountain, where pumping test data was available, discrete feature elements were not used to represent the lineaments in that area. In this area, the lineaments were simulated by adjusting the hydraulic conductivity of the three-dimensional elements along the trend of the lineament. This method was adopted as it provided more accurate simulation of water level drawdown along the lineament in response to transient pumping test data.

5.1.6 Model Calibration

Calibration Targets

The hydrogeologic model was calibrated to static hydraulic head data contained within the water well database. These included water levels recorded by drillers at the time of well installation, water levels reported at start of pumping tests, and water levels recorded by Sylvia Kenny in June and July 2004. As discussed in Section 2, water levels were reviewed prior to being incorporated in the calibration to eliminate data that were likely erroneous.

The hydrogeologic model was also calibrated to water levels recorded at pumping and observation wells during eight pumping tests. These pumping tests were selected for calibration purposes because the wells were located near two communal/commercial groundwater users (Bear Mountain Golf Course and Rivers Crossing). The data collected were used to refine the inferred lineament/fracture network in this area.

In addition to water levels, the model was calibrated to the stream flow measurements recorded by Golder during September 2007. These measurements were collected at the end of the dry season and therefore provide an approximate estimate of the contribution of groundwater discharge to these streams.

Calibration Results

Calibration of the groundwater model involved iterative adjustment of the model input parameters until there was a reasonable match between the simulated and measured hydraulic heads and stream flows. The model was run under steady-state conditions for the prediction of static hydraulic heads and flows, and under transient conditions, for the simulation of the eight pumping tests, which were generally three days in length. During model calibration, some model parameters, including hydraulic conductivity and storage properties, were adjusted to improve the match between model predictions and calibration targets. The model parameters that resulted in best calibration are presented in Table 3 and shown on Figure 14.

During calibration, the hydraulic conductivity of the Leech River Complex in the western portion of District of Highlands was reduced slightly from the estimated initial value. In addition, within the Leech River Complex, the vertical hydraulic conductivity was inferred to be an approximately 16 times lower than the horizontal hydraulic conductivity. The lower hydraulic conductivity is attributed to the more massive metabasalt that is present within the Leech River Complex and is supported by the relatively high groundwater elevations present in the western portion of the Highlands.

Although this change was applied, portions of the Leech River Complex are inferred from pumping test data to have a locally higher hydraulic conductivity (on the order of 1 x 10^{-6} m/s), relative to assigned hydraulic conductivity of 8 x 10^{-4} m/s. These more permeable areas may correspond to areas of chlorite schist. Since none of the major users are present in the Leech River Complex, the exclusion of these localized high hydraulic conductivity zones was not considered to affect the capture zone or water balance conclusions of this report.

In addition to adjustments to the hydraulic conductivity of the Leech River Complex, minor changes were made to the recharge applied to the top of the model (decreased from 10 percent to 8.5 percent of average annual precipitation) and the hydraulic conductivity of the Wark-Colquitz Complex (decreased from 3 x 10^{-7} m/s to 1.5 x 10^{-7} m/s). An assessment of the uncertainty in model predictions as a result of the uncertainty in recharge and hydraulic conductivity was included in the sensitivity analysis portion of the water balance and capture zone predictions.

Figure 15 presents a graph of model-predicted hydraulic head versus measured head at the water wells across the Highlands. The normalized root mean square error between model predictions and field observations, calculated for the calibration points, is about 4 percent for water levels contained in the MoE water well records and 7 percent for water levels contained in reviewed hydrogeological reports. In general, the model slightly over-predicts the water levels in the Highlands. Figure 16 presents a graph of model-predicted declines in hydraulic head versus measured declines in head at observation wells for the eight pumping tests. The normalized root mean square error between model predictions and field observations is approximately 3 percent. Overall, the model is considered to be reasonably well calibrated to observed conditions considering the degree of uncertainty in the hydraulic head data set. Therefore, the calibrated model is considered capable of predicting the extent of the capture zones and water balance for the Highlands with a reasonable degree of accuracy.

6.0 WATER BALANCE ANALYSIS

Water balance analyses were conducted to assess the sustainability of current and future groundwater withdrawals. The calibrated hydrogeologic model was used to conduct the water balance assessment for the bedrock aquifer within the District of Highlands. The analyses consisted of an estimate of water quantity input and output to the aquifer. The results of the water balance assessment provide information required to efficiently manage the groundwater resource.

6.1 Scope of Water Balance Analysis

Steady-state model simulations were conducted to determine the water balance under current conditions and four future build-out scenarios. Model predictions are considered representative of average annual conditions and do not reflect conditions during different seasons of the year. Although the model is capable of simulating transient conditions, running these simulations with the model are not recommended at this time as transient calibration data (e.g. seasonal water level measurements in monitoring wells) are not available. The transient data are needed to ensure the storage properties assigned to the hydrostratigraphic units are appropriate and that the model reasonably predicts the short-term increases and decreases in water levels in response to changes in daily precipitation.

For two of the four future build-out scenarios, the effects of climate change were included. Potential impacts of climate change may include less precipitation during the summer months in southern BC and increased precipitation during the winter months (Environment Canada, 1997). Although the intensity of winter storms is predicted to increase, infiltration into the bedrock is controlled by the bedrock properties. Therefore, more intense storms are anticipated to result in increased surface runoff and not increased infiltration. The primary impact of climate change is anticipated to be a longer potential summer drought condition. Presently, the results of pumping tests for individual wells in the Highlands have been extrapolated to 100 days to represent summer drought conditions. In consultation with the Task Force, it was agreed that future conditions should look at the effects of increasing the summer dry period from 100 days to 120 days, with the corresponding wet season decreased from 265 days to 245 days, resulting in groundwater recharge from precipitation decreasing by approximately 8 percent. Given the current estimated recharge is 8.5 percent of the annual precipitation (1205 mm/year), the recharge was adjusted for climate change scenarios from 8.5 percent to approximately 7.8 percent of the annual precipitation.

A description of the water balance scenarios and associated assumptions is provided below.

Current Conditions

For the steady-state simulation performed for current conditions, the model utilizes the average annual values of recharge and water use that was determined during model calibration.

Future Build-Out Conditions

Four scenarios were considered for future build-out conditions.

Scenario 1 – Future build-out with 20% secondary suites

In Scenario 1, the number of primary residences is assumed to increase from 674 residences to 1020. The number of secondary suites is assumed to be 20 percent of the primary residences (in contrast to the 8% that was estimated under current conditions in Section 2.2.3). The number of persons assigned to each primary or secondary residence, and the per capita water consumption were not changed from current conditions.

Relative to current conditions, changes were made to the communal/commercial water users according to information provided by the District of Highlands. These changes included: the expansion of the River’s Crossing Retreat Centre to include an additional 20 guest house units, dining facilities and commercial units; the expansion of the Hannington Estates Subdivision to include an additional 54 new primary residences; the commissioning of an additional pumping well (Well 411) at Bear Mountain Golf Course; and, the closure of the water slide facilities at All Fun Recreation. Impacts of these changes to estimated water consumption are provided in Table 2.

For Scenario 1, the potential impacts of climate change were not assessed. For the steady-state simulation performed for Scenario 1, the model utilizes the average annual values of recharge and water use that was determined during model calibration.

Scenario 2 – Future build-out with 50% secondary suites

In Scenario 2, the number of primary residences is assumed to increase from 674 residences to 1020. The ratio of secondary suites is assumed to increase from 20 percent of the primary residences to 50 percent of the primary residences. The number of persons per primary or secondary residence, and the per capita water consumption were not changed from current conditions. Changes to the major users are identical to Scenario 1.

For Scenario 2, the impacts of climate change were not assessed. For the steady-state simulation performed for Scenario 2, the model utilizes the average annual values of recharge and water use that was determined during model calibration.

Scenario 3 – Future build-out with climate change and 20% secondary suites

Conditions for Scenario 3 are identical to Scenario 1 except for the incorporation of climate change. To simulate the potential effects of climate change, the average annual value of recharge was decreased by 8 percent.

Scenario 4 – Future build-out with climate change and 50% secondary suites

Conditions for Scenario 4 are identical to Scenario 2 except for the incorporation of climate change. To simulate the potential effects of climate change, the average annual value of recharge was decreased by 8 percent.

6.2 Results

The results of the water balance analysis for the Highlands bedrock aquifer is presented on Table 4. The water balance has been summarized with respect to major sources of groundwater inflow and outflow to illustrate the relative contributions of precipitation, surface water, and anthropogenic water use to groundwater flow within the bedrock aquifer.

In general, the water balance analysis indicates that under current conditions, precipitation is the primary source of groundwater recharge (83%), with smaller contributions from surface water (7%), anthropogenic sources (5%), and groundwater inflow from adjacent jurisdictions (5%). Of the groundwater outflow, approximately 61% discharges to surface water bodies in the Highlands, including local creeks, wetlands, lakes and drainage courses, and 18% discharges to Finlayson Arm. An estimated 11% of groundwater is naturally discharged to neighbouring jurisdictions. Groundwater withdrawals from major and minor water users comprise 3% and 7% of the groundwater outflow, respectively.

Under future build-out conditions and assuming no climate change (Scenarios 1 and 2), the groundwater balance is not expected to change significantly. Groundwater consumption by major and minor water users is expected to increase slightly, with the total water consumption estimated to be approximately 5 percent and 8 percent of the total groundwater inflow respectively (versus 3 percent and 7 percent under current conditions). The volume of groundwater discharging to surface water is predicted to decrease by approximately 4%, on average. Overall, comparison of Scenario 1 results to Scenario 2 results indicates the number of secondary suites (i.e., 20 percent versus 50 percent of the primary residences) does not significantly affect the results.

Under future build-out conditions and assuming an 8 percent reduction in precipitation infiltration as a result of climate change (Scenarios 3 and 4), the total groundwater inflow to the Highlands is expected to decrease by approximately 6 percent. Under these conditions, groundwater consumption by major and minor water users would constitute 3 percent and 8-9 percent of the groundwater outflow, respectively. In addition, the volume of groundwater discharging to surface water would be expected to decrease by approximately 13 percent. Groundwater discharge generally maintains a portion of the base flow of creeks, so it can be expected that stream levels could decline under these scenarios.

6.3 Overall Uncertainty Associated with Water Balance Predictions

The water balance analysis results presented on Table 4 is considered to be the ‘best estimate’ of groundwater inflow based on the calibrated model. However, as input parameters to the model are subject to some uncertainty, the actual groundwater inflow could be slightly higher or lower than predicted. Therefore, an assessment of the relative uncertainty in the water balance analysis resulting from the uncertainty in model input parameters was performed.

During the calibration, the estimated hydraulic conductivity of the bedrock was considered to be the most sensitive parameter affecting model results. Thus, the uncertainty in model predictions was evaluated using the groundwater model with the values of hydraulic conductivity of all bedrock units adjusted by a factor of +/- 2 from the calibrated values. This uncertainty factor was determined by running the model repeatedly with different values of hydraulic conductivity and determining the required precipitation recharge rate required to maintain model calibration (the match between model predicted and measured data). For a hydraulic conductivity increase by a factor of 2, the rate of groundwater recharge from precipitation had to be increased to approximately 15 percent of the annual precipitation. For a hydraulic conductivity decrease by a factor of 2, the rate of groundwater recharge from precipitation had to be decreased to approximately 3 percent of the annual precipitation. These rates of precipitation were considered to be at the outer limits of what is reasonable for this hydrostratigraphy.

During the sensitivity analysis, no changes were made to the hydraulic conductivity of the lineaments. If the hydraulic conductivity of the lineaments were adjusted, it was found that the predicted declines in water levels did not match the observed water level changes for the eight pumping tests used in calibration.

Results of the sensitivity analysis are summarized on Table 5. These results indicate that the estimated total groundwater inflow is sensitive to estimated hydraulic conductivity and recharge assigned to the model. Overall, groundwater inflow could be approximately 80% higher or 36% lower than predicted for the best calibration as result of the assigned recharge. These limits represent the reasonable upper and lower bound estimates of the total groundwater inflow in the District given the range of uncertainty in the model input parameters.

The estimated uncertainty in the predicted groundwater inflow indicates that the relative impact of water supply consumption in the Highlands could be slightly more than predicted for the best calibration if the hydraulic conductivity and recharge are inferred to be lower. Water supply use by Highlands comprises approximately 15 percent of the total groundwater outflow in the lower bound estimate, as compared to lower proportions predicted for the best calibration (10 percent) and upper bound case (5 percent).

7.0 TASK 6 – CAPTURE ZONE ANALYSIS

A capture zone is defined as the portion of an aquifer from which groundwater is derived by a pumping well1. Travel-time zones are sub-regions of the capture zone from which groundwater is derived in a fixed period of time. An understanding of the well ‘capture zone’ and the ‘time of travel’ zones is required to efficiently manage and protect a groundwater resource. Once the capture zone and time of travel zones are estimated, protective measures can be implemented within the zones, ensuring the safety of the water supply.

The extent of the capture zone is dependent on pumping rates, together with aquifer hydraulic conductivity, aquifer thickness and hydraulic gradient. Generally, capture zones tend to be relatively small and elongated in highly permeable, thick aquifers with high hydraulic gradients. Other factors controlling the extent of capture zones include the presence of nearby surface water bodies and locations of aquifer boundaries. For example, if a well is installed in an unconfined aquifer near a large creek, its capture zone could be truncated along this creek.

This section outlines the methodology used in the current study, presents the well capture zones, and discusses the results and limitations of the analysis.

7.1 Methodology

The calibrated model for current conditions was used to delineate capture zones and time of travel zones for the select communal/commercial groundwater users within the District of Highlands. These included wells operated by 1) the Bear Mountain Golf Course and 2) River’s Crossing Retreat Centre and Hannington Estates Subdivision. Capture zones were not delineated for residential properties, commercial users associated with Millstream Industrial Park and Top Line Roofing/Independent Concrete Ltd., or groundwater users in adjacent jurisdictions (*e.g.*, All Fun Recreation), because these users are considered to be minor in comparison and/or not located in the District of Highlands.

To estimate the capture zones, imaginary particles were placed in the model around the wells and tracked backwards from the well through the calibrated groundwater flow field. The estimates of travel time for these particles were based on the literature value for

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[1] The capture zone for a well is not equivalent to the zone of well influence (i.e., the area over which water levels are lowered as result of pumping). The capture zone for a pumping well will generally extend predominately up-gradient of a well, whereas the effects of pumping on water levels can also be observed (to a more significant extent than the capture zone) cross-gradient and down-gradient of the well.

effective porosity of 0.01 (Maidment, 1993). Currently, no field measurements or calibration data were available for this parameter.

Time-dependant particle path lines were used to delineate the following time of travel zones:

- 250 days: estimated maximum time required for microbial contaminants in groundwater to degrade (Taylor et. al. 2004);
- 5-years: average time necessary to implement groundwater remedial measures in response to a contamination event according to the US Environmental Protection Agency (1987); and,
- 20-years: the convention established by most European countries is to define the total capture zone for a well as the area corresponding to the 20-year time of travel boundary (Matthess et. al., 1985).

Capture zones were defined assuming that all major users would operate simultaneously at their current pumping rates.

7.2 Results

The capture zones and time of travel zones predicted by the model for the wells that are currently operated by the two major users within the Highlands are presented on Figure 17. Relative to Bear Mountain Golf Course wells (Wells 405 and 407), a smaller capture zone was predicted for the single pumping well at the River’s Crossing Retreat Center and Hannington Estates Subdivision. In general, the size of the capture zones were influenced by the estimated pumping rates of the wells, the presence of lineaments, and well interference effects.

The River’s Crossing Retreat Centre and Hannington Estates subdivision well is located to the east of the Bear Mountain Golf Course. The capture zone for this well is relatively narrow when compared to the Bear Mountain wells, and extends to the southwest. The capture zone is approximately 1,000 m long by 250 m wide.

At the Bear Mountain Golf Course, there are two wells that are currently being pumped (Wells 405 and 407). The western well, Well 407, is inferred to be pumped at a higher rate than Well 405, and the predicted capture zone is therefore larger. The capture zone for Well 407 appears to be strongly influenced by the presence of a northwest-trending lineament in the area of the well. Water from Well 407 captures water from this lineament and from the area up-gradient of the lineament. The capture zone is inferred to cover an overall area of 900 m by 900 m.

The lineament present in the area of Well 407 was assessed by Thurber (2007) as part of a series of pumping tests conducted within a network of wells at the golf course. The full extent or length of the lineament, however, could not be determined from the data. If the lineament is longer than was assumed in the model, it is possible that the capture zone of Well 407 could potentially be larger than that described above. Additional monitoring wells and pumping tests would be required to refine the estimated extent of this lineament.

The capture zone predicted for the second Bear Mountain Golf Course Well, Well 405, may be influenced by the capture zone of Well 407. The capture zone for Well 405 extends approximately 900 metres to the southwest and is approximately 600 m wide.

7.3 Uncertainty in the Extent of Capture Zones

An assessment was made of the uncertainty in the predicted extent of the capture zones resulting from the uncertainty in the model input parameters. Similar to the water balance assessment, the uncertainty in model predictions was evaluated using the groundwater model with the values of hydraulic conductivity of all bedrock units adjusted by a factor of +/- 2 from the calibrated values. Recharge was adjusted to maintain model calibration.

The capture zones were delineated using particle tracking for the adjusted values of bedrock hydraulic conductivity and average annual recharge. These changes in hydraulic conductivity and recharge resulted in changes in the shape and size of the capture zones for individual wells that reflect the uncertainty in their extent. The reasonable upper-bound extent of each capture zone, defined by the 20-year time of travel zone, is presented on Figure 18. In general, it was found that the extent of the capture zone was more certain for the well pumping at a relatively low rate (the River’s Crossing Retreat Centre and Hannington Estates subdivision well) and more uncertain for the larger capacity wells (Bear Mountain Golf Course Wells).

8.0 TASK 7 – PRELIMINARY GROUNDWATER QUALITY AND WATER-LEVEL TESTING

The objective of Task 7 was to designate unused wells as monitoring wells in strategic locations in the Highlands and initiate a preliminary quarterly groundwater monitoring program comprising the following activities:

- Collect water-level data to monitor seasonal and long-term changes in the groundwater flow regime and to verify and refine the numerical modeling results;

- Collect groundwater quality samples for analysis of general potability parameters, including total metals, anions, physical parameters and bacteriological constituents (total coliform and *E.Coli*), to establish baseline groundwater chemistry conditions; and,

- Based on the results of Phases 1 and 2 of the Groundwater Protection Study, collect and analyse groundwater samples for general potability parameters and potentially additional constituents (*i.e.*, organic parameters such as volatile organic compounds and hydrocarbons) to provide early warning of impending water quality problems.

Based on the preliminary results of Phase 1 of the Groundwater Protection Study, Golder recommended implementing the groundwater monitoring program in a phased approach. After reviewing the preliminary results of the water balance analysis, Golder recommended selecting monitoring wells at locations that would provide water level information required to refine the numerical model and establish baseline chemistry data representative of general water quality in the Highlands. Currently, long-term, seasonal water level monitoring data are not available for the Highlands. Golder and the Groundwater Task Force discussed installing electronic data loggers in the designated monitoring wells to permit the collection of water levels on a more refined schedule (*e.g.*, daily, hourly, etc.) to assess seasonal changes. A work plan for the purchase and installation of electronic data loggers in selected monitoring wells was provided to the Highlands in Golder's letter dated July 29, 2008 (Golder file number 07-1414-0014, E/08/333). An order for the purchase of the electronic data loggers was placed by the Highlands on September 16, 2008.

Golder proposes to expand the monitoring well network during Phase 2 of the Groundwater Protection Study after reviewing the results of the Contaminant Inventory (Task 1) and the Chemical Storage Inventory (Task 2). The objective of these monitoring wells will be to address potential water quality concerns in specific areas of the Highlands.

8.1 Methodology

During the meeting that was held at the Highlands Municipal Office on June 18, 2008, Golder and the Groundwater Task Force reviewed the results of the inventory of unused water wells (Task 3) and the water balance analysis (Task 5). Based on the results of that meeting and subsequent correspondence with the Groundwater Task Force, Golder identified unused wells that could be potential monitoring well locations.

Golder conducted a preliminary monitoring well inspection program on September 8, 2008 at the potential monitoring well locations to inspect the conditions of the reported unused wells and assess their suitability for use in the groundwater quality and water-level monitoring program.

8.2 Results

Eight properties with unused wells were identified for consideration as potential monitoring locations. Golder determined that five of these properties were located in suitable areas and conducted an inspection of these wells on September 8, 2008. Based on the results of the preliminary monitoring well inspection program, three of the unused wells were selected as monitoring wells. The locations of these wells are presented on Figure 11.

Golder proposes to arrange for a qualified water well driller or water well pump installer to complete the three selected monitoring wells with lockable caps. Golder will coordinate these activities with the installation of the electronic data loggers and completion of the first sampling event of the groundwater monitoring program. Golder will continue to assess wells in the eastern Highlands to identify additional potential monitoring wells.

9.0 DISCUSSION

9.1 Conceptual Model

The Highlands study area can be characterized as a fractured metamorphic bedrock aquifer. Groundwater flow with the Highlands is governed by the rate of recharge by precipitation, the hydraulic properties of the bedrock, and the presence of lineaments. Overall, the water table within the bedrock aquifer is inferred to be a subdued impression of the local topography.

The bedrock aquifer within the Highlands is cover by a thin, discontinuous layer of surfical sediments. As such, the aquifer is moderately vulnerable to contamination from surface sources, with the risk being less in areas where confining units are present.

9.2 Development and Use of the Numerical Model

The numerical hydrogeological model developed for this study represents a compilation of geological, hydrological and hydrogeological data from across the Highlands. This effort represents a significant step towards long-term groundwater protection for the bedrock aquifer present within the District. This model should be considered as a "working tool", which should be continually refined as additional information becomes available.

The hydrogeologic model developed for the Highlands is a regional-scale model capable of assessing average groundwater conditions over large areas. As such, it can be used as an effective planning tool in assessing long-term groundwater management strategies. The model is appropriate for estimating the water balance for the bedrock aquifer and it is capable of assessing regional impacts on the water levels due to population growth, land use changes, and climate change.

In the absence of comprehensive calibration data, the model is currently used to predict average annual groundwater conditions. As such, the model is presently not suitable for the prediction of seasonal changes in groundwater conditions. The model is also not currently suitable for local scale applications such as well field design and optimization. In other words, the model cannot be presently used to optimize the location of an individual well in a field.

9.3 Aquifer Water Balance

The hydrogeological model was used to conduct an aquifer water balance analysis for the average annual conditions in Highlands. The results of this analysis provides a basis for the Highlands to address some of its concerns related to maintaining sustainable groundwater withdrawals and understanding how climate change may impact groundwater supply.

9.3.1 Future Development

Overall, the water balance indicated that current groundwater withdrawals for water supply in the Highlands represent a small component of the overall water balance. In addition, the analysis indicated that the simulated growth (full build-out) will not have a significant effect on the current average groundwater conditions within the Highlands, both in terms of total average groundwater flow to surface water and groundwater flow to and from neighboring jurisdictions.

Simulations of future development assumed that increased residential build-out would be spread evenly across the Highlands. If future development were to be more spatially concentrated, it is possible that impacts to stream base flow and water levels within the area of the development could be more significant. In addition, impacts to water levels and stream flows could be more significant if a centralized municipal sewer system were installed in the Highlands because groundwater recharge from anthropogenic sources would be reduced.

Comparison of predicted average annual water levels from Scenario 2 to current conditions indicates that water levels could decline by up to 5 m on residential near the major users. To refine the predicted impact of increased water demand by the major users, it is recommended that additional data be collected on current conditions, including water levels within the residential developments and base flows in nearby streams.

9.3.2 Climate Change

Simulation of the four future scenarios indicates that climate change could have a significant impact on average groundwater conditions within the District of Highlands. Comparison of predicted water levels for Scenario 4 (full build-out with climate change) to water levels predicted for current conditions indicates that water levels could decline by up to 16 m in the higher elevations of the Highlands. Less effect is observed in groundwater discharge areas (*i.e.*, in the valleys present within the Highlands).

Although the simulation results do not indicate a significant effect related to future residential development (full build-out), effects related to climate change may be more significant. Water conservation programs would help offset the impacts of climate change in the Highlands.

9.4 Well Capture Zone

The numerical hydrogeological model was used to delineate capture zones and time of travel zones for the two major water users in the Highlands. The capture zone assessment assumed all wells operated simultaneously at their current average annual pumping rates. The capture zones for the simulated wells vary in size and shape depending on the presence of lineaments, well interference effects, and pumping rate. Some variation in the capture zones presented in this report may occur if pumping rates are changed significantly, or if new large-capacity wells are added in the vicinity of these existing wells.

The delineation of capture zones represents the first step required for the District to protect the quality of its water supply. Once additional information concerning potential contaminant threats is assembled and reviewed (Phase 2), consideration could be given to establishing provisions for groundwater protection within entire capture zones, or on an incremental basis within the various time of travel zones (Phase 3).

9.5 Inventory of Unused Water Wells

An inventory of unused water wells was compiled in the Highlands database and used to identify candidate wells for the water quality monitoring program. The results of the inventory will be incorporated into the public education tasks under Phase 2 of the Groundwater Protection Study. Golder will continue to update the inventory of unused water wells during Phases 2 and 3 if additional information becomes available.

9.6 Preliminary Groundwater Quality and Water-Level Testing

Based on the results of the numerical model and water balance analysis, three monitoring well locations were selected in areas that will provide water level information required to refine the numerical model and establish baseline chemistry data representative of general water quality in the Highlands. The monitoring well network will be expanded during Phase 2 of the Groundwater Protection Study to address potential water quality concerns identified from the Contaminant and Chemical Storage Inventories.

10.0 RECOMMENDATIONS

10.1 Additional Data Requirements and Model Refinement

Additional data were identified during the development of the numerical model that, if obtained, could assist with the ongoing assessment of model predictions, refinement of the model to reduce the uncertainty in the model predictions and enable assessment of seasonal variations. Recommendations for additional data gathering are summarized below.

Water-Level Monitoring

As discussed in Section 2.0, the water-levels used in the model calibration are representative of those measured in individual wells at the time of drilling or prior to pumping tests, rather than a representative "snap-shot" in time across the District. It is recommended that a network of surveyed monitoring wells (ten to twenty) be established across the District of Highlands to allow water levels to be measured (manually) at a single point in time under conditions representative of both dry and wet seasons. It is also recommended that a portion of these wells be located in key recharge areas of the model and in areas where any new high capacity groundwater wells are anticipated. These water level data will also provide calibration data to support refining the model for transient conditions.

The proposed network described above can include the three locations selected for the groundwater quality and water-level monitoring. Continuous water-level monitoring at these wells will provide suitable data for calibrating the model to transient data. Golder will coordinate the installation and use of the electronic data loggers in the selected wells in order to obtain continuous water-level data at these locations.

Baseflow Monitoring

Limited information is available on baseflows within the Highlands, particularly over time. It is recommended that regular baseflow monitoring be undertaken in major fish-bearing creeks or water courses that are known to be used as a water supply source. This monitoring data would provide a means of assessing the predicted reductions in groundwater discharge to specific creeks and streams as a result of climate change or future residential or business growth and allow for future refinement of the model, if necessary.

Additional Pumping Test and Water Well Installation

Consideration should be given to further investigation of the extent of the northwest-trending lineament in the area of the Bear Mountain Golf Course. This is anticipated to require the installation of a pumping well and/or several observation wells near the currently defined limits of the lineament to facilitate conducting a long-term (72 hr or more) pumping test. These data could be used to refine the model calibration and to reduce the uncertainty in the model predictions in this area (*i.e.*, extent of the well capture zones).

Model Refinement

Once some of the additional data outlined above are available, consideration could be given to refining the numerical model to provide more refined predictions of water balance and capture zones. Specifically, once available, seasonal water-level and baseflow monitoring data will allow for transient predictions of groundwater conditions in the Highlands. Additional input data, including recent precipitation data from the four UVIC weather stations and water level data from MoE observation well no. 372, will be available in the future for input into the model; the MoE observation well was established in 2007 (see Figure 5). Once more data related to seasonal variations is available, more refined predictions of potential climate change scenarios can also be developed with climate impact tools available from sources such as the Pacific Climate Impacts Consortium (PCIC).

10.2 Groundwater Management – Next Steps

Once the results of the Phase 1 Groundwater Protection Study are finalized and the final report is issued, it is anticipated that the Highlands will initiate Phase 2 of the Groundwater Protection Study. The purpose of Phase 2 is to compile a contaminant inventory, establish the foundation for groundwater protection planning and educate the public about groundwater protection, conservation and the viability of the resource over time. Golder recommends that the Groundwater Task Force and Golder review the Tasks that are proposed for Phase 2 of the Groundwater Protection Study and refine the activities, if required. In particular, consideration should be given to the following:

- **Task 1 –** Contaminant Inventory: A contaminant inventory should be carried out to identify areas where potential contamination may occur, what contaminants may affect groundwater quality, and the potential sources of future contamination.

- **Task 2 –** Chemical Storage Inventory: As discussed in our work plan, a chemical storage inventory should be undertaken of local businesses to identify types and quantities of chemicals used by the businesses. Consideration could also be given to conducting a preliminary review of chemicals likely to be stored on residential properties and potential impacts to groundwater quality. The preliminary review of residential properties should be coordinated with the activities proposed under Task 4.

- **Task 3** – Preliminary Groundwater Protection Planning: Preliminary recommendations for the protection of groundwater quality and quantity should be developed based on the results of the Phase 1 study and contaminant inventory.

- **Task 4 –** Recommendations for Public Education: The detailed door-to-door canvass that was originally proposed under Task 3 of Phase 1 of the Groundwater Protection Study could be considered as a potential public education mechanism during Phase 2 under Task 4. Both the anticipated benefits and potential costs of completing a door-to-door canvass should be assessed.

- **Task 5 –** Recommendations for Groundwater Monitoring: Three unused wells were identified in Phase 1 for groundwater quality monitoring related to the overall characterization of groundwater quality within the Highlands. During Phase 2, it is recommended that the monitoring well network be expanded to include general areas not covered by the three proposed locations (*i.e.*, a well in the eastern portion of the Highlands) and additional wells where potential water quality problems are identified as a result of the contaminant inventory. Task 5 consists of the identification of wells for this program, together with a suitable suite of constituents for analysis and sampling frequency.

- **Task 6 –** Preliminary Groundwater Quality Testing: This task consists of the continued groundwater monitoring of the three wells identified in Phase 1 for general characterization purposes.

11.0 LIMITATIONS AND USE OF REPORT

This report was prepared for the exclusive use of the District of Highlands. In evaluating the requirements of Phase 1 of the groundwater protection study, Golder Associates Ltd. has related in good faith on information provided by sources noted in this report. We accept no responsibility for any deficiency, misstatements or inaccuracy contained in this report as a result of omissions, misstatements or fraudulent acts of others.

The investigation program followed the standard of care expected of professionals undertaking similar work in British Columbia under similar conditions. No warranty expressed or implied is made.

The report is based on data and information collected during the investigation conducted by Golder Associates Ltd.'s personnel and is based solely on the conditions observed at the times of the site reconnaissances described in this report.

The scope of work for this study was intended to provide an overview only and did not include such items as subsurface investigations, contaminated sites assessment, geotechnical assessment, or hydrogeological field studies.

If new information is discovered in the future, Golder Associates Ltd. should be requested to re-evaluate the conclusions of this report and to provide amendments as required prior to any reliance upon the information presented herein. The report, which specifically includes all tables and figures, is based on data and information collected during the investigations conducted by Golder Associates Ltd. The report must be read and understood collectively, and can only be relied on in its totality.

Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Golder Associates Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

12.0 CLOSURE

This report presented the results of Phase 1 of the Groundwater Protection Study for the Highlands.

We trust that the information contained in this report meets the Highlands requirements and look forward to your comments.

GOLDER ASSOCIATES LTD.

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Table 1
Summary of Information Collected for Data Review
District of Highlands, BC

Publication / Information	**Source**[1]	**Description**
All Fun Recreation Park. 2007/08. Telephone enquiries. Water use information	AFRP	Information on water consumption at 2207 Millstream Road
Bear Mountain Golf Course. 2008. Telephone enquiries. Water use information	BMGC	Information on water consumption for golf course irrigation at Bear Mountain Golf Course
Blyth, H.E. and Rutter, N.W. 1993. *NTS 92B/5: Surficial Geology of the Sooke Area, NTS 92B/6: Surficial Geology of the Victoria Area, NTS 92B/11: Surficial Geology of the Sidney Area*	BC MEMPR[2]	Surficial geology information
British Columbia Integrated Land Management Bureau, Base Mapping and Geomatic Services. TRIM data	BC ILMB[3]	Terrain Resource Information Management (TRIM) topographic data
British Columbia on-line MINFILE Search. BC Ministry of Energy, Mines and Petroleum Resources. Maps	BC MEMPR	Geological information
British Columbia Ministry of Energy, Mines and Petroleum Resources. 1995. *Minfile Mineral Occurrence Map 092B Victoria*	BC MEMPR	Geological information
British Columbia Ministry of Forests and Range, Forest Science Program. 2003. *Biogeoclimatic Zones of British Columbia*. Map. Victoria, BC	BC MFR[4]	Biogeoclimatic information
British Columbia on-line Water Resources Atlas. BC Ministry of Environment, Water Stewardship Division	BC MOE[5]	Hydrogeological (wells and aquifers) and hydrological (surface water licenses) information
Capital Regional District, Information Technology and GIS Services.	CRD[6]	Detailed ortho-photos of the Highlands area

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[1] Source from which Information/Data was collected
[2] British Columbia Ministry of Energy, Mines and Petroleum Resources
[3] British Columba Integrated Land Management Bureau
[4] British Columbia Ministry of Forests and Range
[5] British Columbia Ministry of Environment

Table 1
Summary of Information Collected for Data Review
District of Highlands, BC

Publication / Information	Source[1]	Description
Capital Regional District on-line Natural Areas Atlas	CRD	Geographic information including hydrogeology (wells), hydrological (watersheds), transportation, property, etc., and estimated per capita water demand for the Capital Regional District
Capital Regional District, Planning and Protective Services. 2006 Census data	CRD	Census data on average household size, District of Highlands
Capital Regional District, Water Services. 2008. Telephone enquiries. Water Use Statistics	CRD	CRD water use statistics
Corewater Management. 2008. Telephone enquiries. Water use information	CM	Information on water consumption for the Hannington Estates subdivision and River’s Crossing Retreat Centre
District of Highlands. 2007. Telephone and email correspondence. Information on large volume users in the Highlands	DoH[7]	Identification of large volume users in the Highlands and immediate vicinity and population estimates in the Highlands
District of Highlands. 2007. *District of Highlands Official Community Plan Maps*	DoH	Information on development and context for groundwater protection
District of Highlands. 2007. *District of Highlands Official Community Plan: Schedule A to Bylaw No. 277*	DoH	Information on development and context for groundwater protection
District of Highlands. 2001. *District of Highlands Subdivision or Development of Land Bylaw*	DoH	Information on development and context for groundwater protection

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[6] Capital Regional District
[7] District of Highlands

Table 1
Summary of Information Collected for Data Review
District of Highlands, BC

Publication / Information	Source[1]	Description
Enkon Environmental Limited. 2002. *Proposed Fish Habitat Mitigation and Compensation: Bear Mountain Project, Langford, BC*	DoH	Baseline surface water conditions in vicinity of Bear Mountain development
Environment Canada. 2005. Municipal Water Use 2001 Statistics	EC[8]	Survey statistics on residential water flows and metering rates
Environment Canada on-line Archived Hydrometric Data	EC	Hydrometric data for Craigflower Creek station
Environment Canada on-line National Climate Data and Information Archive	EC	Precipitation data for Highlands weather station and temperature data for Victoria International Airport weather station
Environment Canada on-line Station Information Map Viewer	EC	Climate and hydrometric station location information
Environment Canada. Pacific and Yukon Region. 1997. *Responding to Global Climate Change in British Columbia and Yukon. Volume I of the Canada Country Study: Climate Impacts and Adaptation.*	EC	Potential impacts of climate change on the physical environment in southern BC
Fischl, P. 1992. *Limestone and Dolomite Resources in British Columbia*	BC MEMPR	Geological information
Focus Intec. 2002. *Bear Mountain – Highlands: Final Stormwater Management Plan*	DoH	Details on stormwater management plans for Bear Mountain construction activities
Focus Intec. 2003. *Bear Mountain Phase 2- On 18: Stormwater Facilities Temporary & Permanent Operations & Maintenance*	DoH	Details on stormwater management plans for Bear Mountain construction activities
Focus Intec. 2003. *Bear Mountain Phase 3- Briarwood: Stormwater Facilities Temporary & Permanent Operations & Maintenance*	DoH	Details on stormwater management plans for Bear Mountain construction activities

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[8] Environment Canada

Table 1
Summary of Information Collected for Data Review
District of Highlands, BC

Publication / Information	Source[1]	Description
Franz Environmental Inc. 2005. *Groundwater Baseline Study, District of Highlands, BC*	DoH	Results of well owner survey and hydrogeological information
Highwest Waste Recycler. 2008. Telephone enquiries. Water use information	HWR	Information on well details and estimated water consumption on 1943 Millstream Road property
Hodge Hydrogeology Consulting. 2004. *Certification of Well Capacity and Groundwater Quality (Potability) – 925 River Road, Highlands District*	DoH	Yield estimates and specific information for select wells in Highlands
Journeay, M. 2008. Natural Resources Canada, Earth Sciences Sector. Lineament Data for Georgia Basin Study	NRC[9]	Regional coverage of lineament data for District of Highlands
Kenny, S. 2004. *Aquifers of the Capital Regional District*	BC MoE	Information on classification of local aquifers
Kenny, S., Wei, M., Telmer, K. 2006. *Factors Controlling Well Yield in a Fractured Metamorphic Bedrock Aquifer, District of Highlands, Vancouver Island, British Columbia, Canada.* Sea to Sky Geotechnique	CGC[10]	Information on relationships observed between estimated well yields and geologic characteristics
Kenny, S. 2004. *Factors Related to Variable Well Yield in a Fractured Metamorphic Bedrock Aquifer, District of Highlands, Vancouver Island, BC.* University of Victoria	DoH	Information on relationships observed between estimated well yields and geologic characteristics
Lowen Hydrogeology Consulting. 2003. *Highlands Estates – Stage 2: Feasibility of Well Water Supply for Proposed Residential Development*	DoH	Yield estimates and specific information for select wells in Highlands

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[9] Natural Resources Canada

[10] Canadian Geotechnical Conference and 7th Joint IAH-CNC (International Association of Hydrogeologists – Canadian National Chapter) Groundwater Specialty Conference, October 2006

Table 1
Summary of Information Collected for Data Review
District of Highlands, BC

Publication / Information	Source[1]	Description
Lowen Hydrogeology Consulting. 2003. *Highlands Estates – Stage 2 Revised Report: Feasibility of Well Water Supply for Proposed Residential Development*	DoH	Yield estimates and specific information for select wells in Highlands
Lowen Hydrogeology Consulting. 2003. *Kingco 2000 Developments Ltd. – Highlands District, BC: Well Water Supply and Impact Assessment for Four Lots*	DoH	Yield estimates and specific information for select wells in Highlands
Lowen Hydrogeology Consulting. 2003. *Kingco 2000 Developments Ltd. – Highlands District, BC: Well Water Supply and Impact Assessment for Four Lots; Lot D*	VIHA[11]	Yield estimates and specific information for select wells in Highlands
Lowen Hydrogeology Consulting. 2003. *Well Water Supply and Impact Assessment for Water Utility Application*	GAL[12]	Yield estimates and specific information for select wells in Highlands, and abandoned well information
Lowen Hydrogeology Consulting. 2004. *Highlands Estates – Phase 4: Feasibility of Well Water Supply for Proposed Residential Development*	DoH	Yield estimates and specific information for select wells in Highlands, and information on abandoned wells
M. Miles and Associates Ltd. 2002. *Millstream Creek Watershed Water Detention Study*	DoH	Assessment of hydrology in Millstream Creek watershed
Muller, J.E. 1980. Map 1553A Victoria West of Sixth Meridian. Geological Survey of Canada	GSC[13]	Bedrock geology of Highlands area

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[11] Vancouver Island Health Authority
[12] Golder Associates Ltd.
[13] Geological Survey of Canada

Table 1
Summary of Information Collected for Data Review
District of Highlands, BC

Publication / Information	**Source**[1]	**Description**
Payne Engineering Geology. 1999. *Reports on: (1) Ground Water Resources and (2) Surface Water Resources for Eagles Lake Estates, a Four-Lot Subdivision of Lot 2, Plan 28503, Section 22 and 39, Highland Land District.* Prepared for Svec Land Development Consultants	DoH	Yield estimates and specific information for select wells in Highlands
Six Mile Environmental Consultants. 2002. *Community Water Stewardship in the Highlands*	DoH	Preliminary water balance of Fork Lake
Statistics Canada. 2006. on-line Census Data	SC[14]	Census data for the District of Highlands
Tchobanoglous, G. and Burton, F.L., 1991. Wastewater Engineering Treatment Disposal and Reuse Third Ed., McGraw-Hill Inc., USA	GAL	Typical water use estimates for commercial facilities
Thurber Consultants. 1988. *Eagle Lake Estates Inc. Highlands District Property Groundwater Supply and Septic Waste Disposal Study*	DoH	Yield estimates and specific information for select wells in Highlands
Thurbur Engineering. 1995. *Flitton Management Ltd. Highlands North Project: Stage 2 – Water Well Program*	DoH	Yield estimates and specific information for select wells in Highlands
Thurber Engineering. 1995. *Molnar Developments Ltd. Highlands North Project: Stage 1 – Water Well Program*	DoH	Yield estimates and specific information for select wells in Highlands, and abandoned well information
Thurber Engineering. 1995. *West Millstream Development Phase A & B – Water Well Program*	BC MOE	Yield estimates and specific information for select wells in Highlands, and information on abandoned wells

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[14] Statistics Canada

Table 1
Summary of Information Collected for Data Review
District of Highlands, BC

Publication / Information	Source[1]	Description
Thurber Engineering. 1996. *Western Forest Products Highlands North Project Stage 3 – Water Well Program*	DoH	Yield estimates and specific information for select wells in Highlands, information on abandoned wells
Thurber Engineering. 1997. *Groundwater Supply Well Drilling Program WFP – Highlands East Development Lot 1, Plan 9340, Sections 14 & 34, Section 21 and Part of Section 11, Highlands District*	DoH	Yield estimates and specific information for select wells in Highlands
Thurber Engineering. 1998. *Western forest Products Highlands East Project Water Well Program*	DoH	Yield estimates and specific information for select wells in Highlands, information on abandoned wells
Thurber Engineering. 1998. *Western forest Products Limited Highlands South Golf Community Groundwater Supply Program*	DoH	Yield estimates and specific information for select wells in Highlands, abandoned well information
Thurber Engineering. 2002. *Highlands 1 Holding Ltd. Highlands Estates – Stage 'C' Water Well Program*	DoH	Yield estimates and specific information for select wells in Highlands, abandoned well information
Thurber Engineering. 2003. *Bear Mountain Golf & Country Club Langford Golf Course Groundwater Supply Report*	DoH	Yield estimates and specific information for select wells in Highlands
Thurber Engineering. 2004. *Robertson Subdivision Highlands Well Assessment Program Lots 1-6, Wells #650-655*	DoH	Yield estimates and specific information for select wells in Highlands
Thurber Engineering. 2007. *Bear Mountain Golf & Country Club Highlands Golf Course Groundwater Supply Report 2006 – 2007 Program*	DoH	Yield estimates, consumption estimates and specific information for select wells in Highlands
Top Line Roofing Ltd. 2008. Telephone enquiries. Water use information	TLR	Information on estimated well locations for 2023 Millstream Road property

Table 1
Summary of Information Collected for Data Review
District of Highlands, BC

Publication / Information	Source[1]	Description
Turner Groundwater Consultants. 1994. *Groundwater Report: Highland Estates Groundwater Assessment*	DoH	Qualitative assessment of groundwater in specific area of Highlands
Vancouver Island Health Authority. 2007. Telephone enquiries. Water use information	VIHA	Information on known water works/systems in the Highlands and immediate vicinity
West Shore Environmental Services. 2008. Telephone enquiry. Sewerage Collection Service	WSES	Information on extent of municipal sewage collection coverage in Langford
Western Grater Contracting Ltd. 2007. Telephone enquiries. Water use information	VIHA	Information on well details and estimated water consumption for Millstream Industrial Park, 2015 Millstream Road
Wright Parry. 2001. Earsman Creek Watershed Study	DoH	Assessment of storm water impacts from development in specific area of Highlands
Yorath, C.J., Nasmith, H.W. 1995. *The Geology of Southern Vancouver Island*	DoH	Bedrock geology of the Highlands area

Table 2

Estimated Average Annual Pumping Rates at Wells Operated By Commercial/Communal Water Users
District of Highlands, BC

Communal/Commercial User	Well Tag No.	Well ID No.	Average Annual Estimated Pumping Rate (m^3/day)	
			Current Conditions	Future Conditions
River's Crossing Retreat Centre and Hannington Estates Subdivision	85183	409	32.3	71.7
Bear Mountain Golf Course	81690	407	218	218
	81689	405	117	117
	unknown Well Tag No.	411	0	249
Millistream Industrial Park	80741	-	1.1	1.1
	85633	-	1.1	1.1
	85634	-	1.1	1.1
Top Line Roofing / Independent Concrete Ltd.	29408	-	1.1	1.1
	unknown Well Tag No.	-	1.1	1.1
	unknown Well Tag No.	-	1.1	1.1
All Fun Recreation	37114	-	0.3	0.3
	75659	-	24.2	17.6
	75592	-	3.7	2.7
	75658	-	24.2	17.6
	93669	-	13.4	9.7

Note:
Operator identified three wells that were active at Top Line Roofing / Independent Concrete Ltd. Only one well could be linked to a Well Tag No.

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Table 3
Initial and Calibrated Values of Hydrogeological Parameters, District of Highlands, BC

Initial Values of Hydrogeological Parameters (Prior to Model Calibration)

Hydrostratic Unit	Depth Interval	Horizontal Hydraulic Conductivity (m/s)	Vertical Hydraulic Conductivity (m/s)	Effective Porosity*	Specific Yield*	Specific Storage*
Bedrock	0-150m	3×10^{-7}	3×10^{-7}	0.01	0.01	1×10^{-6}
Bedrock	>150m	5×10^{-8}	5×10^{-8}	0.005	0.005	1×10^{-6}
Lineaments	0-150m	5×10^{-7}	5×10^{-7}	0.005	0.005	1×10^{-6}

* based on values published in Maidment, 1993 for similar lithology

Calibrated Values of Hyodrogeological Parameters

Hydrostratic Unit	Depth Interval	Horizontal Hydraulic Conductivity (m/s)	Vertical Hydraulic Conductivity (m/s)	Effective Porosity*	Specific Yield*	Specific Storage*
Bedrock - Leech River Complex	0-150m	8×10^{-8}	5×10^{-9}	0.01	0.01	1×10^{-6}
Bedrock - Leech River Complex	>150m	5×10^{-9}	5×10^{-9}	0.005	0.005	1×10^{-6}
Bedrock - Wark-Colquitz Complex	0-150m	1.5×10^{-7}	1.5×10^{-7}	0.01	0.01	1×10^{-6}
Bedrock - Wark-Colquitz Complex	150-300m	2.5×10^{-8}	2.5×10^{-8}	0.005	0.005	1×10^{-6}
Bedrock - Wark-Colquitz Complex	>300m	8×10^{-9}	8×10^{-9}	0.005	0.005	1×10^{-6}
Lineaments	0-150m	5×10^{-7} to 8.5×10^{-6}	5×10^{-7} to 8.5×10^{-6}	0.01	0.01	1×10^{-6}

* based on values published in Maidment, 1993 for similar lithology

Table 4
Predicted Water Balance for Current and Future Conditions
District of Highlands, BC

Sources of Groundwater Inflow and Outflow	Best Calibration (m^3/day)	Future Scenarios (m^3/day)			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Inflow					
Recharge from Precipitation	10650	10650	10650	9700	9700
Recharge from Anthropogenic Sources	650	750	800	750	800
Recharge from Surface Water Bodies	950	950	950	1050	1050
Groundwater Flow from Neighbouring Jurisdictions	550	500	500	500	500
Total	**12800**	**12850**	**12900**	**12000**	**12050**
Outflow					
Groundwater Withdrawals by Major Users	350	650	650	650	650
Groundwater Withdrawals by Minor (Residential) Users	850	1000	1050	1000	1050
Groundwater Discharge to Surface Water (except Finlayson Arm)	7800	7500	7450	6750	6700
Groundwater Discharge to Finlayson Arm	2300	2300	2300	2200	2200
Groundwater Discharge to Neighbouring Jurisdictions	1500	1400	1450	1400	1450
Total	**12800**	**12850**	**12900**	**12000**	**12050**

Sources of Groundwater Inflow and Outflow	Best Calibration (% of Total)	Future Scenarios (% of Total)			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Inflow					
Recharge from Precipitation	83%	83%	83%	81%	80%
Recharge from Anthropogenic Sources	5%	6%	6%	6%	7%
Recharge from Surface Water Bodies	7%	7%	7%	9%	9%
Groundwater Flow from Neighbouring Jurisdictions	5%	4%	4%	4%	4%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Outflow					
Groundwater Withdrawals by Major Users	3%	5%	5%	5%	5%
Groundwater Withdrawals by Minor (Residential) Users	7%	8%	8%	9%	9%
Groundwater Discharge to Surface Water (except Finlayson Arm)	61%	58%	58%	56%	56%
Groundwater Discharge to Finlayson Arm	18%	18%	18%	18%	18%
Groundwater Discharge to Neighbouring Jurisdictions	11%	11%	11%	12%	12%
Total	**100%**	**100%**	**100%**	**100%**	**100%**

Note:
Scenario 1: Future Build-out. Secondary residences assumed to present at 20% of the primary residences.
Scenario 2: Future Build-out. Secondary residences assumed to present at 50% of the primary residences.
Scenario 3: Future Build-out with Climate Change. Secondary residences assumed to present at 20% of the primary residences.
Scenario 4: Future Build-out with Climate Change. Secondary residences assumed to present at 50% of the primary residences.

Table 5
Sensitivity Analysis Results for Predicted Water Balance
District of Highlands, BC

Sources of Groundwater Inflow and Outflow	Current Conditions (m^3/day)		
	Best Calibration	Upper Bound	Lower Bound
Inflow			
Recharge from Precipitation	10650	19500	6800
Recharge from Anthropogenic Sources	650	650	650
Recharge from Surface Water Bodies	950	1900	400
Groundwater Flow from Neighbouring Jurisdictions	550	950	300
Total	**12800**	**23000**	**8150**
Outflow			
Groundwater Withdrawals by Major Users	350	350	350
Groundwater Withdrawals by Minor (Residential) Users	850	850	850
Groundwater Discharge to Surface Water	7800	14500	4900
Groundwater Discharge to Finlayson Arm	2300	4550	1200
Groundwater Discharge to Neighbouring Jurisdictions	1500	2750	850
Total	**12800**	**23000**	**8150**

Sources of Groundwater Inflow and Outflow	Current Conditions (m^3/day)		
	Best Calibration	Upper Bound	Lower Bound
Inflow			
Recharge from Precipitation	83%	85%	83%
Recharge from Anthropogenic Sources	5%	3%	8%
Recharge from Surface Water Bodies	7%	8%	5%
Groundwater Flow from Neighbouring Jurisdictions	5%	4%	4%
Total	**100%**	**100%**	**100%**
Outflow			
Groundwater Withdrawals by Major Users	3%	2%	4%
Groundwater Withdrawals by Minor (Residential) Users	7%	3%	11%
Groundwater Discharge to Surface Water	61%	63%	60%
Groundwater Discharge to Finlayson Arm	18%	20%	15%
Groundwater Discharge to Neighbouring Jurisdictions	11%	12%	10%
Total	**100%**	**100%**	**100%**

Note:

For the upper bound estimate the hydraulic conductivity was increased by a factor of two and recharge was increased to 15%.
For the lower bound estimate the hydraulic conductivity was decreased by a factor of two and recharge was decreased to 3%.

LEGEND

Study Area

5 0 5

SCALE 1:250,000 KILOMETRES

PROJECT

DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE

KEY PLAN

Golder Associates
Burnaby, B.C.

PROJECT NO. 08-1411-0114		SCALE AS SHOWN	REV. 0
DESIGN	WL	18 Aug. 2008	
GIS	AL	20 Aug. 2008	
CHECK	JL	21 Oct. 2008	
REVIEW	MB	21 Oct. 2008	

FIGURE 1

REFERENCE

NTS 92B - 250K Mapsheet provided by CanMatrix.
Datum: NAD 83 Projection: UTM Zone 10

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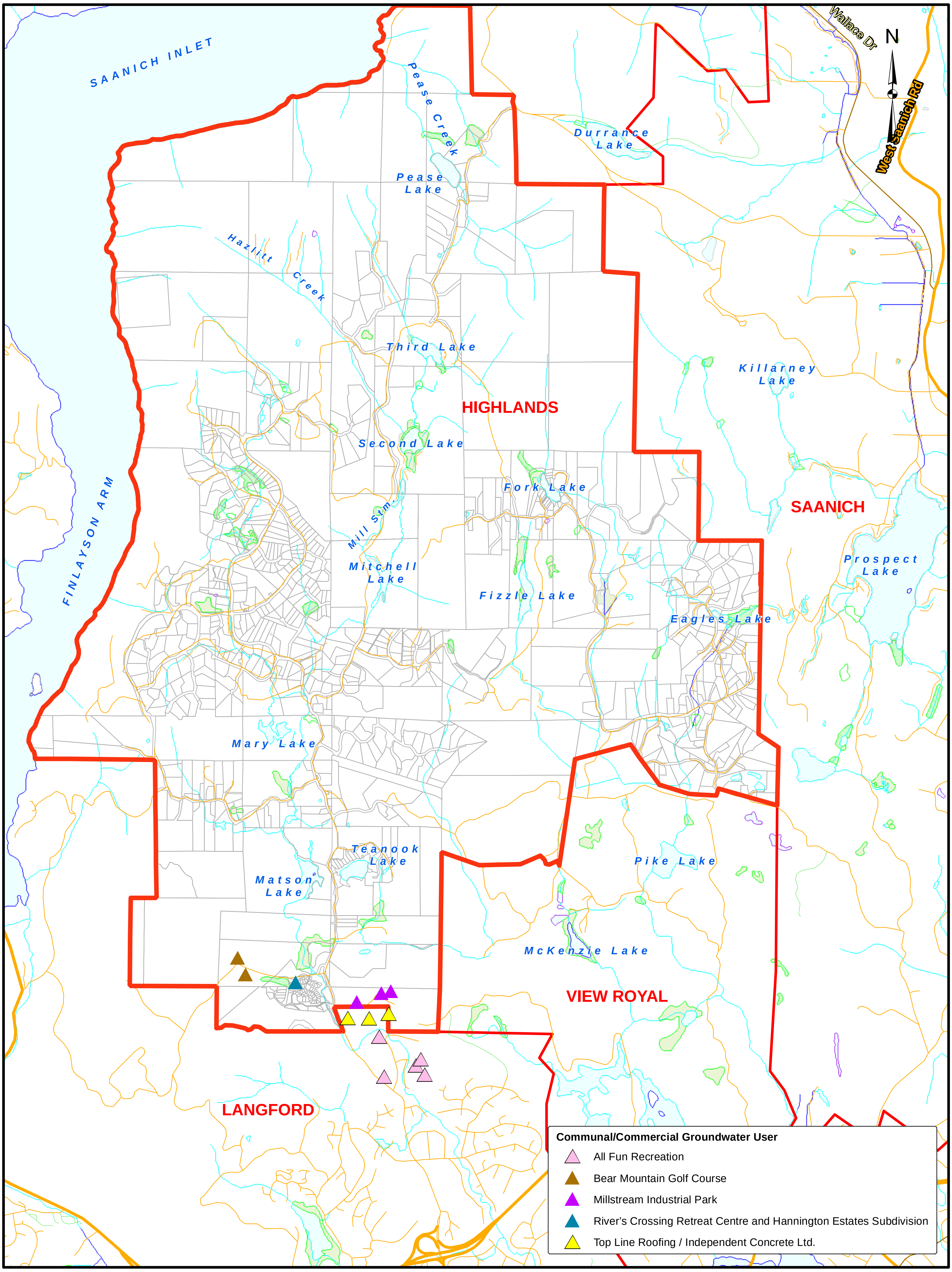

LEGEND

- ☐ Cadastre Information
- 🟥 Municipality Boundary
- ☐ Lake
- ▨ Marsh
- 🟩 Swamp
- — River/ Stream
- — Marsh/ Swamp

Transportation

- — Expressway
- — Major Road
- — Local Road
- — Trail

875 0 875

SCALE 1:35,000 METRES

REFERENCE

Data provided by the District of Highland and BC ILMB.
Base data provided by the Ministry of Environment, WMS.
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 10

PROJECT

DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE

LOCATION AND JURISDICTION BOUNDARIES

Golder Associates
Burnaby, B.C.

PROJECT No. 07-1414-0014			SCALE AS SHOWN REV. 0
DESIGN	JL	27 Aug. 2008	FIGURE 2
GIS	AL	27 Aug. 2008	
CHECK	JL	21 Oct. 2008	
REVIEW	MB	21 Oct. 2008	

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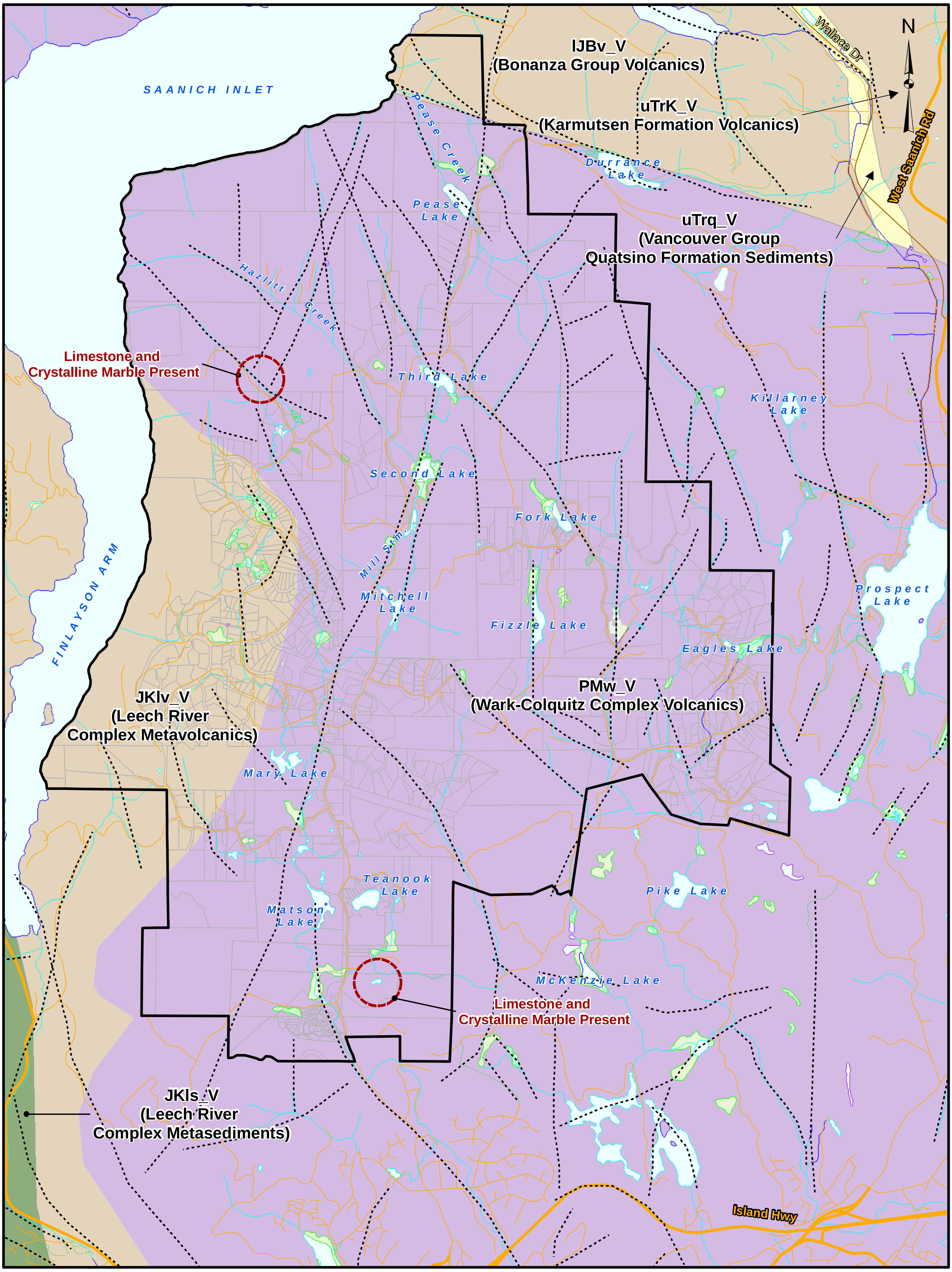

LEGEND

━ Highlands Municipal Boundary

┈ Georgia Basin Lineaments

☐ Cadastre Information

Rock Class

🟪 Intrusive rocks

🟩 Metamorphic rocks

🟨 Sedimentary rocks

🟫 Volcanic rocks

Transportation

━ Expressway

━ Major Road

━ Local Road

━ Trail

━ River/ Stream

━ Marsh/ Swamp

▭ Lake

▭ Marsh

▭ Swamp

875 0 875

SCALE 1:35,000 METRES

REFERENCE

Data provided by the District of Highland, BC ILMB and Geology BC.
Base data provided by the Ministry of Environment, WMS.
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 10

PROJECT
DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE
BEDROCK GEOLOGY AND MAJOR LINEAMENTS

Golder Associates
Burnaby, B.C.

PROJECT No. 07-1414-0014			SCALE AS SHOWN	REV. 0
DESIGN	JL	27 Aug. 2008	FIGURE 3	
GIS	AL	27 Aug. 2008		
CHECK	JL	21 Oct. 2008		
REVIEW	MB	21 Oct. 2008		

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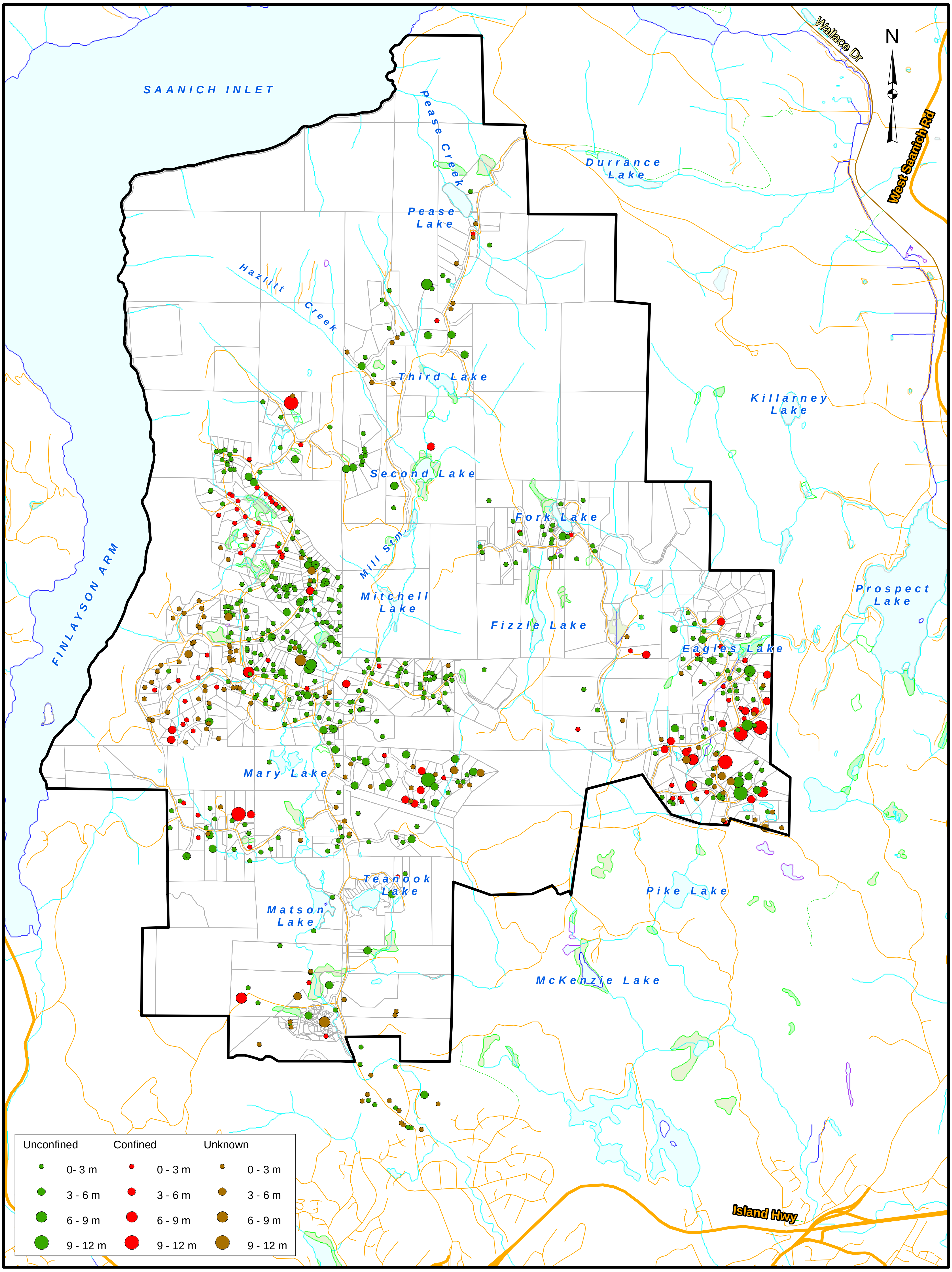

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LEGEND

Highlands Municipal Boundary
Cadastre Information
River/ Stream
Marsh/ Swamp
Lake
Marsh
Swamp

Transportation
Expressway
Major Road
Local Road
Trail

875 0 875

SCALE 1:35,000 METRES

REFERENCE

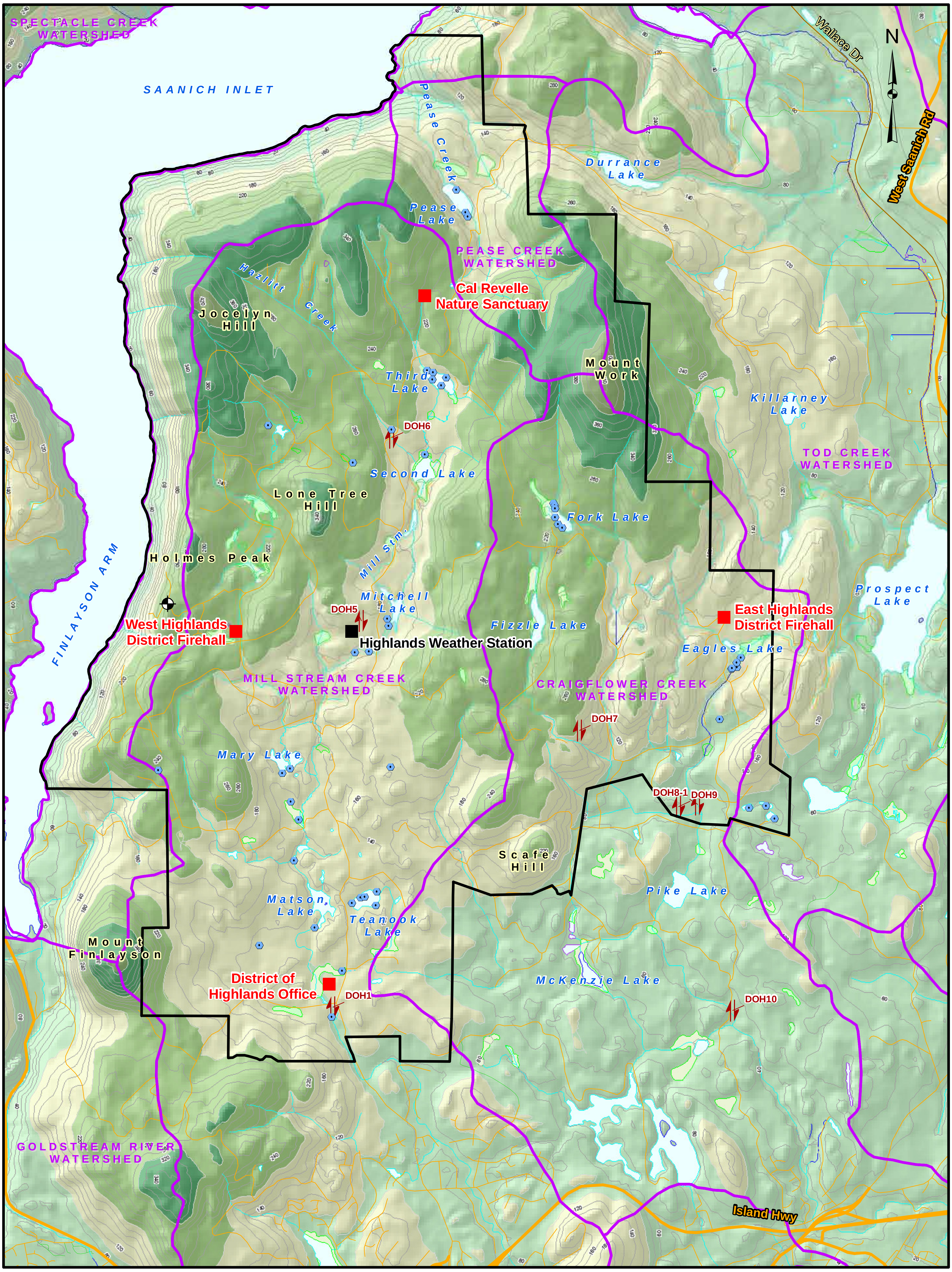
Water Well Locations and Soil Depth information from Ministry of Environment with Well Records.
Base data provided by the Ministry of Environment, WMS.
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 10

PROJECT
DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE
SURFICIAL SEDIMENT DEPTHS AS
REPORTED ON AVAILABLE WELL LOGS

Golder Associates
Burnaby, B.C.

PROJECT No. 07-1414-0014			SCALE AS SHOWN	REV. 0
DESIGN	JL	27 Aug. 2008	FIGURE 4	
GIS	AL	27 Aug. 2008		
CHECK	JL	21 Oct. 2008		
REVIEW	MB	21 Oct. 2008		



LEGEND

- Contour - (100m Interval)
- Contour - (20m Interval)
- River/ Stream
- Marsh/ Swamp
- Lake
- Marsh
- Swamp
- Highlands Municipal Boundary
- Active Surface Water License
- Stream Flow Measurement Location
- Ministry of Environment Observation Well
- ■ Environment Canada Weather Station
- 🟥 University of Victoria Weather Station
- Major Watershed Boundary

Transportation
- Expressway
- Major Road
- Local Road
- Trail

Elevation (masl)
- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500

875 0 875

SCALE 1:35,000 METRES

REFERENCE

Data provided by the District of Highland, BC ILMB.
Weather Station Location supplied by Victoria Highland Environment Canada Weather Station.
Base data provided by the Ministry of Environment, WMS.
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 10

PROJECT
DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE
TOPOGRAPHY AND WATERSHED BOUNDARIES

Golder Associates
Burnaby, B.C.

PROJECT No. 07-1414-0014			SCALE AS SHOWN	REV. 0
DESIGN	JL	27 Aug. 2008	FIGURE 5	
GIS	AL	27 Aug. 2008		
CHECK	JL	21 Oct. 2008		
REVIEW	MB	21 Oct. 2008		

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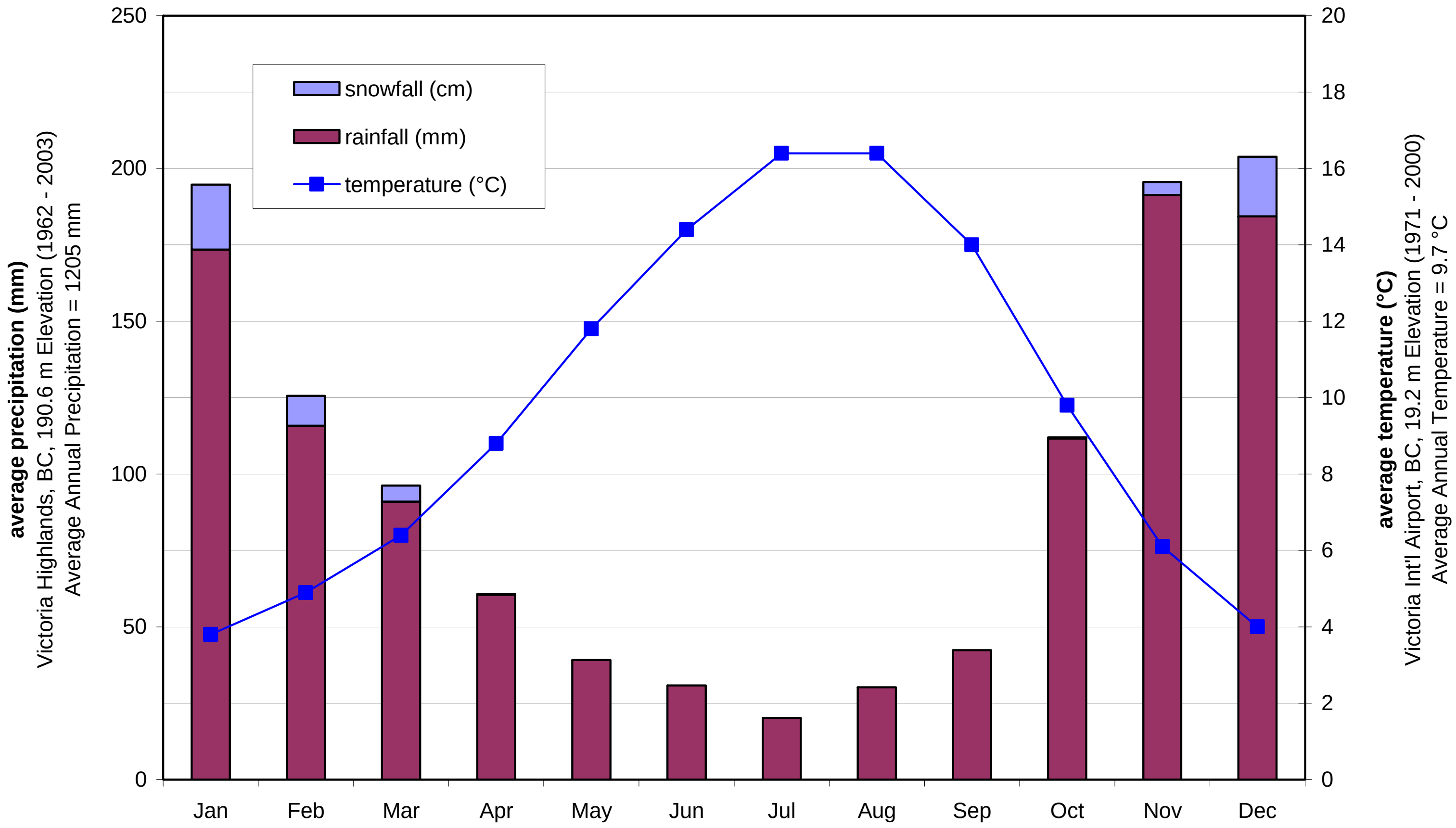


Note:

Precipitation and Temperature from Environment Canada National Climate Archive. Precipitation recorded at Victoria Highlands Weather Station and Temperature at Victoria International Airport.

PROJECT

DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE

ESTIMATED TEMPERATURE AND PRECIPITATION FOR THE DISTRICT OF HIGHLANDS

Golder Associates

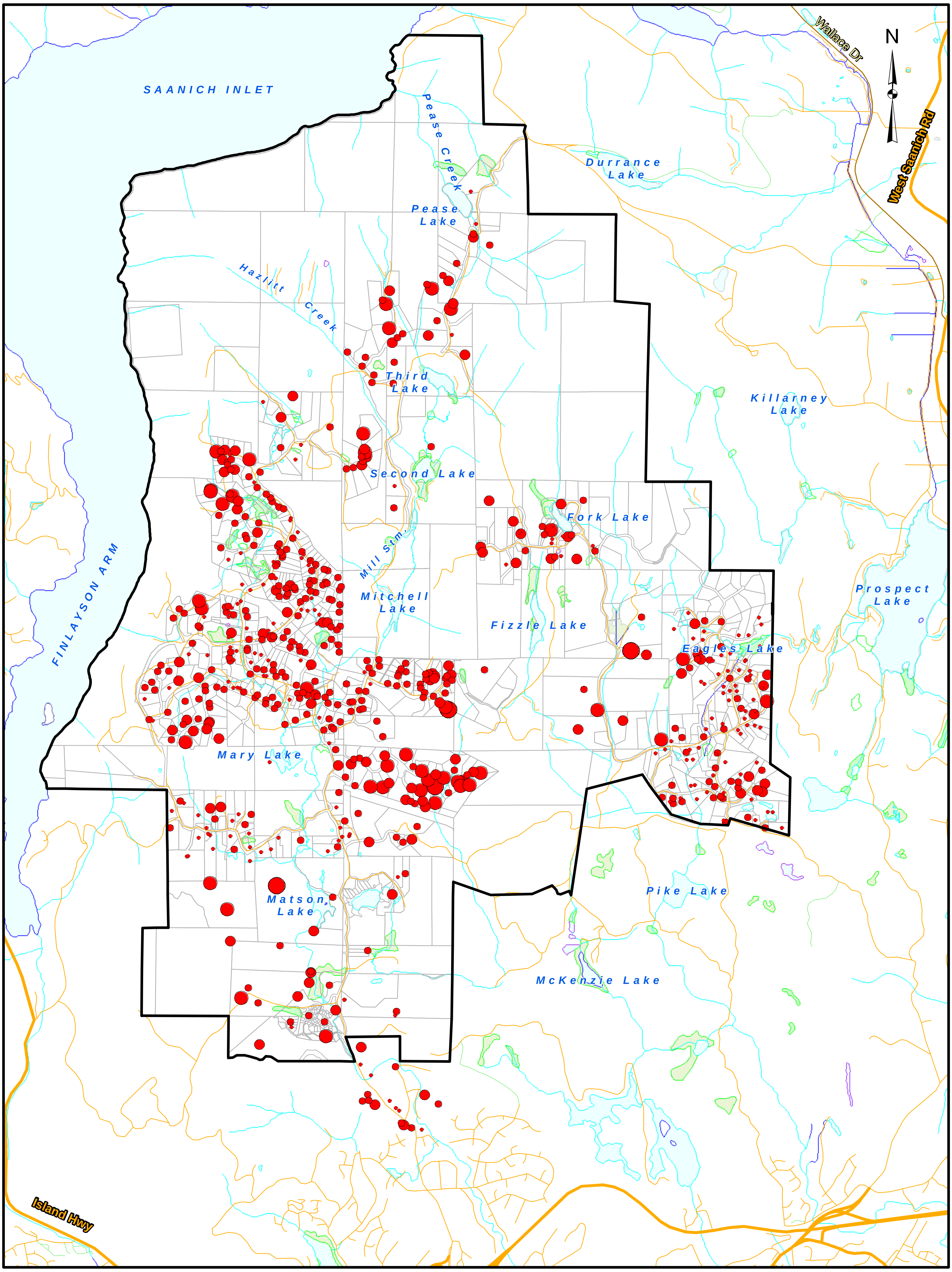
PROJECT No. 07-1414-0014		
DESIGN	MB	01SEP08
CADD	JL	01SEP08
CHECK	MB	02SEP08
REVIEW	JL	21OCT08

FILE No. ----

SCALE NTS

REV.

FIGURE 6



LEGEND

Highlands Municipal Boundary
River/ Stream
Marsh/ Swamp
Lake
Marsh
Swamp

Borehole Depth (m)
0 - 50
50 - 100
100 - 150
150 - 200
200 - 250

Transportation
Expressway
Major Road
Local Road
Trail

875 0 875
SCALE 1:35,000 METRES

REFERENCE

Data provided by the District of Highland, BC ILMB.
Water Well information and Borehole Depths from Ministry of Environment Water Well Records.
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 10

PROJECT
DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE
WATER WELL LOCATIONS
AND WELL COMPLETION DETAILS

Golder Associates
Burnaby, B.C.

PROJECT No. 07-1414-0014			SCALE AS SHOWN	REV. 0
DESIGN	JL	27 Aug. 2008	FIGURE 7	
GIS	AL	27 Aug. 2008		
CHECK	JL	21 Oct. 2008		
REVIEW	MB	21 Oct. 2008		

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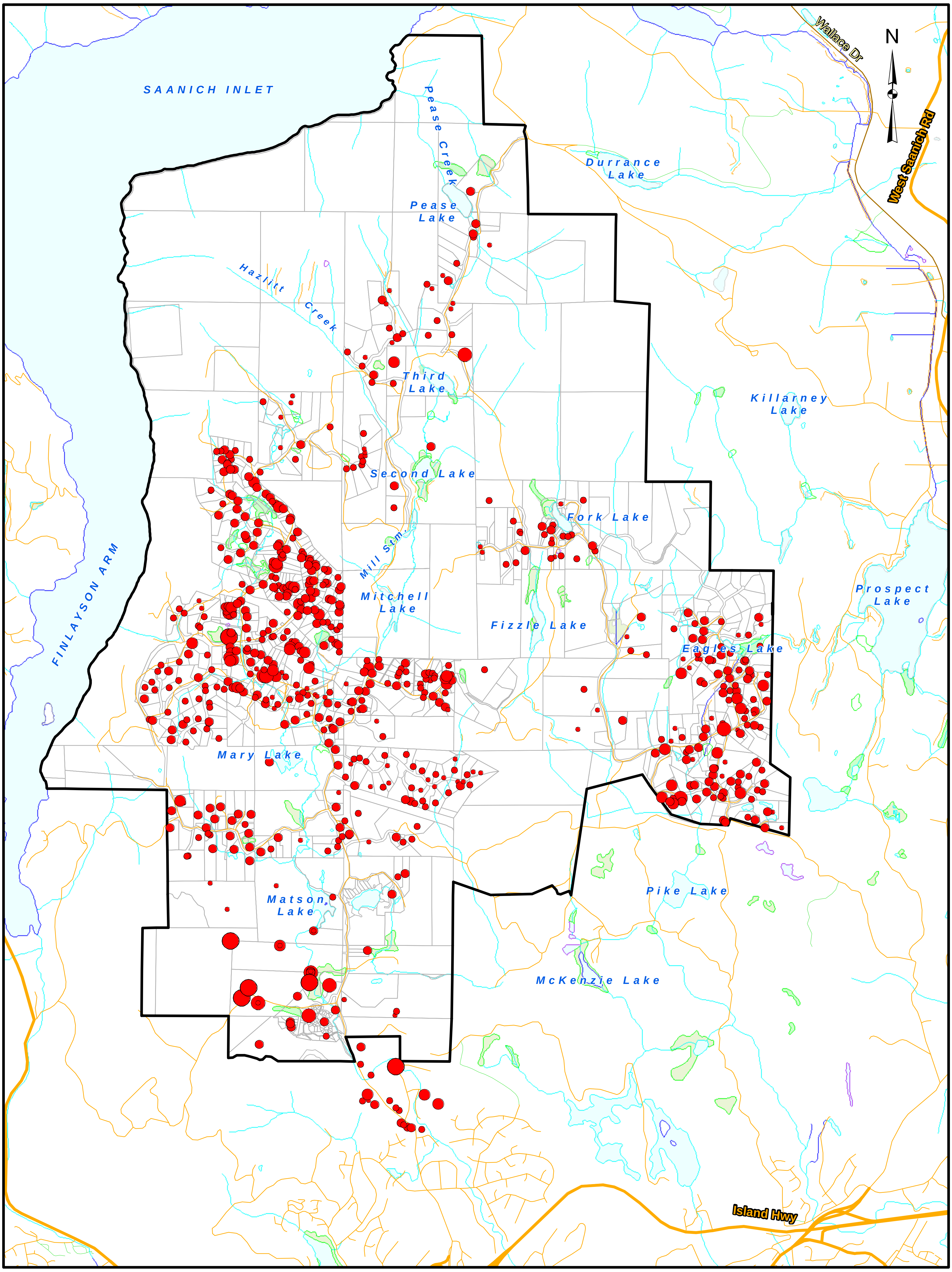

LEGEND

- Highlands Municipal Boundary
- River/ Stream
- Marsh/ Swamp
- Lake
- Marsh
- Swamp
- Cadastre Information

Well Yield (US gpm)

- ● 0- 1
- ● 1 - 5
- ● 5 - 25
- ● 25 - 50
- ● 50 - 100
- ● 100 - 300

Transportation

- Expressway
- Major Road
- Local Road
- Trail

875 0 875

SCALE 1:35,000 METRES

REFERENCE

Data provided by the District of Highland, BC ILMB.
Water Well Locations and Yields from Ministry of Environment Water Well Records.
Base data provided by the Ministry of Environment, WMS.
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 10

PROJECT

DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE

WATER WELL LOCATIONS AND
REPORTED WELL YIELD

Golder Associates
Burnaby, B.C.

PROJECT No. 07-1414-0014			SCALE AS SHOWN	REV. 0
DESIGN	JL	27 Aug. 2008	FIGURE 8	
GIS	AL	27 Aug. 2008		
CHECK	JL	21 Oct. 2008		
REVIEW	MB	21 Oct. 2008		

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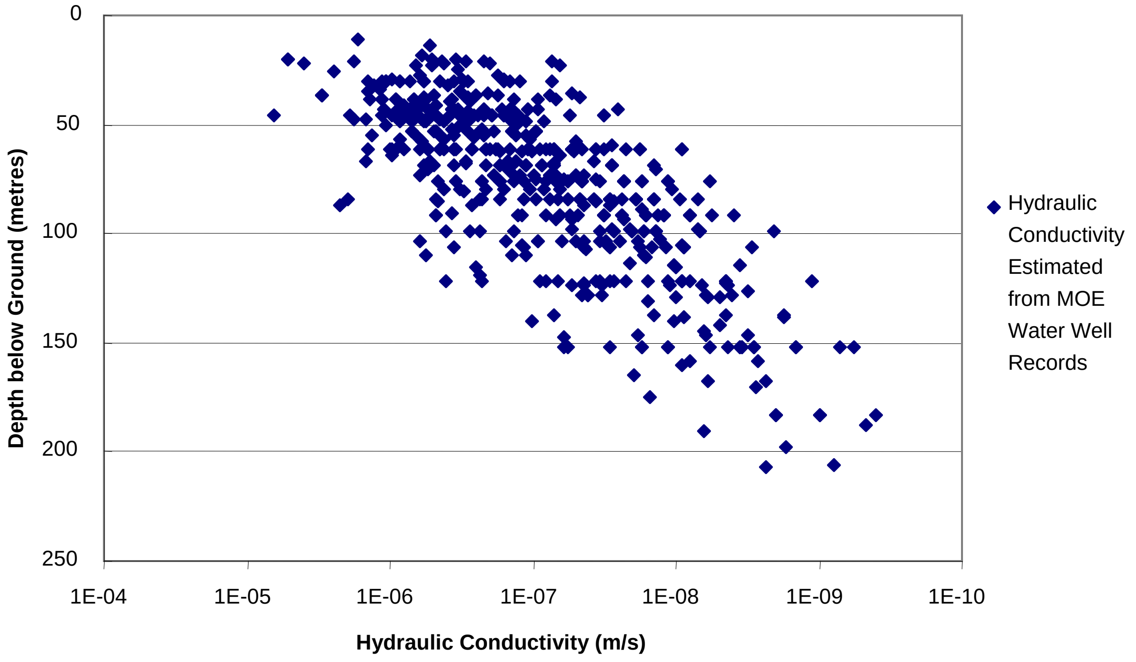
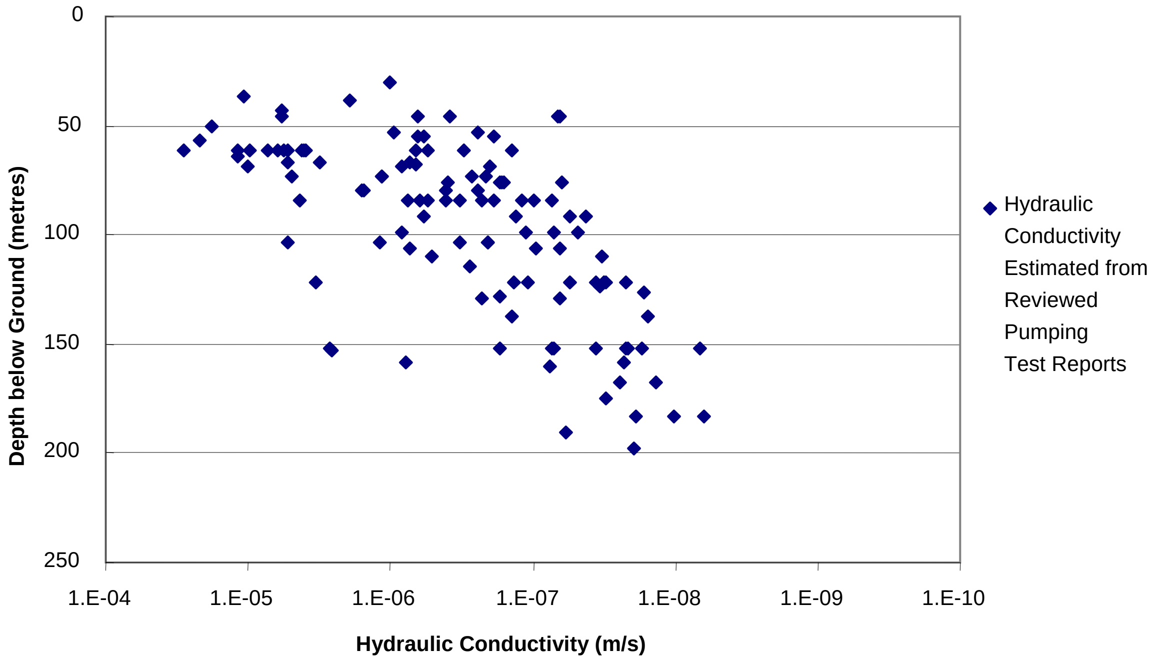
REVISION DATE: OCTOBER 21, 2008 BY:JL FILE: N:\FINAL\2007\1414\07-1414-0014 DoH Groundwater Monitoring\rep 102208 DoH Phase 1\rep 102208 Components\Figures\Figure 9, 10 and 12 to 16.pdf





PROJECT

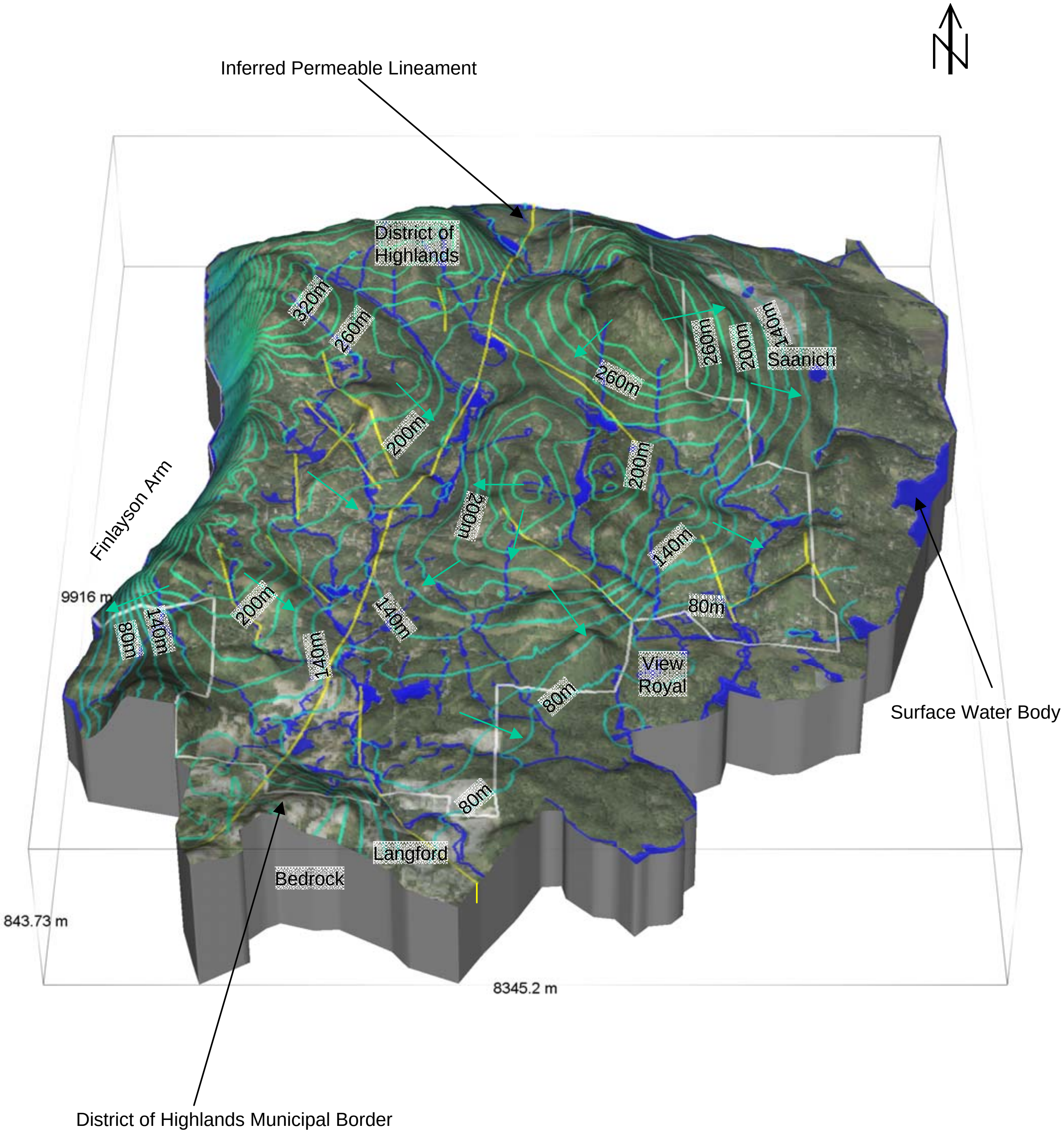
DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE

HYDRAULIC CONDUCTIVITY VERUS DEPTH

Golder Associates

PROJECT No. 07-1414-0014			FILE No. ----	
DESIGN	JL	28AUG08	SCALE NTS	REV.
CADD	JL	28AUG08	**FIGURE 9**	
CHECK	WZ	02SEP08		
REVIEW	MB	21OCT08		



→ Inferred Groundwater Flow Direction

— Hydraulic Head Contour (20 m contour interval)

Hydraulic head contours estimated from Ministry of Environment water well records, data in published reports and surface water elevations.

2x vertical exaggeration.

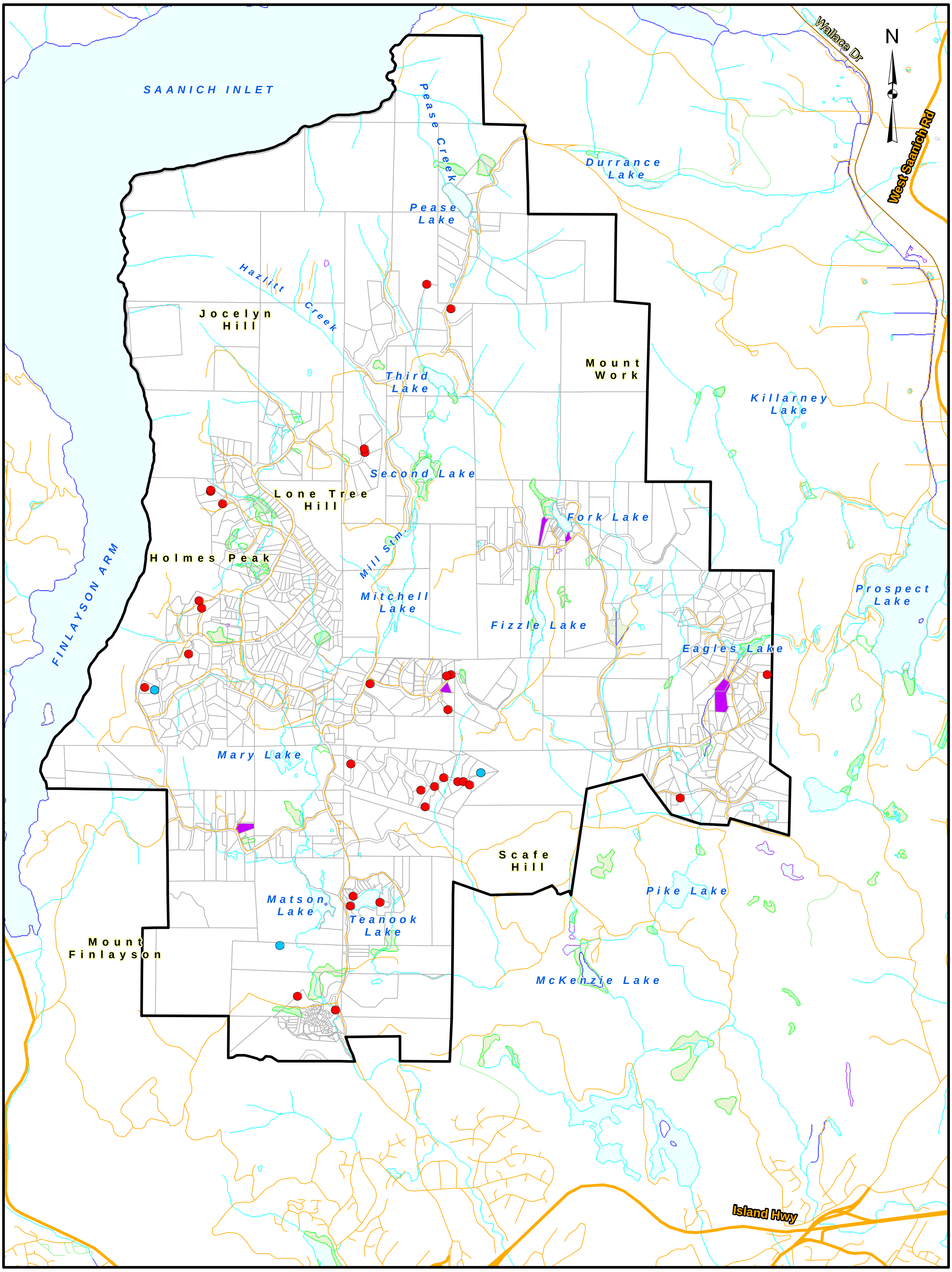
PROJECT
DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE
CONCEPTUAL GROUNDWATER MODEL

Golder Associates

PROJECT No.	07-1414-0014		FILE No. ----
DESIGN	JL	28AUG08	SCALE NTS REV.
CADD	JL	28AUG08	**FIGURE 10**
CHECK	WZ	02SEP08	
REVIEW	MB	21OCT08	

REVISION DATE: OCTOBER 21, 2008 BY:JL FILE: N:\FINAL\2007\1414\07-1414-0014 DoH Phase 1\rep 102208 DoH Groundwater Monitoring\rep 102208 Components\Figures\Figure 9, 10 and 12 to 16.pdf



LEGEND

Contour - (100m Interval)
Contour - (20m Interval)
River/ Stream
Marsh/ Swamp
Lake
Marsh
Swamp

Transportation
Expressway
Major Road
Local Road
Trail

● Proposed Water Level Monitoring Well
● Unused Well
Highlands Municipal Boundary
Unused Well on Property
Cadastre Information

875 0 875

SCALE 1:35,000 METRES

REFERENCE

Data provided by the District of Highland, BC ILMB.
Base data provided by the Ministry of Environment, WMS.
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 10

PROJECT

DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE

LOCATIONS OF UNUSED WELLS

Golder Associates
Burnaby, B.C.

PROJECT No. 07-1414-0014			SCALE AS SHOWN	REV. 0
DESIGN	JL	27 Aug. 2008	FIGURE 11	
GIS	AL	27 Aug. 2008		
CHECK	JL	21 Oct. 2008		
REVIEW	MB	21 Oct. 2008		

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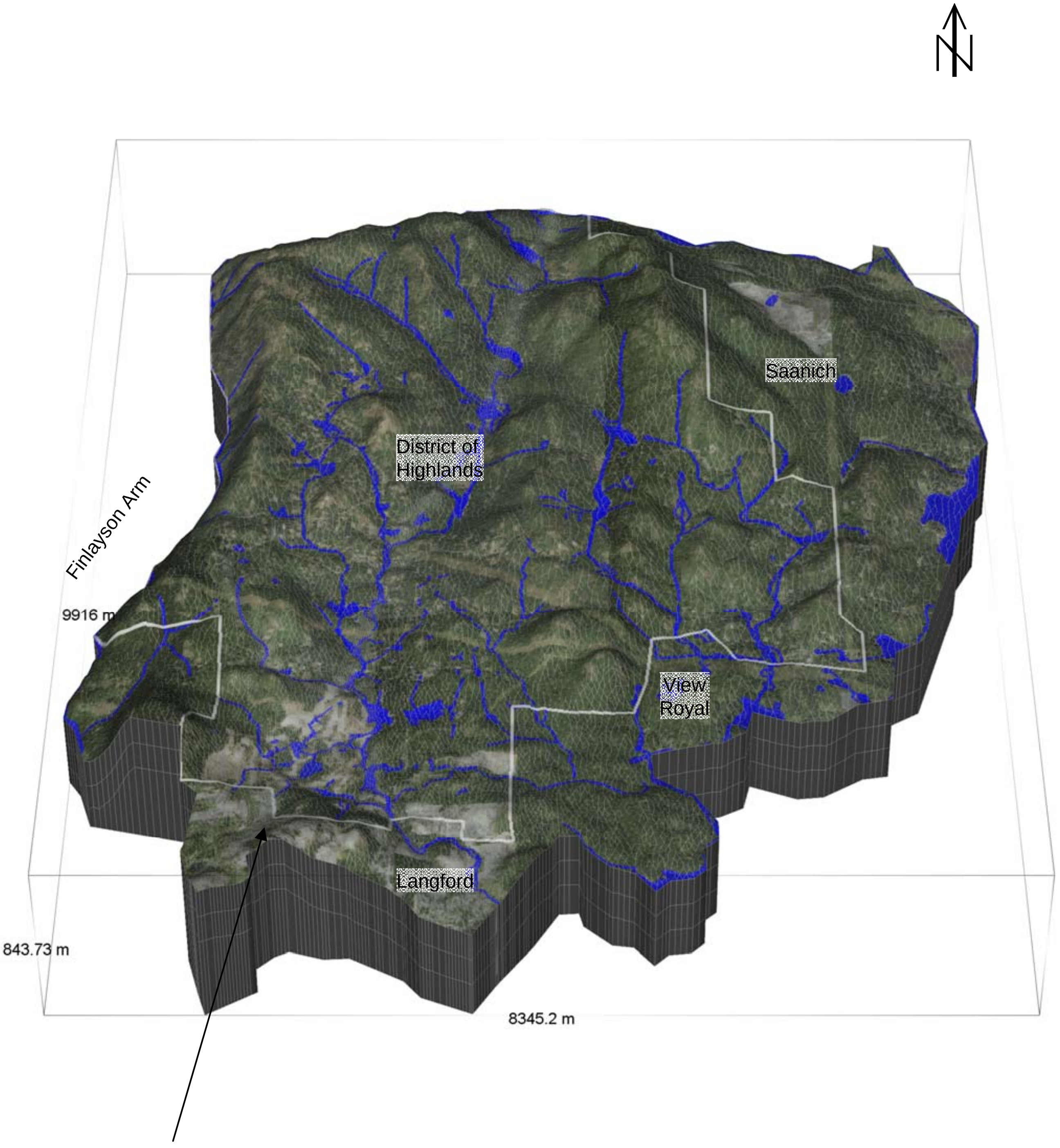


District of Highlands Municipal Border

2x vertical exaggeration.

PROJECT

DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE

GROUNDWATER MODEL
FINITE ELEMENT MESH

Golder Associates

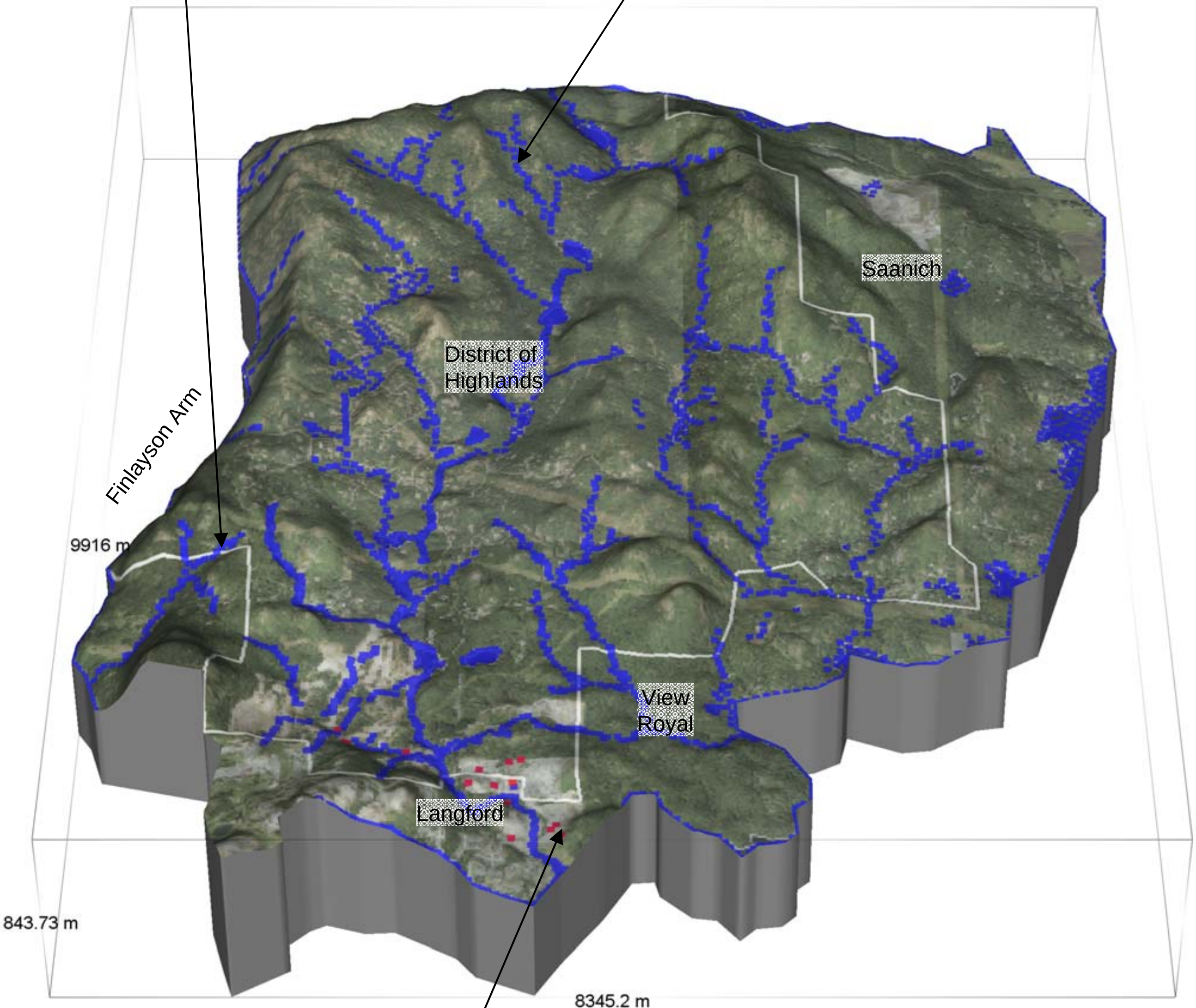
PROJECT No.	07-1414-0014		FILE No.----
DESIGN	JL	28AUG08	SCALE NTS REV.
CADD	JL	28AUG08	**FIGURE 12**
CHECK	WZ	02SEP08	
REVIEW	MB	21OCT08	

REVISION DATE: OCTOBER 21, 2008 BY:JL FILE: N:\FINAL\2007\1414\07-1414-0014 DoH Groundwater Monitoring\rep 102208 DoH Phase 1\rep 102208 Components\Figures\Figure 9, 10 and 12 to 16.pdf

REVISION DATE: OCTOBER 21, 2008 BY:JL FILE: N:\FINAL\2007\1414\07-1414-0014 DoH Groundwater Monitoring\rep 102208 DoH Phase 1\rep 102208 Components\Figures\Figure 9, 10 and 12 to 16.pdf

District of Highlands Municipal Border

Specified Head Boundary – Set to Ground Elevation (creeks, rivers, wetlands and drainage courses)
Note: Intermittent water courses were constrained to only allow groundwater outflow.



Specified Flux Boundary – Set to Average Annual Pumping Rate (communal/commercial water users)

2x vertical exaggeration.

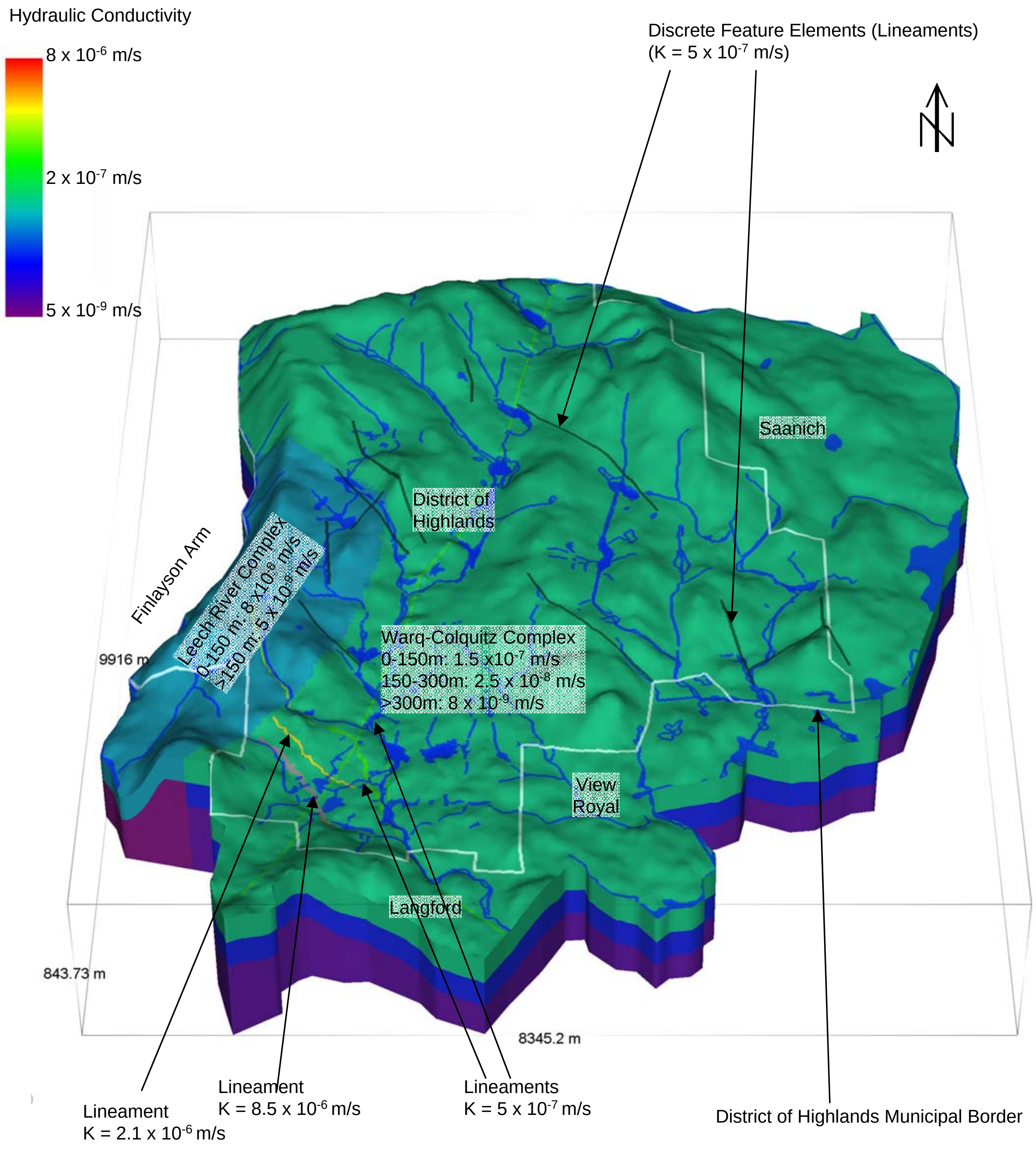
Note:
In addition, two specified flux boundaries were assigned everywhere along the top of the model. The first specified flux boundary representing recharge was initially set to 10% of the average annual precipitation (1205 mm/year), and following calibration was reduced to 8.5%. The second specified flux boundary represented recharge from anthropogenic sources (septic water return). This boundary was set to 70% of the estimated water consumption for residential, communal and commercial properties except Bear Mountain and All Fun Recreation (no septic water return assumed).
All remaining model boundaries were set to zero-flux (no flow).

PROJECT
DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE
GROUNDWATER MODEL
BOUNDARY CONDITIONS

Golder Associates

PROJECT No.	07-1414-0014		FILE No.	----
DESIGN	JL	28AUG08	SCALE NTS	REV.
CADD	JL	28AUG08	**FIGURE 13**	
CHECK	WZ	02SEP08		
REVIEW	MB	21OCT08		



2x vertical exaggeration.

PROJECT

DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE

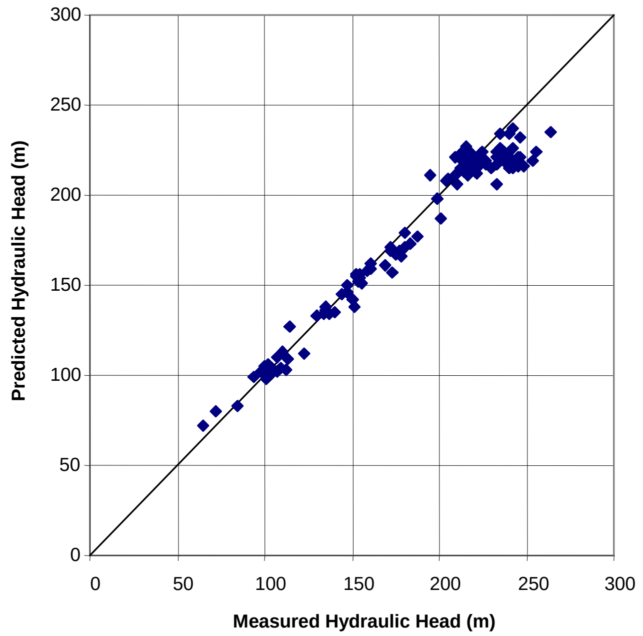
GROUNDWATER MODEL
CALIBRATED HYDRAULIC CONDUCTIVITY

Golder Associates

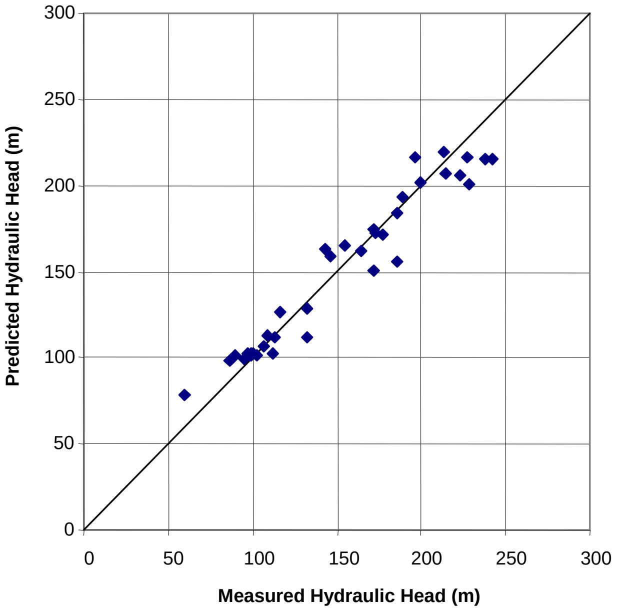
PROJECT No.	07-1414-0014		FILE No.	----
DESIGN	JL	28AUG08	SCALE NTS	REV.
CADD	JL	28AUG08	**FIGURE 14**	
CHECK	WZ	02SEP08		
REVIEW	MB	21OCT08		

REVISION DATE: OCTOBER 21, 2008 BY:JL FILE: N:\FINAL\2007\1414\07-1414-0014 DoH Phase 1\rep 102208 DoH Groundwater Monitoring\rep 102208 Components\Figures\Figure 9, 10 and 12 to 16.pdf

Records from the Ministry of Environment Water Well Database



Records from Reviewed Hydrogeological Reports



PROJECT

DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

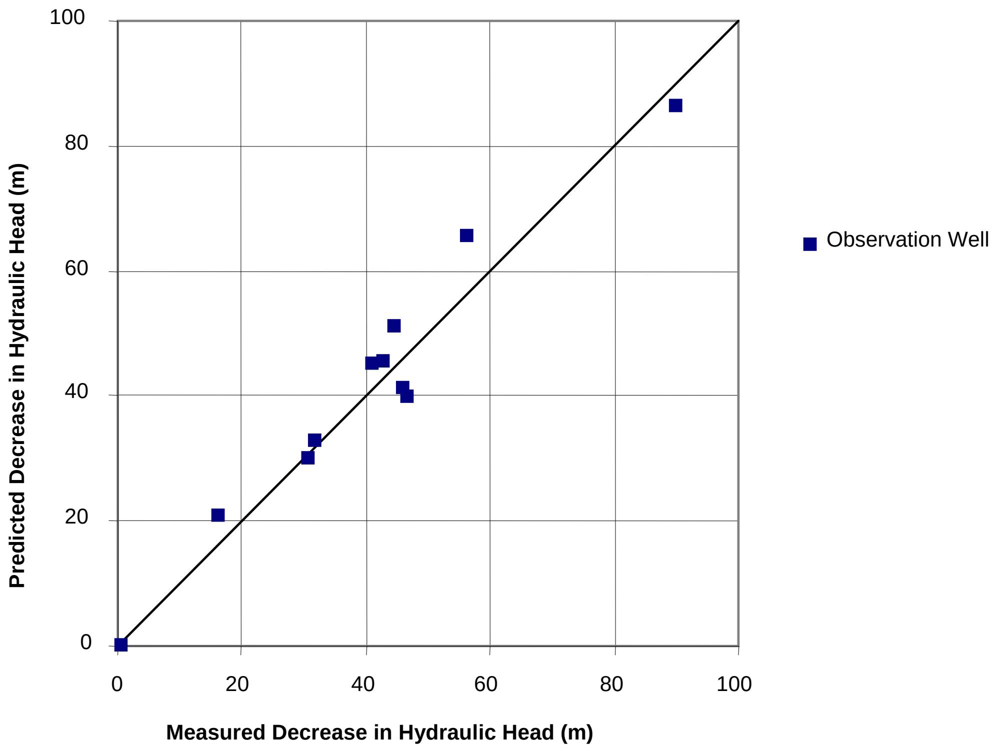
TITLE

RESULTS OF MODEL CALIBRATION
HYDRAULIC HEADS

Golder Associates

PROJECT No. 07-1414-0014			FILE No. ----	
DESIGN	JL	28AUG08	SCALE NTS	REV.
CADD	JL	28AUG08	**FIGURE 15**	
CHECK	WZ	02SEP08		
REVIEW	MB	21OCT08		

REVISION DATE: OCTOBER 21, 2008 BY:JL FILE: N:\FINAL\2007\1414\07-1414-0014 DoH Groundwater Monitoring\rep 102208 DoH Phase 1\rep 102208 Components\Figures\Figure 9, 10 and 12 to 16.pdf



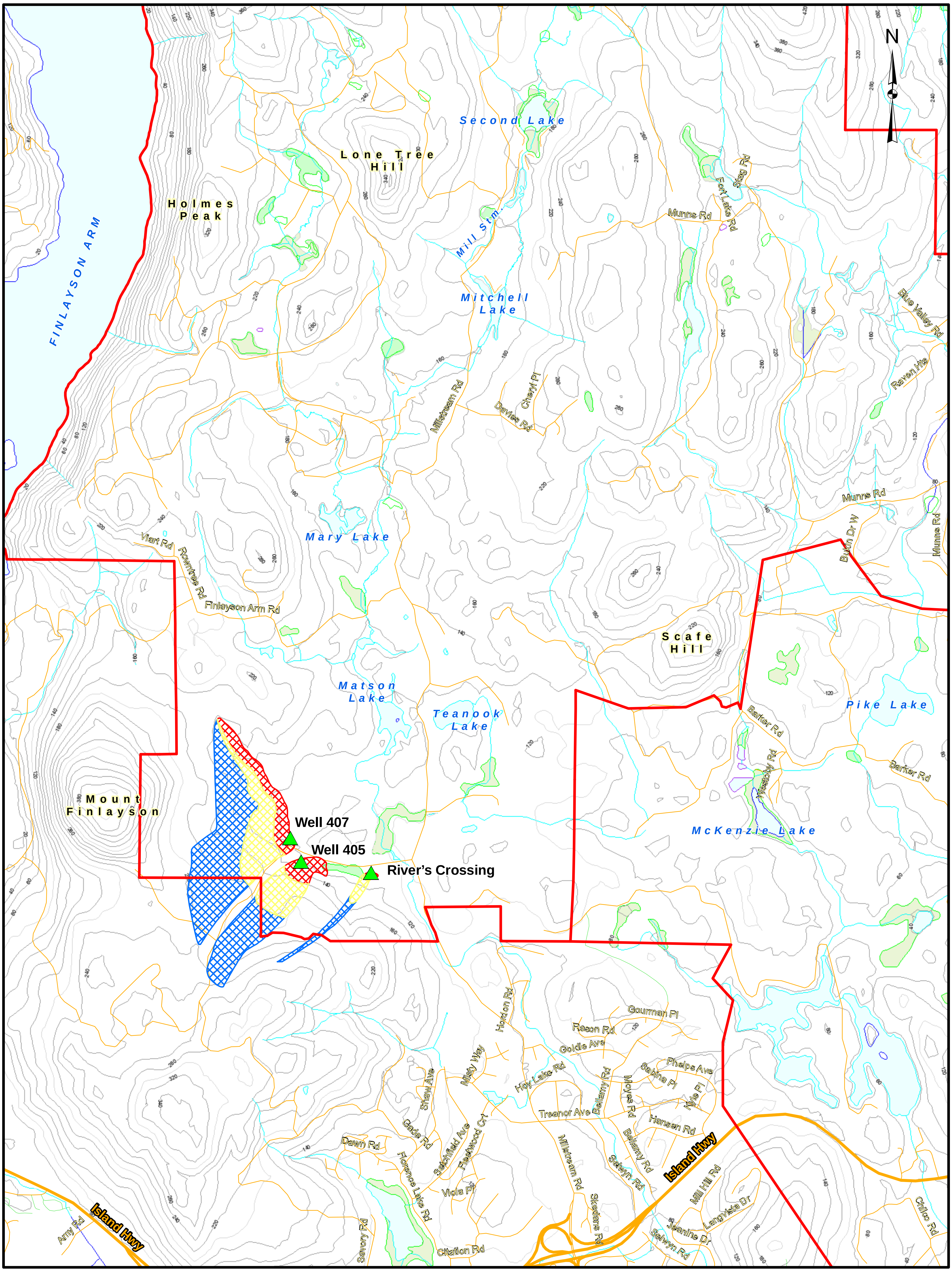
PROJECT
DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE
RESULTS OF MODEL CALIBRATION PUMPING TESTS

Golder Associates

PROJECT No.	07-1414-0014		FILE No. ----	
DESIGN	JL	28AUG08	SCALE NTS	REV.
CADD	JL	28AUG08	**FIGURE 16**	
CHECK	WZ	02SEP08		
REVIEW	MB	21OCT08		

REVISION DATE: OCTOBER 21, 2008 BY:JL FILE: N:\FINAL\2007\1414\07-1414-0014 DoH Groundwater Monitoring\rep 102208 DoH Phase 1\rep 102208 Components\Figures\Figure 9, 10 and 12 to 16.pdf



1,000 0 1,000

SCALE 1:25,000 METRES

LEGEND

River/ Stream

Marsh/ Swamp

Lake

Marsh

Swamp

Transportation

Expressway

Major Road

Local Road

Trail

Highlands Municipal Boundary

▲ Communal/Commercial Groundwater User

Capture Zone

▨ 250 Days

▨ 5 Years

▨ 20 Years

REFERENCE

Airphoto from the Capital Regional District.
Capture Zones supplied by Golder Associates.
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 10

PROJECT

DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE

CAPTURE ZONES PREDICTED FOR
CURRENT PUMPING CONDITIONS

Golder Associates
Burnaby, B.C.

PROJECT No. 07-1414-0014			SCALE AS SHOWN	REV. 0
DESIGN	JL	27 Aug. 2008	FIGURE 17	
GIS	AL	02 Sept. 2008		
CHECK	JL	21 Oct. 2008		
REVIEW	MB	21 Oct. 2008		

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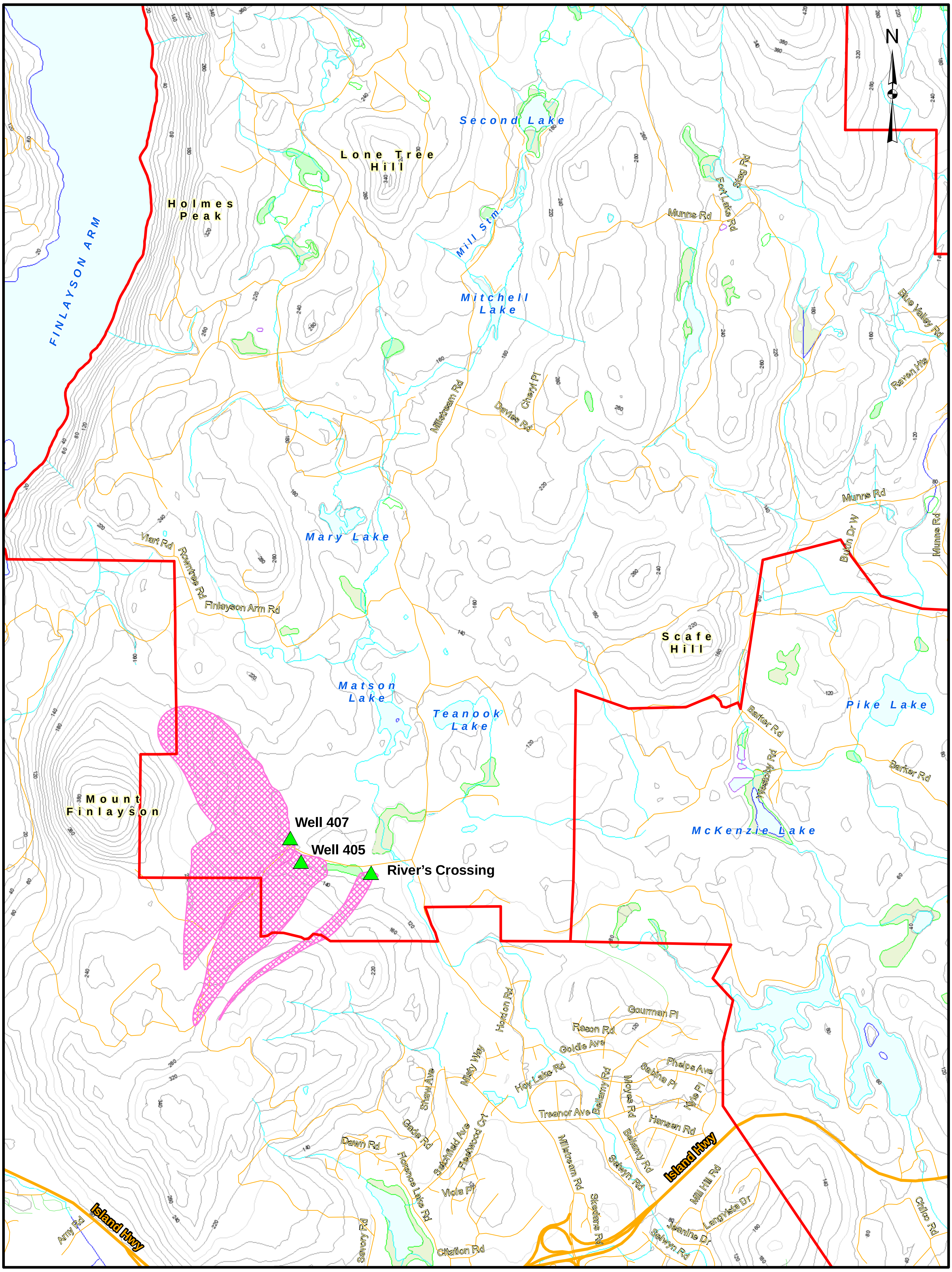

LEGEND

River/ Stream
Marsh/ Swamp
Lake
Marsh
Swamp
Transportation
Expressway
Major Road
Local Road
Trail

Highlands Municipal Boundary
▲ Communal/Commercial Groundwater User
▨ Maximum Extent of Capture Zone Based on Assessment of Uncertainty

REFERENCE

Airphoto from the Capital Regional District.
Capture Zones supplied by Golder Associates.
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 10

1,000   0   1,000
SCALE 1:25,000   METRES

PROJECT
DISTRICT OF HIGHLANDS
GROUNDWATER PROTECTION STUDY
HIGHLANDS, B.C.

TITLE
UPPER BOUND EXTENT OF CAPTURE ZONES FOR CURRENT PUMPING CONDITIONS

Golder Associates
Burnaby, B.C.

PROJECT No. 07-1414-0014			SCALE AS SHOWN	REV. 0
DESIGN	JL	27 Aug. 2008	FIGURE 18	
GIS	AL	02 Sept. 2008		
CHECK	JL	21 Oct. 2008		
REVIEW	MB	21 Oct. 2008		

N:\Bur-Graphics\Projects\2007\1414\07-1414-0014\GIS\projects\figure-18_Ultimate_Captures.mxd

APPENDIX I

SUMMARY RESULTS OF STREAMFLOW MONITORING PROGRAM

Table I-1
Summary of Results from Streamflow Monitoring Program
September 27 and 28, 2007
District of Highlands, BC

Location	Comments
1	• Location: Millstream creek below Hannington Rd. bridge • Creek was flowing • Estimated discharge ~ 5.5 L/s (2 cross sections, tennis ball current meter method)
2	• Authorization to visit this site was not obtained (Bear Mountain property)
3	• Authorization to visit this site was not obtained (Bear Mountain property)
4	• Location: 712 Lorimer, back of property • Creek bed was dry • Adjacent to the house there is a pond maintained for fire fighting purposes • Owner maintains a small dam to divert water to the pond
5	• Location: upstream of the Millstream Lake Rd. bridge crossing • Creek was flowing • Water was pooled in creek with flow over bedrock steps, flow was measured by filling a 0.5 L water sampling container. • Approximate flow rate of creek ~ 0.15 L/s (0.5 L filled in apprxoimately 4 – 5 seconds, captured 80 – 90% of flow)
6	• Location: Where creek crosses Millstream Lake Rd. near driveway to 377 Millstream Lake Rd. • Creek was not flowing, creek bed was dry.
7	• Location: 3975 Munn Rd. • Fizzle Creek • Creek was not flowing, creek bed was dry
8	• Location: Several sites on 2627 Bukin Dr. E. • Some water was pooled in the low lying areas near Bukin Rd, at other sites visited the creek was not flowing and creek bed was dry
9	• Location: back of 2811 Bukin Dr. W. • Creek was not flowing, creek bed was dry
10	• Location: Craigflower creek where if flows under Highland Rd. • Creek was not flowing, water was pooled in creek bed.

APPENDIX II

CURRENT GROUNDWATER USE INFORMATION

Table II-1
Summary of Surface Water License Information
District of Highlands, BC

LICENSE NO.	PURPOSE	LICENSE STATUS	QUANTITY	UNITS	QUANTITY	UNITS	SURFACE WATER BODY	LOCATION	
								EASTING	NORTHING
C055997	DOMESTIC	CURRENT	500	GD	1.90	CMD	Hazlitt Creek	462696.336057	5374937.284212
C053010	DOMESTIC	CURRENT	500	GD	1.90	CMD	Second Lake	462996.473533	5374714.939088
C056135	DOMESTIC	CURRENT	2000	GD	7.58	CMD	Third Lake	463018.354327	5375475.422918
C056135	DOMESTIC	CURRENT	2000	GD	7.58	CMD	Third Lake	463070.632273	5375456.998572
C056135	DOMESTIC	CURRENT	2000	GD	7.58	CMD	Third Lake	463066.043099	5375391.906244
C056135	DOMESTIC	CURRENT	2000	GD	7.58	CMD	Third Lake	463188.992859	5375409.985177
C056135	DOMESTIC	CURRENT	2000	GD	7.58	CMD	Third Lake	463144.937910	5375338.342968
C118028	DOMESTIC	CURRENT	500	GD	1.90	CMD	Fork Lake	464202.061982	5374081.179751
C065705	DOMESTIC	CURRENT	500	GD	1.90	CMD	Fork Lake	464241.615139	5374050.977635
C050894	DOMESTIC	CURRENT	500	GD	1.90	CMD	Eagles Lake	465859.559640	5372873.322389
C051286	DOMESTIC	CURRENT	500	GD	1.90	CMD	Eagles Lake	465825.627098	5372787.063503
C061285	DOMESTIC	CURRENT	500	GD	1.90	CMD	Eagles Lake	465775.432167	5372771.630988
C040178	DOMESTIC	CURRENT	500	GD	1.90	CMD	Munn Creek	465666.084789	5372317.148414
C049218	DOMESTIC	CURRENT	500	GD	1.90	CMD	Pease Lake	463365.703054	5376907.267098
F044530	DOMESTIC	CURRENT	500	GD	1.90	CMD	Pease Lake	463283.141975	5377109.250119
C101065	DOMESTIC	CURRENT	500	GD	1.90	CMD	Fork Lake	464162.777654	5374273.270290
C101084	DOMESTIC	CURRENT	500	GD	1.90	CMD	Fork Lake	464175.654396	5374145.226236
C120576	DOMESTIC	CURRENT	500	GD	1.90	CMD	Pease Lake	463386.336788	5376866.333540
C105586	DOMESTIC	CURRENT	500	GD	1.90	CMD	Eagles Lake	465821.939902	5372830.262638
C025721	DOMESTIC	CURRENT	2000	GD	7.58	CMD	Mitchell Lake	462780.755022	5373436.978854
C025721	DOMESTIC	CURRENT	2000	GD	7.58	CMD	Mitchell Lake	462656.891090	5373226.428289
C024311	DOMESTIC	CURRENT	1000	GD	3.79	CMD	Mill Stream	462491.008258	5372930.143508
C101157	DOMESTIC	CURRENT	500	GD	1.90	CMD	Fork Lake	464173.915475	5374250.057988
C101159	DOMESTIC	CURRENT	500	GD	1.90	CMD	Fork Lake	464178.103930	5374224.820064
C026194	DOMESTIC	CURRENT	1000	GD	3.79	CMD	Saul Spring	460583.514006	5371852.891722
C118030	DOMESTIC	CURRENT	500	GD	1.90	CMD	Teanook Lake	462337.053797	5370652.239001
C055266	DOMESTIC	CURRENT	500	GD	1.90	CMD	Teanook Lake	462412.987480	5370701.305769
F053853	DOMESTIC	CURRENT	500	GD	1.90	CMD	Teanook Lake	462452.894164	5370706.521709
C058583	DOMESTIC	CURRENT	500	GD	1.90	CMD	Teanook Lake	462561.366859	5370754.722607
C053414	DOMESTIC	CURRENT	500	GD	1.90	CMD	Teanook Lake	462551.837521	5370631.028610

Table II-1
Summary of Surface Water License Information
District of Highlands, BC

LICENSE NO.	PURPOSE	LICENSE STATUS	QUANTITY	UNITS	QUANTITY	UNITS	SURFACE WATER BODY	LOCATION	
								EASTING	NORTHING
C017097	DOMESTIC	CANCELLED	1000	GD	3.79	CMD	Mill Stream	462199.524362	5369503.663005
C059093	DOMESTIC	ABANDONED	100	GD	0.38	CMD	Munn Creek	465367.081212	5373169.876178
C059712	DOMESTIC	ABANDONED	500	GD	1.90	CMD	Harris Creek	465286.679702	5371950.053622
C055265	DOMESTIC	ABANDONED	500	GD	1.90	CMD	Teanook Lake	462377.246322	5370682.255442
C111445	FIRE PROTECTION	CURRENT	0.2	AF	0.00	CMY	Menaro Swamp	462344.664193	5374639.569274
C113384	FIRE PROTECTION	CURRENT	0.1	AF	0.00	CMY	Rathbone Swamp	462685.518731	5371884.572037
C059093	IRRIGATION	ABANDONED	1.5	AF	0.00	CMY	Munn Creek	465367.081212	5373169.876178
Z102304	IRRIGATION	ABANDON. APPL.	3	AF	0.00	CMY	Corcoran Swamp	461676.653617	5374908.814459
C024312	LAND IMPROVE	CURRENT	0	TF	0.00	CMD	Mill Stream	462362.566976	5372920.939734
C117633	LAND IMPROVE	CURRENT	0	TF	0.00	CMD	Mill Stream	462152.042303	5369619.007491
C122188	LAND IMPROVE	CURRENT	79.4	AF	0.06	CMY	Mill Stream	462000.035630	5370429.986650
C122118	LAND IMPROVE	CURRENT	30	AF	0.02	CMY	Osborn Creek	461499.539698	5370268.013947
C114305	LAND IMPROVE	CURRENT	0.3	AF	0.00	CMY	Jasper Spring	461577.752705	5374976.499156
C114932	LAND IMPROVE	CURRENT	22	AF	0.02	CMY	Foden Pond No. 3	466166.569972	5371414.707509
C114932	LAND IMPROVE	CURRENT	22	AF	0.02	CMY	Foden Pond No. 2	466087.655741	5371530.401432
C014943	LAND IMPROVE	CURRENT	40	AF	0.03	CMY	Mill Stream	462669.575400	5373159.511561
C044261	LAND IMPROVE	CURRENT	42	AF	0.03	CMY	Eagles Lake	465779.471683	5372778.697093
C029482	LAND IMPROVE	CURRENT	0.0	TF	0.00	CMD	Earsman Brook	461705.420344	5371828.622586
C029482	LAND IMPROVE	CURRENT	0.0	TF	0.00	CMD	Earsman Brook	461776.893721	5371869.480598
C018495	LAND IMPROVE	CURRENT	0.0	TF	0.00	CMD	Mill Stream	461781.916795	5371571.023020
C018495	LAND IMPROVE	CURRENT	0.0	TF	0.00	CMD	Mill Stream	461853.711569	5371407.167589
C018495	LAND IMPROVE	CURRENT	0.0	TF	0.00	CMD	Mill Stream	461812.208613	5371037.572604
Z102304	PONDS	ABANDON. APPL.	10	AF	0.01	CMY	Corcoran Swamp	461676.653617	5374908.814459
C110308	RES. LAWN/GARDEN	CURRENT	0.3	AF	0.00	CMY	Foden Pond No. 1	465933.066020	5371513.658565

Table II-1
Summary of Surface Water License Information
District of Highlands, BC

LICENSE NO.	PURPOSE	LICENSE STATUS	QUANTITY	UNITS	QUANTITY	UNITS	SURFACE WATER BODY	LOCATION EASTING	LOCATION NORTHING
C105851	RES. LAWN/GARDEN	CURRENT	0.3	AF	0.00	CMY	Hatcher Swamp	462248.845830	5370036.725825
C122118	STORAGE	CURRENT	82.7	AF	0.07	CMY	Osborn Creek	461499.539698	5370268.013947
C105851	STORAGE	CURRENT	0.3	AF	0.00	CMY	Hatcher Swamp	462248.845830	5370036.725825
C059094	STORAGE	ABANDONED	1.6	AF	0.00	CMY	Munn Creek	465367.081212	5373169.876178
C122118	WATERING	CURRENT	52.7	AF	0.04	CMY	Osborn Creek	461499.539698	5370268.013947

Notes:

GD = gallons per day
AF = acre feet per year
CMD = cubic meters per day
CMY = cubic meters per year

Table II-2
Estimated Current Residential Groundwater Use
District of Highlands, BC

Highlands population in 2006 census[1]: 1903

Total Private residences in 2006 census: 730[2]

Total number of developed lots (primary residences): 674[3]

Estimated number of secondary suites: = 730 – 674 = 56

Estimated population in secondary suites: = 56 * 1.5 people/suite = 84

Estimated population in principal residences: = 1903 – 84 = 1819[4]

Estimate for water consumption for principal residences: 450 L/c/day[5]

Estimate for water consumption for people in secondary suites[6]: 314 L/capita/day[7]

Total residential groundwater use in Highlands: = (1819*450) + (84*314) = 844.9 m^3/day

Average residential groundwater use in Highlands: = 844.9 / 674 = **1.254 m^3/day/developed lot**

---

[1] Includes people living in secondary suites (Stats Canada 2006 data)

[2] District of Highlands Official Community Plan, Schedule A to Bylaw No. 277, March 2007

[3] Highlands Cadastral map information

[4] 6 houses in Hannington Estates and 4 houses in River's Crossing Centre are estimated to have not been within the 2006 census data

[5] Estimated from EC Municipal water use statistics (where average residential consumption is 425 L/c/d in BC, 446 L/c/d in municipalities <2000, and 464 L/c/d in municipalities 2000-5000 population).

[6] Assumed to be a lower estimate as residents in secondary suites are not anticipated to have high demand for irrigation as this is accounted for in principle residence estimate

[7] 2007 estimate - telephone correspondence with CRD Water Services, March 11, 2008

Table II-3
Estimated Current Large Volume Groundwater Use
District of Highlands, BC

User	Well No.[1]	Well Tag No.	Average Estimated Current Groundwater Use	Comments
River's Crossing Retreat Centre (RC) and Hannington Estates Subdivision (HE) River Road and Hannington Road	409 (active) 500 (backup)	85183 85184	**Current:** HE = 6 homes, RC = 4 homes + conference centre Volumes measured from well 409[2]: Feb 2008 – 663 m^3 Jan 2008 – 1579 m^3 Dec 2007 – 835 m^3 Nov 2007 – 1276 m^3 Oct 2007 – 771 m^3 Sept 2007 – 641 m^3 Aug 2007 – 1019 m^3 Based on volume estimates from previous 7 months, estimate a daily demand of **32.3 m^3/day** ***note 1:*** *RC currently includes a 360,000 gallon pond (built/engineered) that is sourced from water system (well 409)*	**Future Use:** at full build-out, Hannington Estates will include 58 single family homes plus one duplex (total of 60 residences), and the River's Crossing Retreat Centre will include 4 homes, a resort for up to approximately 150 guests and a conference centre
Bear Mountain Golf Course	405 407	81689 81690	**Current:** irrigation wells pumped during summer season (in 2005 June 10th through September 19th) at volume of **225 USgpm (14 L/s)**[3], (407 is the high producing well)[4]	**Future Use:** plan to bring Well No. 411 online to produce an additional 165 USgpm (10.5 L/s)[5] for future golf course requirements

---

[1] Well No. refers to number provided in previous reports (not on the BC Water Resources Atlas)
[2] Volumes and water levels provided by Corewater Management
[3] Thurber Engineering Ltd. 2007. Bear Mountain Golf and Country Club Highlands Golf Course Groundwater Supply Report 2006-2007 Program

Table II-3
Estimated Current Large Volume Groundwater Use
District of Highlands, BC

User	Well No.[1]	Well Tag No.	Average Estimated Current Groundwater Use	Comments
Millstream Industrial Park 2015 Millstream Road		80741 85633 85634[6]	**Current:** Estimated consumption of **800 – 1000 USgpd** (gallons per day) (as per the property manager)	Demand estimated from communication with Western Grater, in discussion with property manager **Future Use:** est. to be consistent with current operations
Top Line Roofing / Independent Concrete Ltd. 2023 Millstream Road		29408	Major water user is estimated to be the portion of the property rented to ICL (Independent Concrete Ltd.) Based on estimates provided by property manager for adjacent Millstream Industrial Park, water use estimated to be **800 – 1000 USgpd** (gallons per day) for this property (similar operations to Millstream Industrial Park)	Operator did not provide detailed information but advised that consumption was high in the property rented to ICL Operator advised that, in addition to Well Tag No. 29408, there are two other wells on the property (to the east of 29408)

---

[4] Bear Mountain Golf Course

[5] Thurber Engineering Ltd. 2007. Bear Mountain Golf and Country Club Highlands Golf Course Groundwater Supply Report 2006-2007 Program

[6] Wells 85633 and 85634 estimated from information provided by Western Grater (property manager) and correlated to wells identified on property with BC Water Resources Atlas – well details on Water Resources Atlas do not correlate to those estimated by Western Grater

Table II-3
Estimated Current Large Volume Groundwater Use
District of Highlands, BC

User	Well No.[1]	Well Tag No.	Average Estimated Current Groundwater Use	Comments
Highwest Waste Recycler 1943 Millstream Road				Operator advised that they do not use groundwater at the site
All Fun Recreation 2207 Millstream Road		37114 75659 75592 75658 93669[7]	Well 37114: well for single occupant residence = **0.314 m^3/day**[8] Wells 75592, 75659, 75658, 93669: current operations include a race track, recreation vehicle park, waterslides **RV park:** estimated at equivalent to 45 permanent residences (est. 2 people per residence) and 55 transient residences in the summer – therefore, estimated at approx. 75 residents on a monthly basis (75 × 2 people × 314 L/day) = **47 m^3/day** **Concession and restroom facilities:** estimate = **0.6 m^3/day**[9] **Waterslides:** estimate = **17.9 m^3/day**[10]	Well locations estimated from discussions with operator and comparison to MoE database Wells 75592, 75659, 75658, 93669 all feed into common water supply – contribution is assumed to be proportional to size of pump in each well **note:** waterslides are closed permanently as of 2008 and will not be included in future groundwater use estimates

---

[7] Wells estimated through discussions with operator and comparison to wells on BC Water Resources Atlas

[8] Minimal irrigation assumed

[9] See calculations below

[10] See calculations below

Table II-3
Estimated Current Large Volume Groundwater Use
District of Highlands, BC

Calculations for All Fun Recreation Facility:

Water Slide facility:

Main pool volume estimated to be approximately 20 m x 8 m x 1 m = 160 m^3

Other pool facilities estimated to be approximately 1.5 times the volume of the main pool = 240 m^3

Estimated 3 times the volume of water needed for slides 3 x (160 m^3 + 240 m^3) = 1200 m^3

Estimated 5% loss per day to evaporation, leaks, etc. 1200 m^3 x 0.05 = 60 m^3/day

Estimated 100 days operation 60 m^3 x 100 days = $\underline{6{,}000\ m^3}$

Shower and restroom facilities estimated at 20 L per person x 275 people/day x 100 days = $\underline{550\ m^3}$

Annual demand = (6,000 m^3 + 550 m^3)/365 days = **17.9 m^3/day**

Concession and restroom facilities:

Race Track: approx. 30 events at estimated avg. attendance of 800 people/event at 6 L/person (assume 30% usage of restroom facilities at 18 L/use and 0.6 L for concession) = 24,000 people x 6 L/person = $\underline{144\ m^3}$

Flea Market: approx. 24 events at estimated avg. attendance of 200 people/event at 4.2 L/person (assume 20% usage of restroom facilities at 18 L/use and 0.4 L for concession) = 4,800 people x 4 L/person = $\underline{19\ m^3}$

Batting Cages, GoCarts, etc.: approx. 100 people/day for approx. 150 day season at 4.2 L/person (assume 20% usage of restroom facilities at 18 L/use and 0.4 L for concession) = 15,000 people x 4 L/person = $\underline{60\ m^3}$

Annual demand = (144 m^3 + 19 m^3 + 60 m^3) / 365 days = **0.6 m^3/day**

APPENDIX III

FUTURE GROUNDWATER USE ESTIMATES

Table III-3
Estimated Future Residential Groundwater Use
District of Highlands, BC

1. Residential Groundwater Use at Full Build-Out

Full build-out number of principal residences: 1020 = an increase of 132 principal residences (1020 – 674 – 64[1] – 150[2])

Increased principal residence population at build out: 132 * 2.7 = 356 principal residents

Full build-out number of secondary suites: 132 * 20% = 26 secondary suites

Increased secondary suite population at build out: 26 * 1.5 = 39 secondary suite residents

Estimate for water consumption for principal residences: 450 L/c/day[3]

Estimate for water consumption for people in secondary suites[4]: 314 L/capita/day[5]

Private residential groundwater use at full build-out: = current demand[6] + (356*450 L/c/d) + (39*314 L/c/d) = **1,017 m^3/d**

Residential groundwater use for large water users[7] at full build-out = current well use + increased groundwater use

H.E. = new principle residences + new secondary suites

= [(60 – 6) * 2.7 * 450 L/c/d] + [(60 – 6) * 20% * 1.5 * 314 L/c/d] = 70.7 m^3/d

R.C. = estimate for proposed 20 suites and facilities

= (20 units*50% capacity*3 d/week*52 wks)*(40 USgpd + 9 USgpd)[8] + (10*5 d/wk*52 wks*10 USgpd)[9] = 1.06 m^3/d

Residential groundwater use for large volume users at full build out: 70.7 m^3/d + 1.0 m^3/d = **71.7 m^3/d**

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[1] Hannington Estates (58 homes + 1 duplex) and River's Crossing houses (4) are included in the full build-out number of 1020 but sourced from well 409

[2] Bear Mountain development will include 150 single dwelling lots that are not permitted to be sourced by groundwater (and will be on municipal sewer)

[3] Estimated from Environment Canada Municipal water use statistics

[4] Residents in secondary suites are not anticipated to have high demand for irrigation as this is accounted for in principle residence estimate

[5] 2007 estimate - telephone correspondence with CRD Water Services, March 11, 2008

[6] Current residential groundwater use estimated to be 844.9 m^3/day (see Table II-2)

[7] Groundwater supply from well 409

[8] Per capita water use for guest house and restaurant, respectively, from Tchobanoglous, G. and Burton, F.L., 1991

[9] Per capita water use for commercial facility employees from Tchobanoglous, G. and Burton, F.L., 1991

Table III-3
Estimated Future Residential Groundwater Use
District of Highlands, BC

2. Additional Groundwater Use with Secondary Suites at 50% at Full Build-Out

Number of additional secondary suites at build out: 132 * (50% – 20%)[10] = 40 additional secondary suites

Increased secondary suite population at 50%: 40 * 1.5 = 60 secondary suite residents

Total additional groundwater use at 50% suites: 60 * 314 L/c/d = **18.8 m^3/d**

Residential groundwater use for large water users at full build-out:

Additional demand on Well 409 at 50% suites and full-build out: = (60 – 6)*(50% - 20%)*1.5 people*314 L/c/d = **7.6 m^3/d**

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[10] Increase from 20% to 50% secondary suites