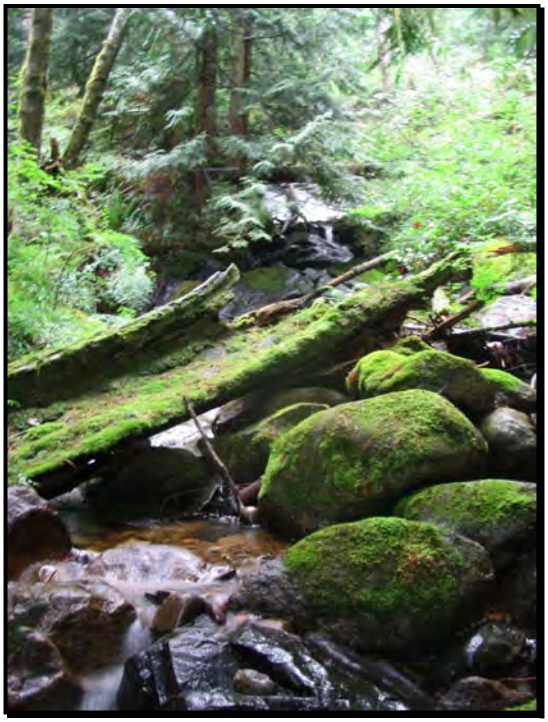

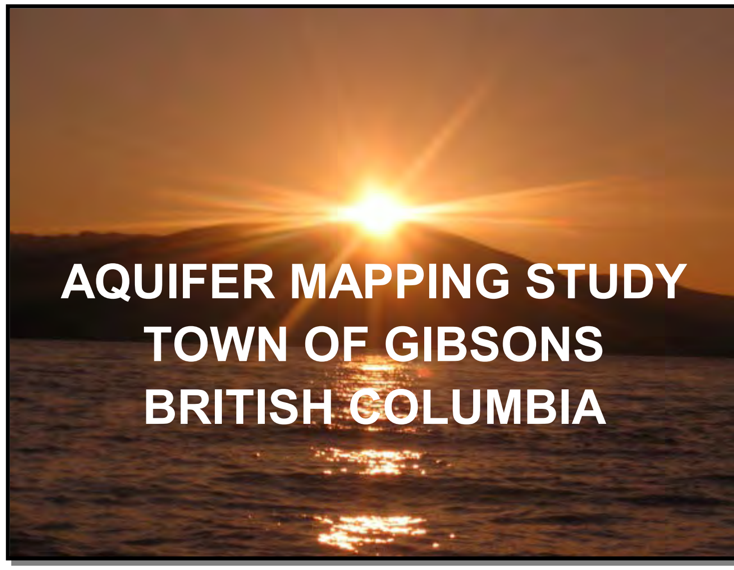

AQUIFER MAPPING STUDY TOWN OF GIBSONS BRITISH COLUMBIA

Submitted To:

TOWN OF GIBSONS

Town of Gibsons
474 South Fletcher Road
Box 340, Gibsons, BC
V0N 1V0

Submitted By:

Waterline Resources Inc.

Nanaimo, British Columbia

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Waterline wish to express our appreciation and thanks to staff members at the Town of Gibsons for their assistance and cooperation to help facilitate the completion of the aquifer mapping project. Special thanks to Dave Newman and Norma Brow for providing historical water-related data and assistance in coordinating drilling and groundwater monitoring programs. We also wish to thank Mr. Fielder, Jeff Collins and the Eagle Crest Condo Association, and Julian Burtnick for participating in the groundwater monitoring program by providing access to their respective water wells.

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EXECUTIVE SUMMARY

The Town of Gibsons is located at the southern part of the Sunshine Coast, British Columbia and a short ferry ride from the City of Vancouver. It has a population of about 4400 residents. Approximately 73% of its residents are supplied groundwater from a confined sand and gravel beneath the Town. The groundwater supply is not chlorinated prior to distribution. The remaining one-third of Gibsons residents are supplied with treated surface water by the Sunshine Coast Regional District.

As part of its long-term plan to protect the aquifer, the Town commissioned an aquifer mapping study in order gain a better understanding of aquifer boundaries, hydraulic properties, and recharge and discharge to and from the aquifer. The intent of the study was to expand on previous hydrogeological studies and develop a conceptual model of the aquifer to help identify flow characteristics and assess the spatial and temporal variations of key aquifer elements. Waterline Resources Inc was retained to complete the aquifer mapping project. Phase 1 included data compilation, field surveys, and drilling and well installation. Phase 2 involved the University of British Columbia who completed an environmental tracer study and computer modelling. A community outreach program was also completed by Gordon Groundwater Consultancy of Gibsons under contract to Waterline.

In order to evaluate the aquifer, Waterline developed an ARC-GIS geodatabase and established a monitoring well network that included existing and new wells within the Town boundary and adjacent SCRD lands. The monitoring well network was instrumented with data loggers to assess water level changes over time. The Town wells exhibit flowing artesian conditions in Lower Gibsons. The primary goal of monitoring the aquifer was to assess aquifer response to climate, creek runoff, barometric and tidal fluctuations, and human activities such as pumping and diversion of groundwater.

The Gibsons Aquifer is composed of a sand and gravel deposit that extends from beneath Gibsons Harbour to the base of Mt. Elphinstone. The aquifer is capped with a low permeability basal Capilano/Vashon till deposits that creates a confining layer over the aquifer. Although the aquitard is extensive, it is suspected to be discontinuous in creek valleys or beneath Upper Gibsons where younger Capilano deposits may have eroded through the aquitard unit. These areas are believed to form “recharge windows” to the underlying Gibsons Aquifer. Groundwater level monitoring suggests that water levels in the aquifer are stable, indicating that recharge to the aquifer is likely greater than discharge from the aquifer.

Estimates of groundwater flow within the Gibsons Aquifer indicate an average linear groundwater velocity of about 400 m/year. Based on these flow estimates, the time for groundwater to travel from the recharge area near the base of Mt. Elphinstone to the discharge area in Lower Gibsons is approximately 9 years. This is consistent with water chemistry data that also suggests a short residence time for groundwater to travel from Upper to Lower Gibsons.

Groundwater chemistry indicates that the Gibsons Aquifer is dominantly sodium-calcium-magnesium bicarbonate type water with a neutral pH and low TDS. Dissolved chloride and fluoride concentrations are elevated in samples collected from wells completed in the unconfined Capilano Aquifer near the Aquatic Centre. It is unclear if the elevated chloride/fluoride is related to operations at the Aquatic Center or the pool facility located at 913 Gibsons Way.

Aluminum concentrations in groundwater samples collected from WL10-01, WL10-02, MW06-01A, MW06-1B and MW06-2B exceed the Canadian Drinking Water Quality Guideline. Aluminum, iron and manganese likely represent trace metal constituents present in suspended sediment particles. Groundwater samples collected from the Town wells 1, 3 and 4 contained low concentrations of total aluminum, iron and manganese.

Arsenic concentrations have increased over the last three sample events in groundwater from WL10-01, completed near Upper Gibsons, deep in the aquifer near the overburden-bedrock interface. In 2011 and 2012, arsenic concentrations exceeded the Canadian Drinking Water Guideline. The elevated arsenic likely originates from arsenopyrite minerals present in the bedrock. As the Town wells are completed near the top of the aquifer and not near the bedrock interface, no significant risk to the water quality is anticipated to the Town's water supply. The drilling of deep supply wells near the bedrock contact should be avoided. Arsenic levels in groundwater should continue to be monitored.

A groundwater tracer study was completed by the University of British Columbia to assess recharge to the Gibson Aquifer. Tritium, noble gases, oxygen and deuterium stable isotopes, and tritium/helium tracers were assessed. In general, the data suggests that most samples consist of a mixture of sub-modern (older) and modern (more recent) water. The deepest wells completed in the Gibsons Aquifer indicated the oldest groundwater age, coolest recharge temperatures, and the highest estimated recharge elevation. Samples from the shallow unconfined Capilano Aquifer exhibit the youngest apparent ages, the warmest recharge temperatures and the lowest estimated recharge elevation.

Although analysis of chlorofluorocarbons (CFCs) in groundwater had limited value in the groundwater tracer study, it was noted that Town Wells 2 and 3 contained trace concentrations of CFC (12) but elevated 25 to 350 times background levels. The CFC (12) concentrations in the Gibsons Aquifer may be related to sewage effluent or to a refrigerant source. It should be noted that the Town's new sewage treatment plant is located only 180 m up gradient of Town Wells 2 and 3. Further investigation is required to determine the source of the trace levels of CFCs in groundwater.

Three significant aquifer recharge mechanisms have been recognized for the Gibsons Aquifer. These include mountain block recharge, creek recharge, and recharge windows through the Capilano Alluvium. The environmental tracer study indicates that the Mt. Elphinstone mountain block potentially contributes 55% of the recharge to the Gibsons Aquifer. This recharge estimate will vary with climate and anticipated climate change thought to be caused by global warming. However, climate change predictions and potential effects on aquifer recharge are somewhat uncertain and can only be quantified by long-term monitoring trends and assessment of cause and effect response in the aquifer. For the purposes of the predictive analysis, only the worst case climate change scenarios were considered in the model simulations completed by UBC where less recharge to the aquifer is assumed, and the sea level is assumed to rise to an extreme case of about one meter above the current level.

Computer model simulations indicate that the Gibsons Aquifer should be able to meet future demand where the Town is anticipated to grow to 10,000 residents. This assumes that 73% of the population obtain water from Town wells. This is also true under worst case climate change conditions although a new well(s) will eventually need to be drilled some distance from the coast to meet the additional demand for water The following table summarizes the study recommendations and approximate implementation timeline.

Recommendation	Description	Timeline/Term
Community outreach	Ongoing-going public engagement is recommended	Short
Contaminant/Chemical inventory	Identify potential contaminant sources over the aquifer so that a comprehensive analytical program can be developed for water testing of Town wells	Short
Well maintenance	All Town supply wells need to be inspected to determine their condition and the risk of casing failure which could cause uncontrolled release of water from the Gibsons Aquifer due to the artesian pressure. Town Well #1 is the oldest well and is showing signs of reduced efficiency.	Short
Site specific investigations	Determine the source of elevated chloride, fluoride, and CFC (12) in groundwater which may include drilling near Aquatic Center and Sewage Treament Plant.	Short
Establish Groundwater Management Zone	Use aquifer mapping boundaries provided by Waterline and incorporate into groundwater management planning document	Short
Groundwater Management Plan	Town and SCRD to develop a Groundwater Management Plan with appropriate Bylaws and Policies to guide development work that can potentially affect the Gibsons Aquifer yield or quality.	Short to medium
Groundwater monitoring	Water levels, water use, and water quality in existing and new monitoring wells.	Short to long
Installation of new monitoring wells	Three new wells are required in the Gibsons waterfront in the short term to determine artesian pressure in the aquifer in Lower Gibsons to assess risk and to locate salt/fresh water interface. Additional wells are also required but may be added to network as new developments are being considered over the long term.	Short to long
Geotechnical and hydrogeology studies of Gibsons Aquitard	Protecting the integrity of the confining layer over the Gibsons Aquifer is imperitive. Waterline recommends that Geotechnical/hydrogeological investigations be completed in advance of approving new developments in order to assess the risk associated with breaching the Gibsons Aquitard. Drilling and pile driving protocols should be established to avoid creating pathways for uncontrolled artesian discharges or contaminants.	Short to long
Manage artesian flow	The Town should consider using the 275 m^3/day that is currently being diverted to the storm sewer.	Medium to long
Water conservation	Reduce water use, manage runoff, use low volume alternatives such as low flow toilets, shower heads, etc...Longer term objectives may consider rainwater capture and use.	Medium to long
Goundwater quality targets and thresholds	Based on inventory of possible contaminants and baseline water quality data for the specified suite of water quality parameters.	Medium to long
Hydrometric and climate stations	Installation of hydrometric and climate stations is recommended in order to more fully address groundwater-surface water interactions and aquifer recharge.	Medium to long
Significant recharge areas	On-going process to identify and map recharge areas as new developments are being proposed.	Medium to long
Conceptual and numerical model	Will require updating as new data comes available.	Long

Notes: Short term means 1 year, medium term means 2-5 years, long term means > 5 years

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GLOSSARY OF TERMS

Alluvial	Applying to the environments, actions, and products of rivers or streams.
Anthropogenic	Originating or caused by humans.
Aquifer	Any water-saturated body of geological material from which enough water can be drawn at a reasonable cost for the purpose required. A common usage of the term aquifer is to indicate the water-bearing material in any area from which water is most easily extracted.
Aquitard	A water-saturated sediment or rock whose permeability is so low it cannot transmit any useful amount of water. An aquitard allows some measure of leakage between the aquifer intervals it separates.
Baseline concentration	The baseline concentration of a substance in groundwater is the natural concentration of that substance in a particular groundwater zone in the absence of any input from anthropogenic activities and sources.
Bedrock	The solid rock that underlies unconsolidated surficial sediments.
Bedrock aquifer	A fractured bedrock unit that has the ability to transmit significant volumes of water to a well completed within it.
Channel	An eroded depression in the soil or bedrock surface within which alluvial deposits accumulate (i.e. gravel, sands, silt, clay).
Contaminant	A substance that is present in an environmental medium in excess of natural baseline concentration.
Cretaceous	A period of the Mesozoic era thought to have covered the span of time between 140 and 65 million years ago; also, the corresponding system of rocks.
Cumulative Effects	The changes to the environment caused by all past, present, and reasonably foreseeable future human activities.
Evapotranspiration	The process by which water is discharged to the atmosphere as a result of evaporation from the soil and surface-water bodies and transpiration by plants. Transpiration is the process by which water passes through living organisms, primarily plants, into the atmosphere.
Fault	A break in bedrock in which rocks on one side of the break has moved relative to rocks on the other side. In the Coast Mountain Range thrust faults are common and are low angle faults in which older rocks may be 'thrust over' younger rocks.
Fluvial	Sedimentary term describing deposition by the action of a stream or river
Geometric mean	The geometric mean, unlike the arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing transmissivity estimates, which may vary over 10 orders of magnitude. A geometric mean is a log (base 10) transformation of data to enable meaningful statistical evaluations.
Groundwater	All water beneath the surface of the ground whether in liquid or solid state.

Hydraulic Conductivity	The rate of flow of water through a unit cross-section under a unit hydraulic gradient; units are length/time.
Hydraulic Gradient	In an aquifer, is defined as the change of total head (water pressure or water level) over a unit distance. It has both horizontal and vertical components and is visualized as the slope of the water table in an unconfined aquifer or water pressure surface in a confined aquifer.
Hydrogeology	The science that relates geology, fluid movement (i.e. water) and geochemistry to understand water residing under the earth's surface. Groundwater as used here includes all water in the zone of saturation beneath the earth's surface, except water chemically combined in minerals.
Hyporheic	Region beneath and lateral to a stream bed, where there is mixing of shallow groundwater and surface water.
Infiltration	The flow or movement of precipitation or surface water through the ground surface into the subsurface. Infiltration is the main factor in recharge of groundwater reserves.
Instream Flow Needs	The amount of water required in a river to sustain a healthy aquatic ecosystem, and/or meet human needs such as recreation, navigation, waste assimilation or aesthetics.
Lacustrine	Fine-grained sedimentary deposits associated with a lake environment and not including shore-line deposits
LIDAR	Laser Imaging Detection and Ranging. LIDAR is an optical remote sensing technology that can measure the distance to, or other properties by illuminating the target with laser light and analyzing the backscattered light. LIDAR technology has applications in geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing, atmospheric physics, airborne laser swath mapping (ALSM), laser altimetry, and contour mapping.
Lithology	A description of the physical characteristics a rock or sediment sample.
Mini Piezometer	A mini-piezometer is similar to a monitoring well (defined below) but is installed manually at shallow depths, typically less than two meters below ground.
Monitoring Well	A constructed controlled point of access to the subsurface which allows groundwater observations. Small diameter observation wells are often called piezometers.
Mountain Block	The mountain block is a term used to describe the area extending from base of Mt Elphinstone where the topography steepens in Upper Gibsons to the top of the mountain.
Orographic effects.	Orographic lift occurs when an air mass is forced from a low elevation to a higher elevation as it moves over rising terrain.
Overburden	Any loose material which overlies bedrock (often used as a synonym for Quaternary sediments and/or surficial deposits).

Permeability	A physical property of the porous medium providing an indication of how easily water will flow through the material. Has dimensions Length^2. When measured in cm^2, the value of permeability is very small.
pH	The logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral and greater than 7 is more basic and less than 7 is more acidic).
Piper tri-linear diagram	A method that permits the major cation and anion compositions of single or multiple samples to be represented on a single graph. This presentation allows groupings or trends in the data to be identified.
Receptor	Components within an ecosystem that react to, or are influenced by, stressors (see stressor).
Recharge	The infiltration of water into the soil zone, unsaturated zone and ultimately the saturated zone. This term is commonly combined with other terms to indicate some specific mode of recharge such as recharge well, recharge area, or artificial recharge.
Seepage Meters	A seepage meter is a simple device used to gauge groundwater flow into and out of a creek bed.
Significant Aquifer	A permeable water-bearing horizon of sufficient thickness and lateral extent that can yield useable quantities of water. An aquifer in excess of 5 m thick, 100 m or more in width and extending a lateral distance of 500 m or more may be considered a significant aquifer.
Stratigraphy	The geological science concerned with the study of sedimentary rocks in terms of time and space.
Stressor	Physical, chemical and biological factors that are either unnatural events or activities, or natural to the system but applied at an excessive or deficient level, which adversely affect the receiving ecosystem. Stressors cause significance changes in the ecological components, patterns and processes in natural systems.
Strike	The strike line of a bed, fault, or other planar feature is a line representing the intersection of that feature with a horizontal plane.
Subcrop	An occurrence of strata (usually bedrock) situated at shallow depth beneath the ground surface but not exposed at the surface (as opposed to outcrop which means it is exposed at the ground surface).
Surficial Deposits	See Overburden.
Sustainable	A characteristic of an ecosystem that allows it to maintain its structure, functions and integrity over time and/or recover from impact stressors without human intervention.
Target	A management tool, which is somewhere defined through the integrated process to identify a place between natural conditions or variability and a threshold. A target is a numerically defined desired condition for a given indicator.
Thalweg	The line defining the lowest points along the length of a river bed or valley. Also the line defining the central (long) axis of a buried channel or valley.

Threshold	Value not to be exceeded, such that resource health may be maintained including resources with which the resource interacts (i.e. an exceedance of established natural variability at a given location or an agreed-upon published criterion).
Till	A sediment deposited directly by a glacier that is unsorted and consisting of any grain size ranging from clay to boulders.
TEM	Transient Electromagnetic - A geophysical survey method which assesses the electrical resistivity of the underground layers down to a depth of several hundred meters. The method is used routinely in environmental, hydrogeological, energy, and mineral resources investigations.
Total Dissolved Solids	Concentration of all substances dissolved in water (solids remaining after evaporation of a water sample).
Transmissivity	The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient; a measure of the ease with which groundwater can move through the aquifer. Transmissivity units are reported in m^2/day and are defined as the amount of water that can move horizontally through a unit width of fully saturated aquifer under a hydraulic gradient of 1.0.
Trend	The relationship between time series data that shows a general (statistically meaningful) increasing or decreasing pattern.
Water Management	A framework to enable water planning, allocation and framework management of water resources.
Water Management Plan	A plan that provides guidance for water management and sets out clear and strategic directions for how water should be managed.
Watershed	The geographic area of land that drains water to a shared destination. The boundary is determined topographically by ridges, or high elevation points. Water flows downhill, so mountains and ridge tops define watershed boundaries.
Water Well	A hole in the ground for the purpose of obtaining groundwater; “work type” as defined by AEW includes test hole, chemistry, deepened, well inventory, federal well survey, reconditioned, reconstructed, new, old well-test.
Waterra	Waterra inertial samplers are a patented groundwater sampling device that employs a foot valve and tubing system. Water is extracted by moving the device up and down in the borehole which moves water up the tube and eventually to surface.
Yield	A term referring to the amount of water that can be diverted/abstracted safely from a well, aquifer, or surface water body over a specified time.

ACRONYMS AND UNITS

ALR	Agricultural Land Reserve
BP	Before Present
BMP's	Best management practices.
CFC	Chlorofluorocarbons
DEM	Digital Elevation Model
DWPA	Drinking Water Protection Act
EC	Electrical conductivity
GCDWQ	Guidelines for Canadian Drinking Water Quality
GPS	Global Positioning System
GMWL	Global Meteoric Water Line
Ha	Hectares
Km	Kilometer
L/min	Litres per minute
LHAL	Lifetime Health Advisory Level
LPS	Litres per second
LIDAR	Laser Imaging Detection and Ranging
LMWL	Local Meteoric Water Line
mASL	Meters above mean sea level
mAGL	Meters above ground level
mBSL	Meters below mean sea level
mBGL	Meters below ground level
mBTOC	Meters below top of casing
m	metres
mm	millimetres
mg/L	milligrams per litre
NPWL	non-pumping water level also often referred to as static water level
m^2/day	metres squared per day
m^3	cubic metres
m^3/day	cubic metres per day
M.Sc.	Masters of Science
MBR	Mountain Block Recharge
us/cm	microsiemens per centimeter
NPWL	non-pumping water level also often referred to as static water level
NSERC	National Science and Engineering Research Council
OCP	Official Community Plan
ppb	parts per billion
ppt	parts per trillon
SCADA	Supervisory Control and Data Acquisition
SF6	Sulfur-hexafluoride
SCRD	Sunshine Coast Regional District
SWL	Static Water Level
TEM	Transient electro-magnetic survey
Temp	Temperature
TDS	Total dissolved solids
Topo	Topography
TU	Tritium Units.
USEPA	United States Environmental Protection Agency
USgpm	United States gallons per minute
UBC	University of British Columbia
WSC	Water Survey of Canada
WSSP	Water Supply Strategic Plan

1.0 INTRODUCTION

1.1 Study Area

The Town of Gibsons (the Town) is located at the southern part of the Sunshine Coast, British Columbia and is situated at the base of the Coast Mountains where Howe Sound intersects Georgia Strait (Figure 1). The Town is accessible via a short ferry ride across Howe Sound from Horseshoe Bay located northwest of the City of Vancouver.

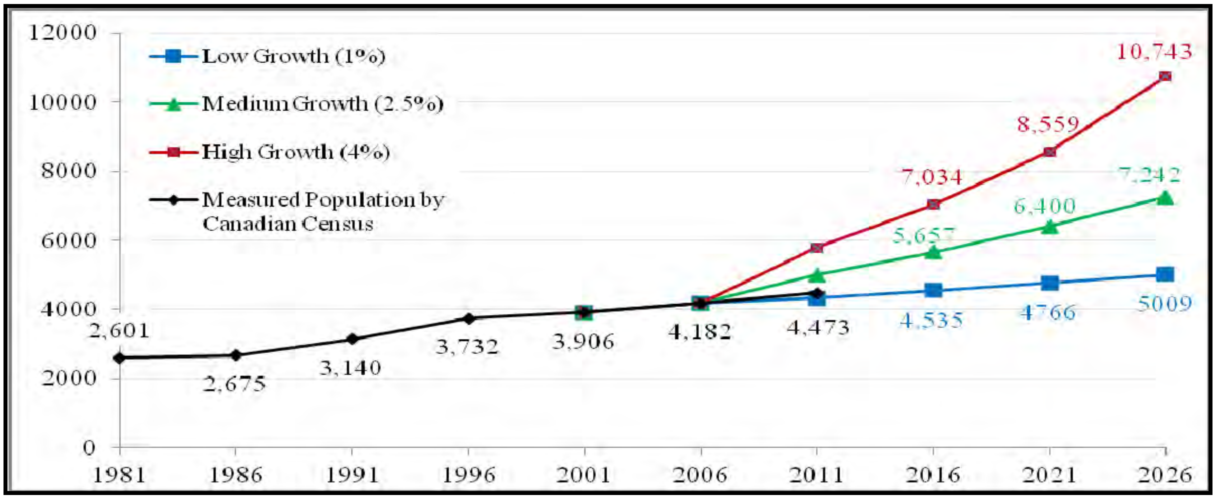
Source: Google Earth and Town of Gibsons (boundary)

Figure 1: Site Location

1.2 Community Planning and Water Supply

According to the 2011 census (Statistics Canada, 2011) the Town has a population of 4437 residents. The population of Gibsons has grown by about 50% since 1981 with corresponding demand for water. The historical population growth rate has been about 1% which is expected to continue at this rate over the next decades (D. Newman, Personal Communication, 2013). However, for planning purposes, the Town has also projected moderate and high growth rates over the next decade whereby the population of Gibsons could grow to 10,000 residents by 2026 (Official Community Plan Bylaw 985, 2005). Figure 2 shows the population projections.

These data were considered as part of the aquifer mapping and groundwater supply assessment presented herein.



Source: Smart Plan (2013)

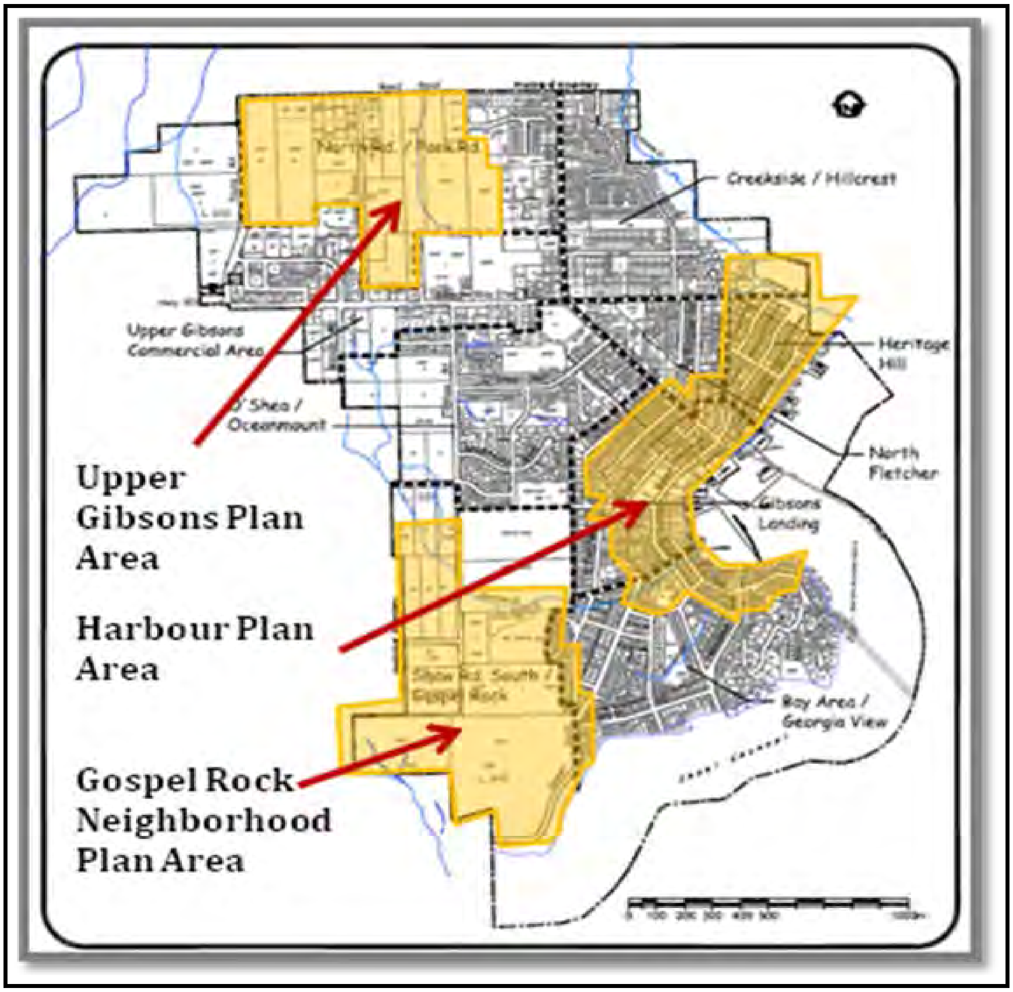
Figure 2: Projected Population Increase – Town of Gibsons

Currently, four water wells located near the waterfront in Lower Gibsons supply water to 73% of Town residents (3239 people). The Gibsons Smart Plan (2005) provides the current Official Community Plan (OCP) which includes Town policies relating to groundwater supply. The Smart Plan states that the Town's long-term objective is to be able to supply potable water to 10,000 people to accommodate the high growth projection. D. Newman (Personal Communication, 2013) indicates that the lower growth rate of 1% is most realistic based on historical data. Figure 3 shows the various planning areas within the Town where expansion is expected to occur.

1.3 Water Distribution and Supply System

Figure 4 shows the water distribution zones in the area near the Town with associated water wells and lines servicing Lower and Upper Gibsons. Approximately 73% of the Town's residents are supplied water from four water wells located in Lower and Middle Gibsons (Figure 4). The supply wells draw groundwater from a confined, flowing artesian, sand and gravel aquifer situated some 10-100 meters below ground level (m BGL). Unlike many municipal water sources, groundwater supply from the Gibsons Aquifer is not chlorinated prior to distribution.

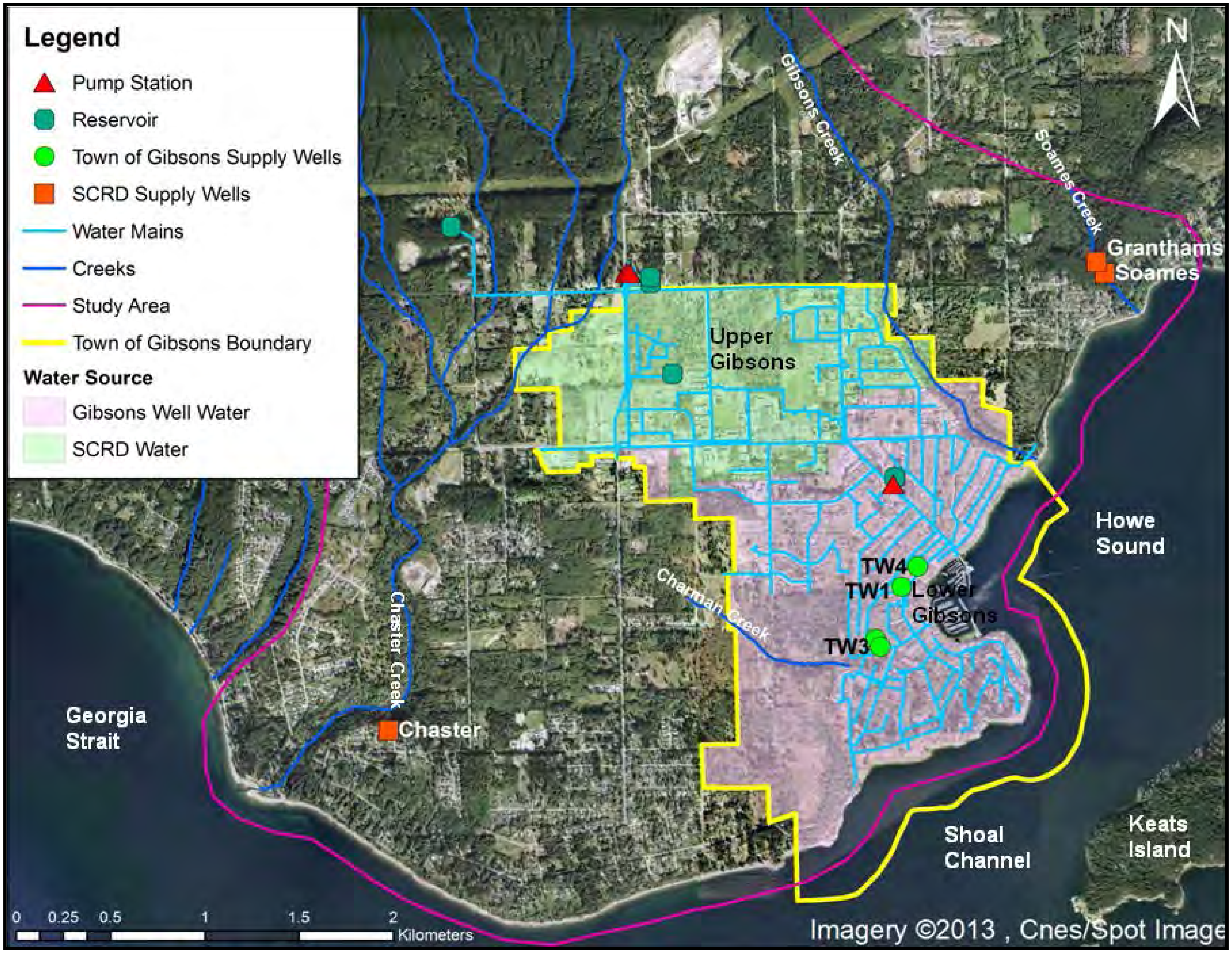
The remaining 27% of residents located in in Upper Gibsons (Figure 4) are supplied water by the Sunshine Coast Regional District (SCRD) from the Chapman Creek watershed located some 15 km northwest of the Town of Gibsons. In addition, the SCRD also provides temporary water supply during summer periods to the Gower Point area from a well located on Night Road near Chaster Creek (Chaster Well, Figure 4)



Source: Modified from the Town of Gibsons (Smart Plan 2013)

Figure 3: Community Planning Areas

In 2005, the Town submitted a groundwater sample to the Berkeley Springs International Water Tasting Contest (http://www.berkeleysprings.com) and was voted as being the world's best drinking water, beating out over 60 municipal entries.



Source: Google Earth and Town of Gibsons

Figure 4: Water Distribution and Supply System

A comprehensive Water Supply Strategic Plan (WSSP) was developed for the Town in 2005 (Delcan 2005). The plan presents a strategy for maintaining a sustainable water supply while providing high quality water to the Town residents. In addition, the long-range water supply strategy is based on servicing Lower Gibsons with untreated groundwater and Upper Gibsons with treated surface water from the SCRD water system.

1.4 Study Objectives

The Town recognizes the value of the Gibsons Aquifer as a high quality resource and therefore initiated a mapping project in 2009 as part of its long-term initiative to manage and protect the aquifer. The Town's primary objective is to continue to supply safe and reliable drinking water to its residents while ensuring that the source and distribution system meets or exceeds the requirements under the Drinking Water Protection Act (BC DWPA, 2001). In addition, the Town wish to preserve and maintain an un-chlorinated groundwater supply for residents of Lower Gibsons.

1.5 Background and Scope of Work

Waterline Resources Inc (Waterline) was awarded the aquifer mapping project in July, 2009. Gordon Groundwater Consultancy (GGC) was also retained by the Town as the project coordinator. The first phase of the study involved compilation of existing water and geology-related information, and also included various field programs. Phase one of the project involved compiling new and existing data and developing an understanding of the physical aquifer properties, boundaries, and understanding the aquifer "plumbing system" which defines groundwater flow in the subsurface beneath the Town. The following Phase 1 program tasks were completed by Waterline:

- Compilation of background information for the region and the local area. This included: topography, physiographic features, soils geology, hydrogeology, climate, and tidal data, water well records, pumping data from Town wells and other monitoring wells, and relevant data from previous consulting studies and reports.
- A field survey to verify the existence of water wells identified in the provincial water well database. The field survey included visiting and conversing with well owners to assess the condition of their well(s) and any past history of water use and water levels. The intent was to identify suitable monitoring wells to integrate into the Town's monitoring well network.
- A creek survey within the study area in order to map/confirm the surfical geology, and measure electrical conductivity and temperature of creek water to assess interactions of the creeks with the underlying aquifers.
- As there was some information suggesting the possibility of submarine discharge of fresh groundwater into Gibsons Harbour from the Gibsons Aquifer, Waterline also conducted an electrical conductivity survey along the seabed in Gibsons Harbour.

- A geophysical survey at specified locations within the Town to gain a better understanding of subsurface layering of sediments and to fill in data gaps where no borehole or well data existed.
- Monitoring well installation to fill in information gaps including: the depth to bedrock, contacts of the various formations/materials in the subsurface, aquifer properties such as permeability, water level, water quality, etc.
- Grain-size distribution analysis of sediment samples collected during the study to help classify the sediments in terms of aquifer or aquitard properties.
- Deployment of data loggers in the well network to establish a long-term monitoring program in the Gibsons aquifer. The monitoring well network included existing Town supply wells, privately-owned domestic wells, existing monitoring wells, and new monitoring wells installed during the Waterline study.
- Collection and chemical analysis of surface water and groundwater samples. Groundwater and surface water samples collected during the study were analyzed for routine chemistry, trace metals and selected samples underwent specialized testing in order to aid in determining the source(s) and age of groundwater in the aquifer.
- Database design and construction to house the hydrogeology data and develop ARC-GIS hydrogeological layers and the three-dimensional conceptual model of the Gibsons Aquifer.
- An open house to present the preliminary results of the aquifer mapping study in an effort to engage and solicit public participation in the aquifer mapping study. The final report for the Integrated Storm Water Management Plan developed by AECOM (AECOM 2010) was also presented at this public meeting.
- An interim report which was finalized on July 15, 2010 summarizing the preliminary results of the Phase 1 study. The report identified data gaps and the need for long-term monitoring of the aquifer. Waterline also presented a progress update for the Phase 1 program to the Town of Gibsons Council members in June, 2010, and again in May 2012.
- A plan for the Phase 2 Aquifer Mapping program.

An open house was held on November 26, 2009 at the Gibsons Recreation Centre to present the preliminary finds of our Phase 1 study. The primary objectives of the Open House were to provide information, to engage the residents of the Town and surrounding SCRD, and to identify any opportunities for monitoring of existing privately-owed water wells. Despite being well advertised, the low public turnout highlighted the need to provide outreach and education to the community. Therefore, additional tasks identified for Phase 2 included a community outreach and education program which was developed by GGC of Gibsons.

Other data gaps identified during the Phase 1 program was the uncertainty with assessing the source and pathways for aquifer recharge. Waterline and GGC consulted with Professors Tom Gleeson and Uli Mayer at the University of British Columbia (UBC) and an environmental tracer study was recommended. The tracer study looked at a variety of natural and human-made chemicals which become locked into the molecular structure of the water and was used to assess recharge to the Gibson Aquifer. Jessica Doyle began a Masters of Science Degree in

Hydrogeology at UBC researching the applicability of environmental tracers for use in assessing recharge to the Gibsons Aquifer. Ms. Doyle applied for NSERC funding with Waterline as her industry sponsor and Drs. Sue Gordon (GGC), Tom Gleeson (UBC/McGill) and Uli Mayer (UBC) as academic supervisors. The NSERC grant was approved in January of 2011, at which time Phase 2 of the Gibsons Aquifer mapping project was initiated.

The following scope of work was completed during the Phase 2 part of the study:

- On-going monitoring of the well network established during the Phase one program. This included downloading of data loggers, hydraulic testing of wells, and groundwater sampling. UBC conducted three sampling events from April 2011 to October 2012. In addition to the routine analysis, groundwater samples were analyzed for tritium, chlorofluorocarbons (CFC's), noble gases, and sulfur-hexafluoride for use in the environmental tracer analysis.
- Continued refinement of the ARC-GIS Geodatabase developed by Waterline in Phase 1, and finalizing of the three-dimensional conceptual model for the Gibsons Aquifer.
- Used the conceptual hydrogeological model as input to the computer groundwater flow model. The computer model was used to assess the groundwater budget. Predictive simulations were run to assess the impact of the future groundwater demands on the Gibsons Aquifer. This analysis considered such variables as increase water supply demand on the aquifer resulting from population increase, and possible climate change variables which could increase or decrease recharge, and also cause a rise in sea level which can affect the aquifer.
- Prepared a report integrating the Phase 1 and 2 studies including the finalized conceptual hydrogeological model for the Gibsons Aquifer, a summary of the UBC work on environmental tracers and numerical flow modelling, recommended groundwater monitoring and management to assess long-term aquifer performance, development of a groundwater management framework, and provide the results of the community outreach program developed by GGC.

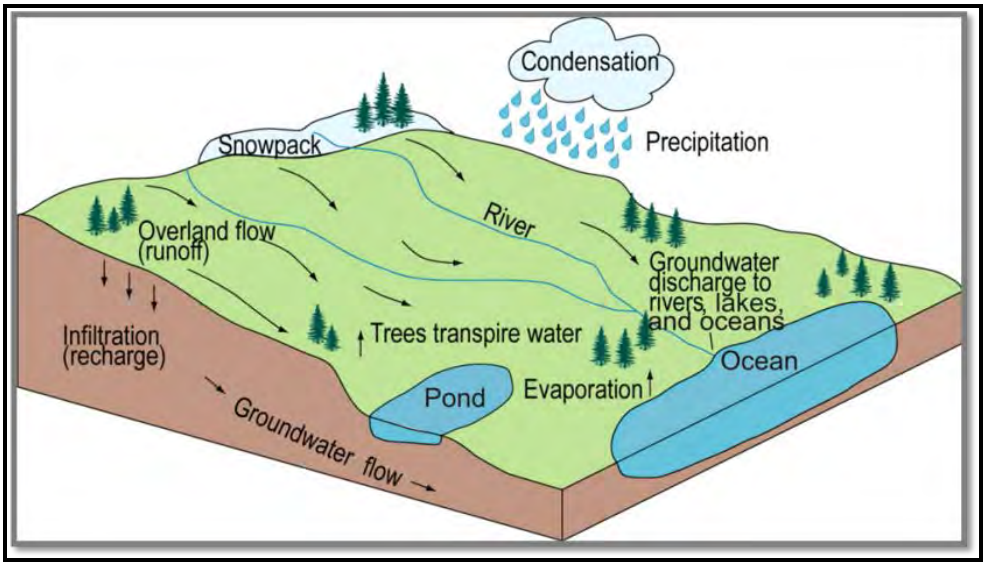
Jessica Doyle's M.Sc. Thesis is currently "In Press" and will likely be available in the summer of 2013. A summary of the community outreach/education program was prepared by GGC under separate cover but is appended to this report for completeness (Appendix G).

2.0 UNDERSTANDING GROUNDWATER FLOW

2.1 The Water Cycle

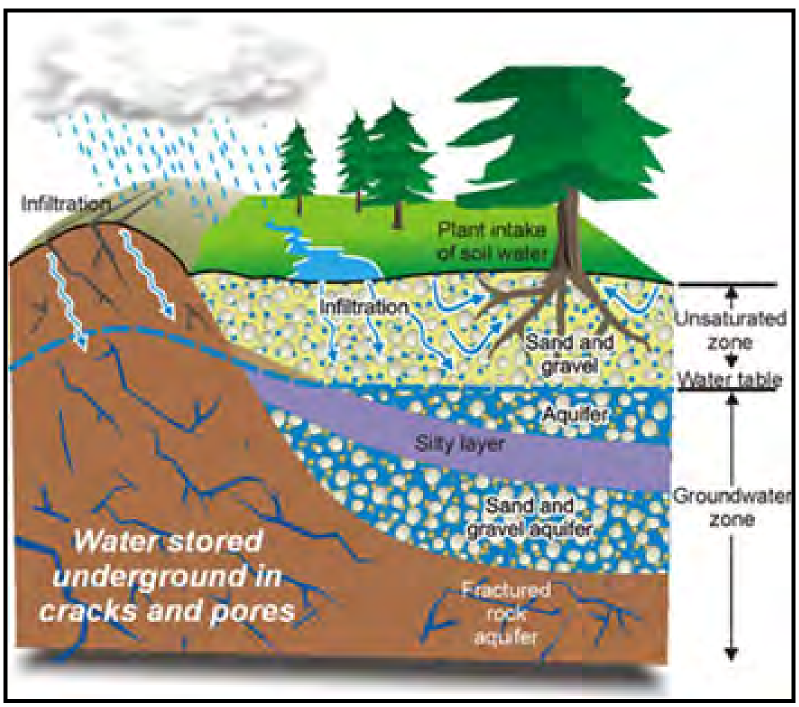
Groundwater contained in the Gibsons Aquifer originates as precipitation either as rain or snow melt. Precipitation falling to the ground percolates through the soil and bedrock layers and eventually recharges the underlying groundwater aquifer system(s). Figure 5 shows a schematic of the main components of the water cycle and illustrates how water will cycle from the atmosphere to aquifers beneath the ground surface. Many of the surface components such as runoff/overland flow, evaporation, and transpiration have been addressed in AECOM's report on the Integrated Stormwater Management Plan (2010) and will not be discussed in detail.

The primary focus of Waterline's aquifer mapping study was to assess the infiltration or recharge and the groundwater flow components which characterize the Gibsons Aquifer. Figure 6 shows a more detailed schematic of subsurface flow and how groundwater is stored in underground cracks (fractures and faults) in consolidated bedrock formations, and between the individual grains that make up the sand and gravel deposits which form the Gibsons Aquifer.



Source: Waterline 2010

Figure 5: Water Cycle Schematic.



Source: The Regional District of Nanaimo Website (2013)

Figure 6: Schematic of Subsurface Flow and Groundwater Storage

2.2 Approach to Aquifer Mapping

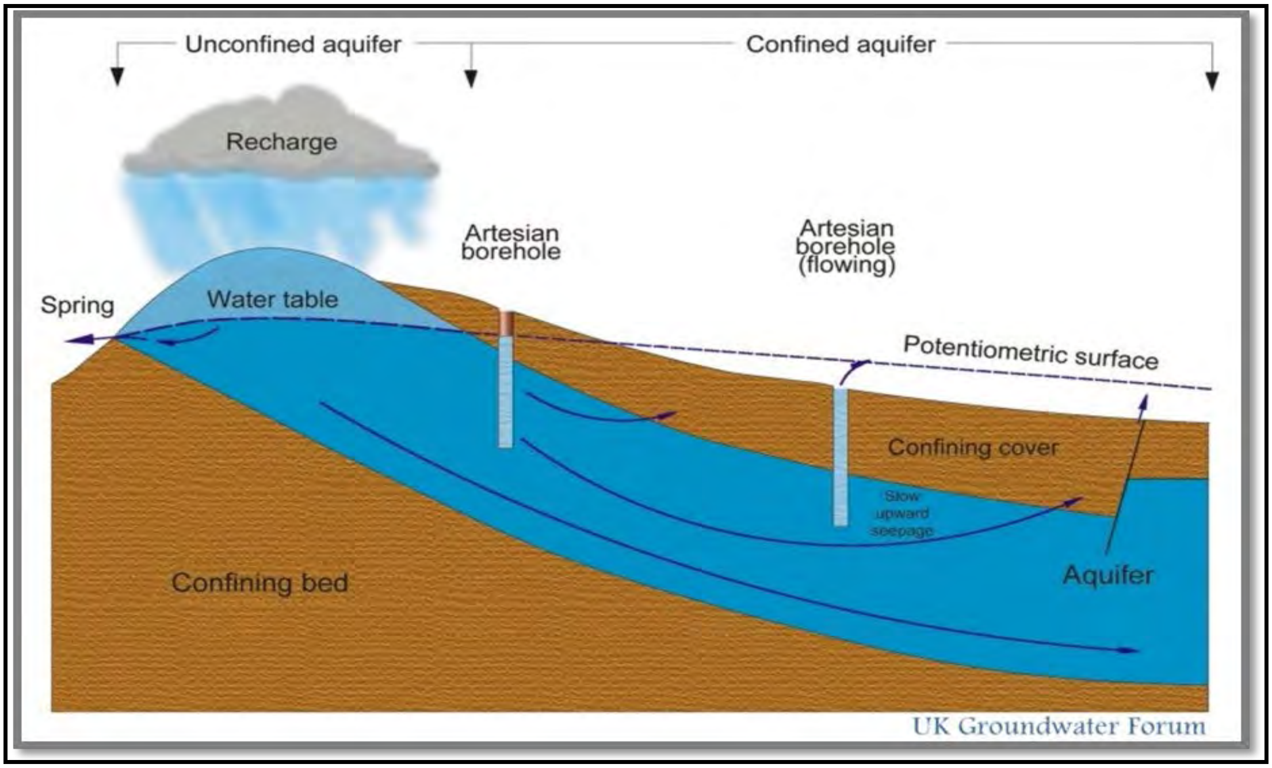
Over the last few decades, some hydrogeological work has been completed on the Gibsons Aquifer in terms of water well drilling and testing, groundwater quality and quantity measurements, and assessment of Town well capture zones. In addition to this information, provincial mapping of the surficial and bedrock geology and the drilling of over 100 water wells provides a significant repository of data from which to construct a conceptual hydrogeological model of the Gibsons Aquifer.

To meet the objectives of the study, the available geology and hydrogeology information was compiled by Waterline into a comprehensive electronic geodatabase. The electronic information was then used to develop an up-to-date conceptual model of the Gibsons Aquifer. This 3D model was used to assess water movement and exchange between various aquifer and watershed elements. An important aspect of the study was to assess environmental controls on groundwater availability such as climate, topography, soil/geology, land cover, aquifer geometry, etc., and to determine how each of these parameters may affect the water balance in the aquifer.

Based on existing geological and hydrogeological information, the Gibsons aquifer is composed of a sand and gravel deposit situated at depths exceeding 100 m below ground in Upper Gibsons, and less than 10 m beneath the ground surface near the water front in Lower Gibsons. Although unmapped, the aquifer is also thought to extend beneath Gibsons Harbour for some unknown distance.

The aquifer is generally confined from the surface by a dense, low permeability, glacial till material. Due to the steep slope to the ocean, water supply wells located in Lower Gibsons exhibit flowing artesian conditions. Artesian flow from the aquifer is caused by transmission of groundwater pressure through the entire aquifer system which is thought to extend upslope to the area beneath Upper Gibsons and to the base of Mt. Elphinstone. In some cases, the natural artesian flow from the Town supply wells exceeded 750 Litres per minute (L/min) or 200 USgpm at the time of drilling. This suggests that the Gibson Aquifer is a highly permeable system and the driving force or hydraulic gradient is controlled by water entering the system at higher elevations.

The pore spaces between the sand and gravel grains in the aquifer forms the aquifer “plumbing” system through which groundwater is transmitted from areas of high topographic elevation to areas of low elevation. Figure 7 shows a schematic cross-section of how groundwater likely moves through the Gibsons Aquifer.



Notes: potentiometric surface is the pressure surface of the water in a confined aquifer. Source: UK Groundwater Forum

Figure 7: Schematic Cross Section of a Typical Artesian Aquifer.

In order to understand the aquifer plumbing system it was important to develop physical model of the geology, and also to establish continuous long-term groundwater monitoring data (water levels and water quality) in the Gibson Aquifer and adjoining systems. In addition to providing data for evaluating groundwater flow and inter-connections in the aquifer, long-term monitoring will also reveal an aquifer's response to natural phenomena such as precipitation events, creek runoff, tidal fluctuations, and human activities such as pumping and contamination from surface activities. In the event of negative impact to the aquifer, a monitoring network of wells also serves as an early-warning system to detect adverse impact. This is a critical component in terms of aquifer protection and management. Should adverse impact occur, the monitoring network should provide and early warning system whereby corrective or remedial action could be implemented quickly to preserve the health of the aquifer.

With the above in mind, Waterline designed an aquifer mapping and evaluation program to provide an understanding of the Gibsons Aquifer system. The development of an accurate conceptual model is the foundation from which issues relating to the sustainability of groundwater supply and requirements for aquifer management and protection can be initiated.

3.0 METHODOLOGY – DATA COLLECTION AND ANALYSIS

3.1 Data Sources and Compilation

Data collection and compilation for the present study consisted of gathering as much of the available data as possible. The following list of information was reviewed as part of the project:

1. Town of Gibsons ARCGIS database system reviewed to confirm data structural elements.
2. Additional information provided by the Town included soils, groundwater quality, water level data and permeability (transmissivity) data, and historical records on water quantity and quality collected by the Town of Gibsons.
3. Government maps and reports including Geological Survey of Canada, British Columbia Geological Survey Mapping Database, British Columbia Water Well Record database, Government Soil Maps (e.g., Ministry of Mines and Petroleum).
4. Stream flow gauging data available from Environment Canada or other local conservation/environmental groups (E.g.: Charman Creek Master Plan or SCRD studies).
5. Review of historical climate data available from the Gower Point climate station, the Environment Canada Climate Station in Gibsons, and other climate data in areas of higher elevation that helped assess precipitation, snow accumulation, and other climatic information at higher elevations near Mount Elphinstone.
6. Historical tidal tables near Gibsons to help assess the possible geometry of the salt water intrusion wedge that likely exist beneath the fresh water discharge area.
7. Various consulting reports including Piteau Associates Engineering Ltd. Reports on Groundwater Supply Studies completed for the Town of Gibsons (1997, 1999, 2000, 2005, 2006, 2007, and 2009).

3.2 Field Verified Well Survey

A total of 124 wells were identified from the provincial BC water-well-database (BC Water Resources Atlas, 2010) within the study area (Figure 8). The majority of wells (85) in the provincial database are completed in the shallow, unconfined, Capilano Aquifer which is generally less than 20 metres below ground. Waterline verified 27 wells, of which 11 still existed, 6 wells were confirmed by the landowner as having been abandoned, and 10 wells were identified as springs which had been developed for water supply. Although Waterline attempted to verify the remaining 70 wells, many of the landowners visited were unaware that wells had existed on their land. The status of those wells is unknown.

The field verification survey involved visiting each well site to meet with the owner and collect information such as well head elevation, well depth, water use (if any), water quality information, and any other information that may be pertinent to the outcome of the aquifer mapping study. Where direct contact could not be made with a landowner or occupant, an information package was placed in the mail box; including a business card and a prepaid return envelope. As part of the survey, well owners were also asked to participate in the regional groundwater monitoring program. Several landowners agreed to participate but some residents declined due to what Waterline staff believed to be related to uncertainty regarding the Town of Gibsons' motivation and objectives for the aquifer mapping project. The concerns raised by those residents ranged from the Town raising property taxes or decommissioning wells, or requiring future payment for the use of the aquifer water.

Of the privately-owned wells identified as part of the field verification survey, only one well was confirmed to be active. This well belongs to the Georgia Mirage Strata complex located on Eaglecrest Road in Middle-Upper Gibsons (Figure 8). The well is actively used to fill ponds and a water feature, and for irrigation of gardens on the property. As there has been no historical monitoring of this well, it is not known with any degree of certainty the amount of groundwater which is being diverted from the aquifer. The owners of the Strata agreed to allow water level monitoring of their well during the study by installing a data logger in the well. However, due to the well head configuration, it was not possible to measure groundwater flow/use from the Strata well.

A summary of the results of the field verified survey is presented in Appendix A. These data were integrated into Waterline's hydrogeological conceptual model developed for the Gibsons Aquifer.

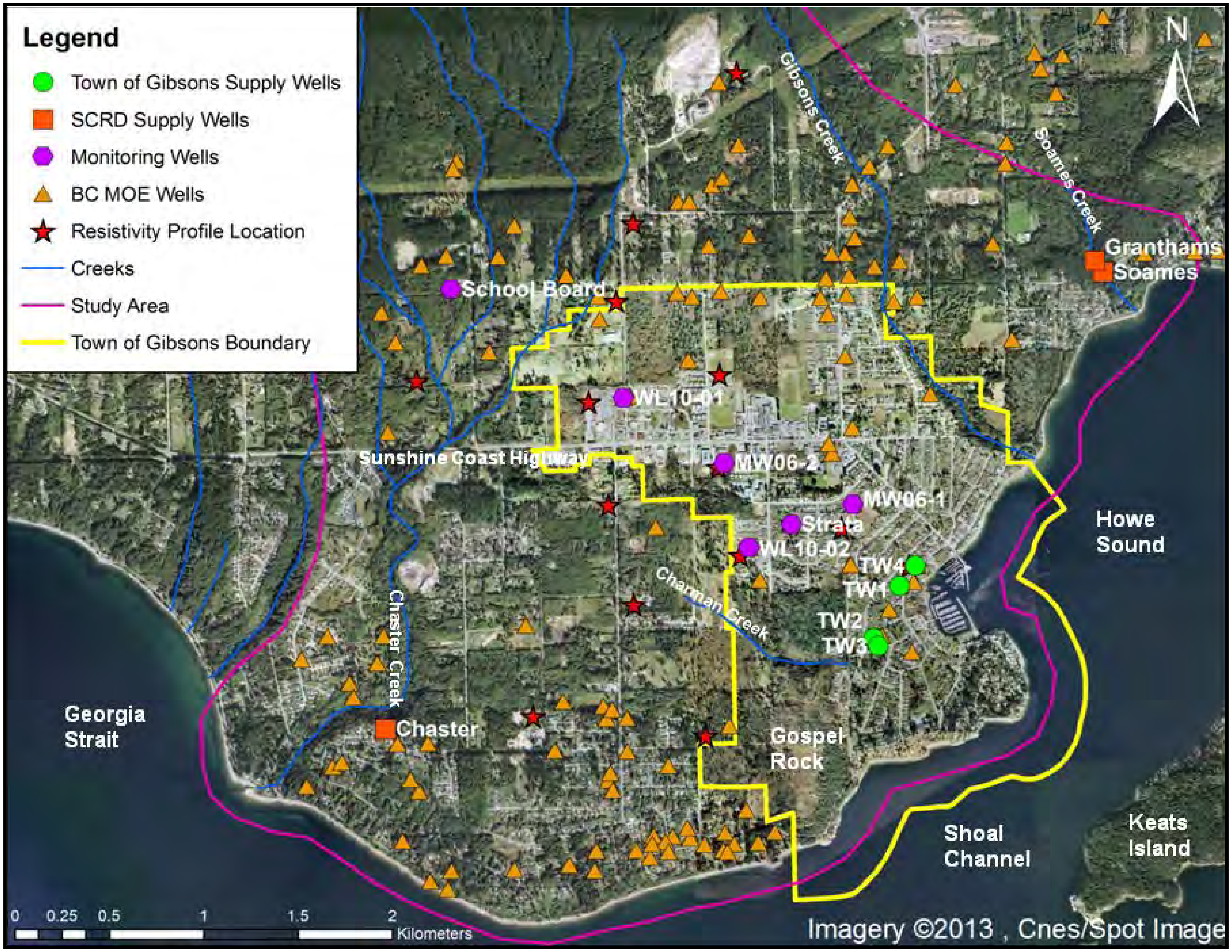
Town water supply wells located in Lower Gibsons are shown as green points on Figure 8. A summary of the construction details of the Town's wells is provided in Table 1 and locations are shown on Figure 4. Well construction logs/reports are presented in Appendix B.

Table 1: Summary of Town Water Supply Wells

Well Name	Location	Northing (m)	Easting (m)	Ground Elev. (mASL)	Well Depth (mBGL)
TW 1	Gower Pt Rd	5472034	463057	13	42
TW 2	Dougal Park	5471757	462924	18	15
TW 3	Dougal Park	5471715	462943	19	26
TW 4	Gower Pt Rd	5472141	463143	13	20

Note: m ASL=metres above sea level, m BGLl=metres below ground level, TW means Town Well.

Well TW3 runs continuously to maintain the level of the reservoir on School Road (Figure 4). TW1 and TW4 supplement TW3 and operates in a duplex arrangement with pumps alternating lead/lag, until demands require that both wells operate together to service the Town's demand for water. TW2 is used for standby purposes, only when TW3 is shut down. TW2 and TW3 cannot be operated simultaneously due to an unacceptable level of drawdown interference between the wells (Piteau, 2006).



Source: Google Earth Basemap

Figure 8: Water Well Locations

3.3 Geophysical Survey

Frontier Geosciences Inc. (Frontier) of Vancouver was contracted by Waterline to conduct a ground geophysics survey in November, 2009. The program was split into two phases. The first phase was intended to fill data gaps prior to initiating the drilling and monitoring well installation program. The second phase was completed to target any data gaps that may have been missed by the first program.

The purpose of the geophysical survey was primarily to determine the lithological contacts between the major geologic units and to establish the bedrock depth at various locations in the study area where data was incomplete or absent. A transient electro-magnetic (TEM) resistivity profiling survey was selected as the most suitable method given the geologic environment. Figure 8 shows the locations of the resistivity profiling survey completed as part of the study. Frontier's report is provided in Appendix C for reference. The geophysical information obtained from the surveys was incorporated into Waterline's geodatabase and conceptual model.

3.4 Installation of Monitoring Wells

Following an initial compilation of the geomodel and conceptual hydrogeological model, two sites were selected for installation of monitoring wells into the Gibsons Aquifer. The program was developed to fill in some data gaps in the deepest part of the Gibsons Aquifer and provide a better understanding of aquifer/aquitard properties of the various layers above and within the Gibsons Aquifer. It was necessary to penetrate to the base of the aquifer in Upper Gibsons to determine the full thickness of the Vashon Till Aquitard (protective cover) and the Gibsons Aquifer. In addition, the drilling program also provided some new information to help determine the thickness of the Capilano alluvial deposit that was suspected may be related to the aquifer recharge system. The location of the new wells are shown on Figure 8 and are labelled as WL10-1 and WL10-02.

Drillwell Enterprises Ltd. (Drillwell) was contracted to install the monitoring wells using an air rotary rig. Waterline staff was on site to supervise the drilling and well installation program (Figure 9).

Sediment samples were collected during the drilling program and described for textural and lithologic features. Selected samples were analyzed for grain size distribution. Wells WL10-01 was drilled to the top of bedrock at 143.26 m and completed at 141.13 m, and WL10-02 was drilled to 157.0 and completed at 123.4 m below ground level (m bgl). Well WL10-02 did not intersect bedrock. Well logs and grain size distribution plots are provided in Appendix D.

Figure 9: Photo of Drilling Operation at WL10-01

3.5 Well Development and Testing

Once the monitoring wells were installed, well development was completed by air-lifting groundwater from the wellbore. Final well development was determined when the electrical conductivity of groundwater became consistent and sediment free water was removed from the well. The water level in the well was then allowed to recover to a static condition before a hydraulic test was performed on the well. Water level recovery was monitored following the test and the data was used to estimate the transmissivity of the Gibsons Aquifer material at each well location. Once well construction was complete, Waterline staff installed data loggers in all wells that formed part of the groundwater monitoring network.

3.6 Field Mapping and Electrical Conductivity Surveys

In an effort to assess the possible surface-groundwater interactions, Waterline conducted field surveys in Charman, Chaster, and Gibsons Creeks. The following assessment work was completed as part of the aquifer mapping study:

1. Waterline hydrogeologists traversed major creeks and mapped the surficial deposits to confirm the geology and attempted to gauge stream flow wherever possible. Information was collected and reconciled with previous studies wherever possible (e.g., Charman Creek Master plan, AECOM Stormwater Management Plan). Mapping of the creek beds in terms of observed changes of geologic materials was also completed to assess where the creeks gain, and/or lose water, and/or potentially exchange water with the Gibsons Aquifer.
2. An electrical conductivity (EC), pH, and temperature survey was completed in the creeks to assess any changes in water quality that may distinguish areas of groundwater discharge from surface runoff. Higher EC or total dissolved solids (TDS) readings in the surface environment may indicate that groundwater is discharging to the creeks in the region.
3. Surface water samples were collected at various points within the creek based on monitoring of field parameters. The samples were submitted to the lab for chemical analysis.

Although Waterline attempted to install mini-piezometers and seepage meters in creek beds, we had limited success due to the presence of very coarse-grained materials which proved difficult for installing such devices.

Figure 10 shows a photo of Charman Creek near the Gibsons waterfront. Figure 11 shows a photo of the Basal Capilano/Vashon Till material which will be described later in the report. Figure 12 shows a photo taken in the upper reaches of Chaster Creek where surface water can be seen at the surface and then quickly disappears into the subsurface over short disctances. Figure 13 shows the numerous GPS locations (green triangles) visited in Chaster, Charman, and Gibsons Creeks along with surface water sampling locations (red squares).

Figure 10: Field Reconnaissance – Charman Creek

Figure 11: Field Reconnaissance – Gibsons Creek (Basal Capilano Outcrop)

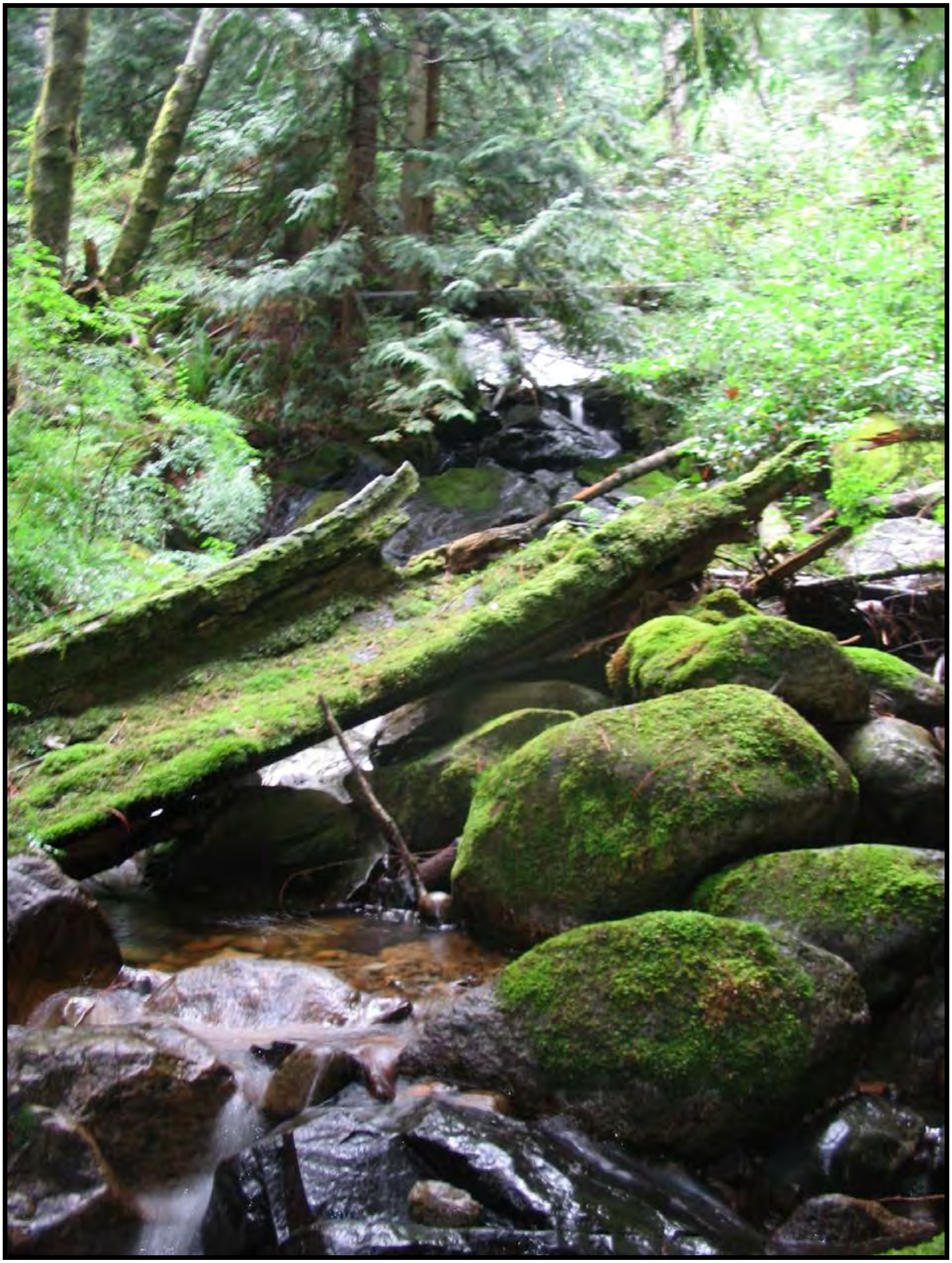
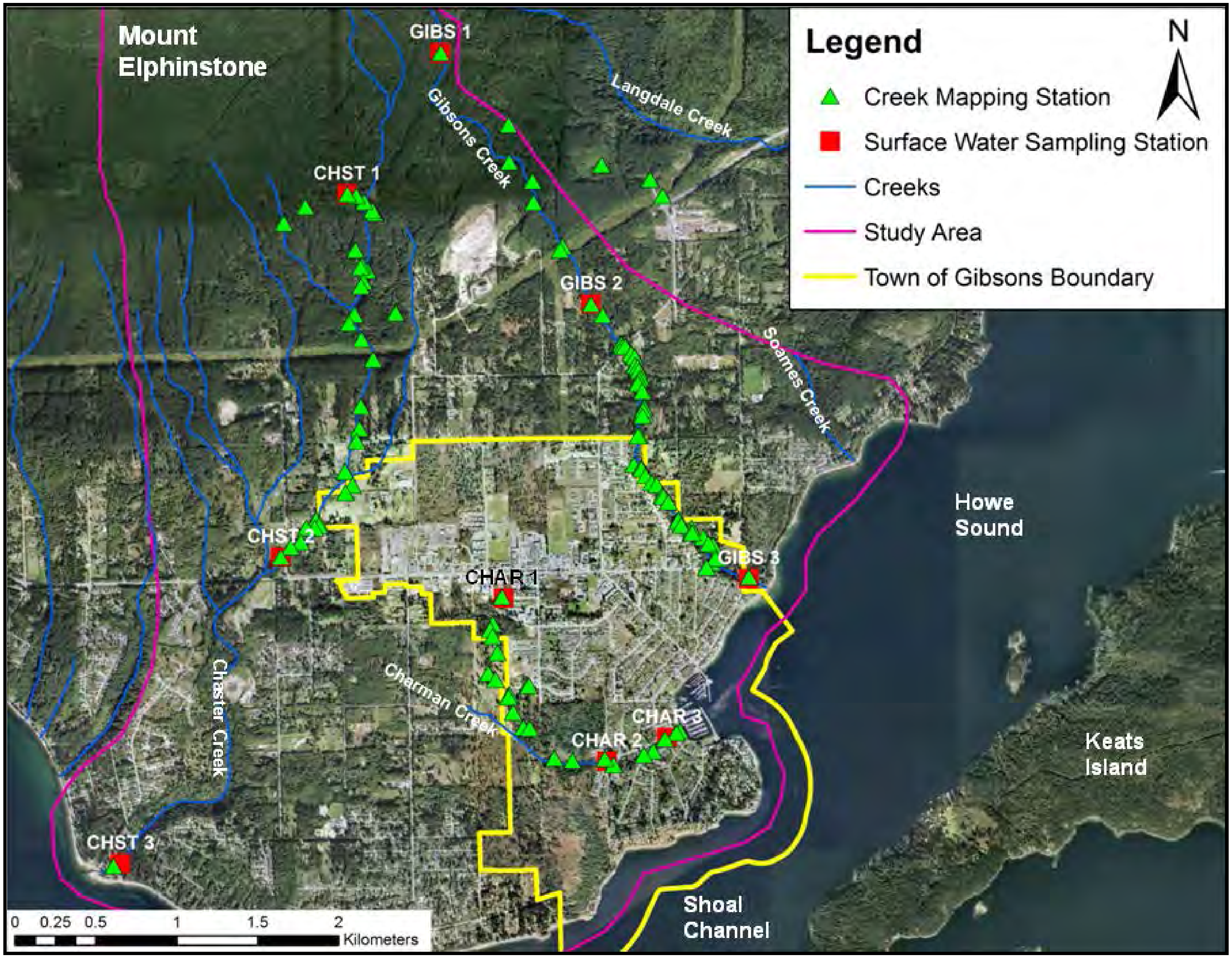


Figure 12: Field Reconnaissance – Upper Chaster Creek



Source: Google Earth Base map, Boundary from the Town

Figure 13: Creek Mapping Station and Surface Water Sampling Locations

3.7 Natural Springs

Waterline also conducted an assessment of all major springs within the study area. Figure 14 shows the locations of springs mapped in the foreshore area near the Town, as well as several locations mapped within SCRD lands north of the Town boundary.

3.8 Groundwater Sampling Program

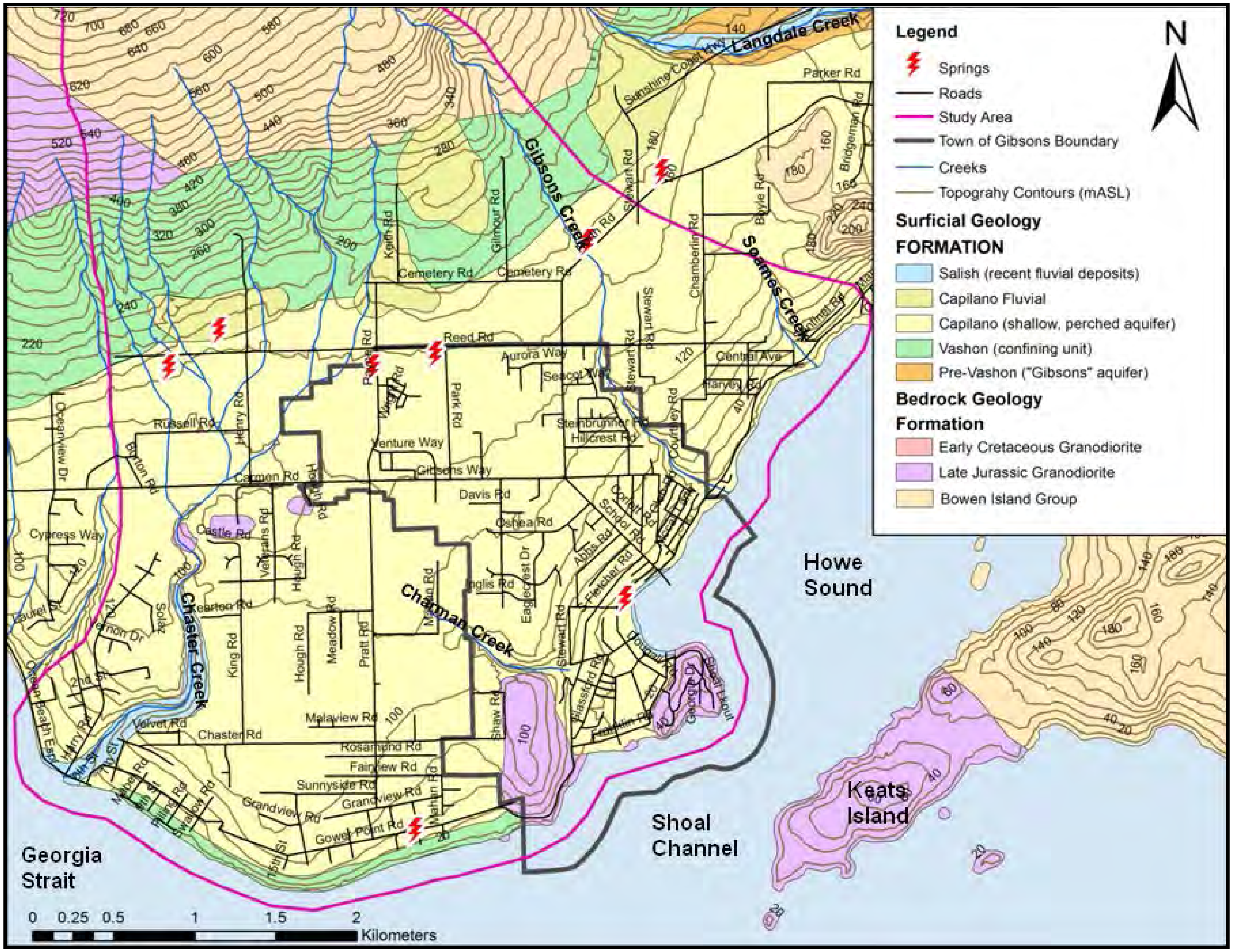
A groundwater sampling program was initiated during the summer of 2009 and completed in October 2012. Table 2 summarizes the wells sampled during the Waterline study.

Table 2: Groundwater Monitoring Well Network

Well Name	Location	Northing	Easting	Ground Elev.	Well Depth	Hydro-Stratigraphic Unit	Water Level Level
		(m)	(m)	(mASL)	(mBGL)		(mBTOC)
School Board	School Board Yard Henry Rd	5473736	460524	178	139	Bedrock	101.5
52733	Fielder Well 967 Henry Rd.	5474249	460691	266	38	Capilano	29.6
MW06-1A	Spyglass Place	5472468	462812	110	78	Pre-Vashon	74.9
MW06-1B	Spyglass Place	5472468	462812	110	78	Capilano	3.9
MW06-2A	Behind Gibsons Aquatic Centre	5472688	462130	126	102	Pre-Vashon	97.2
MW06-2B	Behind Gibsons Aquatic Centre	5472688	462130	126	102	Capilano	2.9
Strata Condo	Behind Georgia Mirage condos near pond	5472360	462486	113		Pre-Vashon	87.6
TW 1	Gower Pt Rd	5472034	463057	13	42	Pre-Vashon	NA
TW 2	Dougal Park	5471757	462924	18	15	Pre-Vashon	NA
TW 3	Dougal Park	5471715	462943	19	26	Pre-Vashon	NA
TW 4	Gower Pt Rd	5472141	463143	13	20	Pre-Vashon	NA
WL10-01 WID#33706	Payne Rd	5473033	461597	147	141	Pre-Vashon	106.7
WL10-02 WID#33707	Oceanmount Blvd	5472238	462263	115	123	Pre-Vashon	84.4
70651	Chaster Rd	5471290	462156	93	116		NA

Notes: All coordinates at Zone 10, NAD 83, mASL means meters above mean sea level, mBGL means meters below ground level, m BTOC means meters below top of casing, TW means Town Well.

The sampling program was completed using existing well pumps (where available) or a combination of stainless steel bailers, Waterra inertial samplers, or passive samplers such as the HydraSleeve used for deep (>100m) monitoring wells. The HydraSleeve uses a check valve apparatus to ensure that while being lowered into a well, the sleeve remains sealed and no water enters the sampler device. When the sleeve is raised from the base of the well, it fills up to the check valve level and seals automatically. The high transmissive capacity of the Gibsons Aquifer was well suited to passive sampling using the HydraSleeve where no well purging was needed.



Source: Base map from Map Place (2009)

Figure 14: Location of Natural Springs

It should be noted that during the monitoring program, the data loggers installed in the Chaster Road monitoring well and the Strata well became entangled in the pump wiring and cannot be removed without pulling the pumps in those wells.

3.9 Laboratory Analysis Program

Table 3 summarizes the sampling events undertaken as part of the water quality sampling program. Surface water and groundwater samples collected for routine chemistry were submitted Maxxam Analytics (previously Cantest) of Burnaby, BC.

Environmental isotopes were also analyzed as part of the study. These are naturally occurring elements that are contained in the chemical structure of water. Analyzing for these elements provides a fundamental tool for tracing the groundwater source, recharge, and history. Further definition of isotopes is provided in Section 5.7.3 of this report.

The stable isotope samples collected during Phase 1 were submitted to the University of Victoria, BC. The first round of tritium analyses were submitted to the University of Waterloo Isotope Laboratory in Waterloo Ontario. During Phase 2, the stable isotope analysis was completed by Jessica Doyle at UBC's lab in Vancouver. Tritium and Noble gas analysis were completed at the University of Utah at their Dissolved and Noble Gas Laboratory in Salt Lake City, Utah. The chlorofluorocarbon and sulfur-hexafluoride analysis were completed at the University of Miami's Tritium Laboratory. A summary of water chemistry and laboratory certificates of analysis are provided in Appendix E for reference.

Table 3: Water Quality Sampling Program

Well Name	Location	Sampled by	Date	Analytes
School Board	School Board Yard Henry Rd	Waterline	September 2009	Routine, trace metals
52733	Fielder Well 967 Henry Rd.	UBC	April 2011	Stable Isotopes, major anions
MW06-1A	Spyglass Place	Waterline	September 2009	Routine, trace metals
		UBC	April 2011	Tritium, Stable Isotopes, Noble Gases, CFCs, SF_6, routine, trace metals (dissolved)
		UBC	June 2011	Major anions, stable isotopes
		Waterline	October 2012	Routine, trace metals (dissolved)
MW06-1B	Spyglass Place	Waterline	September 2009	Routine, trace metals
		Waterline	October 2012	Routine, trace metals (dissolved)
MW06-2A	Behind Gibsons Aquatic Centre	Waterline	September 2009	Routine, trace metals
		UBC	April 2011	Tritium, Stable Isotopes, Noble Gases, CFCs, SF_6, routine, trace metals (dissolved)
		Waterline	October 2012	Routine, trace metals (dissolved)
MW06-2B	Behind Gibsons Aquatic Centre	Waterline	September 2009	Routine, trace metals
		UBC	April 2011	Tritium, Stable Isotopes, Noble Gases, CFCs, SF_6
		Waterline	October 2012	Routine, trace metals (dissolved)
Strata Condo	Behind Georgia Mirage condos near pond	UBC	April 2011	Tritium, Stable Isotopes, Noble Gases, CFCs, SF_6
		UBC	June 2011	Stable isotopes, major anions
TW 1	Gower Pt Rd	Waterline	September 2009	Routine, trace metals
		UBC	April 2011	Tritium, Stable Isotopes, Noble Gases, CFCs, SF_6, routine, trace metals (dissolved)
		UBC	June 2011	Stable isotopes, major anions

Well Name	Location	Sampled by	Date	Analytes
		Waterline	October 2012	Routine, trace metals (total and dissolved)
TW 2	Dougal Park	Waterline	September 2009	Routine, trace metals
		UBC	April 2011	Tritium, Stable Isotopes, Noble Gases, CFCs, SF_6
		UBC	June 2011	Stable isotopes, major anions
		Waterline	October 2012	Routine, trace metals (total and dissolved)
TW 3	Dougal Park	Waterline	September 2009	Routine, trace metals
		UBC	April 2011	Tritium, Stable Isotopes, Noble Gases, CFCs, SF_6, routine, trace metals (dissolved)
		UBC	June 2011	Stable isotopes, major anions
		Waterline	October 2012	Routine, trace metals (total and dissolved)
TW 4	Gower Pt Rd	UBC	April 2011	Tritium, Stable Isotopes, Noble Gases, CFCs, SF_6
		UBC	June 2011	Stable isotopes, major anions
		Waterline	October 2012	Routine, trace metals (total and dissolved)

Notes: Noble gases include helium, neon, argon, krypton, xenon, and radon; CFC's are chlorofluorocarbons, and SF6 is sulfurhexafluoride, TW means Town Well.

3.10 Geodatabase, Geomodel and Groundwater Flow Modeling

3.10.1 ESRI ARC-GIS Database

Geological and hydrogeological datasets were processed electronically so they could be entered into Waterline's Geodatabase where the information could be synthesized and evaluated. Borehole information was compiled and assessed using software developed by Mount Pleasant Software (2010). This allowed for the development of a conceptual hydrogeological/geological 3D model for visualization of the subsurface geology and hydrogeology. Numerous other licensed software packages were used in the preparation of the report, tables, figures, maps, cross-sections, and 3D visualization (Eg: Leapfrog Hydro, and ARC HydroGroundwater).

3.10.2 Geological Modeling

Geological modeling was completed by UBC using Leapfrog Hydro (Doyle, 2013). The program allows for importing of geological and hydrogeological data from ARC GIS. This includes well log data, cross sections, maps, elevation grids, and other relevant mesh, line and point data. It allows for easy integration and rapid and effective visualization of raw and processed data. The tools within Leapfrog allow for 3D geological modeling, and the ability to layer and drape topography, landmarks such as roads, surficial and bedrock geology, and allows for the development of conceptual model of the Gibson Aquifer system.

Considerable time and effort was spent by UBC (Doyle 2013) refining the geomodel to properly integrate all datasets. Once completed, the geomodel formed the input into the numerical model described in the following section.

3.10.3 Groundwater Flow Modeling

Visual Modflow (McDonald and Harbaugh, 1988) was used to simulate groundwater flow in the Gibsons Aquifer. MODFLOW is industry standard, three-dimensional groundwater flow modeling software.

A computer model of the Gibsons Aquifer was constructed based on the conceptual model developed as part of this project. The purpose of the groundwater modeling exercise was to evaluate the potential impact to the aquifer from the increased water demand due to the projected population growth. In addition, the Town was interested is assessing likely climate change scenarios indicated for the Pacific Northwest coastal region.

4.0 PHYSICAL SETTING

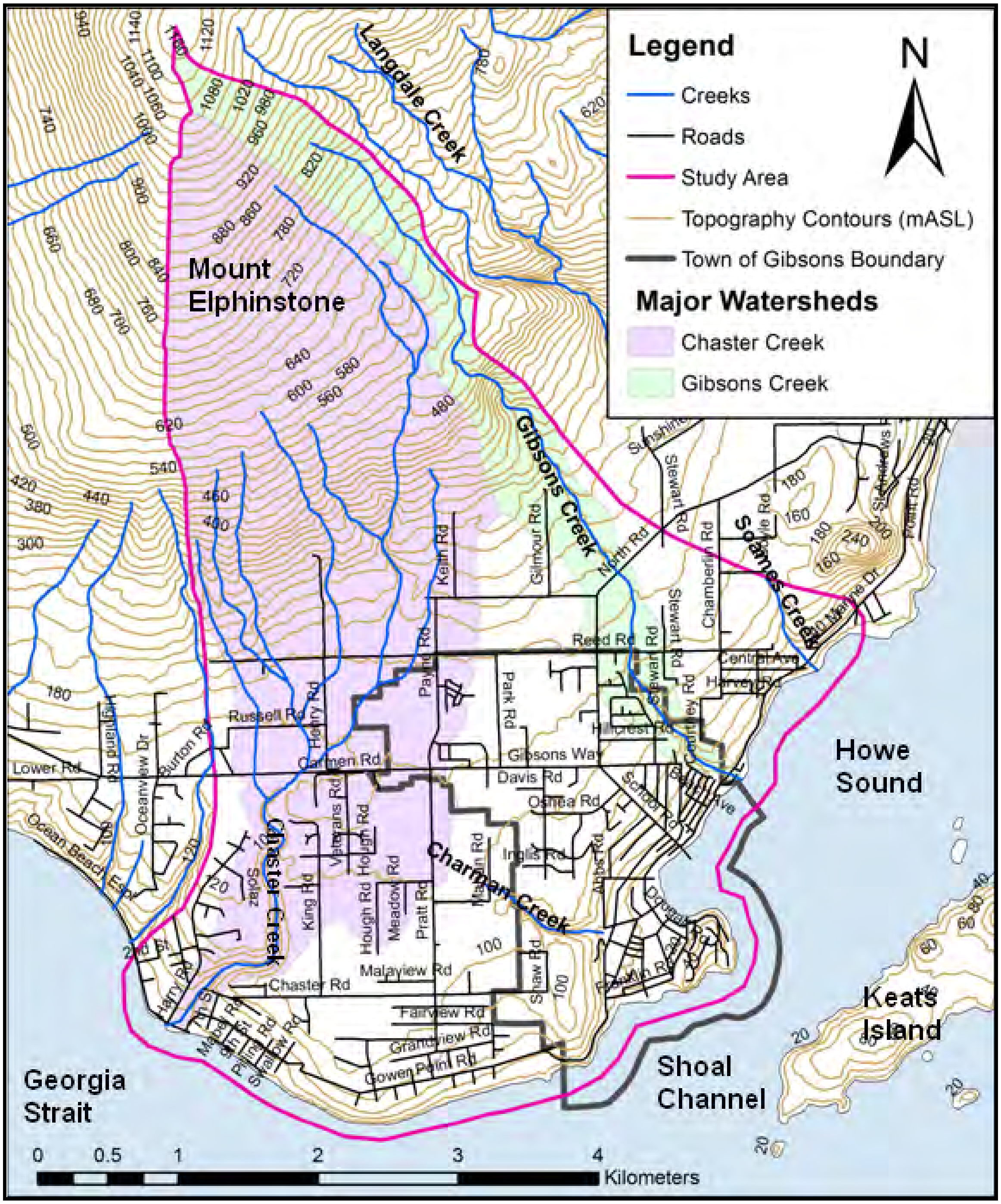
4.1 Project Boundaries

The project boundaries are shown in Figure 15 and extend from the waterfront in Lower Gibsons, to the top of Mt. Elphinstone in the northwest. The western boundary was extended to include the Chaster Creek watershed, and the eastern boundary includes the Gibsons Creek Watershed. The final study area was selected based on the mapped foot print of the Gibsons Aquifer and the watershed areas that are expected to contribute a portion of the recharge to the underlying Gibsons Aquifer.

4.2 Land Cover and Use

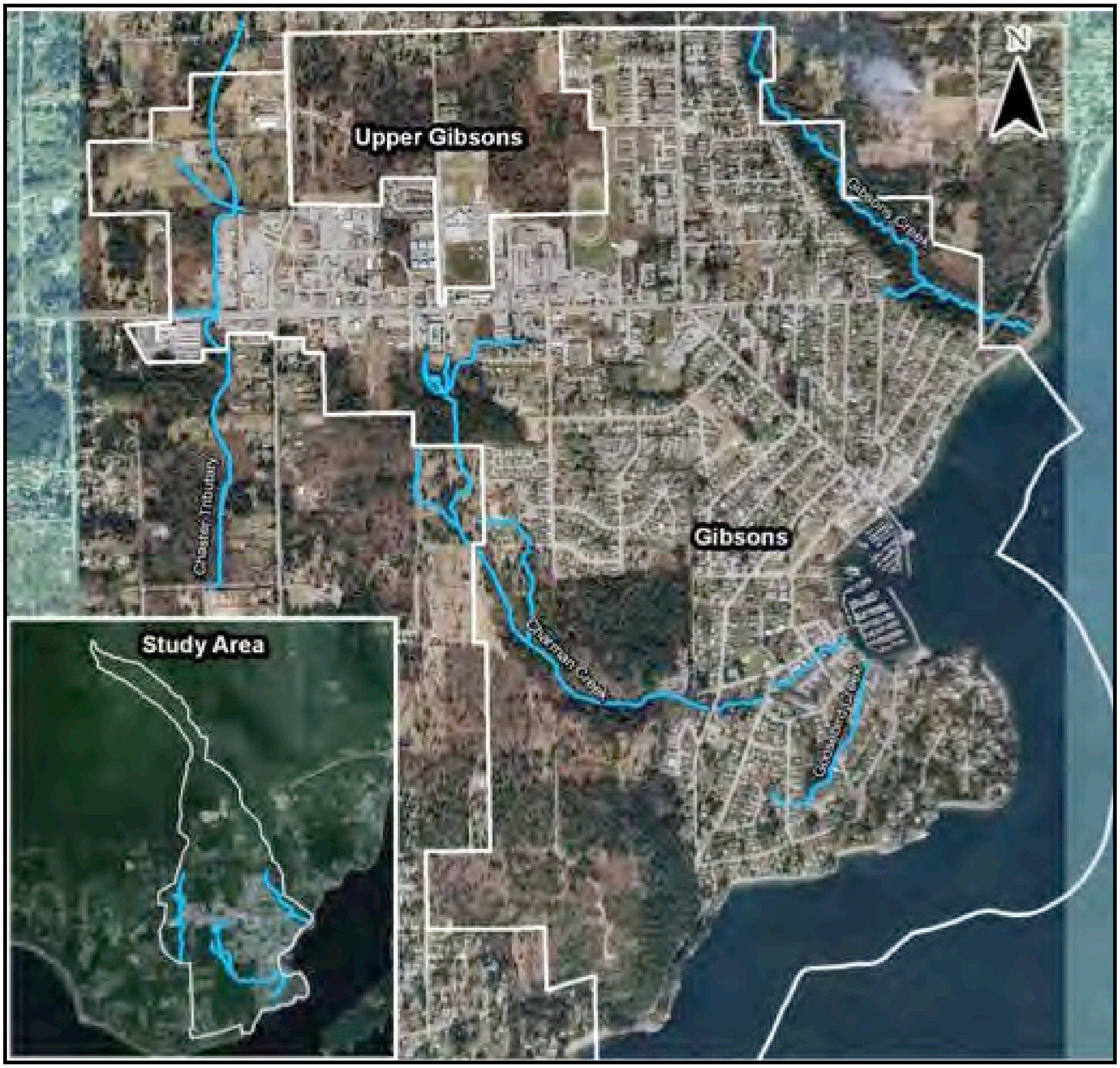
Although an important aspect of assessing aquifer recharge, a comprehensive land cover assessment was not completed as part of the aquifer mapping study as it was outside the scope of the project. The Integrated Storm Water Report by AECOM (2010) discusses the land cover, and present and future proposed land use within the Town of Gibsons boundary (Figure 15). Figure 16 shows the extent of the AECOM (2010) study which coincides with the Town of Gibsons boundary.

Land cover outside the Town boundary, where predominantly lower density residential land use exists, is typical of rural settings. These areas comprise of a combination of manicured lots, bare land, but generally exhibit fewer impermeable areas than are observed within the Town boundary. The upper and lower slopes of Mt. Elphinstone are designated as rural forest lands within the Agricultural Land Reserve (ALR) in the SCRD OCP (2008).



Source: Watershed outlines BCGS, Roads from SCRD, Topo Contours provided by the Town of Gibsons

Figure 15: Study Boundaries



Source: AECOM (2010)

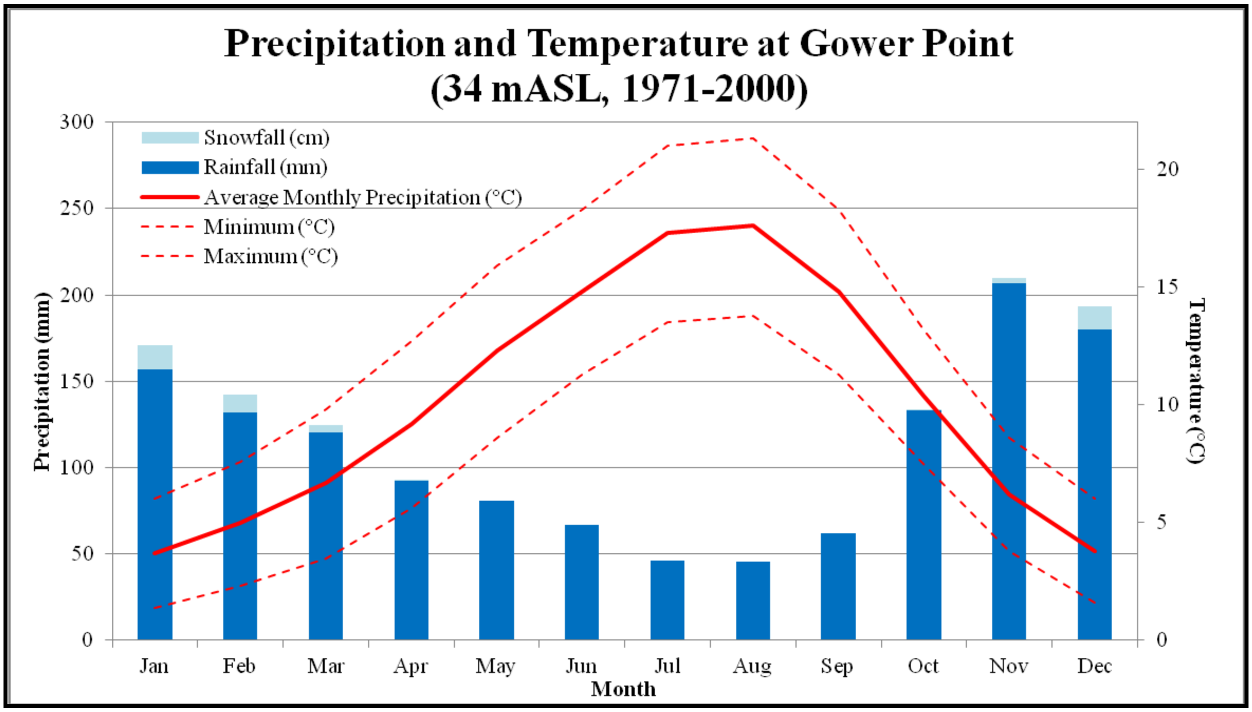
Figure 16: AECOM Stormwater Study Boundaries and Creeks

4.3 Topography and Physiography

The topographic elevation across the study area ranges from sea level in Lower Gibsons, to over 1150 mASL at the peak of Mt. Elphinstone. The ground surface slopes moderately towards the ocean in Lower Gibsons, increases in slope towards Upper Gibsons where a gently sloping bench extends to the base of Mt. Elphinstone just north of the Town boundary (Figure 15). Thereafter, the topographic relief rises sharply to the top of the mountain which forms part of the Coast Mountain Range. The topography in the region is strongly influenced the depositional environment and, as will be shown, controls and defines the subsurface geometry and groundwater flow through the Gibsons Aquifer.

4.4 Climate

The region has a temperate coastal climate which is described as "Mediterranean-like" (Environment Canada, 2012). Much of the precipitation recorded falls during winter months as rain at lower elevations, and snow at higher elevations. Summers are generally warm and dry. The closest Environment Canada climate station to the Town was located at Gower Point near the coast at 34 mASL. This climate station was discontinued in 2000. Based on the climate record, the average annual air temperature is reported as 10.2°C, and average annual precipitation is recorded as 1369 mm. Approximately 97% of precipitation (1324 mm) occurs as rain (Environment Canada, 2012). Figure 17 summarizes monthly average climate data collected from 1971 to 2000 at the Gower Point climate station.



Source: Environment Canada (2012)

Figure 17: Precipitation and Temperature Record – Gower Point Climate Station

No climate stations exist at higher elevations in the region. However, precipitation has been projected to the Mt. Elphinstone area by Chapman and Reksten (1991) which indicates mountain tops in the region could receive up to 2250 mm precipitation per year. The data also indicates that precipitation increases towards the north and east due to orographic effects. Orographic lift occurs when an air mass is forced from a low elevation to a higher elevation as it moves over rising terrain (Wikipedia, 2013).

At elevations higher than about 700 mASL, precipitation falls as snow during the winter months and accumulates to create a snowpack in the Coast Mountains. The Water Stewardship Division of the Ministry of Environment (MOE 2012) have historical snow survey data for Chapman Creek located at 1022 mASL (record: 1993-2003). The station is located approximately 15 km north of the Town of Gibsons. Additional snow survey data is available at Hollyburn, which is situated at approximately 1100 m ASL (record: 1945-1987) some 25 km to the east of Gibsons (Doyle 2013). Based on these data, the maximum snow accumulation in the Coast Mountains in this area occurs in April of each year. Spring snowmelt begins in May each year and in some years extends into June at higher elevations. Based on the available data the snowpack appears highly variable given the large range of maximum and minimum snow accumulation values. It is reasonable to assume that snowpack accumulated on Mt. Elphinstone may be similar to what is observed in Chapman Creek and Hollyburn snow record.

4.5 Surface Water Resources

Three major creeks flow through the study area. These include:

- Gibsons Creek to the northeast of the Town;
- Charman Creek within the Town boundary; and
- Chaster Creek along the west project boundary and generally outside the Town Boundary.

The creeks are shown on Figure 16 and both Chaster Creek and Gibsons Creek catchments extend to higher elevations on Mt. Elphinstone. A fourth smaller creek (Goosebird Creek) is located to the west of the Gibsons' Marina over shallow overburden and bedrock but is not expected to interact with aquifer recharge.

The watercourse features for each creek were previously described in the Integrated Stormwater Management Plan prepared by AECOM (2010). The scope of AECOM's Stormwater study was limited to within the Town of Gibsons boundary and therefore does not provide sufficient coverage to fully address groundwater-surface water interactions relating to Waterline's aquifer mapping study. This has been identified as a data gap and Waterline recommends that climate and hydrometric stations be established within major creeks in an effort to further assess runoff and groundwater-surface water interactions.

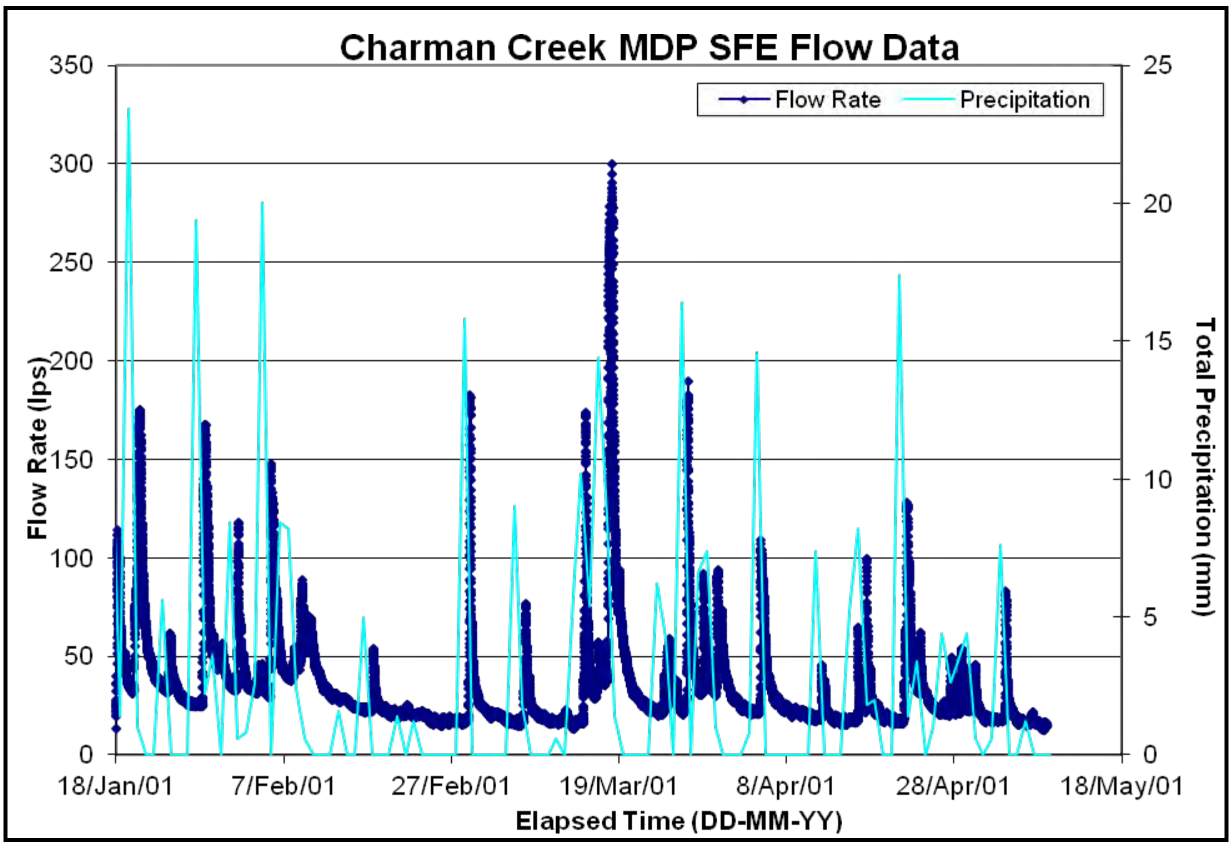
4.5.1 Gibsons Creek

Gibsons Creek extends approximately 6.5 km from the headwaters below the peak of Mt. Elphinstone at approximately 1170 mASL, and empties into Howe Sound just east of Town. The boundary between the Town of Gibsons, the SCRD, and Squamish Lands is situated in lower reaches of Gibsons Creek. The total size of the Gibsons Creek catchment is 323 Ha. The creek drains water from 264 Ha of forest lands along the slope of Mt. Elphinstone before reaching the residential area within the Town boundary at Reed Rd. Three storm sewer outfalls from the Town flows into Gibsons Creek prior to being diverted through a culvert under Marine Drive and then discharges to the ocean. No long-term hydrometric flow data is available for Gibsons Creek.

4.5.2 Charman Creek

The headwaters of Charman Creek catchment are located in Middle to Upper Gibsons (Figure 16). The land use in this area is a combination of residential/recreational, commercial, industrial and residential. Flow in the watercourse begins at about the intersection of Park Road and Gibsons Way and flows approximately two kilometers before entering Howe Sound near Gibsons Landing. Runoff collects from two tributaries south of Gibsons Way, which flow into the White Tower Park area through a series of engineered ponds, and then flows south towards a culvert at Inglis Road through undeveloped land. Charman Creek then continues south, collecting water from a small tributary that captures residential run-off, then flows east under Gower Point Road towards Howe Sound through residential areas. In total, the catchment is 159 Ha and drains a mixture of urban and agricultural land.

Seasonal flow within Charman Creek is highly variable and is fed by rainfall and stormwater drainage from Upper Gibsons. Figure 18 shows a hydrograph of flow in Charman Creek from January to May 2001. Total precipitation is plotted over the same time period. As shown, flow in the creek exhibits a slight delay from the precipitation trend but is directly related to rain and snow melt. Monthly baseflow in Charman Creek was estimated by AECOM (2010) and ranged from a high of about 40 litre per second (Lps) from November to February each year, to a low of 1 Lps from August to October each year.



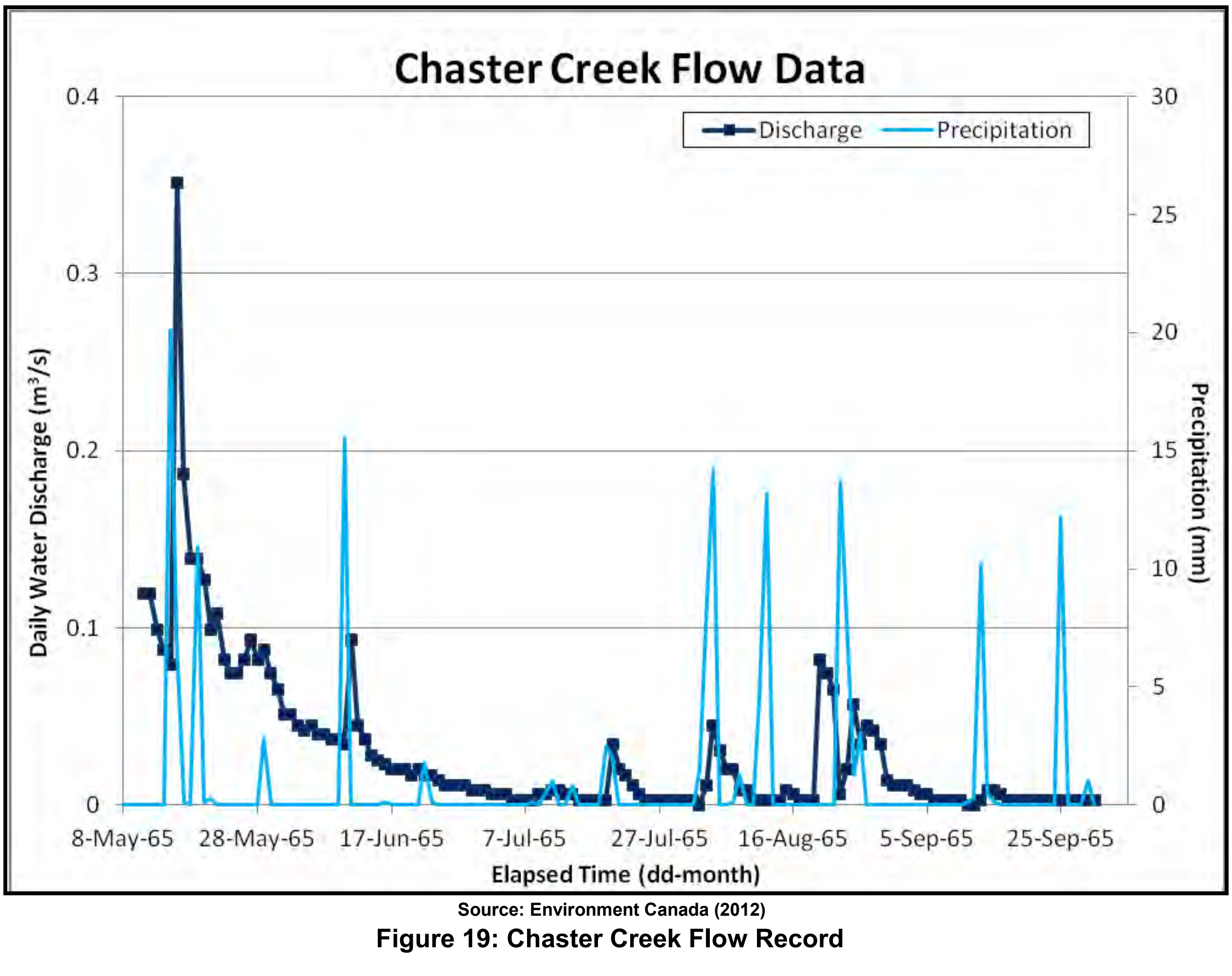
Source: Environment Canada (2012)

Figure 18: Charman Creek Flow Record

4.5.3 Chaster Creek

Chaster Creek originates from several tributaries which extend from about 350 to 900 mASL along the slopes of Mt. Elphinstone (Figure 15). Only a small portion of one of the tributary branches of Chaster Creek flows along the northwest Town boundary. The creek flows south-southwest before exiting into Georgia Strait near the Gower Point area. The Water Survey of Canada recorded flow data from Chaster Creek above Highway 101 from May to October 1965 (Environment Canada, 2012). No other hydrometric records are available for Chaster Creek.

Figure 19 shows the hydrograph of the flow and precipitation data in Chaster Creek over the short period of record. The data show that flow generally fluctuates with precipitation. However, higher base flow measurements observed in May and June (1965) may be related to late snowmelt or possibly groundwater contribution to creek flow. Further study is required to confirm this information which is now over 45 years old.



Source: Environment Canada (2012)

Figure 19: Chaster Creek Flow Record

4.5.4 Goosebird Creek

Goosebird Creek is an urbanized, 0.7 km long watercourse that drains approximately 31 Ha of residential area originating from a 450 mm culvert at Glassford Road. A series of culverts and ditches guides the flow east into Gibsons Harbour (Figure 16). Flow through the creek is largely controlled by storm flow and is usually dry in the summer.

4.6 Local and Regional Geology

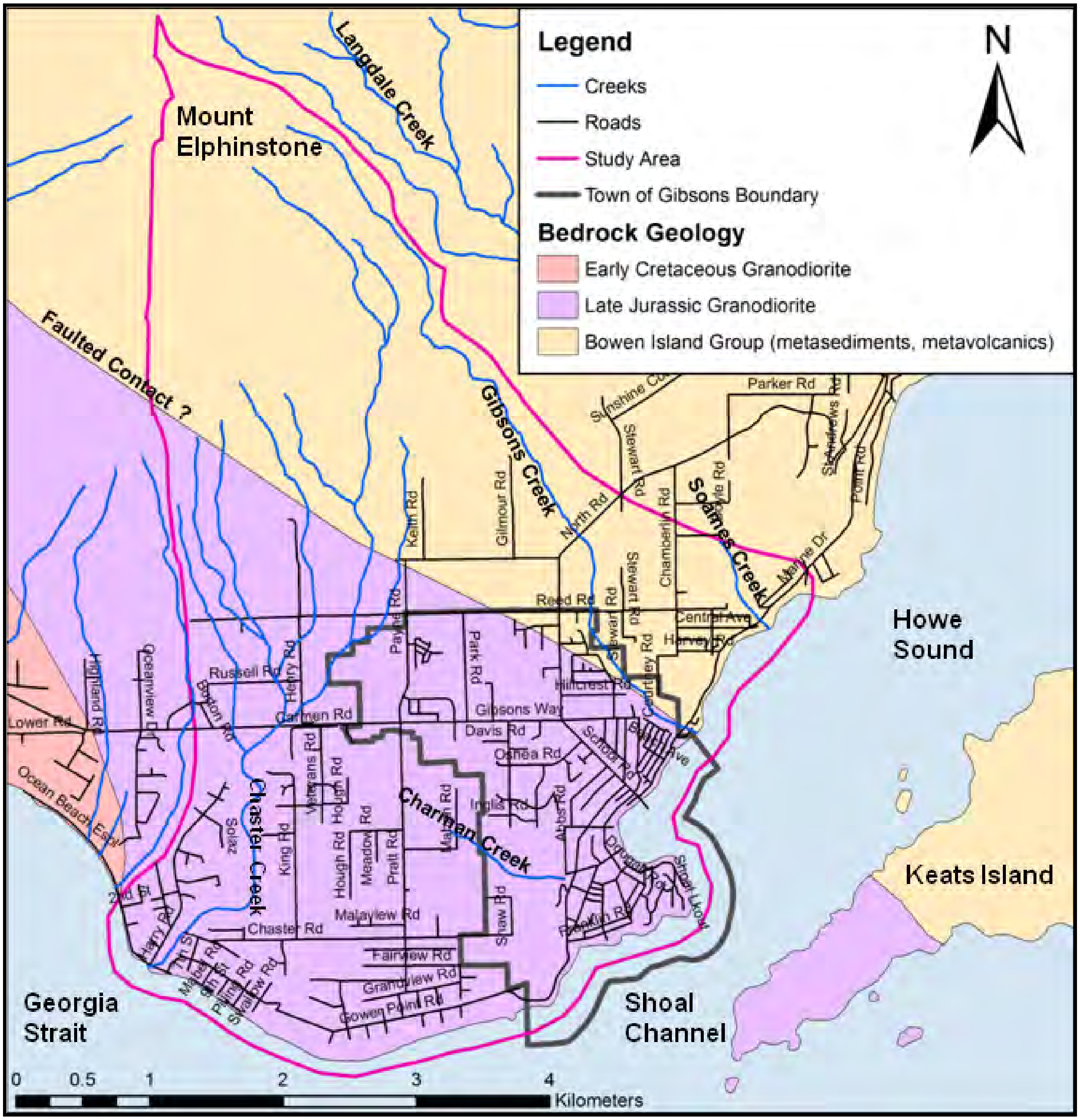
The geological history of Gibsons of the area around the Town of Gibsons is complex, involving plate tectonics over several million years, and pre-glacial and glacial activity that took place some 20,000 to 50,000 years ago. A detailed account of the depositional history is presented in various references (Eg: Monger, 1994; Friedman et al., 1990, and Journeay and Monger, 1994a and 1997) and is also summarized in Doyle 2013. The main focus this section is to provide a high level overview of the geology that forms the Gibsons Aquifer and Aquitard system.

4.6.1 Bedrock

Figure 20 presents the bedrock geology which was mapped by the BC Ministry of Mines and Energy (Map Place, 2009). Granitic intrusions of quartz-diorite and granodiorite underlie most of the Town. Gospel Rock and the bedrock hill west of Gibsons Marina are of similar origin and typical of local Late Jurassic granitic intrusions in the region.

The granite bedrock extends to the northeastern most part of the Town boundary where it forms a sharp contact with Bowen Island Group bedrock (Figure 20). This sharp contact parallels some of the major faults that have been mapped in the area. However; it is not known if this contact is fault-related. As will be discussed later in the report, a better understanding of the contact zone between the granite and meta-sedimentary/meta-volcanic bedrock may be required in order to fully understand the relationship between the Mt. Elphinstone mountain block, and the role it plays in directing recharge to the Gibsons Aquifer. If the contact is faulted, it is possible that this zone acts as a deep conduit for directing lateral recharge from the mountain block into the Gibsons Aquifer. More discussion is provided on this subject in the groundwater geochemistry and environmental tracer part of the report.

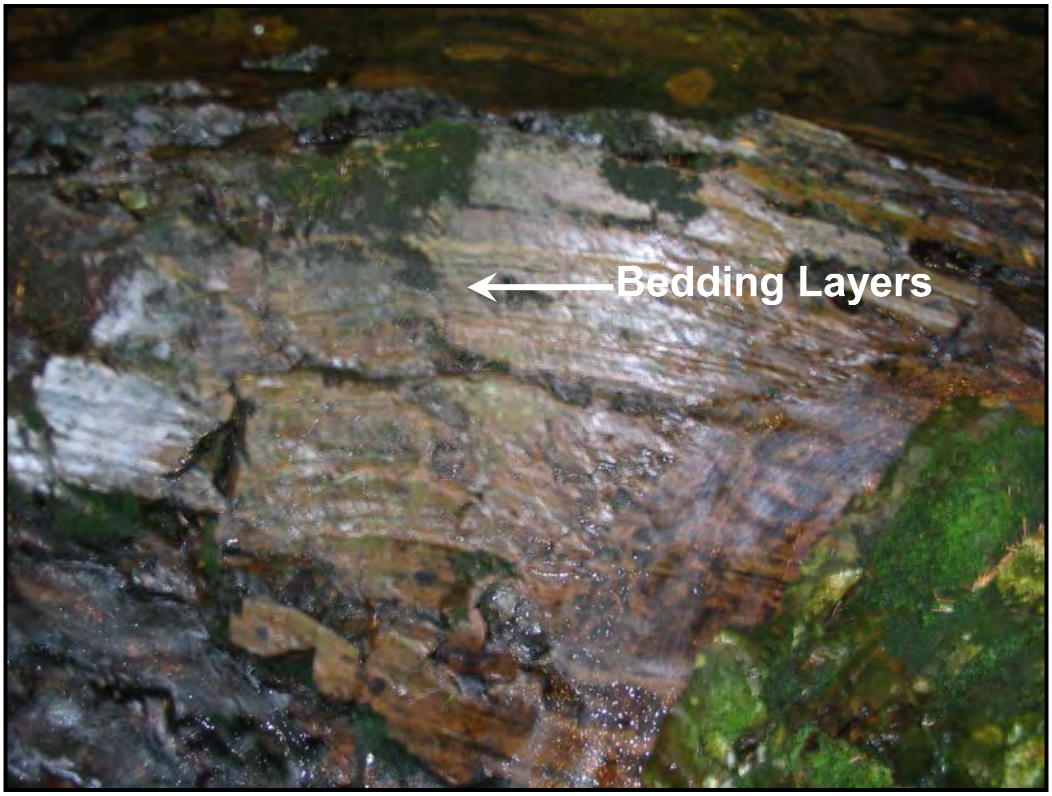
The Bowen Island Group is an assemblage metamorphic sedimentary and meta-volcanic rocks. Friedman et al. (1990) describes exposures of the Bowen Island Group on Mt. Elphinstone as strongly foliated, fine-grained, interbedded with green chlorite schist. Local bedrock exposures appear as pale grey, white and green fine-grained schistose meta-volcanic rock. Friedman et al. (1990) notes that the bedrock assemblage transitions from volcanic-rich in the southeast near Bowen and Gambier Islands, to sedimentary dominated towards the northwest near the Town of Gibsons.



Source: Base map from Map Place (2009))

Figure 20: Bedrock Geology Map

Field mapping completed by Waterline confirms the dominance of meta-sedimentary rocks near the base of Mt. Elphinstone. Fine-grained schistose meta-volcanic rock were also identified on the eastern slopes and summit of Mt. Elphinstone as well as on Soames Hill located east of the Town Boundary. Figure 21 shows a photo of metamorphosed sedimentary outcrop mapped near the upper reaches of Chaster Creek.



Source: Waterline (2010)

Figure 21: Meta-sedimentary Rock Exposed in Upper Reaches of Chaster Creek

The bedrock structure was also assessed during Waterline field surveys in an effort to evaluate flow through fractures or discontinuities in the rock mass. The Bowen Island group meta-volcanic bedrock was found to be jointed, blocky, and had frequent near vertical fractures. The orientation of fractures was essentially parallel to the granite/meta-sediment contact shown in Figure 20. The structure is perpendicular to the northwest-trending Prince of Whales normal fault that was mapped near Langdale which is situated east of the Town of Gibsons.

The orientation of both the Late Jurassic and Early Cretaceous intrusions, as well as the general trend of Langdale, Gibsons and Chaster Creeks, appear to roughly parallel the Prince of Whales Normal Fault. This suggests that surface and subsurface drainage may be controlled by major regional fault and fracture discontinuities observed in the area. Fractures in intrusive rocks have been recorded in well logs within the study area, some of which have been noted as being water-bearing. This is relevant, as fracture permeability in the mountain block could provide significant lateral recharge to the Gibsons Aquifer where the mountain is in contact with the aquifer.

4.6.2 Unconsolidated Deposits

Most of the landscape and landforms observed in Gibsons, and across the Sunshine Coast in general, resulted from glacial and interglacial processes operating during the last 50,000 years. The latest and largest glaciation was the Fraser Glaciation which started approximately 29,000 year before present (BP) due to a deteriorating (colder) climate. In southwestern BC, mountain glaciers formed between 19,000 and 30,000 BP before they advanced, coalesced, and thickened to create the maximum extent of the ice sheet that covered Georgia Strait nearly 15,000 BP. At this time, the ice surface was at about 2300 mASL and towered over 1000 m above the present-day peak of Mt. Elphinstone. After about 14,500 BP, the regional climate began to warm causing ice to melt and glaciers to retreat over the next 5,000 years (Clague, 1994).

During the advancement phase, glaciers from the southwest Coast Mountains and Vancouver Island flowed towards and coalesced with ice flowing south along the Salish Sea (present day Strait of Georgia), producing a large glacier lobe that extended down into the Puget Lowlands in Washington, USA. The Town of Gibsons was situated at the confluence of this Georgia Strait glacier lobe, and another glacier flowing southwest from Howe Sound.

Quaternary sediments up to 300 m thick underlay the lowlands bordering the Strait of Georgia. Throughout this region, sediments were deposited during the glacial advance and retreat and in some areas during older glacial and intervening interglacial cycles. Loading and unloading of the ice sheet caused significant land rebound and sea level fluctuations. Along the Strait of Georgia, sea level rose up to almost 200 m above present-day sea level, leaving various marine deposits observed across the Sunshine Coast at elevations up to 180 mASL (McCammon, 1975). Figure 22 shows the mapped surficial deposits within the study area.

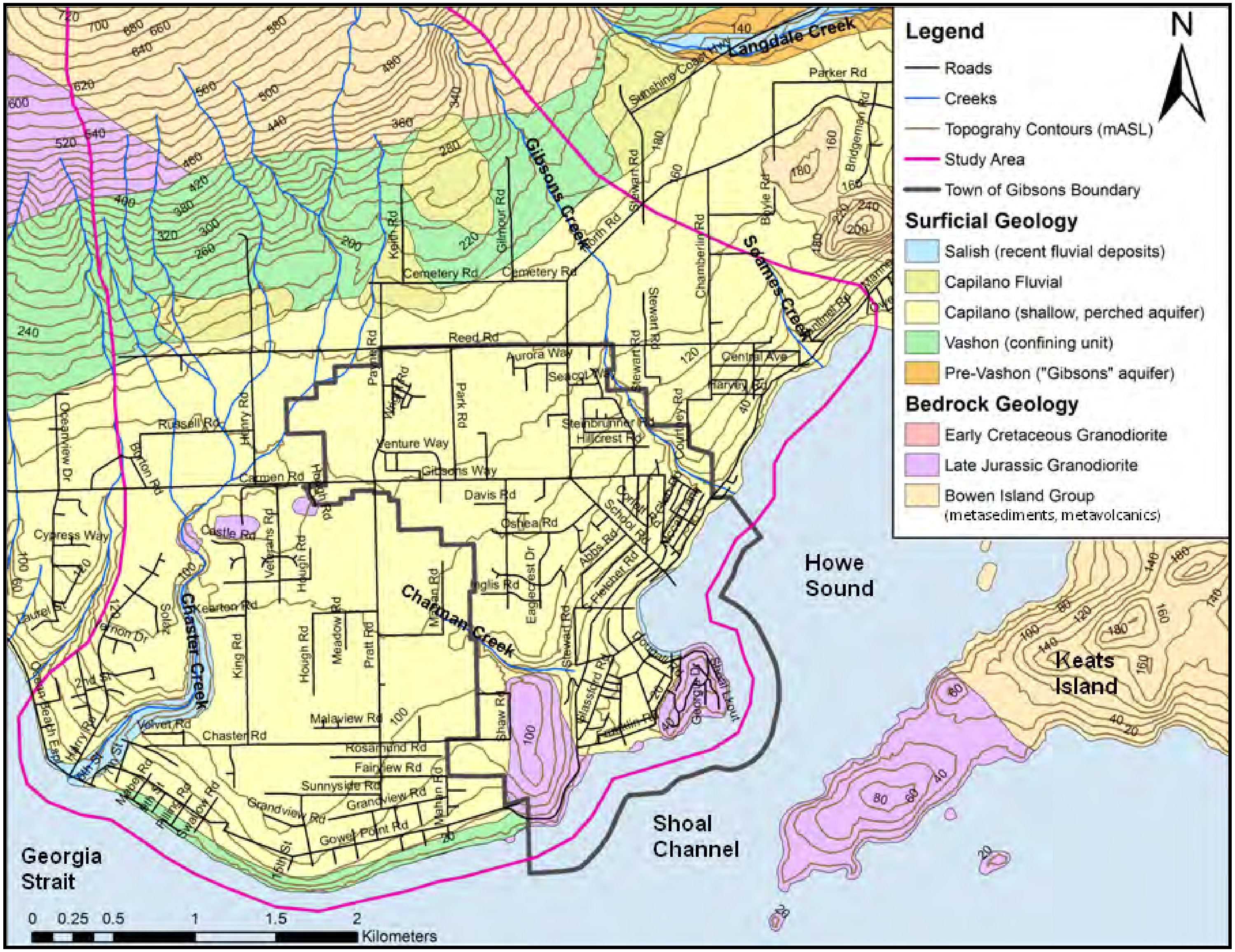
The following describes each unit from the oldest deposits which sit on top of bedrock, to youngest deposits which are currently exposed at the surface within the study area.

4.6.2.1 Pre-Vashon Deposits (Gibsons Aquifer)

Prior to glaciation, marine deposits consisting of silt, sand and gravel were laid down on top of the bedrock in the vicinity of the present-day Town of Gibsons. The coarse, sand and gravel deposits form what we understand to be the Gibson Aquifer, and are locally referred to as Pre-Vashon sediments. The basal deposits are laminated and composed of stony clays that record a period of marine submergence (Clague, 1977). The upper deposits are fluvial, possibly the result of a series of coalescing river deltas (Fyles, 1962 and 1963) and tend to appear below the 100 mASL contour interval (Clague, 1977). Beneath the Town of Gibsons the Pre-Vashon deposits consist of flat-lying interbeds of silt, sand and gravel that sit on top of the bedrock. Exposures of the Pre-Vashon deposits have only been mapped along the Langdale Creek valley to the east of the Town of Gibsons and otherwise are only recorded in well logs.

4.6.2.2 Vashon Till/Drift (Gibson Aquitard)

These deposits are of glacial origin and include glacial till, glacial fluvial (river deposits) and glacial lacustrine (lake deposits) sediments that are likely the result of alpine glaciation (mountain glaciers). An erosional surface defines the contact with the underlying Pre-Vashon sediments (Fyles, 1963). The thickness of the Vashon Drift has been recorded up to 30 metres and comprises hard packed silt, clay, sand, gravel and stones. It is primarily found below 1000 mASL.



Source: Base map from Map Place (2009)

Figure 22: Surficial Geology Map

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In the Sunshine Coast region, the Vashon Till consists of a concrete-like mixture of pebbles in a sandy matrix. It is brown when weathered (Figure 23), and a blue-grey color when unweathered. In areas where Pre-Vashon sediments have been eroded away by the advancing glacier, the Vashon Till lies directly on bedrock (McCammon, 1977).

Despite the apparent coarse-grained nature of the Vashon Till deposit in some areas (Figure 23), compaction and cementation has resulted in the development of a deposit with aquitard-like properties which forms a low permeability cover over the Gibsons Aquifer. In Upper Gibsons, this unit impedes the downward movement of water (recharge) from the surface. In Lower Gibsons it forms a cap over the aquifer that contains the water pressure in the Gibsons Aquifer, resulting in flowing artesian properties of the Town supply wells.

Whether the Vashon Till cover extends over the entire region is not known with certainty. However, as is discussed below, the Gibsons Aquitard may in fact be a combination of the Basal Capilano deposit and the Vashon Till deposit. In either case, the confining layer over the Gibsons Aquifer is thought to be a regional feature that extends from Lower Gibsons to Upper Gibsons, and likely to the base of Mt. Elphinstone.

Source: Waterline (2010)

Figure 23: Vashon Till Outcrop Near Gower Point (Gibsons Aquitard)

4.6.2.3 Capilano Sediments (Basal Aquitard and Unconfined Aquifer)

As the glaciers in the region continued to melt and retreat, ocean water once again inundated the Gibsons area, depositing more clay and sand and gravel sediments over the Vashon Till deposit. These late-stage glacial deposits are known as Capilano marine and glacio-marine deposits and are generally found at elevations below 180 mASL, (McCammon, 1977).

The basal unit of the Capilano sediments is a marine/glacio-marine clay-rich veneer observed to be a few centimeters and up to 9 metres thick and often composed of stony till-like clay, commonly referred to as hardpan in well driller records (Figure 24). This basal unit likely also forms a cap over the Gibsons Aquifer and is thought to be part of what is referred to as the Gibsons Aquitard.

The upper Capilano sediments are composed of coarse grained, sand and gravel deposits that extend over the entire study area. These coarser deposits form a perched, unconfined aquifer in the vicinity of Upper Gibsons which is referred herein as the Capilano Aquifer. Historically, the Capilano Aquifer has been used for water supply. Although some water wells still exist, based on the field verified survey completed by Waterline the Capilano Aquifer appears to be no longer in use. However, only about 30% of the wells listed in the MOE database could be verified during Waterline's field verification survey.

Source: Waterline (2010)

Figure 24: Basal Capilano Outcrop in Gibson Creek (Part of Gibsons Aquitard)

4.6.2.4 Salish Sediments

Once glacial ice had melted from the region some 10,000 years ago, naturally eroded sediments from higher elevations were deposited near the base of Mt Elphinstone where a series of gravel pit operations are currently in operation. These coarse, sand and gravel deposits are referred to as Capilano alluvium. Figure 22 shows the location of the Capilano alluvium (yellow colour) and Figure 25 shows a photo of the Fiedler pit where gravel is being mined for aggregate resource.

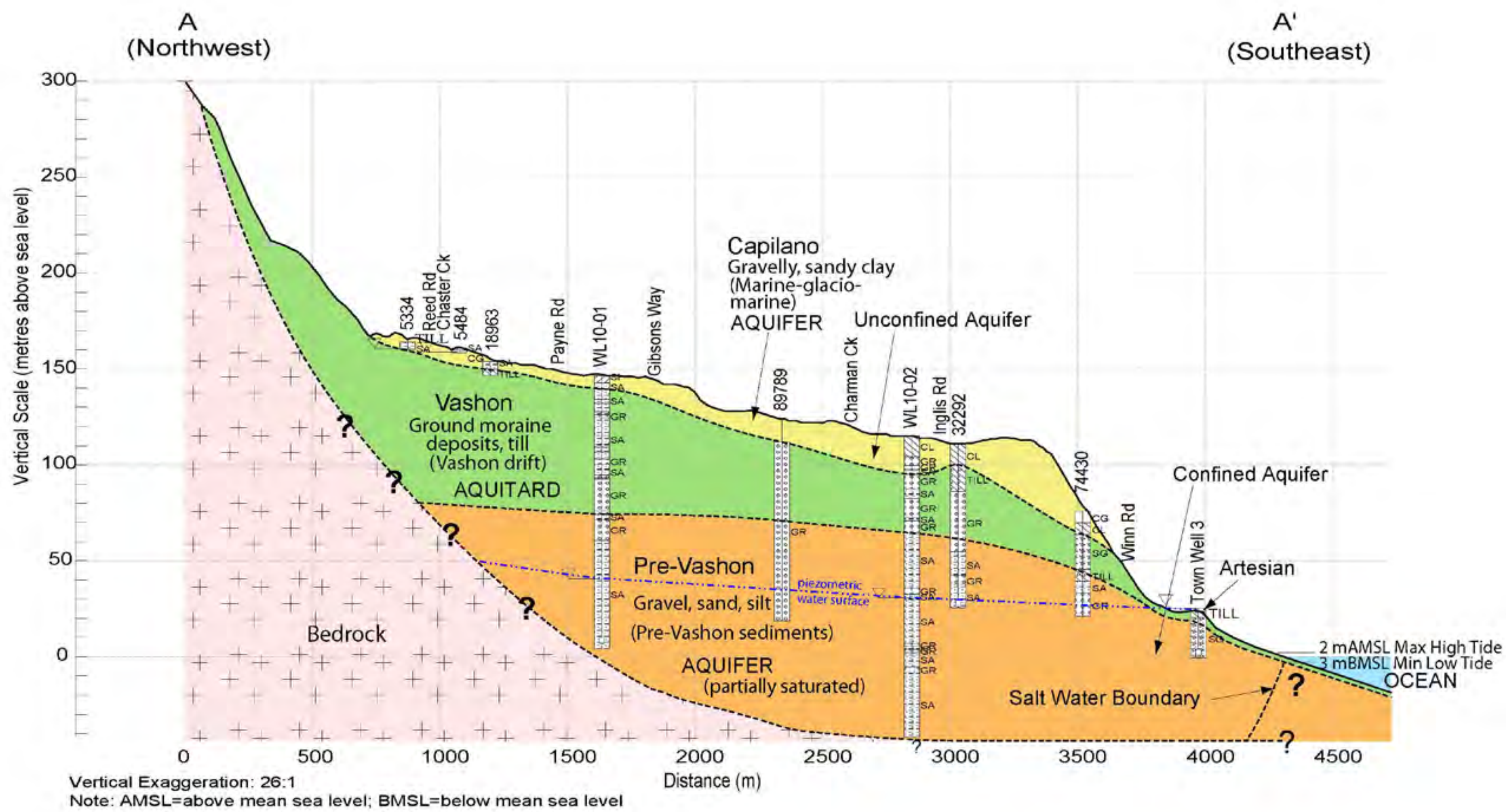
Source: Waterline (2010)

Figure 25: Salish Sediments (Capilano Alluvial), Fiedler Pit

5.0 HYDROGEOLOGICAL ASSESSMENT

5.1 Gibsons Aquifer and Aquitard System

Figure 26 is a northeast to southwest schematic geological cross-section through the Gibsons area that shows the relationship between the various unconsolidated deposits described above. The cross-section trace is shown on Figure 27. The Pre-Vashon aquifer (Gibsons Aquifer) is shown at the base of the stratigraphic sequence and capped with the Vashon Till (green) and Capilano sediments (yellow).



Source: Waterline (2010)

Figure 26: Schematic Geological Cross-Section through the Gibsons Aquifer

Although the Vashon Till is shown as the aquitard layer over the Gibsons Aquifer, as discussed previously, the Basal Capilano marine deposits likely also form a low permeability barrier over the Gibsons Aquifer and should also be considered as part of the Gibsons Aquitard.

As can be seen in Figure 26, a portion of the Gibsons Aquifer that is located in Middle and Upper Gibsons is only partially saturated (ie: the water level is below the top of the aquifer). This is supported by the observation of “blowing wells” in the Gibsons Aquifer. Waterline observed this phenomenon at monitoring well MW06-1A located in Upper Gibsons and completed in the Gibsons Aquifer. Anecdotal information provided by landowners during Waterline’s field verified survey indicates a similar behavior was observed in former water supply wells in Upper Gibsons.

Further investigation by Waterline and UBC showed that barometric pressure fluctuations caused by changes in weather over the Town resulted in the observed blowing or sucking well depending on the observed barometric pressure. This phenomenon has been observed elsewhere and can be explained as follows: A barometric pressure low which is typically associated with storm front, causes compression of the air space in the unsaturated portion of the Gibsons Aquifer and results in a “blowing well” where a draft of air can be felt exiting the well. Conversely, when good weather rolls into Town (high pressure front), the reverse is observed and well MW06-1A stops blowing and a slight suction develops at the well head. This was recognized during the Phase 1 program and confirmed during the Phase 2 program through field measurements (Doyle 2013).

The observation of blowing and sucking wells is significant as it suggests that the Vashon Till/Basal Capilano confining layer, although largely intact regionally, may be directly connected to atmosphere somewhere in the system. Although not known with certainty, it is expected that the various creeks that flow over the region may have eroded the aquitard or that in some places the aquitard is discontinuous, causing a more direct connection to the underlying Gibsons Aquifer. This finding may also be important in terms of understanding recharge to the Gibsons aquifer. It is likely that “recharge windows” exist where the Vashon/Capilano Aquitard becomes thinner or is absent, and water from the overlying unconfined Capilano Aquifer directly enters into the Gibsons Aquifer.

Source: Base map from Map Place (2009)

Figure 27: Geological Cross-Section Trace

5.2 Mapped Aquifer Extent and Groundwater Flow

Figure 28 shows the mapped extent of the Gibsons aquifer. The figure shows the confidence level of the aquifer mapping exercise based on the available geology and hydrogeology data. The figure also shows potentiometric (pressure) surface contours of the groundwater contained in the Gibsons Aquifer. This represents the elevation to which groundwater rises in wells completed within the main part of the aquifer. Groundwater flow is indicated by the blue arrows and indicates that flow within the aquifer essentially follows the local topography moving from northwest to the southeast and discharging in the vicinity of Gibsons Harbour. Based on the data collected, the groundwater pressure surface slopes at an average slope of approximately 2% from Upper Gibsons to Lower Gibsons. These data, in conjunction with aquifer transmissivity data presented below, were used to assess the groundwater flow velocity and residence time within the Gibsons Aquifer system.

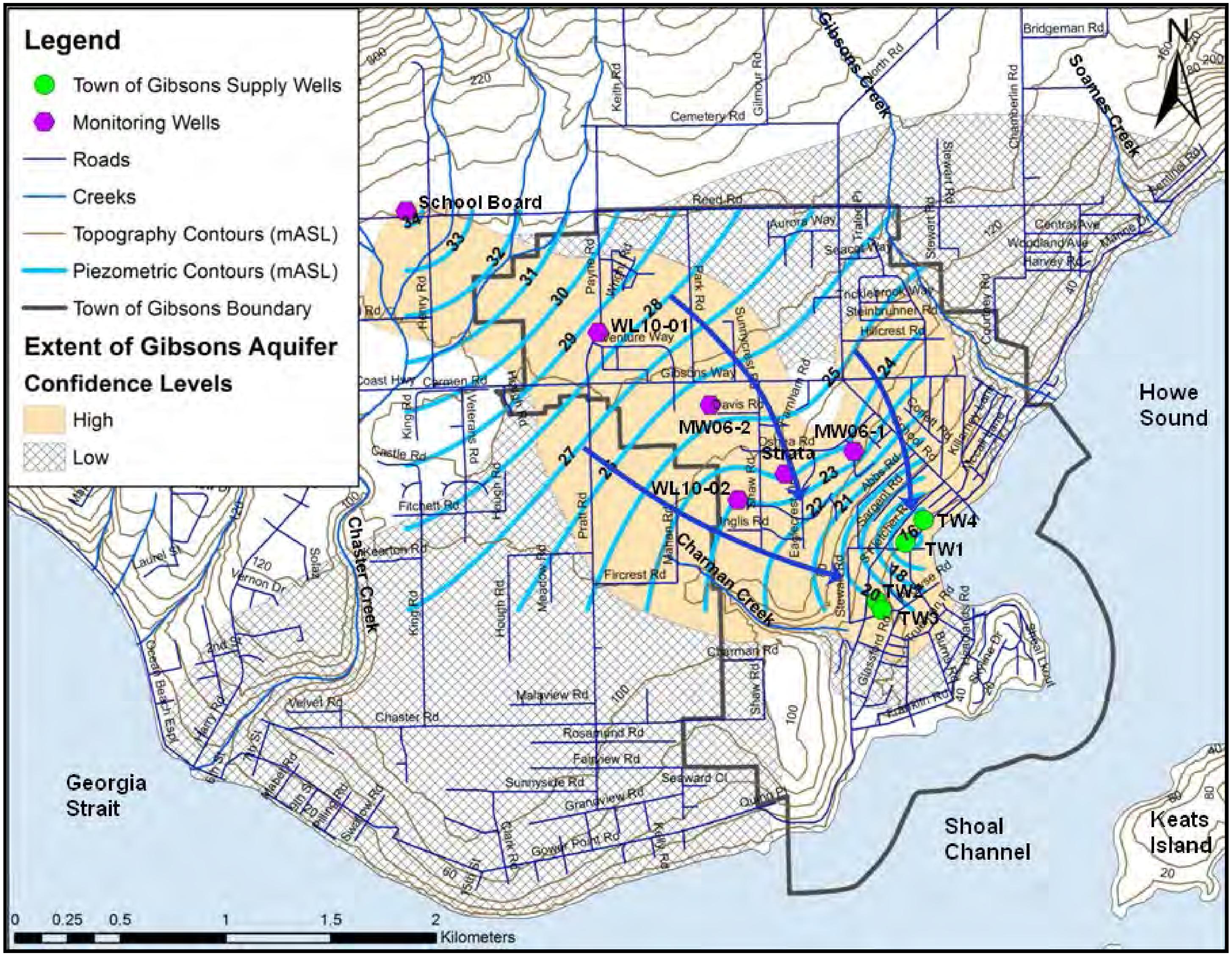
5.3 Aquifer Transmissivity and Average Linear Groundwater Velocity

Aquifer transmissivity is defined as the ability of the aquifer to transmit groundwater through the pore space between the sand and gravel material. Moderate to high transmissivity values have been reported for the Gibsons Aquifer material ranging from approximately 86 to 1728 m^2/day. The lower transmissivity value is based on re-analysis of pump test data for the Chaster Road well (Aqua-Flow Testing & Equipment Ltd., 1991) and Town of Gibsons well TW97-1 (Piteau, 1997). The upper range value was determined from a test of the Soames Point well (E. Livingstone Associates, 1979).

Table 4 presents a summary of aquifer hydraulic parameter data available for well bores completed within the Gibsons Aquifer compiled during the Waterline study.

Three methods of analysis were used to determine aquifer hydraulic parameters as follows:

- Cooper Jacob (1946) and Hantush (1962) methods for determination of aquifer transmissivity and storativity parameters using pumping test data;
- Hvorslev (1951) method for single well slug test analysis; and
- The Hazen (1892) method for hydraulic conductivity estimates using grain size distribution data.



Source: Base map provided by the Town of Gibsons

Figure 28: Mapped Aquifer Extent and Groundwater Flow

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Table 4: Aquifer Hydraulic Parameters

Well	Well Elev. (mASL)	Top of Aquifer or Top of Water Table (mBGL)	Sample Depth or Base of Aquifer (mBGL)	B (m)	S	K (m/s)	T (m^2/d)	Method	Reference
TW1	12.7	6.4	25.3	18.9	NA	NA	NA	NA	NA
TW2	18.5	12.8	15.2	2.4	NA	NA	NA	NA	NA
TW3	18.0	16.5	25.6	9.1	NA	NA	NA	NA	NA
TW4	14.0	5.5	18.6	13.1	NA	1.0E-04	38	Cooper-Jacob	Piteau, 2000
			14.3			3.0E-03	3,396	Hazen	Piteau, 2000
			15.2			1.0E-02	11,318	Hazen	Piteau, 2000
			17.0			5.0E-03	5,659	Hazen	Piteau, 2000
			18.6			4.0E-03	4,527	Hazen	Piteau, 2000
TW99-01	14.1	3.7	18.3	14.6	4.1E-04	1.4E-04	56	Cooper-Jacob	Piteau, 2000
					5.9E-04	7.8E-05	31	Hantush	Piteau, 2000
					4.9E-04	1.5E-03	596	Cooper-Jacob	Piteau, 1999
			4.9		NA	5.4E-04	681	Hazen	Piteau, 1999
			10.1			8.3E-04	1,047	Hazen	Piteau, 1999
			15.2			1.1E-03	1,388	Hazen	Piteau, 1999
TW99-02	111.9	87.0	114	27.0	NA	NA		NA	NA
			91.4		NA	2.7E-04	630	Hazen	Piteau, 1999
			99.1		NA	7.2E-05	168	Hazen	Piteau, 1999
			106.7		NA	5.4E-03	12,597	Hazen	Piteau, 1999
			109.7		NA	8.6E-04	2,006	Hazen	Piteau, 1999
			114.3		NA	9.5E-04	2,216	Hazen	Piteau, 1999
WL10-01	139.4	106.7	142.3	35.6	NA	4.9E-04	1,495	Hvorslev	Waterline
					NA	1.7E-04	514	Hvorslev	Waterline
			53.3		NA	4.6E-04	1,415	Hazen	Waterline
			109.7		NA	9.6E-05	295	Hazen	Waterline
WL10-02	1 08.1	84.0	123	37	NA	1.3E-04	419	Hvorslev	Waterline
					NA	1.2E-04	387	Hvorslev	Waterline
			42.7		NA	5.3E-04	1,694	Hazen	Waterline
			89.9		NA	3.5E-03	11,189	Hazen	Waterline

Notes: mASL means metres above sea level, mBGL is metres below ground level, B is aquifer thickness, S is aquifer storativity from pumping tests, K is hydraulic conductivity, T is aquifer transmissivity from pumping tests. The TW99 series wells were noted as being low yield and were abandoned by Piteau (1999).

Pumping tests are used to provide a large sample of the aquifer as they are performed over long periods (typically days or weeks, sometimes months), slugs test provide near-wellbore assessment and typically performed over short periods (minutes or hours), and grain size analysis provide an assessment of the physical aquifer material from discrete layers within the system (no water being pumped). All three types of data were evaluated for the Gibsons aquifer and suggest that the aquifer material is highly heterogeneous (not uniform), with discrete layers potentially having very high transmissivity values (Eg: 12,597 m^2/day for a layer in TW99-02 well bore collected from 106.7 m bgl). These very high values are not likely representative of the ability of the aquifer on average to transmit water to a supply well.

Based on the hydraulic conductivity estimates for wells completed in Upper Gibsons (WL10-01 and WL10-02), the horizontal gradients determined above, and an assumed porosity of the aquifer material of 35% (Freeze and Cherry, 1979); a horizontal groundwater flow velocity of 400 m/year was estimated using the following flow equation:

$$V = K\,(dh/dl)/n$$

Where V is average linear groundwater flow velocity, K is average hydraulic conductivity of the aquifer, dh/dl is the average horizontal gradient, and *n* is porosity. In general, the flow rate through low permeability cover materials, such as the Vashon Till or the Basal Capilano deposits, is expected to be on the order of centimeters to a few metres per year. The hydraulic data measured for the Gibsons Aquifer suggests that the residence time for water to travel through the aquifer which extends from the base of Mt. Elphinstone to Lower Gibsons may be as long as 9 years. This is relatively fast in hydrogeological terms. As will be shown with the environmental tracer data collected by UBC, groundwater contained in the Gibsons Aquifer ranges in age from 10 to 80 years suggesting that older groundwater is being recharged from the mountain block and younger water is likely entering the aquifer where the Basal Capilano and/or the Vashon Till cover is thin or absent. The range in groundwater age reflects the two possible sources of groundwater recharge to the aquifer. The basic groundwater flow velocity analysis presented above agrees with the UBC data which is explained in greater detail later in the report.

5.4 Long Term Groundwater Water Level Monitoring Program

Continuous long-term groundwater level monitoring allows for evaluation of an aquifer's response to natural phenomenon such as precipitation and infiltration/recharge events, and tidal fluctuations. Anthropogenic effects from human activities such as groundwater pumping and groundwater use can also be evaluated using long-term monitoring data. This is an important part of the aquifer mapping process as it provides clues to the interactions in the subsurface, and allows hydrogeologists to better understand the "plumbing system" within the aquifer.

The Town of Gibsons began long-term water level monitoring in Town wells and MW06-1 and MW06-2 nested well pairs in Upper Gibsons (Figure 8) prior to the initiations of the aquifer mapping study. In addition to using the existing private wells, Town supply wells, and existing monitoring wells, Waterline installed two deep monitoring wells in Upper Gibsons where no wells previously existed (WL10-01 and WL10-02). Table 2 lists the wells used in monitoring during the Waterline study along with the well construction details. Data loggers were installed in each well to collect water-level data from the aquifer. Well locations are shown on Figure 8.

5.4.1 Water Level Hydrographs – Town Wells

Town wells #1 through #4 are monitored by the Town using a SCADA system. The system collects flow and hydraulic head data among other operational parameters. Town wells #1 and #4 are flowing artesian under non-pumping conditions. These wells have not been sealed and currently discharge artesian overflow to the storm sewer and a fountain feature, respectively.

Figure 29 shows water level hydrographs for Town wells #1, #3 and #4. As indicated previously, Town well #2 is maintained used for backup only, as it has low capacity and cannot be pumped concurrently with Town well #3 due to interference between the two wells.

As Wells #1 and #4 are continually flowing even when pumps are off, it was not possible to measure static water levels in either well or the artesian pressure in the aquifer in Lower Gibsons. Therefore, the maximum water level elevations shown on Figure 29 represent the height of the sewer discharge pipe in each well. Base on the data provided in Figure 29, the pumping water levels in Town Wells #3 and #4 remain above sea level at all times. However, the pumping level in Town well #1 frequently drops to as low as 2 m below sea level. Waterline believes that this may be related to the well efficiency and may not reflect the water level in the aquifer adjacent to the well. As Town Well #1 is the oldest well in the system (>45 years old), it likely has become inefficient since it was first drilled in about 1965. This is possibly due to corrosion at the well screen or near wellbore accumulation of fine material which would cause the water level inside the well to drop over time as the efficiency of passing water through the well screen is reduced. It would be useful to have a monitoring well adjacent to the Town production wells in order to monitor the water pressure/level in the aquifer.

The discharge of artesian overflow from both Town wells #1 and #4 has been monitored for a period of about 23 months. While the wells are in operation, no overflow is observed. However, as Town well #3 is the primary water supply well, Town wells #1 and #4 are almost always flowing water to the storm sewer. The diversion of artesian flow to storm sewer was measured during the Waterline study and ranged from 45 to 205 m^3/day and averaged 163 m^3/day in Town well #1. Artesian discharge from Town well #4 ranged from 2 to 148 m^3/day and averaged 112 m^3/day over the same period. Figure 30 presents the data graphically and shows that the flow varies seasonally.

Spring and winter flows appear to be the highest recorded flows which confirms that recharge to the aquifer is closely linked to the seasonal climate. However, the rates also appear variable from year to year based on the limited available data set. Seasonal fluctuations in storm sewer overflow may also result from changes in in groundwater volume being extracted for water supply.

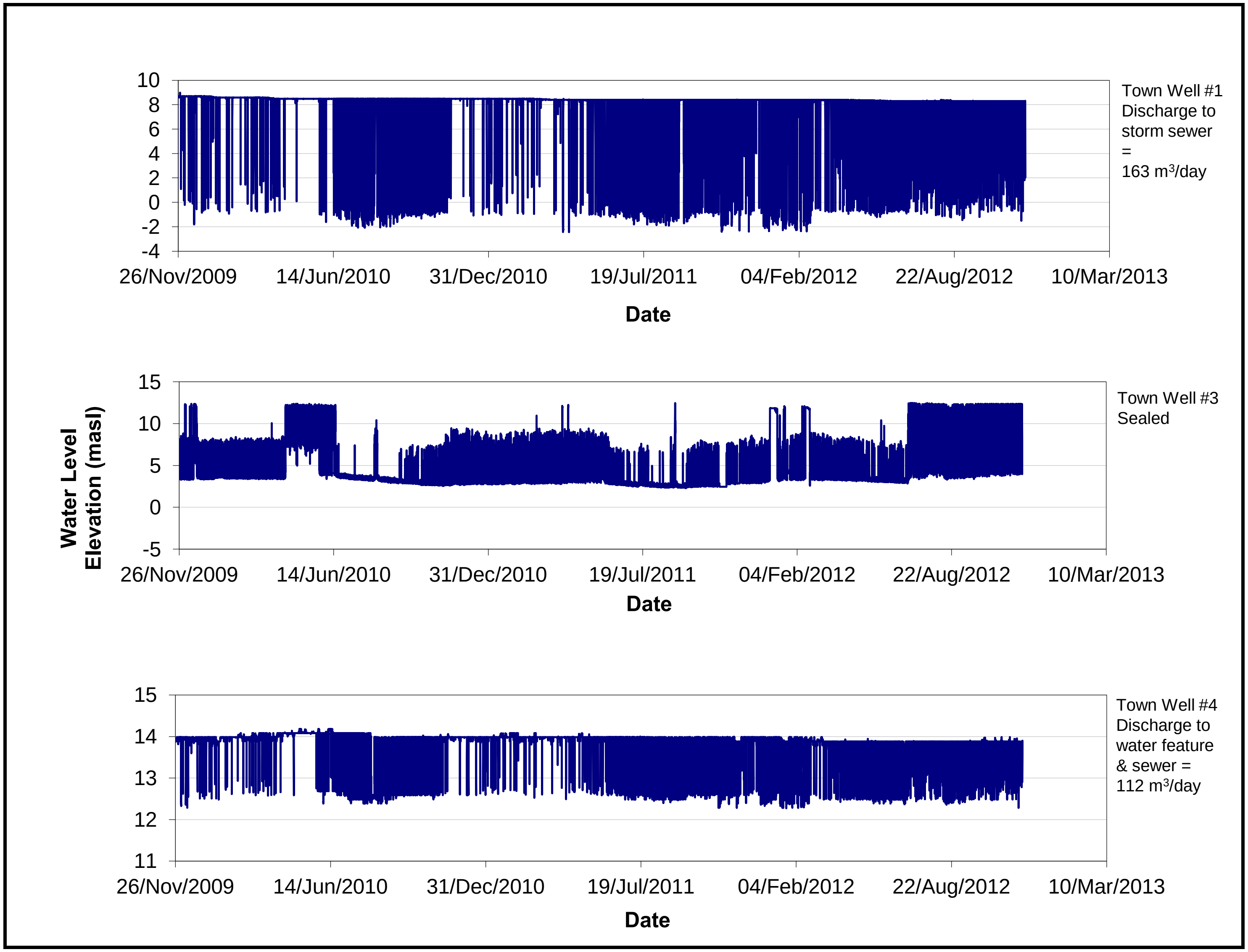


Figure 29: Water Level Hydrographs for Town Wells #1, #3 and #4

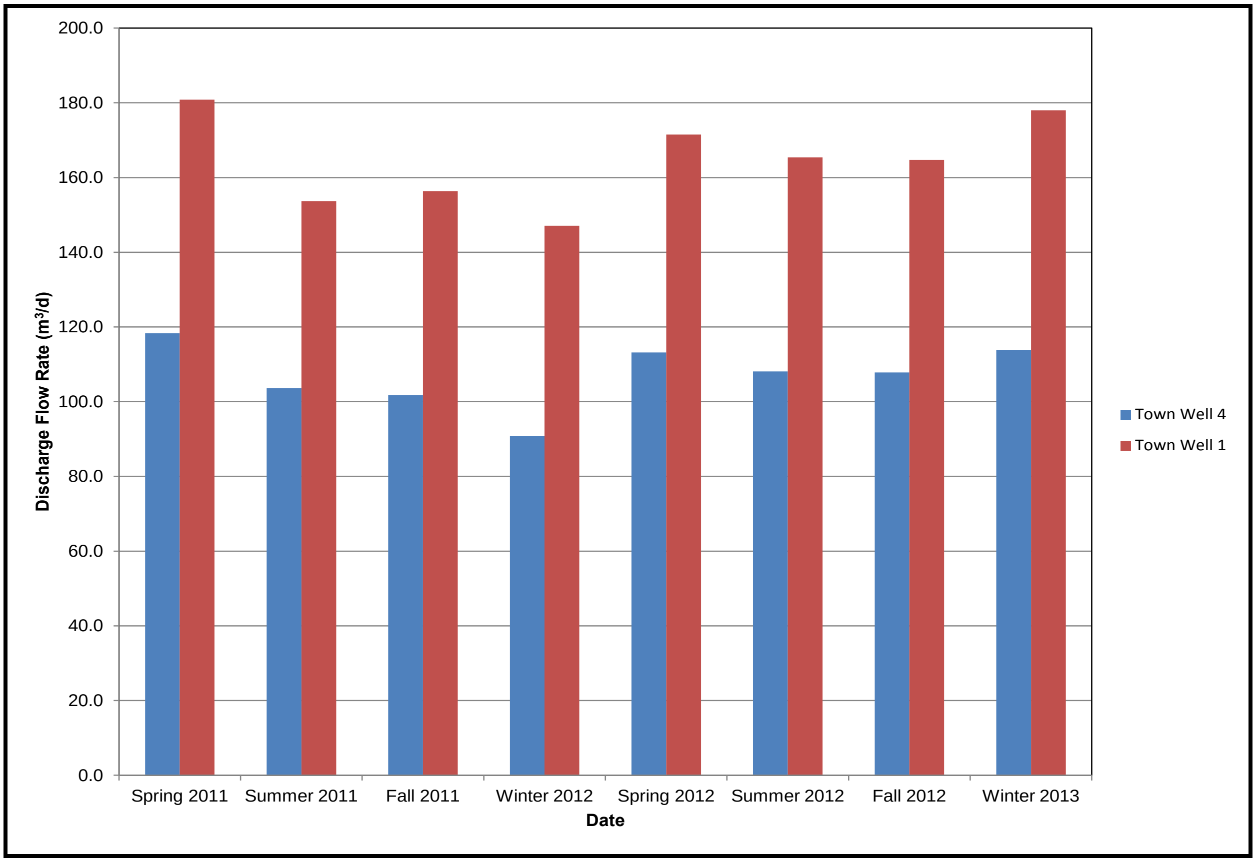


Figure 30: Storm Sewer Overflow (Artesian) - Wells #1 and #4

Town staff who have been monitoring flows over the last year, have noted that following the installation of water meters and upgrades to one of the reservoirs, artesian overflow appears to have increased possibly indicating that reduce groundwater diversion has increased the pressure and flow from the aquifer.

The estimated average artesian overflow directed from the Gibsons Aquifer is approximately 99,000 m^3/year. This is a relatively large volume of fresh water which could be used to provide water supply to about 500 residents based on water use estimates provided. Sealing the Town wells to stop the flow to the storm sewer was considered. However; geotechnical and hydrogeological concerns relating to the potential for increased pressure in the aquifer, and increasing spring discharge in unknown locales in Lower Gibsons, the Town decided to continue diverting the artesian flow to storm sewer.

5.4.2 Aquifer Response to Precipitation Events

Figure 31 and Figure 32 present the hydrographs for selected paired wells completed in the shallow Capilano Aquifer and the deep Gibsons Aquifer. The precipitation data is also provided for the same period.

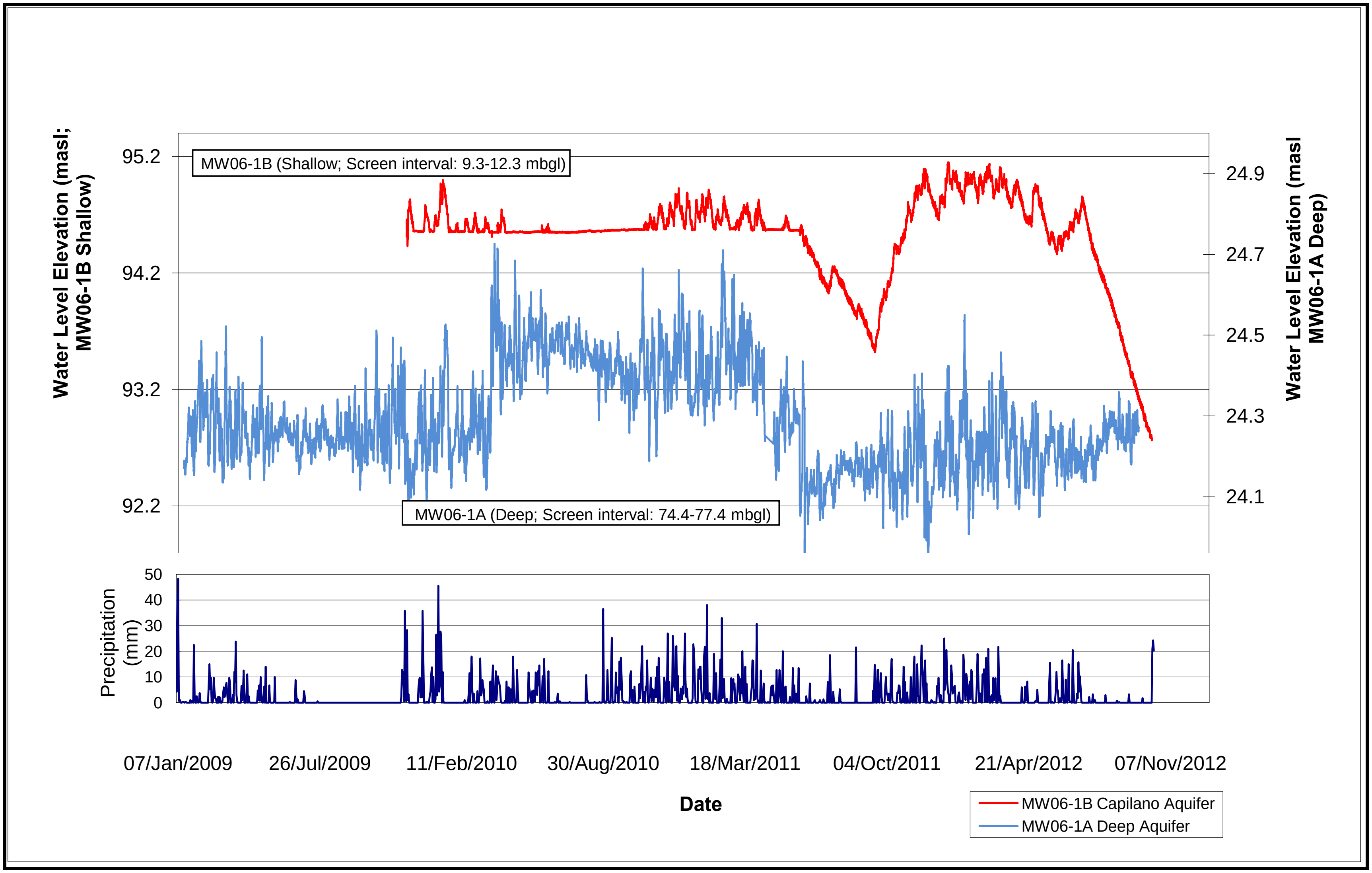


Figure 31: Aquifer Response to Precipitation – Spyglass Place Wells (MW06-1A & B)

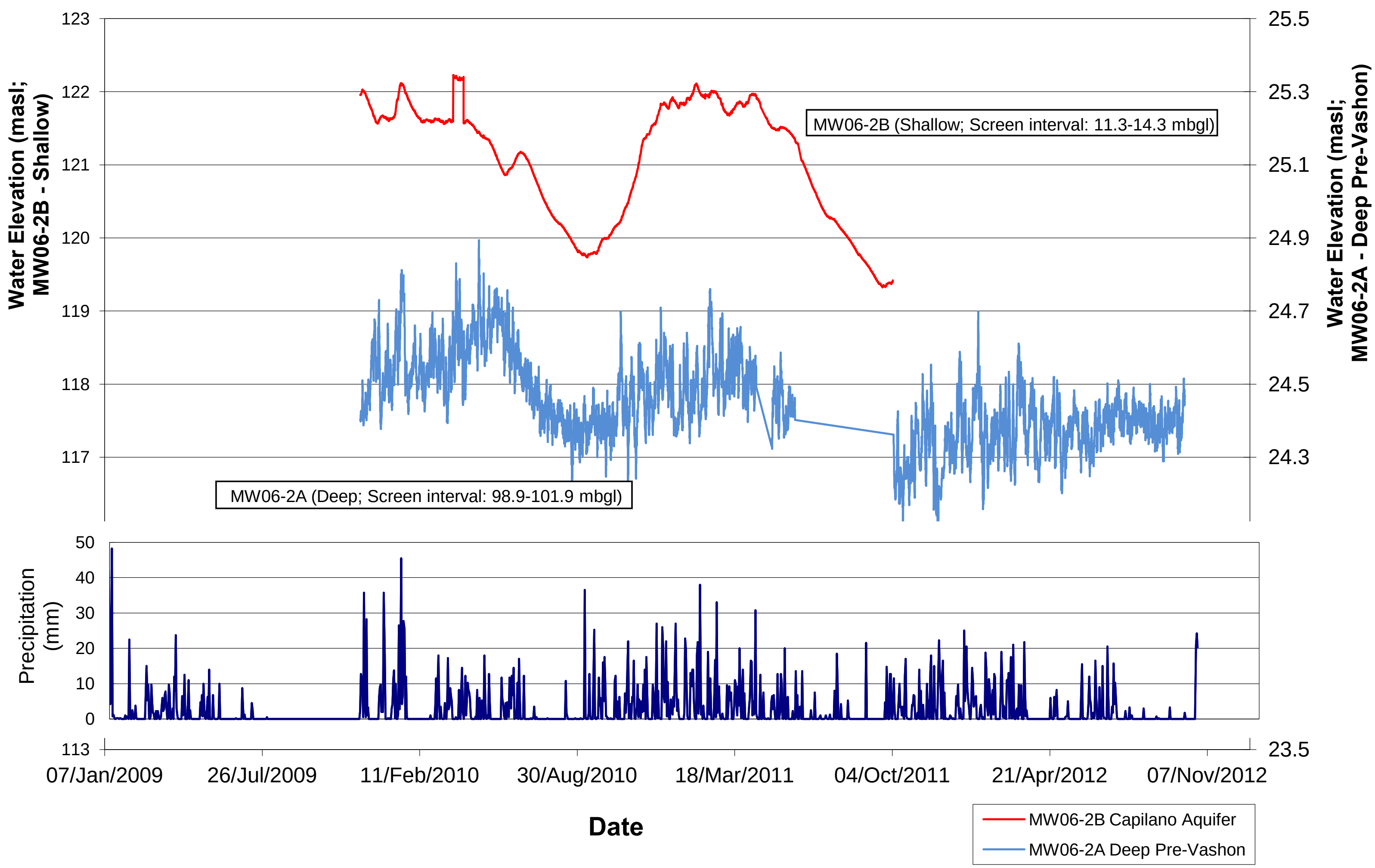


Figure 32: Aquifer Response to Precipitation – Aquatic Centre Wells (MW06-2A and 2B)

Waterline Resources Inc.

Water levels measured from wells, MW06-1A and MW06-2A fluctuate by approximately 0.4 m annually. A similar seasonal fluctuation was observed in other deep wells completed in the Gibsons Aquifer. The data indicates that the water levels in wells completed in the Gibsons Aquifer respond to precipitation events within 2 to 15 days after it has occurred. Water levels in the shallow Capilano Aquifer wells (e.g., MW06-1B or 2B) vary by approximately 2 m per year and show a much more rapid response to precipitation suggesting a more direct connection to surface.

Based on these data, it appears water levels in the shallow unconfined aquifer correlate strongly to the precipitation data. This suggests that the shallow unconfined aquifer is in direct hydraulic communication with the surface and receives direct recharge from precipitation and snow melt through the highly permeable, sand and gravel deposits. Water-level data from the deeper Gibsons Aquifer wells show a reduced correlation with the precipitation record and a more muted water level response. This indicates that Gibsons Aquifer is not in direct connection with the overlying Capilano Aquifer, or with Gibson, Charman, or Chaster Creeks that drain surface water across the region. Nevertheless, the data suggests that a connection exists (albeit indirect) between the surface and the Gibsons Aquifer and is suspected to be in the form of “recharge windows” over yet unmapped areas of the aquifer.

5.4.3 Aquifer Response to Tidal Cycles

Tides in the Gibsons Harbour fluctuate by as much as five metres from the highest to the lowest tides. Tidal data collected from the Gibsons Marina for the period of August 1 to 31, 2010 were compared to groundwater level data from WL10-02. As is shown in Figure 33, the overprinting of the hydrograph by tidal cycles is indicated in the WL10-02 monitoring record. Monitoring wells MW06-2A and the Georgia Mirage Strata well, both completed within the Gibsons Aquifer, also showed minor responses to tidal fluctuation. The monitoring well hydrographs from MW06-1A, MW06-1B, MW06-2B and WL10-01 showed little to no discernible tidal effects on the groundwater levels.

5.4.4 Aquifer Response to Pumping and Groundwater Use

Figure 34 presents the water level hydrograph for well MW06-2A located near the Aquatic Centre. The plot also shows the cumulative groundwater diversion from the Town supply wells plotted on the secondary y-axis. The groundwater levels appear to be influenced by the combined pumping from Town wells 1, 3 and 4. None of the other monitoring wells appeared to be affected by Town pumping activities. Water-level fluctuations in the shallow well completed in the over lying Capilano Aquifer (MW06-2B) shows no correlation with Town well pumping. This is consistent with the knowledge that only minor hydraulic communication exists between the Capilano and the Gibsons Aquifers in this area.

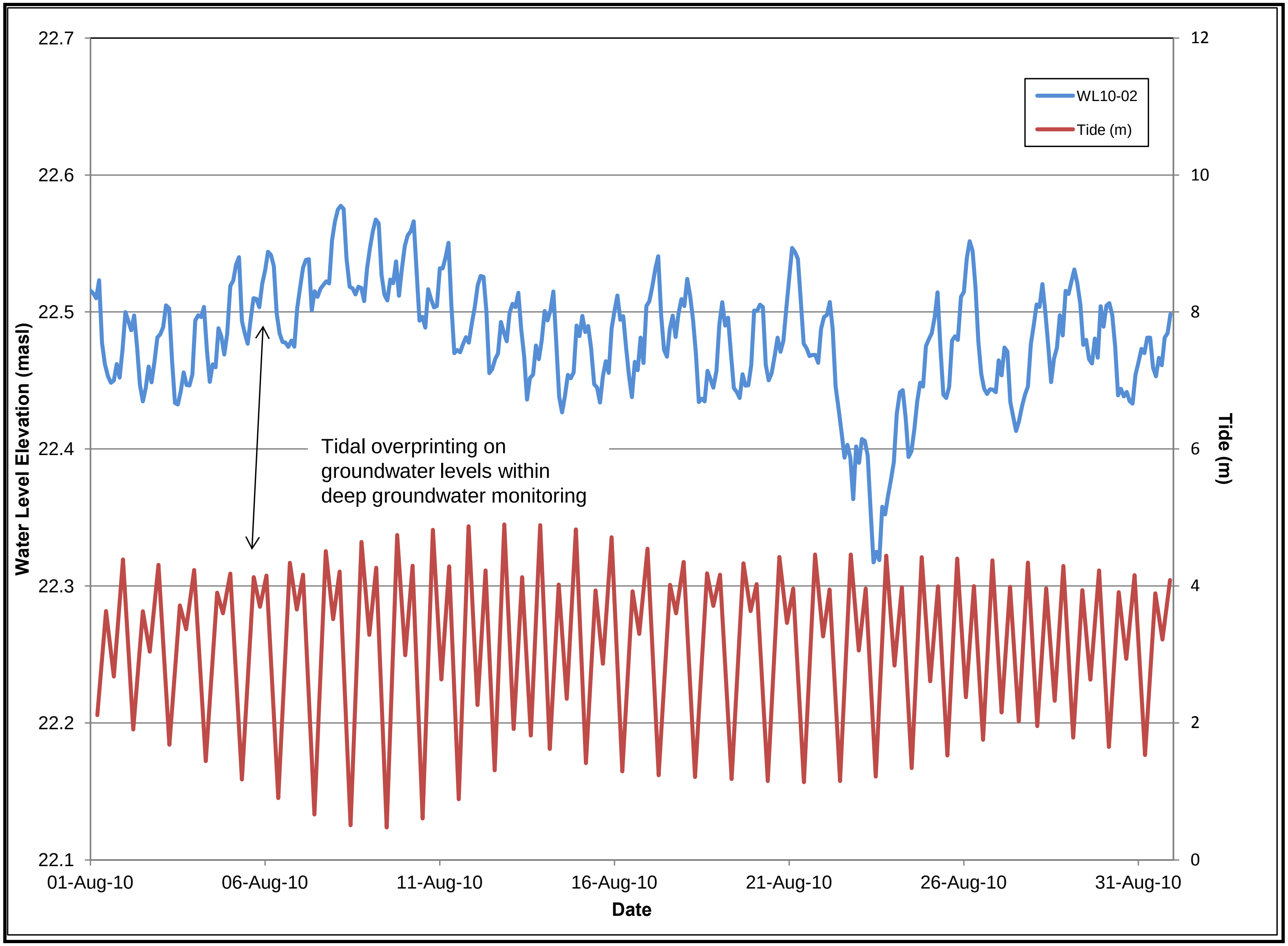


Figure 33: Tidal Response in Gibsons Aquifer (WL10-02)

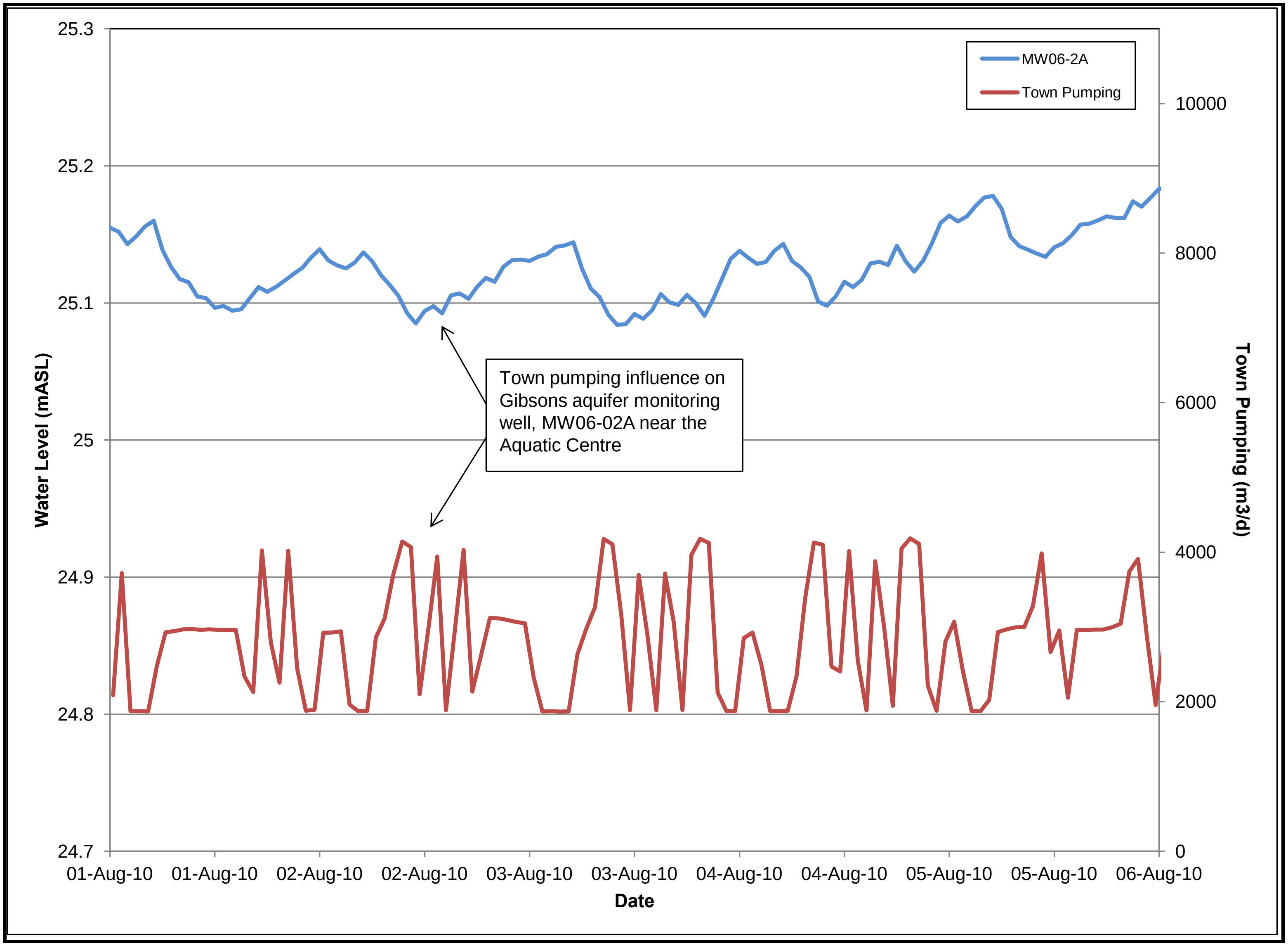


Figure 34: Response to Town Water Supply Diversion in MW06-2A

5.5 Groundwater-Surface Water Interactions

Due to the limited nature of the AECOM study, it was not possible to fully evaluate the potential for groundwater-surface water interactions using surface water flow data. Waterline and UBC conducted numerous other tasks to assess the interactions between groundwater and surface water as it relates to the origin of recharge into the Gibsons Aquifer. These data will be further discussed in the geochemistry and conceptual model sections of the report.

Natural springs mapped in Upper Gibsons are thought to be related to discharge from the shallow unconfined Capilano Aquifer Figure 14. The springs identified in Lower Gibson are thought to be related to the Gibsons Aquifer which is situated less than 10 meters below ground near the Gibsons waterfront. The continued existence of springs in Lower Gibsons indicates that that the pressure in the Gibsons Aquifer in has been maintained even after many decades of development and groundwater diversion and use.

Flow and electrical conductivity of surface water were measured along the length of each of the three main creeks within the Town boundaries. The data collected from Gibsons Creek are presented on Figure 35 relative to the creek elevation and distance from the headwaters. Several key observations were noted during the creek mapping survey completed by Waterline.

Estimates of Creek flow completed by Waterline ranged from zero where the water disappeared beneath the creek bed, to approximately 1300 m^3/day. The higher flows were generally reported in the upper reaches creeks, while flows of less than 325 m^3/day were estimated at lower elevation. This suggests that runoff from Mt. Elphinstone and groundwater discharge from the mountain block is lost along the flow path to the ocean and likely is recharged to the underlying aquifer(s).

Electrical conductivity (EC) measurements ranged from less than 40 microsiemens per centimeter (μs/cm) at high elevation, likely representative of rainwater or snow melt, to greater than 100 μs/cm at lower elevation in the watershed suggesting that groundwater may be discharging to the creeks. It is likely that the creek water recharges the unconfined Capilano Aquifer the upper reaches, while the Capilano Aquifer recharges the various creeks in the lower reaches near the coast.

The Gibsons Aquifer is generally located deeper than the base of local creeks. Recharge derived from the creeks is still considered probable in areas where the Gibsons Aquitard material is thin or non-existent.

Figure 35 shows the results of the EC survey in Gibsons Creek. The survey started at about 1700 m down from the highest point mapped in Gibsons Creek to the ocean located some 6000 m down slope along the coast. The data indicates that the EC of surface water in Gibsons Creek increases tripled at about 200 m elevation and approximately 1000m distance from the coast. This suggests that groundwater is likely discharging to Gibsons Creek and may be sourced from the Capilano Aquifer, and/or the Gibsons Aquifer.

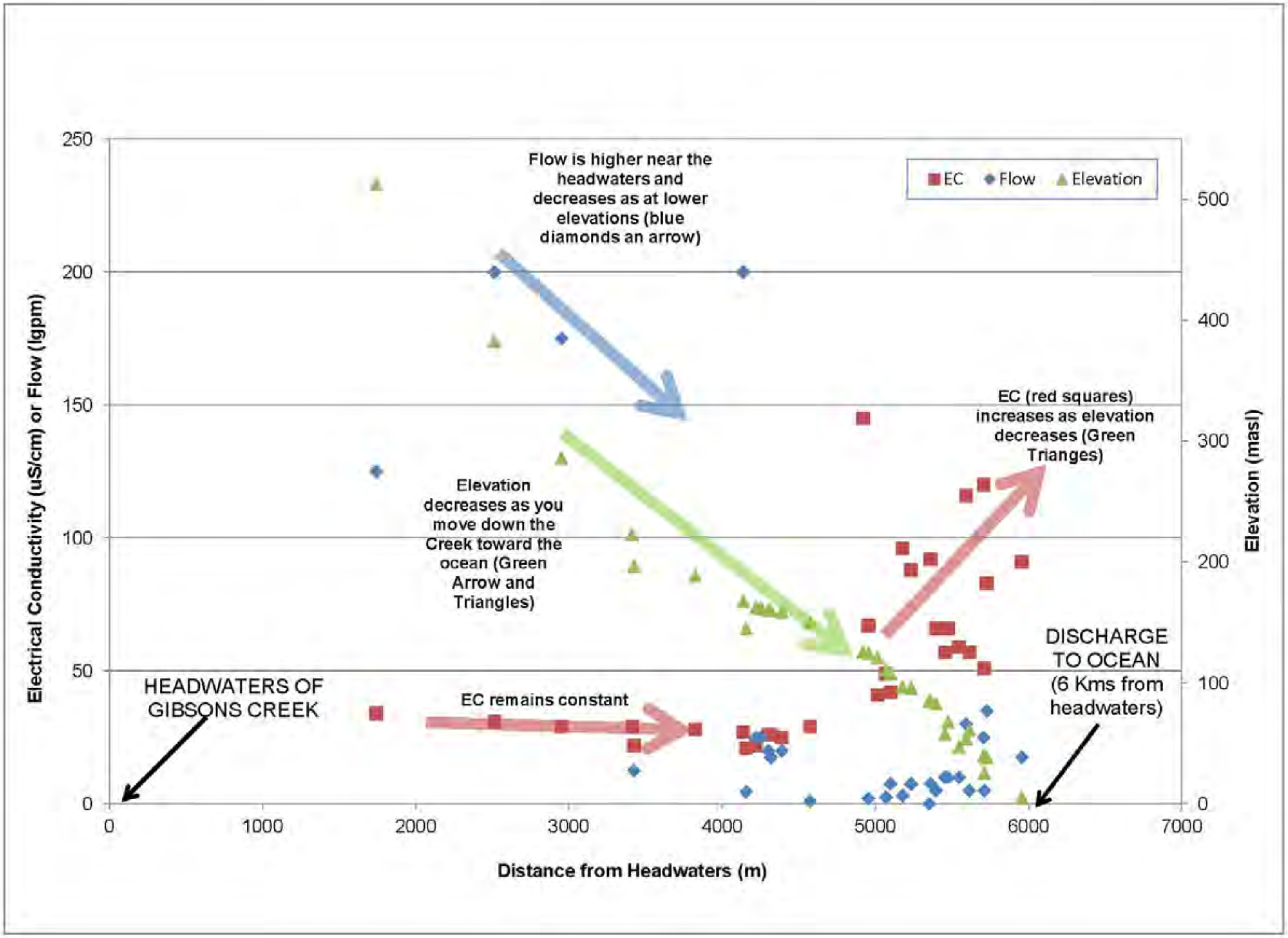


Figure 35: Interaction between the Capilano Aquifer and Gibsons Creek

Although the data indicates discharging conditions as opposed to recharging conditions (ie: groundwater moves from the aquifer(s) to the creek rather than vice versa) the data clearly indicate that groundwater and surface water interaction is occurring. The EC survey data for Charman Creek and Chaster Creek are provided in Appendix A and show a much less pronounced interaction.

5.6 Assessment of Cross-Formational Flow

Figure 36 presents the groundwater elevations within each of the Town monitoring wells. The "B" level wells (MW06-1B and MW06-2B) are completed in the shallow Capilano Aquifer, whereas the all other monitoring wells are completed in the deeper Gibsons Aquifer.

The potential for vertical groundwater flow from the shallow Capilano Aquifer into the Gibsons Aquifer is determined from hydraulic conductivity of intervening materials and the vertical hydraulic gradient between the two aquifers. The vertical gradient is estimated by calculating the difference in water levels in shallow wells completed in the Capilano Aquifer, and deep wells completed in the underlying Gibsons Aquifer, divided by the vertical distance between the well screens. Groundwater moves from high elevation to low elevation and Figure 36 shows that Capilano wells exhibit a higher hydraulic head (water level) than Gibsons Aquifer wells and therefore there is a strong downward gradient or component of groundwater flow between the two units. Multilevel well pairs, MW06-1A and B and MW06-2A and B located at Spyglass Place and the Aquatic Centre, respectively, illustrate this point. Groundwater from the shallow Capilano Aquifer is moving downward to the underlying Gibsons Aquifer. Based on observations during drilling and the observed "blowing" well discussed in Section 5.2, it is understood that the groundwater in the Capilano Aquifer is also 'perched' in some area and the development of an unsaturated zone suggests that the two systems are disconnected at that location.

5.7 Groundwater and Surface Water Geochemistry

5.7.1 Measured Field Parameters

Table 5 summarizes the water quality parameters measured during the initial sampling event. The field EC data indicates that the surface water generally exhibits values of below 100 uS/cm with the exception of Charman Creek samples which indicate slightly higher EC values. The data indicates that Charman Creek is likely receiving recharge from the unconfined Capilano Aquifer and may be related to the elevated chloride and fluoride observed near the Aquatic Centre.

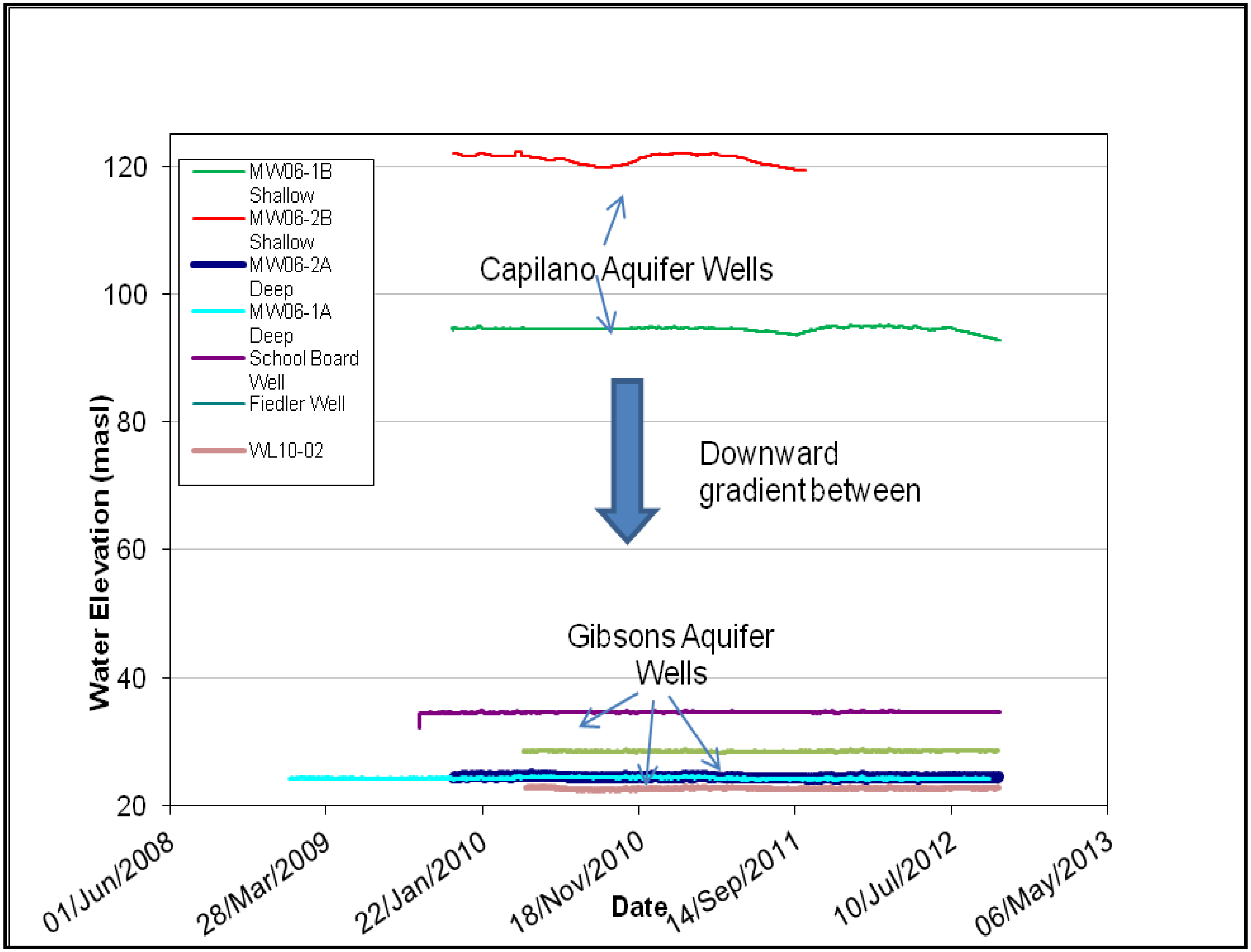


Figure 36: Vertical Gradient Assessment between Capilano and Gibsons Aquifer

Table 5: Field Measured Water Quality Parameters

Station Name	Northing (m)	Easting (m)	Field Parameters		
			pH	EC (uS/cm)	Temp (oC)
CHAR 1	5472645	462147	6.9	56	14.9
CHAR 2	5471637	462787	7.4	112	14
CHAR 3	5471786	463158	7.41	152	14.9
CHST 1	5475141	461181	6.44	25	13.3
CHST 2	5472898	460770	7.32	27	15.1
CHST 3	5471007	459778	7.45	87	15.1
GIBS 1	5476013	461758	7.02	34	12.2
GIBS 2	5474461	462688	6.82	28	14.6
GIBS 3	5472767	463663	7.84	54	13.7
School Board	5473611	460684	7.83	67	11.4
MW06-01A	5472485	462835	7.47	137	13
MW06-01B	5472485	462835	7.04	304	15.3
MW06-02A	5472682	462140	6.81	276	11.9
MW06-02B	5472682	462140	6.82	126	14.1
TW1	-	-	7.85	97	10.9
TW3	-	-	7.22	93	11.2
TW4	-	-	7.69	92	10.9

Notes: Field parameters shown only for the June 2009 sampling event. All other data provide in Appendix E. CHAR means Charman Creek sample, CHST means Chaster Creek sample, GIB means Gibsons Creek, EC means electrical conductivity, Temp means temperature.

5.7.2 Routine Chemistry

A summary of historical routine surface water and groundwater quality data is presented in Table E1 (Appendix E). Analytical results indicate that the groundwater quality from the Gibsons Aquifer within Lower Gibsons has remained relatively consistent. Based on the data, Gibsons Aquifer water is dominantly sodium-calcium-magnesium bicarbonate type water, a neutral pH and low TDS (Figure 37).

Water quality results from Town wells #1 through #4 meet the Guideline for Canadian Drinking Water Quality (GCDWQ) (Health Canada 2012) for parameters tested.

Water quality results from the other monitoring wells reported the following exceedances of the GCDWQ:

- Dissolved fluoride concentrations have been increasing since 2009 in groundwater samples collected from MW06-2B. This well is completed in the Capilano Aquifer near the Aquatic Centre. The fluoride concentration recorded in 2012 exceeded the GCDWQ.
- Aluminum (total and dissolved) concentrations have on occasion exceeded the GCDWQ in groundwater from WL10-01, WL10-02, MW06-01A, MW06-1B and MW06-2B.
- Arsenic concentrations have increased over the last 3 sample events in groundwater from WL10-01. Samples collected in 2011 and 2012 from this well have exceeded the GCDWQ for arsenic.

- Iron and/or manganese concentrations have exceeded the GCDWQ in groundwater samples from WL10-01, WL10-02, School Board well, MW06-1A, MW06-1B and MW06-2B.
- Total coliform bacteria reported for the first round of water sampling from WL10-01 exceeded the GCDWQ.

No other parameter exceedances were noted.

Total aluminum, iron and manganese represent significant constituents in the minerals found in the earth's crust. The observed results for these parameters varied over four orders of magnitude, with the higher total metals concentrations recorded in water samples with corresponding high turbidity results. Turbidity provides an indication of a water sample's cloudiness resulting from suspended sediment. The higher levels of total aluminum, total iron and total manganese likely represent trace metal constituents present within suspended soil particles as a result of the recent installation of the wells, or from a partially developed well. Groundwater samples collected from the Town wells 1, 3 and 4 which are actively pumped contained low concentrations of total aluminum, iron and manganese and correspondingly low turbidity.

The elevated arsenic level in WL10-01 likely originates from the bedrock as arsenopyrite minerals which can occur in bedrock formation. Speciation of the arsenic is required to determine its oxidation state so that the source of the arsenic can be further evaluated. If the arsenic is dominantly in the oxidized form (As 5+), then the well may be causing the arsenic to mobilize as it introduces atmospheric oxygen into the subsurface that was otherwise an oxygen deficient environment prior to well installation. If the arsenic contained in groundwater at WL10-01 is in its reduced form (As 3+), then the arsenic is most likely naturally occurring in the bottom sediments of the aquifer where it is in direct contact with the granite bedrock. As the Gibsons supply wells are completed near the top of the aquifer and not near the bedrock interface, no significant risks is anticipated to the Town's water supply unless new wells are completed near the bedrock contact. This practice should be avoided and arsenic levels should continue to be monitored to confirm initial results.

Some monitoring wells appear to have an upward trend for measured chloride (WL10-02 and MW06-1B), sodium (WL10-01 and WL10-02) and fluoride (MW06-1B and MW06-2B). Each parameter concentration remains relatively low, but the trends should be monitored. Well MW06-2B is of particular interest since it is located adjacent to the Aquatic Center and near another pool facility located at 913 Gibsons Way, which may be the source of the elevated chloride and other constituents.

The geochemical results (major ion concentrations) were evaluated to assess the relationship between the different water sources by plotting the water quality data on a Piper diagram (Figure 37).

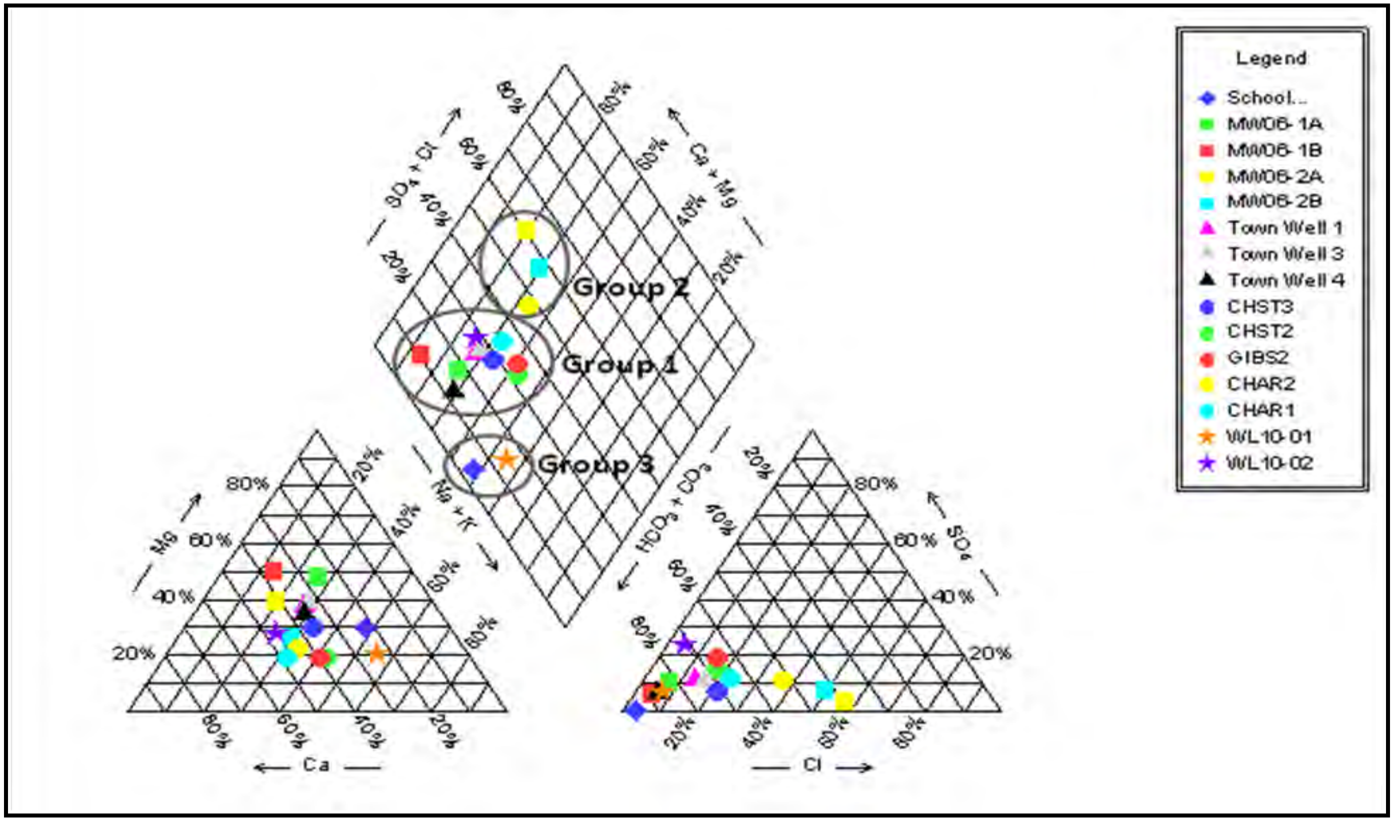


Figure 37: Piper Plot of Gibsons Surface Water and Groundwater Major Ion Chemistry

Group 1 represents water samples from wells completed into Gibsons Aquifer in Lower and Upper Gibsons, samples collected from deeper and shallower levels within the overlying Capilano Aquifer and Vashon Drift, and creek samples. In general, there is a strong similarity in the geochemical signatures between the surface water, the Capilano Aquifer, and Gibsons Aquifer samples suggesting that the groundwater is relatively young and has not undergone significant geochemical evolution.

Group 2 represents water samples from wells completed in the shallow Capilano Aquifer beneath the Gibsons Aquatic Centre and a sample collected in Charman Creek just down gradient of the Aquatic Centre. These samples are also young and are not substantially evolved, but seem to have chloride concentrations that are approximately twice those measured in all other water samples collected (background). The occurrence appears to be localized since the water chemistry for a Charman Creek sample collected further up-gradient near Spyglass Place, and the water quality samples from the Gibsons Aquifer in the Town wells do not show the elevated chloride. One potential source for chloride in this area might be the Aquatic Centre or the pool located at 913 Gibsons Way. Although concentrations remain relatively low, continued monitoring is required to assess the trend. Follow up with the directors of the Aquatic Center and the pool facility at 913 Gibsons Way is recommended to determine water handling practices at each site.

Group 3 represents water quality in the new monitoring well near Payne Road (Gibsons Aquifer) and the School Board monitoring well near Reed and Henry Roads. These wells are completed near the base of the Gibsons Aquifer. The School Board well may actually be completed in bedrock, although no well log is available for this well to confirm its construction. The groundwater in these samples appears to be slightly more evolved in comparison to water in the other samples. This suggests that the groundwater may be sourced from deep in the Mt. Elphinstone Mountain Block.

5.7.3 Environmental Tracer Geochemistry

Environmental isotopes are naturally occurring elements that are part of the chemical structure of water. Analyzing for these elements provides a tool for assessing the groundwater source, recharge mechanism, and flow path history.

5.7.3.1 Stable Isotopes

Isotopes are variants of the same element but have different atomic weight. Water (H_2O) is made up of two hydrogen and one oxygen molecule and therefore assessing oxygen and hydrogen isotopes bond together can help determine the conditions under which the water molecule formed.. For instance, Oxygen-18 (^{18}O) is heavier than Oxygen-16 (^{16}O) and both elements can become part of a water molecule. Similarly, Deuterium (^{2}H) is the heavier isotope of hydrogen (^{1}H) that naturally occurs in water and accounts for approximately 0.015% of all naturally occurring hydrogen. Because water molecules containing ^{18}O and/or ^{2}H or ^{3}H are heavier, they are slightly less volatile and natural processes such as evaporation and condensation can cause enrichments or depletions of the "heavy" isotopes in the water structure. A water molecule made up of lighter isotopes are generally less strongly bonded and therefore require less energy to evaporate or condensate the lighter molecules leaving the water molecules composed of the heavier isotopes. Due to such characteristics, stable isotopes of oxygen and hydrogen can help to determine the origin and history of groundwater.

Water samples analyzed for stable isotopes were collected from creeks, springs and selected monitoring wells during Phase 1 and Phase 2 programs. The Global and Local Meteoric Water Line (GMWL and LMWL) represents the global and local precipitation (meteoric) signature which serves as the benchmark for assess the origin of water in creeks and aquifers. Stable isotopes results of oxygen (^{18}O) versus deuterium (^{2}H) are plotted relative to the Global Meteoric water line (GMWL) and the estimated local meteoric water line (Figure 38). The local meteoric water line (LMWL) was estimated based on the average recorded ^{18}O and ^{2}H values from two of the closest *Canadian Network for Isotopes in Precipitation* monitoring stations which are located on Saturna Island and Victoria (2012).

Charman Creek samples plotted slightly right of the GMWL and very close to the estimated LMWL. This suggests that water in Charman Creek is mainly derived from rainwater that may have undergone some evaporation causing the samples to be enriched in deuterium.

Groundwater and spring samples generally contain the lighter isotope and were depleted in ^{18}O and ^{2}H compared to the surface water samples and therefore plot lower along the GMWL (Figure 38). Based on an understanding of how hydrologic processes affect the isotopic composition of water, rainwater samples plotting further down the GMWL are typically depleted in ^{2}H and ^{18}O when the water molecule formed under cooler conditions, generally at higher latitude and elevation, or as precipitation falling as snow. Conversely, rainwater falling along the coast at lower elevation, or under warmer conditions plot higher along the GMWL, as seen in the Charman Creek samples (Figure 38).

Groundwater and spring samples collected in the study area also show oxygen-18 (O^{18}) depletion and plot to the left of the GMWL and the estimated LMWL. This signature suggests that water recharging the Gibsons Aquifer has a component that originates as snow melt.

Samples collected from Chaster and Gibsons Creek appear to be more depleted in ^{2}H and ^{18}O in comparison to Charman Creek samples, but enriched in ^{2}H and ^{18}O compared to groundwater and springs samples. This relationship suggests that water in Chaster and Gibsons Creeks could be a mixture of rainwater and groundwater, or that precipitation feeding Chaster and Gibsons Creek falls at high elevation or is fed by snowmelt.

The Gibsons Aquifer is located deep below ground (>100m) in Upper Gibsons. Precipitation falling over the area is likely to enter the Gibsons Aquifer via the creeks or percolation and recharge through the Capilano Alluvium, the unconfined Capilano Aquifer, and the low permeability Vashon Till. Given the isotopic results, a significant portion of recharge feeding the Gibsons Aquifer appears to originate from precipitation falling at high elevation over Mt. Elphinstone which likely travels rapidly through the fracture bedrock where the Gibsons Aquifer contacts the mountain block in Upper Gibsons (Figure 26). The other possibility is that precipitation at high elevation on Mt. Elphinstone travels rapidly as runoff due to the steep slope and enters the aquifer where thick Capilano Alluvium occurs in north of the Gibsons Town Boundary. Only minor geochemical or isotopic evolution is indicated to occur along the travel path.

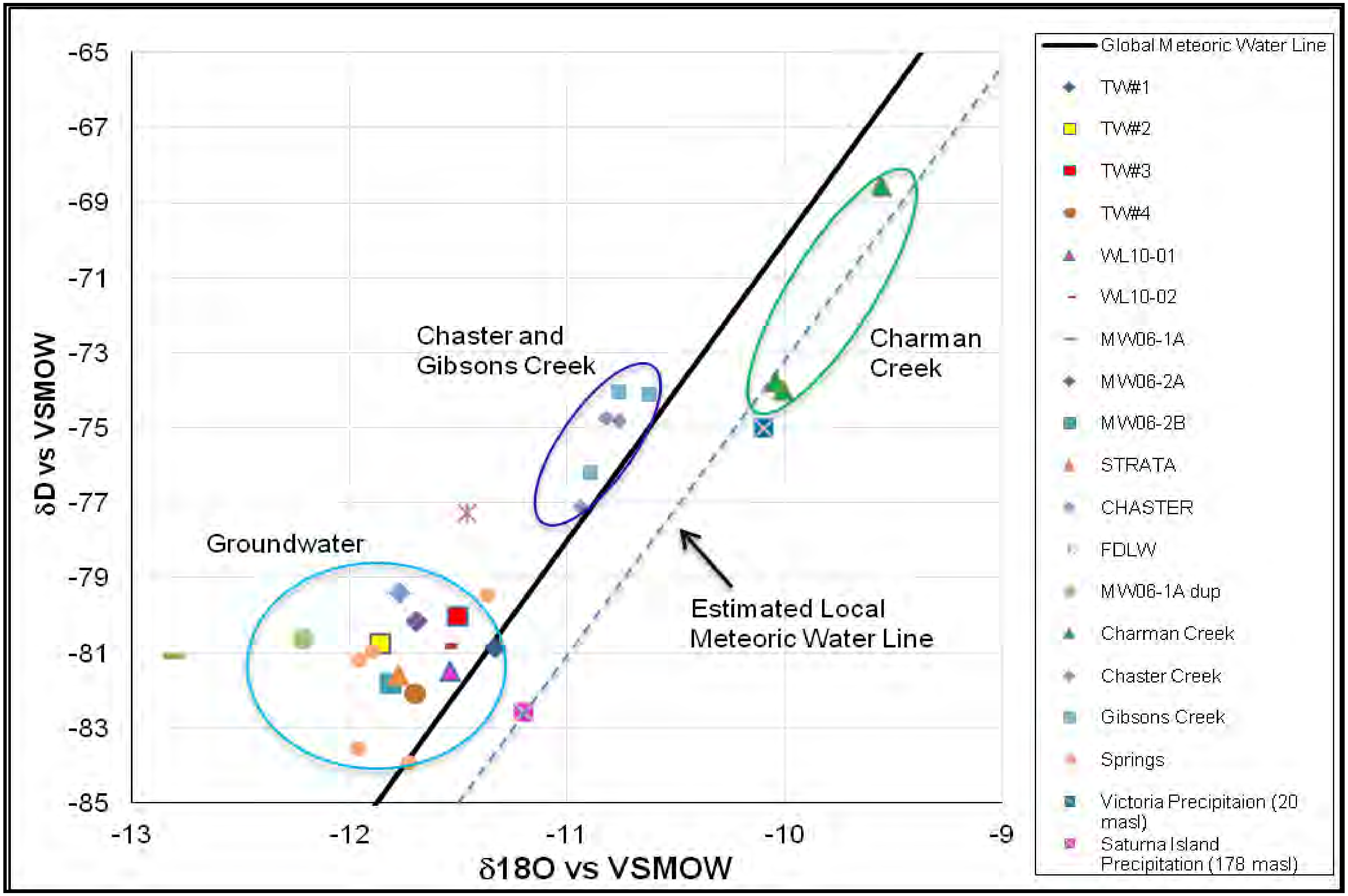
Stable isotope signatures vary seasonally. For a proper, in-depth analysis of stable isotopes in the Gibsons Aquifer, frequent (monthly) samples of groundwater, surface water and precipitation is required over several years. One or two sampling events may not be sufficient to provide a definitive analysis.

5.7.3.2 Radioactive Isotopes

Tritium (^3H) is the radioactive isotope of hydrogen. Natural background concentrations of tritium are regularly introduced into the environment by cosmic rays colliding with the nitrogen atoms in the atmosphere. Natural concentrations of Tritium are typically low, ranging from 2 to 8 Tritium Units (TU). The initiation of the nuclear testing in 1952 introduced high concentrations of tritium to the atmosphere. Atmospheric tritium concentrations steadily increased until 1963 when atmospheric testing was discontinued. After 1963, concentrations have decreased with time, and since about 1990, concentrations have dropped to between 4 and 15 TU in the atmosphere. At present, low concentrations of localized tritium is introduced to the atmosphere by nuclear power plants, nuclear fuel reprocessing plants, and a variety of other smaller sources.

Similar to deuterium, tritium can replace hydrogen in the water molecule structure and form tritiated water (^3H_2O). The concentration of tritium in water reflects the atmospheric tritium concentration at the time the water molecule was formed and shortly before it was recharged. Tritium, however, is radioactive and has a half-life of 12.32 years. Groundwater that has lost contact with the atmosphere for a prolonged period of time (many decades or longer) generally exhibits non-detectable levels of tritium. Therefore, groundwater containing a measurable amount of Tritium indicates that the groundwater has been in circulation for less than 50 years. Tritium concentrations can also be affected by groundwater that is a mixture of water of different ages. Analyzing for Tritium can help determine the age of the water and provide information on groundwater recharge and flow or residence time in the aquifer. The method is semi-quantitative and should always be accompanied by additional age-dating methods. Below are approximate values of tritium compiled by Motzer (2007) to assist in determining groundwater age in water collected from the Gibsons and Capilano Aquifers:

- <0.8 TU indicates sub-modern or older water (prior to 1950s);
- 0.8 to 4 TU indicates a mix of sub-modern and modern or young water;
- 5 to 15 TU indicates modern water (<5 to 10 years);
- 15 to 30 TU indicates tritium originating from nuclear testing;
- >30 TU recharge occurred in the 1960s to 1970s.



Notes: δ D Vs VSMOW means change in deuterium isotopic composition versus Vienna standard mean ocean water, $\delta^{18}O$ Vs VSMOW means change in the isotopic composition versus Vienna standard mean ocean water (delta-O-18 is a measure of the ratio of stable isotopes ^{18}O:^{16}O (oxygen-18:oxygen-16), all concentrations reported in per mil" (‰, parts per thousand). Source: Doyle M.Sc. Thesis (in Press)

Figure 38: Oxygen Versus Deuterium Plot

Table 6 summarizes the results from groundwater samples analyzed for tritium. WL10-01 and WL10-02 were sampled twice, once in 2010 by Waterline and once in 2011, along with the rest of the samples by UBC (Doyle, 2013).

Table 6: Enriched Tritium Tracer Analysis

Well Sampled	Measured ^{3}H (TU)	Age Estimate
MW06-1A	2.7	Mix of sub-modern and modern water
MW06-2A	4.9	Mix of sub-modern and modern water
MW06-2B	3.3	Mix of sub-modern and modern water
WL10-01	<0.8	Sub-modern water (prior to 1950s)
	0.05	
WL10-02	3.9	Mix of sub-modern and modern water
	3.5	
Town Well 1	3.9	Mix of sub-modern and modern water
Town Well 2	5.7	Modern water (<5 to 10 years)
Town Well 3	4.3	Mix of sub-modern and modern water
Town Well 4	5.5	Modern water (<5 to 10 years)
Chaster	1.8	Mix of sub-modern and modern water
Strata	6.6	Modern water (<5 to 10 years)

Tritium concentrations were all found to be low. The data suggests that most samples consist of a mixture of sub-modern and modern water. WL10-01, located closest to the base of Mt. Elphinstone, has less than 0.8 TU indicating sub-modern or older water which likely sourced from the mountain block. Tritium data for Town Well 2, Town Well 4, and the Strata well indicate modern or young water (5-10 years old). Town Well 2 and Town Well 4 are screened at shallower depths into the Gibsons Aquifer than Town Wells 1 and 3, and may contain younger groundwater discharging from shallower flow paths. Although it is difficult to draw definitive conclusions about the source of groundwater in the Gibsons Aquifer, the data indicates that groundwater consists of a mixture of modern and sub-modern water.

5.7.3.3 Noble Gases

Noble gases are naturally occurring gases found in the atmosphere such as helium, neon, argon, krypton, and xenon. When water is in contact with the atmosphere, noble gases dissolve into the water structure at concentrations proportional to the ambient temperature and pressure which relates to the elevation at which the water entered the aquifer (recharge). In groundwater, measured noble gas concentrations reflect atmospheric conditions (temperature and pressure) at the time of recharge, when water was last in contact with the atmosphere.

Groundwater samples from eleven monitoring wells were collected by UBC (Doyle, 2013) and analyzed for noble gases. Analytical results are provided in Appendix E, and more detailed analysis is provided in Doyle (2013). Table 7 summarizes noble gas results and the calculated recharge temperatures and range of recharge elevations for samples collected from each well in the groundwater monitoring network.

Table 7: Noble Gas Results – Recharge Temperature and Elevation

Well Sampled	Calculated Recharge Temperature (°C)	Estimate Recharge Elevation Range (mASL)
MW06-1A	8.6	100 – 310
MW06-2A	9.1	122 – 220
MW06-2B	8.7	122 – 420
WL10-01	5.8	650 – 1150
WL10-02	7.6	140 – 640
Town Well 1	6.0	650 – 1180
Town Well 2	7.6	190 – 680
Town Well 3	5.9	630 – 1140
Town Well 4	7.9	170 – 900
Chaster	5.7	670 – 1210
Strata	6.3	490 – 1020

Noble gas calculated recharge temperatures and estimated recharge elevations indicate that groundwater in WL10-01, Town Well 1, Town Well 3, and the Chaster well was formed under colder conditions (cool recharge temperatures) with corresponding recharge elevations extending up to 1200 m ASL to the top of Mt. Elphinstone. Conversely, groundwater collected from MW06-1A, MW06-2A, and MW06-2B, indicate warmer recharge temperatures and lower recharge elevation. Samples collected from WL10-02, Town Well 2, Town Well 4, and the Strata Condo well exhibit mid-range recharge temperatures and recharge elevation.

The noble gas data indicates that groundwater recharging the Gibsons Aquifer consists of cold water formed at high elevation, and warmer water formed at lower elevations, likely near Upper Gibsons. Samples with mid-range temperatures could either be recharged at mid-range elevations, or could be a mixture of the cold and warm recharged water.

5.7.3.4 Tritium/Helium ($^3H/^3He$) Dating

As discussed above, Tritium is a radioactive isotope with a half-life of 12.32 years. The decay product of tritium (^3H) is tritogenic helium (^3He). When both tritium (^3H) and helium (^3He) are measured in groundwater, the $^3H/^3He$ ratio can be applied to calculate apparent groundwater age (i.e.: how long the water has been underground). Table 8 summarizes the apparent groundwater ages calculated from the $^3H/^3He$ ratio (Doyle, 2013).

Table 8: Calculated Apparent Groundwater Age Using Tritium/Helium Ratio

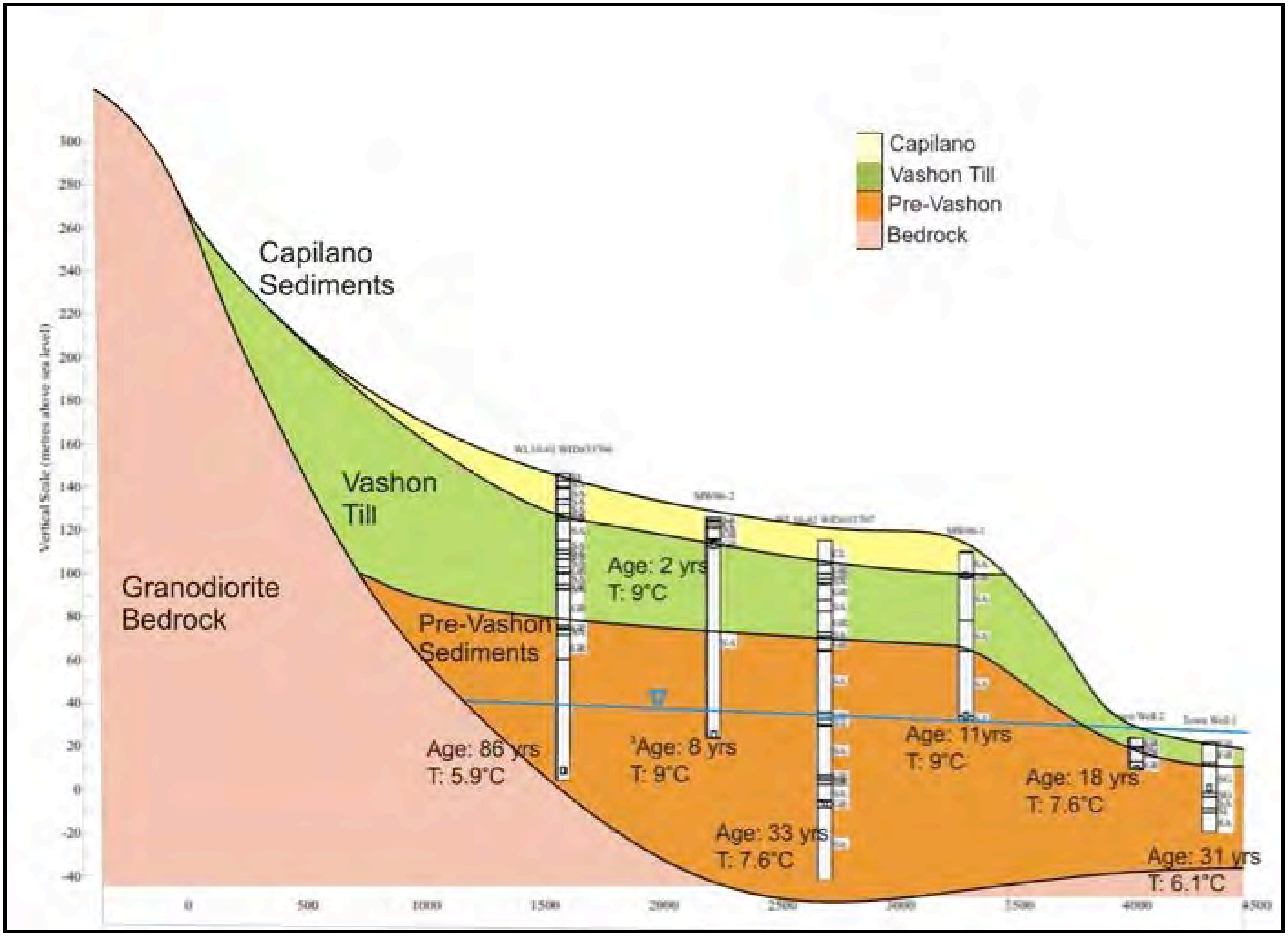
Well Sampled	Apparent Age (years)
MW06-1A	11.8
MW06-2A	8.3
MW06-2B	2.0
WL10-01	85.8
WL10-02	33.0
Town Well 1	31.4
Town Well 2	20.1
Town Well 3	21.9
Town Well 4	17.9
Chaster	11.0
Strata	13.0

Calculated $^{3}H/^{3}He$ apparent ages range from 2 years old in MW06-2B to 86 years old in WL10-01. Figure 39 is a schematic cross section that shows the calculated apparent $^{3}H/^{3}He$ ages as well as the noble gas calculated recharge temperatures discussed above.

Water samples from WL10-01 indicate the oldest groundwater age, coolest recharge temperatures, and a high estimated recharge elevation. This clearly suggests that recharge to the Gibsons Aquifer near this well originates at a high elevation on Mt. Elphinstone. Groundwater flow is expected to occur through fractures in the bedrock and enters the Gibsons Aquifer at the base of the mountain block. This process is known as Mountain Block Recharge (MBR). Samples from MW06-1A and MW06-2A exhibit the youngest apparent ages, the warmest recharge temperatures and the lowest estimated recharge elevations, aside from MW06-2B which is completed in the shallow Capilano Aquifer.

Wells MW06-1A and MW06-2A are completed near the top of the Gibsons Aquifer where the aquifer unit becomes unsaturated. The data indicates that there is a component of recharge that is warmer and younger than the mountain block recharge which likely occurs deeper in the system. The data indicates that recharge could occur near creeks or where the Capilano Alluvial deposits occur near the base of Mt. Elphinstone and are thought to form “recharge windows” where the Gibsons Aquitard is thinner or may be absent.

WL10-02 is located mid-depth in the aquifer and exhibits an apparent groundwater age roughly mid-range between 86 and about 10 years. It also exhibits mid-range recharge temperatures and estimated recharge elevation. This suggests that a mixture of cold, deep water and shallow, warmer water exists at this depth and location within the Gibsons Aquifer.



Data Source: Doyle M.Sc. Thesis (in Press)

Figure 39: Schematic Cross-Section - Apparent Groundwater Age Versus Well Depth

Groundwater samples collected from Town Wells, located within the discharge area of the Gibsons Aquifer, show ages in the 20-30 year timescale (Figure 39) which is significantly younger than the age calculated for groundwater in the WL10-01 well. This suggests that water from wells completed at shallower depths within the Gibsons Aquifer received recharge from a shallow source. Groundwater age, recharge temperature, and recharge elevation in the Town Wells vary with the depth of well completion. Town Wells 2 and 4 have shallower well screen elevations and show relatively younger apparent ages, warmer recharge temperatures and lower recharge elevations. The deeper wells (Town wells 1 and 3) indicate a mixture of the cold, older water likely recharged from the mountain block; and warm, younger water entering the aquifer at lower elevations through the creek beds or the Capilano Alluvium.

5.7.3.5 Chlorofluorocarbons (CFCs) and Sulphur-hexafluoride (SF_6)

Chlorofluorocarbons and Sulphur-hexafluoride are gases that were introduced into the environment by humans. “CFCs” analyzed during the study include three different varieties and include CFC-11, CFC-12 and CFC-113. CFC concentration in the atmosphere began to rise in the mid 1900’s when refrigerants, aerosol cans, and electronics containing CFCs were produced on a large scale. However, since the Montreal Protocol was introduced in 1989 banning these chemical, levels of CFCs in the atmosphere have been on the decline.

Sulphur-hexafluoride (SF_6) was introduced into the atmosphere in 1944 with the production of high voltage insulators, and other consumer products including running shoes. It is still being produced and atmospheric concentrations continue to increase.

Atmospheric concentrations of CFCs and SF_6 have been recorded through time and, similar to noble gases, concentrations of CFCs and SF_6 measured in groundwater reflect the atmospheric concentration of CFCs and SF_6 at the time of recharge.

Groundwater samples were collected by UBC (Doyle, 2013) and analyzed for all three CFCs and SF_6 to obtain an additional data set of apparent groundwater ages. Due to limitations in the method, the depth of the Gibsons Aquifer beneath Upper Gibsons, and the apparent recharge conditions based on the tritium, stable isotope, noble gas and $^3H/^3He$ results, measured concentrations of CFCs and SF_6 were inconclusive. Doyle 2013 further discusses the use of these tracers and sampling results for the Gibsons Aquifer. Table 9 provides a summary of the analytical results for CFC’s.

Table 9: Summary of CFC Analytical Data.

Sample	Date	CFC-11	CFC-12	CFC-113
Units	**mm/dd/yr**	**pptv**	**pptv**	**pptv**
TW1	4/13/2011	37.7	25.1	2.8
TW2	4/13/2011	57.5	1250.2	2.3
TW3	4/13/2011	83.5	17585.4	6.2
TW4	4/13/2011	62.2	74.5	3.0
Chaster	4/19/2011	3.9	80.4	2.4
STRATA	4/22/2011	40.8	24.1	0.3
TW#1 DUP	4/13/2011	33.6	29.7	2.4

Notes: TW is Town Well, mm/dd/yr means month/day/year, pptv means parts per trillion by volume, dup mean duplicate sample

To put the CFC concentration levels in Table 9 into context, one part per trillion (1 ppt) is equivalent to a drop of water in 20 Olympic-size swimming pools. Although the CFC data had limited utility for use in the groundwater tracer study, Town Wells 2 and 3 contained trace concentrations of CFC-12 (also known as Dichlorodifluoromethane) above background levels (<50 ppt). TW2 exhibited a CFC-12 concentration which was over 25 times the background value (1250 ppt). The CFC-12 concentration in water from TW3 was over 350 times higher than the background value (17,585 ppt). CFC-12 has the highest solubility in water of the CFC group of chemicals and the reason why its concentration is higher in water samples than CFC-11 and CFC-113 reported in Table 9.

In terms of acceptable water quality limits, the United States Environmental Protection Agency (USEPA) Lifetime Health Advisory Level (LHAL) for CFC-12 (Dichlorodifluoromethane) is 1000 parts per billion (ppb or ug/L) which is equivalent to 1,000,000 parts per trillion or ppt (USEPA, 2009). Health advisory values are used by USEPA for guidance and are based on non-carcinogenic health effects for different durations of exposure (e.g., one-day, ten-day, and lifetime). The 17,585 ppt value of CFC-12 in TW3 is therefore well below the USEPA, LHAL of 1,000,000 ppt.

Numerous possible sources of CFC-12 exist and are generally related to domestic and industrial aerosols. These include household and industrial sprays where CFC's were used as the propellant and were banned in the 1990's. CFC-12 is also found in refrigerants which may still be in use (E.g.: Freon-12 was used in automobile and home air-conditioners). CFC-12 can also be found in sewage effluent (Healy, 2010) which is otherwise not treated using standard municipal treatment processes. It is of interest that the Town's new sewage treatment plant, upgraded several years ago, is located approximately 180 m up gradient of TW2. It is possible that the elevated CFC-12 in the Town Wells is related to operations associated with the former sewage treatment plant (D. Newman, Personal Communication, 2013). Further investigation is required to determine the source of CFC-12 in the Gibsons Aquifer Wells.

Although CFC-12 concentrations in groundwater from the Gibsons Aquifer appear to be at trace levels relative to USEPA regulatory criteria, the presence of CFC's in Town wells indicates that surface activities involving the handling and management of contaminants have the potential to enter the Gibsons Aquifer and adversely affect the water quality. Another issue that should be considered by the Town is the possibility that other chemicals, not currently being tested by the Town, could be present in groundwater. In order to fully assess the water quality in the Gibsons Aquifer, Waterline recommends that Town wells be re-sampled to confirm the initial CFC results, and that the analytical program be expanded to include other chemical species. The list of recommended analysis could include, but not limited to: microbiological, hydrocarbon compounds, volatile organic compounds, pesticides/herbicides, heavy metals, and other synthetic compounds (E.g.: hormones, caffeine, and perhaps pharmaceuticals). If confirmed through re-sampling, then further site-specific investigations are recommended to identify the source of the CFC-12 or other compounds.

5.8 Conceptual Hydrogeological Model

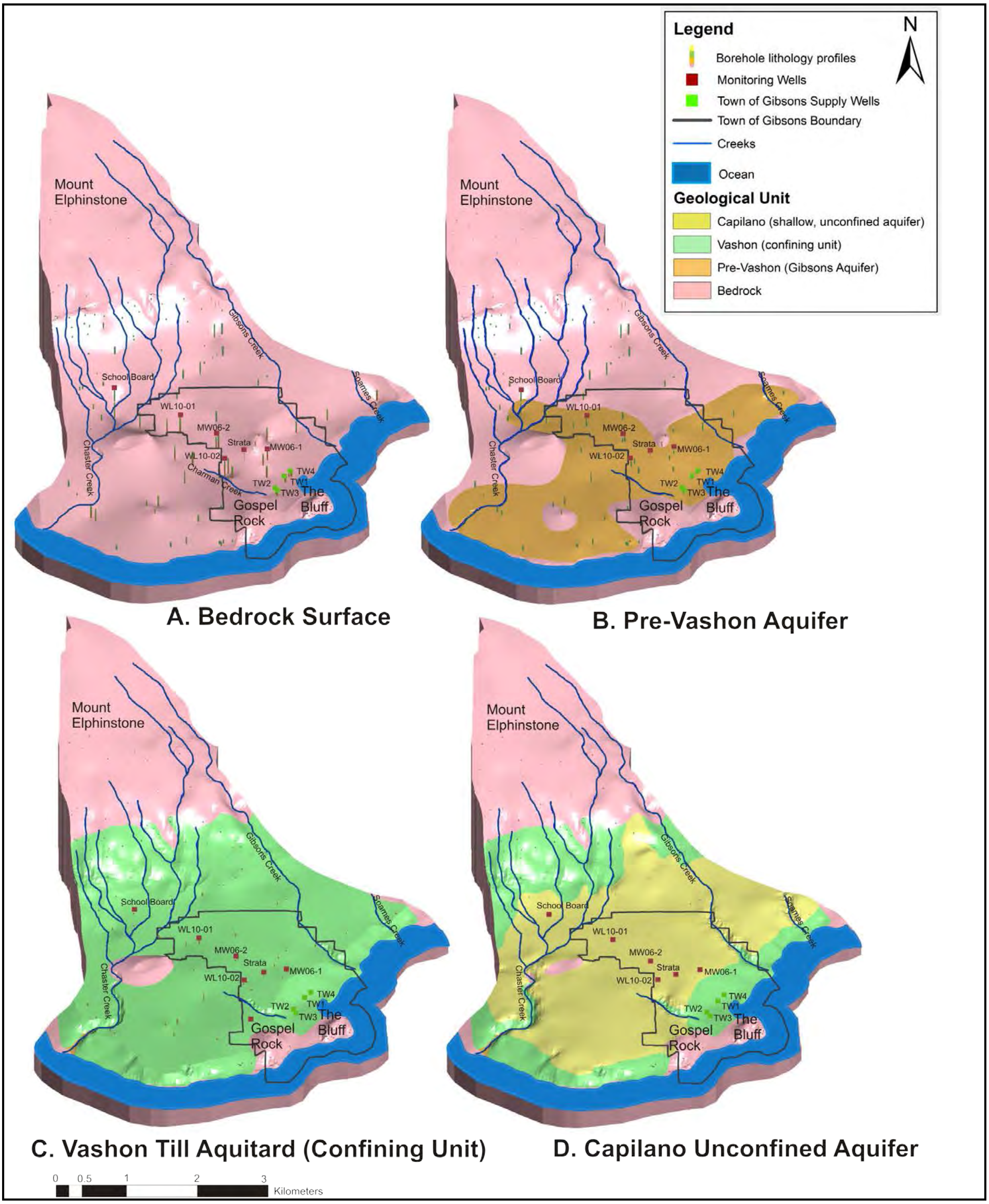
5.8.1 Gibsons Aquifer Geomodel

The final geological/hydrogeological conceptual model was constructed by UBC. The geomodel input data included re-processed water well lithology and well construction information, new geophysical survey information, information collected by Waterline during Phase 1 and 2, bedrock and surficial geology information, and digital elevation mapping information provided by the SCRD. Figure 40 shows the geomodel layers in three dimensions (3D).

Figure 40 (a) shows a 3D image of the bedrock surface. The main bedrock landmarks include Gospel Rock and the Bluff which outcrop west of Gibsons Harbour and the elevated bedrock subcrop just east of the Strata Condo and west of Gibsons Creek. Figure 40 (b) shows the Pre-Vashon (Gibsons Aquifer) layer that sits on top of bedrock. Although the foot print of the aquifer extends beyond the Town boundary, the level of confidence decreases both to the southwest and northeast as the quality of geological data decreases in those areas (see Figure 28). Figure 40(c) shows the extent of the Vashon Till/Basal Capilano cap (Gibsons Aquitard) over the Gibsons Aquifer. Figure 40 (d) shows the unconfined Capilano Aquifer mapped in the Gibsons area. Note that the green color in the geomodel includes the Basal Capilano and does not differentiate the Vashon Till exposed in Lower Gibsons.

5.8.2 Visualization of Subsurface Interactions

Once the 3D geomodel was constructed using Leapfrog Hydro, it was possible to create hundreds of cross sections profiles through the Gibsons Aquifer in order to visualize the subsurface geology and hydrogeology. Figure 41 presents a slice through the Gibsons Aquifer geomodel orientated in a southwest to northeast direction. The profile was selected so that it extends through Charman and Gibsons Creeks. The image shows the relationship between the Gibsons Aquifer and the overlying Gibsons Aquitard and the unconfined Capilano Aquifer.



Data Source: Doyle M.Sc. Thesis (in Press)

Figure 40: Gibsons Aquifer Mapping Geomodel

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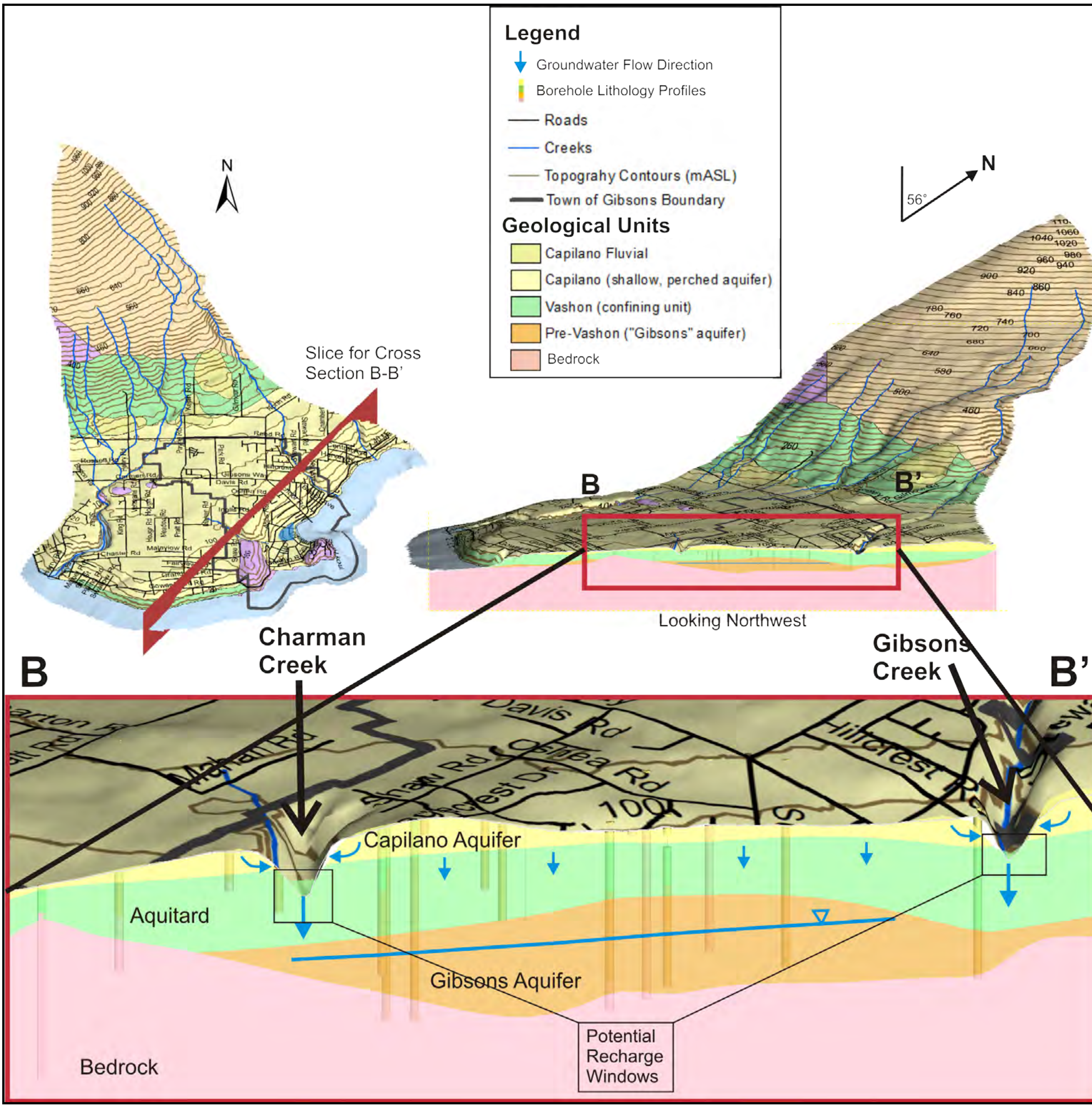


Data Source: Doyle M.Sc. Thesis (in Press)

Figure 41: Gibsons Aquifer - 3D Profile B-B'

The unconfined Capilano Aquifer is recharged directly by precipitation at the surface and discharges groundwater to the creeks as shown by the blue arrows. Groundwater may also slowly percolate down through the Basal Capilano/Vashon Till Aquitard and into the underlying Gibsons Aquifer. In the B-B' profile (Figure 41), the thick aquitard layer is shown separating the Capilano Aquifer from the Gibsons Aquifer. As the profile is perpendicular to the direction of groundwater flow, the water level in the aquifer is shown as the straight blue line (groundwater coming out of the page). The water level data indicates that the Gibsons Aquifer has become unsaturated at this point beneath Upper Gibsons and the overlying Capilano Aquifer is hydraulically separated from the Gibsons Aquifer and considered "perched". Although not physically mapped as part of Waterline's study, we assume that in areas where aquitard material is thin or doesn't exist, it is likely that a more direct recharge pathway occurs at those locations in the system.

5.8.3 Aquifer Recharge

Aquifer recharge is a difficult parameter to measure as it varies considerably across the study area. It also depends on a number of physical factors, including; land cover, slope, subsurface soil conditions, and change in climate with elevation. As described, the assessment of aquifer recharge was completed by developing an understanding of the physical environment and using geochemical tracers to help assess the likely source and pathway of water entering the Gibsons Aquifer. Although aquifer recharge occurs over the entire study area, albeit at different rates, based on Waterline and UBC's work, three likely aquifer recharge mechanisms have been recognized as follows:

Mountain Block Recharge: Recharge from the mountain block likely moves into the aquifer through deep fractures in the bedrock that are suspected to be in contact with the Gibsons Aquifer near the base of Mt. Elphinstone near Upper Gibsons. The mountain block makes up over 60% of the study area, of which only a portion may provide significant recharge to the underlying bedrock. It may also be likely that the mountain block itself generates runoff which subsequently enters the aquifer where the Capilano Alluvium occurs north of Upper Gibsons.

The environmental tracer study indicates that the mountain block potentially contributes 55% of the recharge to the deep part of the Gibsons Aquifer, but that may not be equally distributed over the mountain block area. There may be areas, for instance, that may promote runoff rather than infiltration and recharge, and may prove to be less important to aquifer recharge than areas that provide more direct pathways to the aquifer. Understanding fault or fracture flow from the bedrock underlying the mountain block is important but cannot be understood using geochemical tracers alone. No well data exists within the mountain block to confirm the existence of a faulted contact between the granite and meta-sedimentary bedrock at the north and east part of the study area.

If there is a future opportunity to evaluate the bedrock contact zone (Figure 20) or the bedrock in general to determine if significant faulting exists, either through drilling or geophysics, then this could provide more insight into lateral recharge to the Gibsons Aquifer from the bedrock in the mountain block.

Creek Recharge: All creeks within the study area appear to be directly connected to the shallow, unconfined Capilano Aquifer. Creek beds may also be connected to the underlying aquifer where the Vashon Till/Basal Capilano Aquitard cover is thin or has been eroded away. Some indication of groundwater discharge to Gibsons Creek was noted in our EC survey at about 200 masl which suggests that the creek has a direct linkage to the Gibsons Aquifer (groundwater discharge to the creek is referred to as an influent creek). However, in areas where creek water enters the aquifer (recharge) it is not possible to assess this interaction using EC survey methods because surface water is leaving the system (effluent creek). The chemistry of groundwater contained in the Gibsons Aquifer indicates that a direct pathway exists and it is reasonable to assume that the creeks play a role in recharging the Gibsons Aquifer. Detailed surface water flow analysis is recommended and vertical profiling of groundwater zones in those areas is needed to confirm the groundwater-surface water interaction.

Recharge Windows through Capilano Alluvium: It is also likely that the late-stage Capilano Alluvium deposits located in north of Upper Gibsons have eroded the Basal Capilano and Vashon Till Aquitard cover, thereby providing a direct pathway for recharge to enter the aquifer near the base of Mt. Elphinstone. The area situated in north of Upper Gibsons within SCRD lands is also the site of a number of gravel pit operations. The gravel deposits in this area are thick (likely > 150 m) and generally well drained (Fielder, Personal Communication., 2009) suggesting that direct recharge from precipitation, snow melt, and the mountain block may be rapid. This is consistent with groundwater age determinations indicating that groundwater in the shallow part of the Gibsons Aquifer is generally quite young (<10 years).

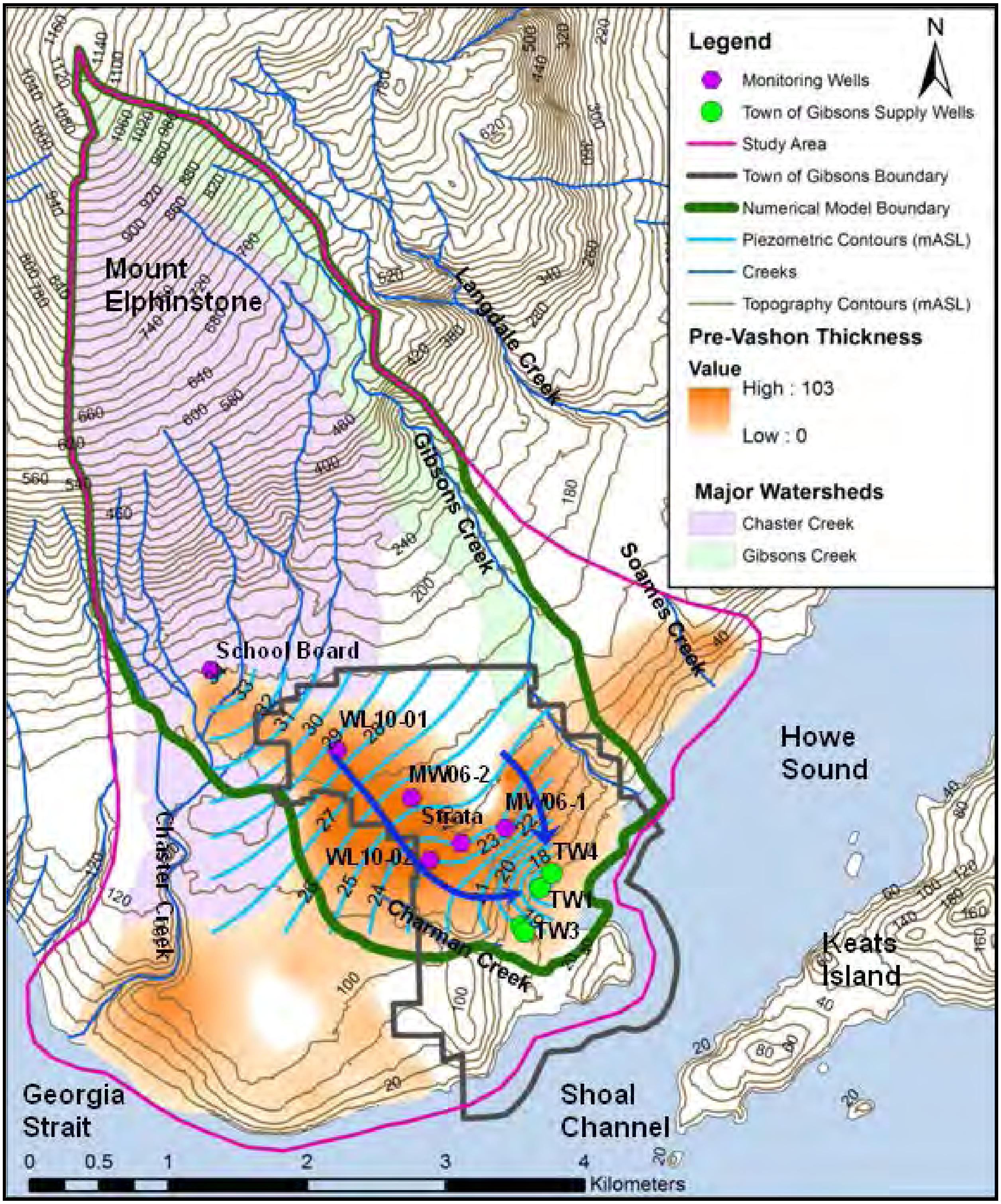
6.0 GROUNDWATER FLOW MODELING

6.1 Model Domain

Groundwater flow modeling was performed by Jessica Doyle of UBC using Visual MODFLOW, Version 2009.1. A detailed discussion of model construction, calibration, sensitivity analysis, and predictive calculations is provided in Doyle 2013 (In Press) and will only be summarized herein.

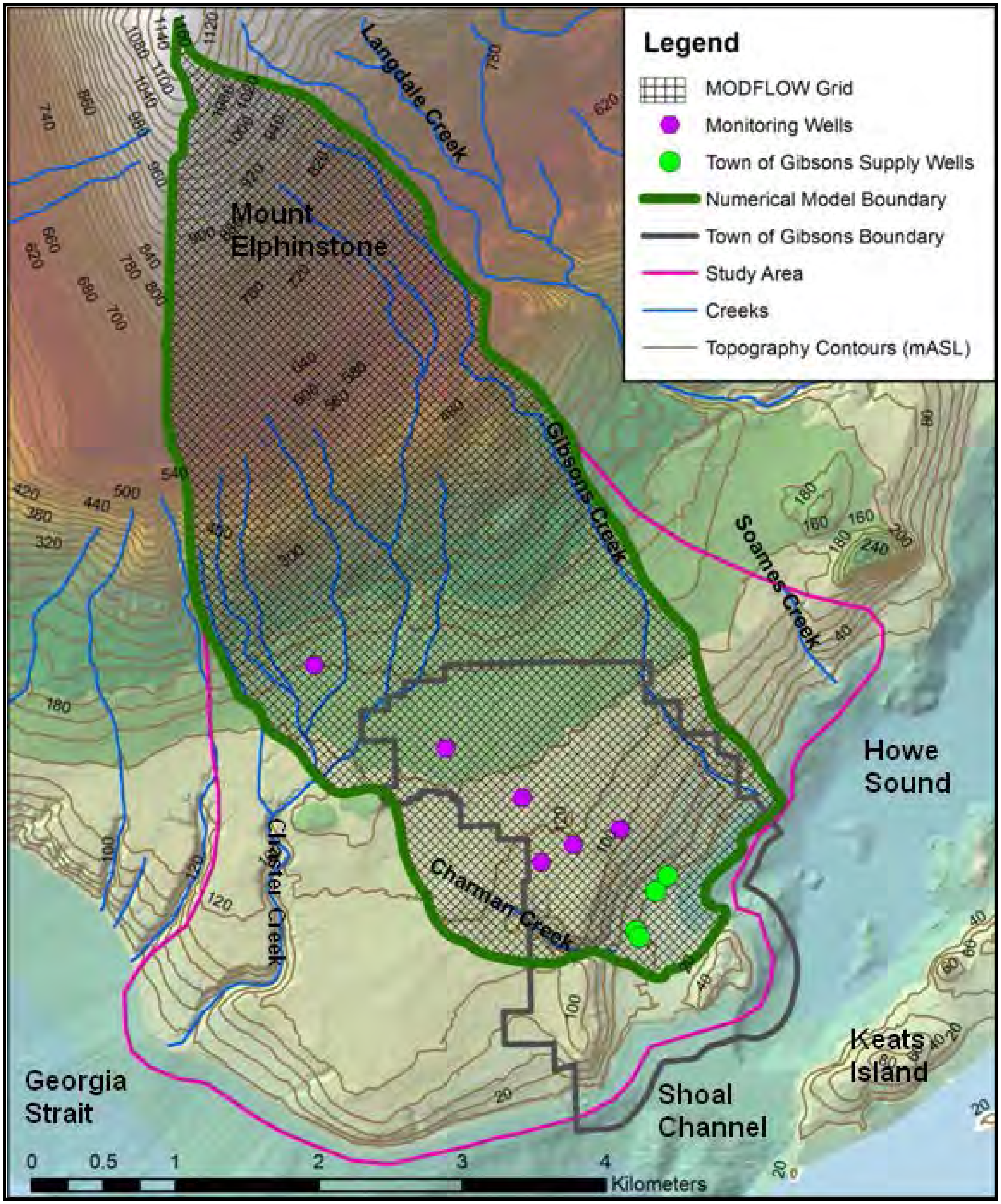
The model was developed as a three-dimensional domain extending from the top of Mt. Elphinstone to the Town of Gibsons waterfront, shown as the model domain in Figure 42. The model grid consists of 140 rows, 70 columns and 5 layers orientated 45° to the northwest which aligns with the principal direction of groundwater flow through the Gibsons Aquifer. Grid cells are uniform with 50 m by 50 m dimension. The model grid is shown in Figure 43.

Only steady state calibration of the model was possible. Once the model was calibrated, it was used to simulate increased groundwater demand related to population growth estimates and possible climate change impacts to the aquifer.



Data Source: Doyle M.Sc. Thesis (in Press)

Figure 42: Computer Model Domain

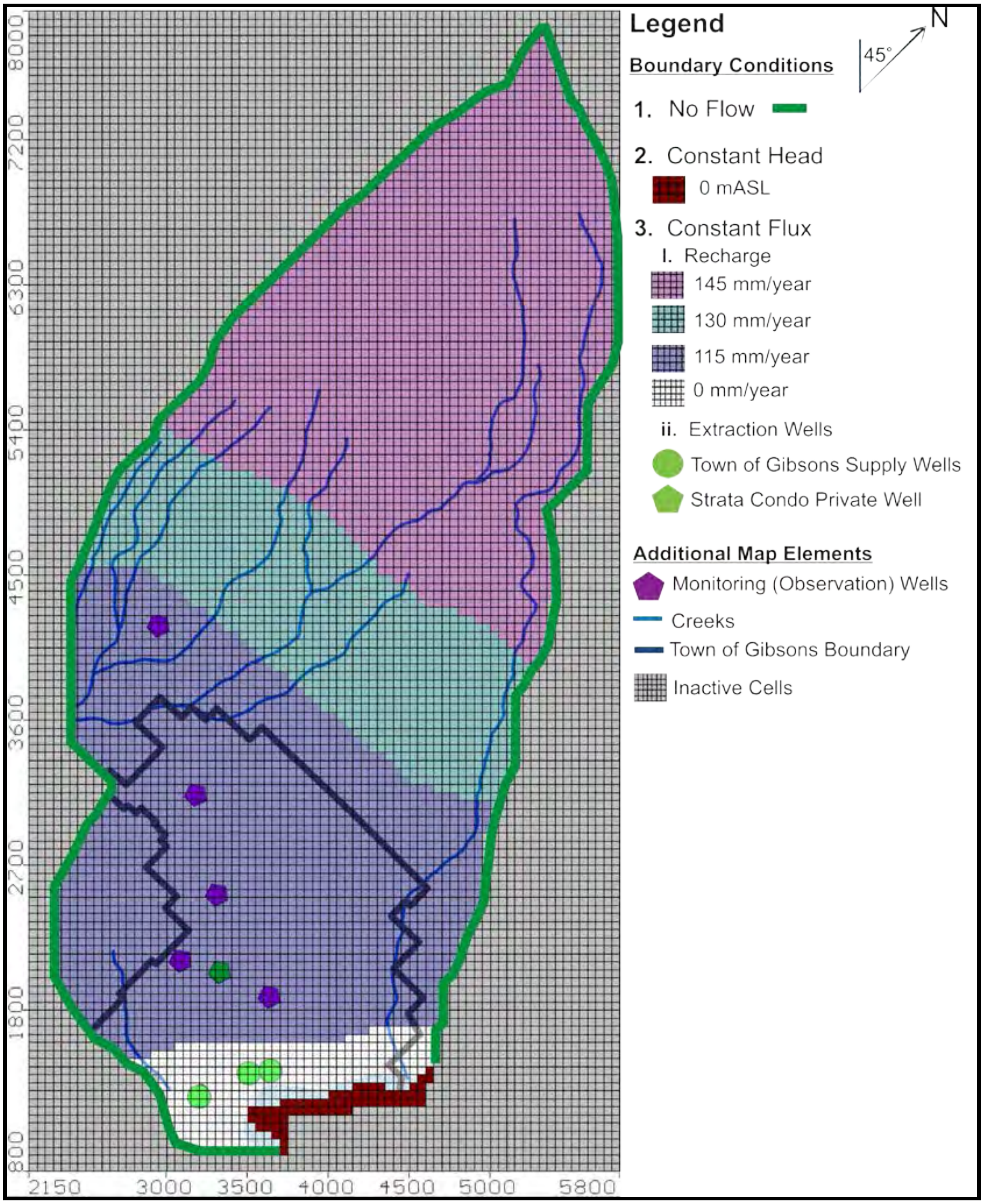


Data Source: Doyle M.Sc. Thesis (in Press)

Figure 43: Computer Model Grid

6.2 Aquifer Boundary Conditions

Three types of boundaries were included in the model as follows: a no flow boundary around the perimeter of the domain, a constant head boundary at the ocean in Lower Gibsons, and constant flux boundaries to represent various recharge zones at different elevations, and pumping wells which are in continuous state of discharge due to the artesian condition of the aquifer in Lower Gibsons. The model boundary conditions are shown on Figure 44.

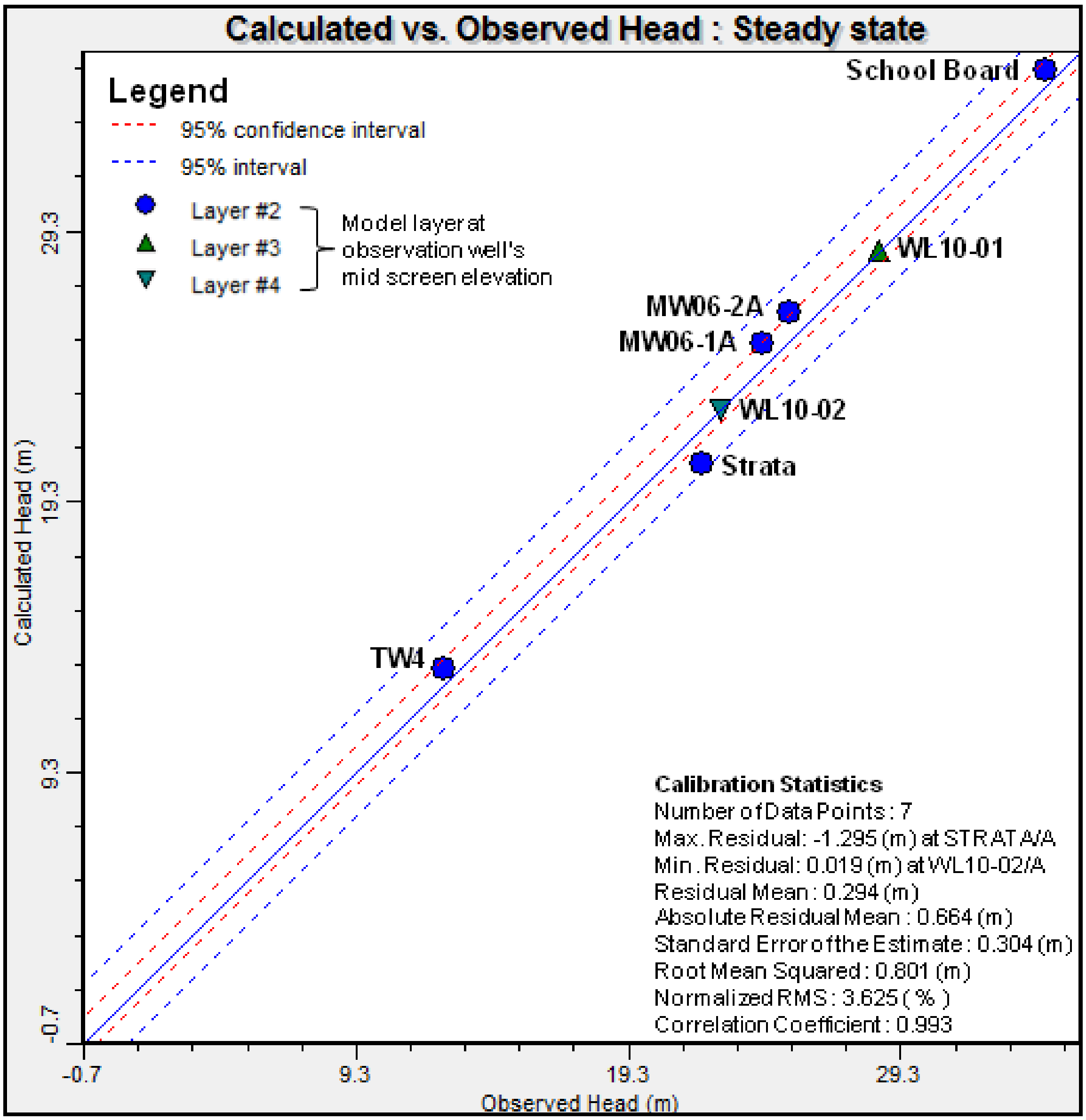


Data Source: Doyle M.Sc. Thesis (in Press)

Figure 44: Boundary Conditions

6.3 Model Calibration

Several computer runs were made to calibrate the numerical model by adjusting hydraulic parameters, aquifer recharge, and aquifer geometry such that the calibration targets were met. A sensitivity analysis was also performed, whereby parameters were adjusted to either their reasonable limit for the system, or until the model did not meet the calibration targets in an effort to test the sensitivity of the model to different input parameters (Doyle 2013). Figure 45 presents the model calibration results. Modeled hydraulic head values fall within 95% confidence level of the average hydraulic heads measured in the Gibsons Aquifer based on observation well data.



Data Source: Doyle M.Sc. Thesis (2013, in Press)

Figure 45: Computer Model Calibration

6.4 Predictive Model Simulations

6.4.1 Future Groundwater Demand Analysis

Figure 2 presents projected population growth rates based on population trends observed since 1981 (Smart Plan, 2005). In order to accommodate the future projected growth, the Official Community Plan (2005) outlines several development plan areas within the Town including; the Upper Gibsons Neighbourhood Plan, Gospel Rock, and the Harbour Plan Area shown in Figure 3. The Smart Plan states that the Town's long-term objective is to be able to supply potable water to 10,000 people to accommodate the high growth projection, although the lower historical growth rate of 1% is likely more realistic based on historical data (D. Newman, Personal Communication, 2013).

6.4.2 Groundwater Use Scenarios

Table 10 presents the input data for various computer model simulations completed to assess the following groundwater demand scenarios:

- **Base Case:** Current population of 4437 and water use based on 2009 to 2011 measured average. Only 73% of the population are on the Gibsons Aquifer groundwater (3239 residents). An average daily per capita use of 0.619 m^3/day/person is estimated;
- **Scenario 1:** Predicted population based on medium growth rates (2.5%) with a total predicted population of 7242 residents (5287 on Gibsons Aquifer water);
- **Scenario 2:** Existing Town wells operating just under the calculated safe yields of each well (Table 11);
- **Scenario 3:** Predicted population based on high (4%) growth rates predicting a total population of 10,000 residents (7300 residents on Gibsons Aquifer water).
  - Scenario 3a: All Town wells pumped at equal rates but below estimated safe yield of supply wells;
  - Scenario 3b: Town wells pumped at varied rates below a 70% of available drawdown threshold limit to the top of the well screen.

While the growth rates in Scenarios 1-3 may be high in comparison to what has been realized since 1980, the approach provide a conservative analysis and allows for some uncertainty in the data.

Table 10: Model Scenario Input Data

Model Scenarios		Base Case*	Scenario 1	Scenario 2	Scenario 3a	Scenario 3b
Population and Water Use	Total Population	4437	7000	8508	10000	10000
	Population on Aquifer Water	3239	5110	6211**	7300	7300
	Average Water Use (m3/day/person)	0.619	0.573	0.573	0.573	0.573
Town of Gibsons Water Supply	TW1 (m^3/day)	172.9	976	1095	1045.7	1095
	TW3 (m^3/day)	1667.1	976	1313	1045.7	1313.0
	TW4 (m^3/day)	164.4	976	1149	1045.7	274.9
	Added Well				1045.7	1500.0
	Total (m^3/day)	**2004**	**2928**	**3557**	**4183**	**4183**
Additional Groundwater Extraction	TW1 Tap (m^3/day)	1.8	2	2	2	2
	TW1 Overflow (m^3/day))	163.3	163.3	163.3	163.3	163.3
	TW4 Overflow (m^3/day)	106.7	106.7	106.7	106.7	106.7
	STRATA Condo*** (m^3/day)	100	100	100	100	100
Grand Total OUT (m^3/day)		**2376**	**3300.0**	**3929.0**	**4555**	**4555**

Notes: * refers to Base Case using average rates and static water levels from 2009-2011 data, ** is the calculated population that could be serviced by existing infrastructure and assuming wells are running at respective calculated safe yield of each well, *** assumed value..

Table 11: Estimated Safe Yields of Town Wells

Well	Safe Yield (m^3/day)
TW1 (operational)	1097
TW2 (not currently operating)	1503*
TW 3 (Operational)	1313
TW4 (Operational)	1149

Notes: Safe yield values taken from Piteau (1997, 1999, 2005, 2007), * means that the well likely cannot produce the indicated safe yield.

In 2011, numerous leaks located and repaired in the Town's distribution system as part of a meter installation program. Following the repairs, the average water use per person appeared to decreased from 0.619 m^3/day to 0.573 m^3/day which likely reflects the losses from the system. The average per capita use was estimated from the total volume of water extracted from the Town Wells (measured) divided by the total population serviced by groundwater from the Gibsons Aquifer. It should be noted that the total consumption is the sum total of commercial and residential uses and system loss, and is therefore not a reflection of the per capita domestic use for an individual resident in the Town of Gibsons. The average per capita water demand in 2011 was used to calculate future average groundwater demand in the model prediction scenarios. As indicated in Table 11, the Town operates Town Wells 1, 3 and 4. However, Town Well 2 is located 50 m away from Town Well 3 and due to observed well to well interference is only operated if Well 3 is down for maintenance. Therefore, all predictive model simulations were run using only Town well 3, and well 2 was assumed to be turned off.

The base case represents the current pumping by the Town and was used to further test the calibration of the Modflow numerical model. Scenario 2 shows that, if Town Wells 1, 3 and 4 are each operated near respective maximum safe yields (Table 11), the existing well system could supply a maximum of 6211 residents at an estimated average per capita water use of 0.573 m^3/day. This assumes that the Town wells can actually achieve the safe yield used, and that 73% of the total population in the Town is supplied by wells completed in the Gibsons Aquifer (3929 m^3/day). The remaining 27% of the water demand (1453 m^3/day) is assumed to be supplied by the SCRD. Therefore the total population that could be serviced using the existing infrastructure is approximately 8,500 residents if estimated individual well yields can still be achieved. This means that another well would eventually need to be drilled to accommodate 10,000 residents. If the overall per capita water demand becomes lower, as is often the case when a metering program implemented, then less water will be required to supply Town residents than was estimated herein and the calculations provide an even more conservative assessment of water demand.

6.4.3 Climate Change Scenarios

6.4.3.1 Predictions for the Southern Coast of BC

A literature review on climate change was completed by Doyle (2013). The research indicates that the Southwest Coast of British Columbia will likely experience increased temperatures of approximately 1.5 degrees Celsius by 2050 as a result of climate change. Annual precipitation is also projected to increase by 6 mm by 2050. However, this value varies seasonally and, in summer months, precipitation could decrease by up to 13%. Snow accumulation in the Coast Mountains is also projected to decrease with increasing air temperatures. In addition, the timing of snow pack melt may more rapid and occur earlier in the spring (Pike et al., 2010).

Considerable debate exists in terms of predicting the effects of climate change on aquifer recharge. Experts indicate that recharge could go up or down and therefore the science is not well understood. Allen et al. (2010) studied the effect that climate change may have on recharge rates to the Sumas Aquifer located in the Fraser Valley. Depending on the global climate model used, results showed that recharge rates could increase by as much as +23.2% or decrease by -10.5%. As discussed, environmental tracer data collected for the Gibsons Aquifer and computer model simulations indicate that 55% of recharge to the Gibsons Aquifer originates from high elevations on Mt. Elphinstone and may enter the Gibsons Aquifer via mountain block recharge or as runoff from the mountain block that enters through the Capilano Alluvium at the base of Mt. Elphinstone. As a result, climate change predictions that decrease snow accumulation and timing of melt may have a more negative effect on recharge rates to the Gibsons Aquifer.

6.4.3.2 Modeled Effects to Overall Aquifer Recharge

Although aquifer recharge rates may increase or decrease, it was assumed that only a worst case scenario would be modeled involving a 15% decreased in recharge over the entire study area. In general, increased recharge would mean more water is available in the Gibsons Aquifer and this would be viewed as favorable. More negative aspects of increased precipitation and recharge include increased runoff and erosion, and the possibility of increasing the pore pressure in the aquifer. Neither of these issues could be investigated within the current project scope. Therefore, a decrease in overall recharge was applied equally across the entire model domain in increments of -5%, -10% and -15% reduction of the base case recharge values used to calibrate the computer model.

6.4.3.3 Modeled Effects to Mountain Block Recharge

All researchers and climate scientists agree that global temperatures are increasing. One of the greatest impacts of increased temperatures is the decline of snow fall and accumulation on the mountain block and the release of spring melt on the Coast Mountains. This change may have a significant effect on mountain block recharge. Noble gas and stable isotope data collected by UBC (Doyle 2013) indicate that recharging water temperatures in the Gibsons Aquifer were cold and, oxygen and deuterium isotopes are enriched in the heavy isotope fraction. This suggests that a large component of recharge to the Gibsons Aquifer is contributed by snowmelt. In order to assess the decrease in potential mountain block recharge, the recharge over the mountain block (Figure 41) was reduced by -10%, -30% and -50% to assess the possible effects of decreasing snow accumulation on Mt. Elphinstone caused by the changing climate.

6.4.3.4 Sea Level Rise

Ferguson and Gleeson (2012) have indicated the following with respect to the vulnerability of coastal aquifers to salt water intrusion caused by predicted sea level rise:

"Coastal aquifers are more vulnerable to groundwater extraction than to predicted sea-level rise under a wide range of hydrogeologic conditions and population densities. Only aquifers with very low hydraulic gradients are more vulnerable to sea-level rise and these regions will be impacted by saltwater inundation before saltwater intrusion. Human water use is a key driver in the hydrology of coastal aquifers, and efforts to adapt to sea-level rise at the expense of better water management are misguided."

This statement emphasizes the point that it is far more important to understand and manage groundwater extraction practices from all wells completed in the Gibsons Aquifer through long-term monitoring. The risk of inducing salt water intrusion into the Gibsons Aquifer is more likely to be caused by groundwater extraction than by sea level rise since drawdown caused by pumping is much more likely to exceed predicted sea level rise caused by climate change.

Climate scientist are predicting global sea level rise as a result of the melting polar ice caps. As the Gibsons Aquifer discharges to the ocean and Town wells are located close to the waterfront, some concern exists with the possibility of salt water intrusion. Sea level rise predictions resulting from climate change modelling range from 0.89 to1.03m along the coast near Vancouver and are based on extreme high level of global sea level rise (Government of Canada, 2008). Mean sea level rise predictions range from +0.20 to 0.33m along coastal areas near the City of Vancouver.

Extreme sea level events, related to intense storms, can result in sea levels reaching one metre above the predicted high tide level. These elevations do not take into account any wave run-up effects, which are controlled by local coastal and seafloor morphology (Government of Canada, 2008). Run-up effects can therefore add significantly to the actual sea level heights experienced at a particular location. Since extreme events add to the sea level conditions at the time, the most hazardous situation would be a major storm system at high tide during an El Niño year when sea levels are elevated due to temperature effects (Government of Canada, 2008).

The exact location of the fresh water-salt water interface at the point where the Gibsons Aquifer discharges to the ocean is not known. Because the Gibson Aquifer has remained under artesian pressure near the ocean, a natural protection exists against salt water intrusion. This is only true as long as groundwater extraction from the Town wells does not cause a reversal of the hydraulic gradient by lowering the pressure (water level) in the aquifer below sea level.

The numerical model simulations were focused on assessing scenarios where drawdown in the Gibsons Aquifer was maintained above mean sea level. In the case where no sea level rise was predicted, an acceptable drawdown threshold value was established at 70% of available drawdown to the top of the well screen in each of the Town wells or to mean sea level, whichever was less. In the extreme climate change case where approximately one meter of sea level rise was consider to represent the highest predicted sea level rise for the region, the acceptable threshold value was set at 70% of the available drawdown to the top of the well screen or to one meter above the base case (present day) mean sea level, whichever was less. The follow section presents the modeling results.

6.4.4 Numerical Modeling Results

Table 12:2 provides a summary of modeling results for each recharge scenario described above where no sea level rise is predicted. Table 13 includes the same results but includes one meter of sea level rise. The values are reported as the predicted groundwater elevation in each well. Results are compared to the elevation at the top of each well screen, as well as the elevation at 70% of the available drawdown in the well. It is important to note that the non-pumping heads in all of the Town wells could not be measured due to the well head construction design that diverts artesian over-flow to the storm sewer. However, based on observations made during drilling, Waterline has assumed that averagel non-pumping heads were two meters above ground level (mAGL). Actual water pressure in the aquifer will need to be measured by installing observation wells adjacent to existing Town wells in Lower Gibsons.

According to the BC Ministry of Environment, it is best practice to prevent drawing water levels down past 70% of the available drawdown, and it is unacceptable to drawdown below the top of screen elevation. The fact that the Town wells are flowing artesian offers some level of protection against salt water intrusion and the best practice is to maintain this condition for as long as practically possible. Favourable model scenarios were therefore evaluated based on the fact that piezometric levels in the aquifer remained above the 70% threshold value and above sea level. The predicted drawdown data provided in Table 12 have been color coded to identify favorable or unfavorable conditions as follows:

- Values in black text indicate that drawdown is predicted to be above the 70% threshold and above mean sea level (Favorable);
- Values in orange text exceed the 70% threshold drawdown but remain above the well screen and above mean sea level (early warning to reduce pumping);
- Values in red text indicate that the drawdown elevation is predicted to drop below the top of the well screen elevation or below mean sea level (unfavorable).

Given the calculated safe yield of individual wells, the Town wells appear to have the capacity to supply up to about 6000 residents at the current average water use estimates which includes domestic and commercial water needs. If the groundwater that is currently being diverted to the storm sewer was captured, and additional 480 residents could be supplied water. This assumes that the existing infrastructure (well pumps in particular) is capable of pumping the volumes indicated, and that there has been no significant degradation of well performance since the safe yield well ratings were originally established. It should be noted, however; that TW1 in particular is showing signs of aging and reduced well efficiency and should be further investigated.

In order for the Town to supply water to more than about 6000 residents, another supply well would have to be drilled into the Gibsons Aquifer. Although climate change could significantly increase recharge to the Gibsons Aquifer, if recharge decreases due to climate change/variability then the risk of salt water intrusion rises and groundwater extraction from the aquifer would need to be reduced to protect the aquifer. Long-term groundwater monitoring is required to assess the performance of the Gibsons Aquifer under varying conditions and properly manage groundwater extraction into the future.

The following summarizes the modeling results for the various scenarios:

Model Base Case: Current population of 4437 (3239 residents on Gibsons Aquifer Groundwater). Model results indicate that the water levels in all Town production wells will be maintained above the threshold limit, even when factoring in extreme case climate change effects to overall aquifer recharge or mountain block recharge (Table 12) and extreme sea level rise (Table 13).

Predictive Model Scenario 1: Total predicted population of 7242 residents (5287 on Gibsons Aquifer water). Model results indicate that the water levels in all Town production wells will be maintained above the threshold limit for each well. The only exception is in Town Well #4 which is closest to the ocean and the predicted water level drops below the 70% threshold value in the well under an extreme climate change impact where mountain block recharge is decreased by 50%.

Predictive Model Scenario 2: Existing wells operating at their calculated maximum safe yields. As described above, this scenario could service approximately 6000 residents (Total population of about 8500, the balance of which would be serviced by the SCRD). Model results indicate that in the absence of climate change, the Gibsons Aquifer could accommodate volume extractions while maintaining water levels in the aquifer above the 70% threshold value and also above mean sea level. However, if a reduction in overall or mountain block recharge occurs, exceedance of the water level threshold value is predicted for Town Well #4. This situation would be further exacerbated when coupled with a one meter rise in mean sea level which has been considered in the calculations provided in Table 13. However, in all cases except for the extreme case of a 50% reduction in Mountain Block Recharge, water levels in Town wells are predicted to be above mean sea level.

Predictive Model Scenario 3a: The maximum predicted population growth for the Town of Gibsons based on the OCP indicates a total population of 10,000 residents (7300 residents on Gibsons Aquifer water). This scenario assumes that a new well is added, and that all wells are pumped at equal rates below estimated safe yield of existing supply wells. Model results indicate that in the absence of climate change, the Gibsons Aquifer could accommodate the required volume extractions while maintaining water levels in the aquifer above the 70% threshold values and also above mean sea level for all wells except Town Well #4. The situation is worsened if a reduction in overall or mountain recharge occurs under the various climate change factors as shown in Table 12. Town Wells 1 and 4 are more susceptible to exceeding threshold values with increase climate change factors as these wells are located the closest to the ocean. This situation would be further exacerbated when coupled with a one meter rise in mean sea level which has been considered in Table 13.

Predictive Model Scenario 3b: This scenario is the same as scenario 3a and assumes that a new well is added, but that the wells are pumped at variable rates (as opposed to equal rates modeled in scenario 3a) and below the estimated safe yield of existing supply wells. Specifically, the groundwater diversion rates were lowered in Wells #1 and #4 located closest to the coast. Model results are slightly improved and indicate that; in the absence of climate change, the Gibsons Aquifer could accommodate the required volume extractions while maintaining water levels in the aquifer above the threshold value and also above mean sea level. Again, the situation is worsened (but better than Scenario 3b) if a reduction in overall or mountain recharge occurs under the various climate change factors as shown in Table 12. In addition, the situation would be further exacerbated if a maximum one meter rise in mean sea level occurred which has been included in the calculations provided in Table 13.

Climate change/variability and the effects on aquifer recharge are somewhat uncertain and can only be quantified by long-term monitoring trends and assessing cause and effect response in the aquifer. For the purposes of the predictive analysis, only the worst case climate change scenarios were considered in the model simulations completed by UBC (Jessica Doyle, 2013).

It is just as likely that the worst case scenarios modelled are not realized, and an increase in aquifer recharge occurs as a result of climate change. In this instance, results indicate no negative impacts from a groundwater quantity perspective, as the increase in recharge would likely result in higher water levels in the Gibsons Aquifer than those predicted in the "No Climate Change" column in Table 12 and Table 13 where a one meter sea level rise has been considered. Conversely, this could cause an increase in pressure in the Gibsons Aquifer which could also become problematic although a depressurization solution could be engineered to address this scenario.

Table 12: Modelling Results - Decreased Recharge Caused by Climate Change

Scenario	Well Name	Top of Screen Elevation (mASL)	Water level Elevation at 70% threshold limit of available drawdown or mean sea level if 70% threshold below sea level (mASL)	No Climate Change	Overall Change in Recharge			Change in Mountain Recharge		
					5% Decrease in Recharge	10% Decrease in Recharge	15% Decrease in Recharge	10% Decrease in Recharge	30% Decrease in Recharge	50% Decrease in Recharge
				Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)
Base Case	Town Well 1	-7.1	0	12.70	11.55	10.38	9.79	11.51	10.07	8.71
	Town Well 3	-2.5	2.4	11.91	10.75	9.57	8.98	10.72	9.25	7.86
	Town Well 4	1.1	3.3	13.14	11.98	10.80	10.19	11.93	10.49	9.11
Scenario 1	Town Well 1	-7.1	0	7.50	6.86	6.67	5.27	6.91	5.42	2.98
	Town Well 3	-2.5	2.4	8.66	8.01	7.86	6.40	8.05	6.55	4.07
	Town Well 4	1.1	3.3	7.47	6.80	6.55	5.15	6.87	5.32	2.78
Scenario 2	Town Well 1	-7.1	0	5.33	4.14	3.09	1.72	4.89	2.52	**-0.31**
	Town Well 3	-2.5	2.4	6.37	5.59	4.09	2.67	5.94	3.52	0.57
	Town Well 4	1.1	3.3	5.20	3.99	2.88	1.44	4.72	2.27	**-0.62**
Scenario 3a	Town Well 1	-7.1	0	2.42	1.95	0.01	**-1.69**	1.12	**-0.77**	**-3.52**
	Town Well 3	-2.5	2.4	3.58	3.10	1.09	**-0.48**	2.23	0.30	**-2.59**
	Town Well 4	1.1	3.3	2.48	1.97	**0.01**	**-1.97**	1.14	**-0.80**	**-3.59**
	New Well	-5	0	3.71	2.56	0.64	**-0.91**	1.74	**-0.11**	**-2.85**
Scenario 3b	Town Well 1	-7.1	0	2.38	1.82	0.76	**-1.09**	1.99	**-0.88**	**-3.21**
	Town Well 3	-2.5	2.4	2.70	2.13	1.02	**-0.79**	2.31	**-0.71**	**-3.24**
	Town Well 4	1.1	3.3	3.37	2.79	1.73	**-0.28**	2.96	**0.13**	**-2.09**
	New Well	-5	0	2.24	1.69	0.63	**-1.13**	1.86	**-1.01**	**-3.38**

Notes: * assumes non-pumping hydraulic head is 2 m above ground level. Sea level rise is not included in the predicted water level drop. Incorporating possible sea level rise would mean dropping the predicted water levels by approximately 1 m which increases impact (see Table 13). Water level elevation in orange indicates that drawdown is below 70% available to the top of the well screen. Water level elevation highlighted in red indicates that predicted water level drops below the top of the well screen or mean sea level whichever is less.

Table 13: Modelling Results – Decreased Recharge and Sea Level Rise

Scenario	Well Name	Top of Screen Elevation (mASL)	Water Level Elevation at 70% threshold limit of available drawdown, or 1 m above mean sea level if the 70% threshold value is below sea level (mASL)	No Climate Change	Overall Change in Recharge			Change in Mountain Recharge		
					5% Decrease in Recharge	10% Decrease in Recharge	15% Decrease in Recharge	10% Decrease in Recharge	30% Decrease in Recharge	50% Decrease in Recharge
				Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)	Predicted Water Level Elevation (mASL)
Base Case	Town Well 1	-7.1	1	12.70	11.55	10.38	9.79	11.51	10.07	8.71
	Town Well 3	-2.5	2.4	11.91	10.75	9.57	8.98	10.72	9.25	7.86
	Town Well 4	1.1	3.3	13.14	11.98	10.80	10.19	11.93	10.49	9.11
Scenario 1	Town Well 1	-7.1	1	7.50	6.86	6.67	5.27	6.91	5.42	2.98
	Town Well 3	-2.5	2.4	8.66	8.01	7.86	6.40	8.05	6.55	4.07
	Town Well 4	1.1	3.3	7.47	6.80	6.55	5.15	6.87	5.32	2.78
Scenario 2	Town Well 1	-7.1	1	5.33	4.14	3.09	1.72	4.89	2.52	**-0.31**
	Town Well 3	-2.5	2.4	6.37	5.59	4.09	2.67	5.94	3.52	**0.57**
	Town Well 4	1.1	3.3	5.20	3.99	2.88	1.44	4.72	2.27	**-0.62**
Scenario 3a	Town Well 1	-7.1	1	2.42	1.95	**0.01**	**-1.69**	1.12	**-0.77**	**-3.52**
	Town Well 3	-2.5	2.4	3.58	3.10	1.09	**-0.48**	2.23	**0.30**	**-2.59**
	Town Well 4	1.1	3.3	2.48	1.97	**0.01**	**-1.97**	1.14	**-0.80**	**-3.59**
	New Well	-5	1	3.71	2.56	**0.64**	**-0.91**	1.74	**-0.11**	**-2.85**
Scenario 3b	Town Well 1	-7.1	1	2.38	1.82	**0.76**	**-1.09**	1.99	**-0.88**	**-3.21**
	Town Well 3	-2.5	2.4	2.70	2.13	1.02	**-0.79**	2.31	**-0.71**	**-3.24**
	Town Well 4	1.1	3.3	3.37	2.79	1.73	**-0.28**	2.96	**0.13**	**-2.09**
	New Well	-5	1	2.24	1.69	**0.63**	**-1.13**	1.86	**-1.01**	**-3.38**

Notes: * Assumes non-pumping hydraulic head is 2 m above ground level. Negative (-) indicates water level is below mean sea level. Water level elevation in orange indicates that drawdown is below 70% available to the top of the well screen and remains at or above 1 m amsl.. Water level elevation highlighted in red indicates that predicted water level drops below the top of the well screen or below mean sea level whichever is less. Yellow highlight indicates new threshold value with 1 m sea level rise added, red text and yellow highlight indicates new threshold value or new exceedance when sea level is coupled with climate change scenarios in Table 12:

In summary, the Gibsons Aquifer should be able to supply the Town's water supply needs even under moderate to extreme climate change predictions. If long-term groundwater monitoring data indicates that threshold limits are being approached, then there may be a need to abandon existing supply wells located near the coast and replace them with wells located further from the coast. Although there are some advantages to locating new wells in Upper Gibsons, the drilling depth could exceed 100 m and the cost of well installation would increase accordingly. This would however avoid flowing artesian conditions identified in Lower Gibsons and would allow for easy groundwater level monitoring, and help to reduce the likelihood of inducing salt water intrusion into the well. It would also help reduce the risks associated with drilling into the artesian aquifer which is discussed in more detail later in the report and also in Appendix B.

In the short term, the Town should consider using the 275 m^3/day that is currently being diverted to the storm sewer as it could potentially support an additional 480 residents at the current average water use estimates which includes domestic and commercial water needs. Several other groundwater conservation measures should also be considered:

- Upgrading leaky water mains – The Town currently loses approximately 20-30% of the water pumped from the wells (Dave Newman, pers. comm., 2012)
- Monitoring and possibly reducing groundwater pumping and use by the Strata Condo. Much of this water is used for irrigation and the excess is directed to the storm sewer. This water could possibly be recycled back into the irrigation circuit. A water budget should be completed to determine actual needs and groundwater extraction should be minimized wherever possible.
- Town residents should consider low volume alternatives such as low flow toilets, shower heads, and reduce water use in irrigation watering/sprinkling.

Other groundwater management measures, such as rainwater capture and managing runoff can also help to reduce the future groundwater requirements.

7.0 GROUNDWATER MANAGEMENT FRAMEWORK

The purpose of a Groundwater Management Framework is to provide tools that allow the Town to develop and implement ongoing practices and activities that support the sustainable management of the Gibsons Aquifer. A Water Management Plan (WMP) is a master document that outlines the approach for a community to achieve a balance between water consumption and environmental protection, while considering economic, social and ecological objectives.

The Town and SCRD should consider collaborating to develop a WMP that considers both surface water and groundwater resources in the region. Although a WMP must be customized to local conditions and needs, several components are common to all WMP's and include information regarding the operation and maintenance (O&M) of water supply system, water accounting/monitoring and utility information, Best Management Practices (BMPs), emergency response, and water management opportunities.

Operating plans, procedure and emergency response manuals are of critical importance as they provide guidance in an emergency situation. For instance, if an uncontrolled artesian discharge caused by casing failure or a breach of the Gibsons Aquitard (either accidental or resulting from an earthquake, for example) an immediate action plan would be required to mitigate adverse impacts to the Gibsons Aquifer as quickly as possible. A contingency plan is also required to identify steps for what can be done in the event of a drought or if salt water intrusion is indicated in the monitoring data.

As part of the WMP process, it will also be important to develop appropriate Bylaws and Policies to guide future land development that can potentially affect the long-term yield and water quality in the Gibsons Aquifer. Development planning should also be considered in conjunction with watershed(s) and aquifer management so that a proper balance can be established and maintained. For instance, establishing development permit areas within the Town and the SCRD may be needed to control the activities that may affect the sustainability and protection of the Gibsons Aquifer. Policies developed by the Town/SCRD should also be integrated with upcoming Provincial Regulations regarding groundwater licensing and use.

The framework identifies the key components of WMP. It also recommends approaches to link the scientific studies (E.g. aquifer mapping), and the Town's water infrastructure initiatives to policies and bylaws and community actions.

The key components of the groundwater management framework components are:

1) Groundwater Management Zone
2) Long Term Groundwater and Surface Water Monitoring Program
3) Groundwater and Surface Water Quantity and Quality Objectives
4) Integration of Groundwater Management Practices into Policies and Bylaws
5) Community Communication and Engagement
6) Update of Database, Conceptual and Numerical Hydrogeologic Model and Report

It is envisioned that the framework will over time evolve into the Gibsons Aquifer Management Plan or overall Gibsons/SCRD WMP for the region.

7.1 Groundwater Management Zone

A groundwater management zone defines an area and depth for activities that the Town and the SCRD participate in to sustain and to protect the Gibsons Aquifer and the Town's groundwater supply. Figure 28 provides the operational management area for the Gibsons aquifer. The larger area shown as the numerical model domain in Figure 42 should serve as the interim surface boundary of the management zone. It is anticipated that this boundary will be refined with time as additional data is obtained.

The vertical extent to the Groundwater Management Zone is determined from the depths of the aquifer across the management area. There is currently no data to define the vertical depth in the area affecting Mountain Block Recharge which could extend from the base to the top of Mt. Elphinstone. The aquifer varies in depth from over 100 m in Upper Gibsons to approximately 10 m in Lower Gibsons but has not been fully defined in all directions. For the purposes of developing the groundwater management framework, the Gibsons Aquifer is defined as the depth below the Basal Capilano/Vashon Till Aquitard to the top of bedrock and, extending from the base of Mt. Elphinstone to some unknown distance beneath Gibsons Harbour.

7.2 Groundwater and Surface Water Monitoring

7.2.1 Groundwater

In addition to monitoring the existing well network, additional wells will likely need to be installed in advance of significant land development in order to understand the cumulative effects that the proposed development will have on the aquifer. It is recommended that a bi-annual review of the data be conducted for any trends of concern. Water levels, triggers/threshold values, and water quality indicator parameters will also need to be re-established after more long term data is collected.

Appendix F provides the recommended groundwater monitoring program; including the recommended locations for additional observation wells. The program also includes an approach for development of threshold/triggers values and actions plans.

7.2.2 Surface Water

Surface water flow data is lacking for major creeks within the study area. Although new hydrometric stations may be required, an immediate and less expensive solution may be to reactivate previously discontinued Water Survey of Canada gauges or former temporary hydrometric monitoring stations if they are found to be suitably located. Although new stream gauging equipment would need to be purchased, reactivation of former WSC stations (if possible) would require less work as stream rating curves have presumably already been established and historical data already exists to calibrate the new equipment. The Town should retain a surface water hydrology firm to assist in the development of an appropriate surface water monitoring program.

7.2.3 Groundwater Quantity and Quality Management Objectives

The basis of a groundwater management plan is to have a clearly written description of a specific set of reference conditions or desired targets and/or threshold values to measure the performance of the Gibsons Aquifer. When developed, the plan should clearly describe how each of the adopted management objectives helps sustain and/or protect the groundwater supply and the Gibsons Aquifer.

As noted above, additional water quantity and quality data is required prior to setting these management objectives. Approaches for interim objectives are also discussed in Appendix F for groundwater flow rates and/or levels and indicator quality parameter concentrations.

7.3 Integration of Groundwater Management into Bylaws and Policies

7.3.1 Development Permit Areas

Development permit areas are likely the best mechanism that the Town of Gibsons and the SCRD have to control the activities discussed below that may affect the sustainability and protection of the aquifer. As is shown on Figure 28, aquifer boundaries do not necessarily coincide with watershed or jurisdictional boundaries. The aquifer management must therefore be a joint effort and will need to incorporate several watersheds and accommodate numerous stakeholders.

7.3.2 Mapping and Protection of Significant Recharge Areas

Waterline's Phase 1 and 2 programs in conjunction with the UBC work provide an assessment of possible recharge mechanisms for the Gibsons Aquifer. Several potentially significant recharge areas have been identified. Further mapping is required to better delineate these areas. In the interim, the Town should undertake to identify the following areas as groundwater recharge areas of potential interest:

- Mountain Recharge Area (Upper Gibsons to top of Mt. Elphinstone);
- Recharge from Creeks (150 m buffer on either side of the Creeks within the study area),
- Recharge windows in the Capilano sediments in Upper Gibsons (suspected to extend from Upper Gibsons to the base of Mt. Elphinstone.

The areas identified cannot be better defined at this time as no site specific subsurface information (borehole, wells, etc....) is available. If land development is undertaken in any of these areas, the proponent should be required to assess potential impacts to the Gibsons Aquifer (if any) prior to proceeding with the development.

7.3.3 Mapping Potential Contaminant Sources and Aquifer Vulnerability

Protection of the untreated groundwater supply from the Gibsons Aquifer is critical to maintaining a safe and reliable water supply. Aquifer protection strategies need to incorporate a thorough understanding of the interactions of the aquifer with potential sources of contamination at the surface and in the subsurface. Although not part of the present scope of work, an inventory of all potential sources of contamination should be completed and become part of the Town of Gibsons Aquifer Management Plan.

Potential contaminants can originate from a variety of sources including, but not limited to, the following:

- Domestic or industrial use of fertilizers and pesticides,
- Fuel-supply dispensing facilities (underground and above-ground storage tanks),
- Landfill operations,
- Runoff from agricultural operations (stables, composting),
- Storm-water,
- Septic fields,
- Historical spills, and

- Industrial operations.

Aquifer contamination often takes many years or even decades to be recognized, and many more years and at great expense to remediate once contamination is apparent (Cherry 1987). The prevention of groundwater contamination is therefore crucial to preserve the quality of this valuable finite groundwater resource. The most effective solution to groundwater contamination problems is prevention (Cherry 1987). It should also be noted that contaminant pathways can be created by old wells that have never been properly abandoned. A number of inactive wells were identified during the field verification survey and consideration should be given to correctly and safely abandoning these wells as soon as practicably possible.

Vulnerability mapping is a method used by the province of BC to communicate high risk activities and/or vulnerable hydrogeologic conditions to the broader community. The BC aquifer classification system categorizes aquifers according to level of development and vulnerability to contamination. A development subclass is determined by assessing water demand verses the aquifer's yield or productivity as shown in Table 14.

Table 14: Aquifer Development Subclass

I	II	III
Heavy (demand is high relative to productivity)	Moderate (demand is moderate relative to productivity)	Light (demand is low relative to productivity)

The vulnerability of an aquifer to contamination from surface sources is assessed based on aquifer type (confined or unconfined), thickness and extent of geologic materials overlying the aquifer, depth to water (or top of confined aquifers), and the type of aquifer materials (sand and gravel or fractured bedrock). The vulnerability subclasses are shown in Table 15.

Table 15: Aquifer Vulnerability Subclass

A	B	C
High (highly vulnerable to contamination from surface sources	Moderate (moderately vulnerable to contamination from surface sources	Low (not very vulnerable to contamination from surface sources

The final aquifer classification is a combination of the three development and three vulnerability subclasses as shown in Table 16.

Table 16: Aquifer Classification

Class	I	II	III
A	IA- heavily developed, high vulnerability aquifer	IIA- moderately developed, high vulnerability aquifer	IIIA–lightly developed, high vulnerability aquifer
B	IB- heavily developed, moderate vulnerability aquifer	IIB - moderately developed, moderate vulnerability aquifer	IIIB–lightly developed, moderate vulnerability aquifer
C	IC–heavily developed, low vulnerability aquifer	IIC – moderately developed, low vulnerability aquifer	IIIC –lightly developed, low vulnerability aquifer

According to the BC Water Resources Atlas (2010), the Gibsons Aquifer is moderately developed (Subclass II). In Lower Gibsons (discharge area) the aquifer has been classified as moderately vulnerable to contamination (Aquifer Classification IIB), and in Upper Gibsons as being of low vulnerability to contamination (Aquifer Classification IIC). Vulnerability mapping data from the BC GSC site maps (http://webmap.em.gov.bc.ca/mapplace/minpot/bcgs.cfm) identifies Lower Gibsons as a high vulnerability area (Aquifer Classification IIA) which obviously differs from the data provided in the BC Water Resources Atlas. This is likely based on the depth to water and the thickness of the Gibsons Aquitard. It is noted that the scale of mapping used by both these methods does not provide the accuracy needed for accurate aquifer management by the Town of Gibsons.

Based on the work completed in the current study, Waterline agrees that the level of aquifer development appears to be moderate given a current average demand for water of 2500 to 3000 m^3/day versus a potential productivity of over twice that amount. The aquifer vulnerability classification is difficult to assess with any degree of certainty but historical water quality data indicate that the moderate vulnerability classification may also be appropriate. It should be cautioned, however; that trace levels of CFC's were identified in water samples from Town wells indicating that surface activities are affecting the aquifer. There is also the concern of whether the analytical testing program being conducted by the Town is sufficiently comprehensive to identify other possible water quality issues. Prior to testing by UBC, the presence of CFC's in the groundwater was not suspected. As indicated previously, a complete inventory of possible historical and current chemical use in the Town and surrounding areas should be completed and a water quality testing program developed accordingly.

Aquifer vulnerability mapping cannot be used as the sole source of information for approving new developments which may impact shallow and deep groundwater quality. Site-specific information and monitoring data is required and must continue to be collected to confirm/update geological and groundwater conditions. More information regarding aquifer vulnerability in Lower Gibsons in relation to geotechnical issues (rather than susceptibility to contamination) is provided in Section 7.4.5 below.

7.3.4 Land Development and Potential Impacts

Development planning should be considered in conjunction with watershed(s) and aquifer management planning so that a proper balance can be established between development requirements and environmental and watershed/aquifer protection and management.

An assessment of potential development impacts was completed by AECOM as part of the Integrated Stormwater Management Plan for the Town of Gibsons. Table 17 presents surface water model simulations to evaluate potential impacts to runoff in the various creeks during pre-development, build out to current land use, and future land use scenarios. Increase in runoff based on current land use projections range from 19% increase in Gibsons Creek, to 76% increase in runoff in Goosebird Creek.

Table 17: Runoff Evaluation Summary

Creek	Modeled Catchment Size (Ha)	Predevelopment	Current Land Use		Future Land Use (no BMP's)	
		Volume (x 1000 m^3)	Volume (x 1000 m^3)	% Increase	Volume (x 1000 m^3)	% Increase
Gibsons	323	763	910	19%	1023	34%
Charman	159	945	1139	21%	1406	49%
Goosebird	31	74	130	76%	202	173%
Chaster Tributary	187	441	603	37%	650	47%

Notes: Ha means hectares, BMP's mean best management practices, Source: AECOM 2010.

The projected increase in runoff based on future land use changes proposed for the Town range from 34% in Gibsons Creek to 173% in Goosebird Creek. Although not known with any degree of certainty, increase in runoff typically results in reduced infiltration into the subsurface which may correspond to reduced aquifer recharge.

Table 18 shows how future land use and development within the Town of Gibsons will increase the percentage of impermeable surfaces. Impermeable surfaces tend to promote runoff and reduce infiltration capacity of the soil.

Table 18: Impervious Surface Assessment - Charman Creek

Condition	Forest (Ha)	Grass (Ha)	Pavement (Ha)	Roof (Ha)	% Impervious
Predevelopment	79.6	79.6	0.0	0.0	0%
Existing	39.7	92.6	10.8	16.2	17%
Future	26.0	60.7	36.2	36.2	46%

Notes: Ha means hectares, Source: AECOM 2010.

Table 19 summarizes how various water budget elements may change within the Charman Creek watershed as a result of future planned development. Runoff is expected to increase from 48% of annual precipitation to 68%, which reflects the increase in impermeable surfaces. Infiltration estimates are projected to decrease by 9% from 37% to 28% at full development.

Table 19: Water Balance Model Results - Charman Creek

Condition	Run-off	Infiltration	Losses
Predevelopment	41%	41%	19%
Current Development	48%	37%	15%
Future Development	62%	28%	10%

Source: AECOM 2010.

Although the recharge contribution of Charman Creek to the Gibsons Aquifer is not likely significant given the small catchment area, the AECOM model estimates illustrate the impact of land use on potential recharge to the subsurface. Therefore, it is prudent that the effects of land use be considered for long-term groundwater management planning.

7.3.5 Protecting the Integrity of the Confining Layer over the Aquifer

Aquifer risk assessment and protection are often based on the threat of contamination of the aquifer. However, Waterline's study has revealed other vulnerability issues relating to the geotechnical environment in Lower Gibsons that may not have been previously considered by the government vulnerability mapping program. As discussed previously, the Gibsons Aquifer beneath Lower Gibsons is under artesian pressure. Historical accounts by Town staff and local contractors indicate that penetrating the Vashon Till cap in Lower Gibsons can create a high risk situation if the artesian pressure cannot be controlled. For instance, during the completion of Town Well #4, artesian flow was encountered and could only be controlled by injecting concrete in the excavation which had been dug to expose the well casing for installation of the pitless adaptor (Nelson Plumbing pers. comm., 2009). During our field verification survey, another situation was communicated to Waterline staff by a local contractor in which the confining aquifer layer was breached along the Gibsons shoreline. In this case, a temporary uncontrolled discharge of groundwater caused significant construction delays and loss of equipment.

The situations described above illustrate the potential vulnerability of the Gibsons Aquifer to future development within Lower Gibsons. In order to ensure the protection of the Gibsons Aquifer, Waterline recommends that geotechnical and hydrogeological aspects of the Vashon Till confining unit be fully evaluated prior to, and during construction.

Recent development work initiated by the Gibsons Harbour Port Authority in the Gibsons waterfront has included driving steel pilings into the seabed and through the Gibsons Aquifer. Waterline was contracted to assist in monitoring a of the pile driving program and evaluate the concern with breaching the Vashon Till aquitard and creating a conduit for the known artesian flow from the Gibsons Aquifer. Preliminary results indicate that fresh water leakage was detected both inside and outside the pile. However, no significant adverse impact to the aquitard or Gibsons Aquifer was observed. The Town's engineering department completed monitoring the monitoring as additional pilings were driven through the Vashon Till Aquitard and the Gibsons Aquifer, and into the underlying bedrock. Although some indication of fresh water leakage was observed, no major uncontrolled breach of the Gibsons Aquitard was indicated during the pile driving program. On-going monitoring is recommended to confirm these initial findings.

7.3.6 Integration with Upcoming Provincial Regulations

Surface water and groundwater protection initiatives are most often driven by regulation, policies or guidelines. Provincial regulatory change is underway with the BC Water Act modernization process (http://livingwatersmart.ca/water-act/groundwater.html) initiated in about 2005. It is anticipated that the groundwater licensing requirements will be roll-out in 2014 (Kevin Ronneseth, BCMOE, April 2013).

7.3.7 Management of Storm Sewer Diversion of Artesian Flow

The well heads for the Town of Gibsons production Wells # 1 and #4 are configured so that when pumps are inactive, the natural artesian flow is directed to the storm sewer which discharges to the ocean. This practice has been on-going since the wells were initially installed in the 1980's and 1990's. The daily measure flow rates have 163 m^3/day in Town well #1; and 112 m^3/day in Town Well #4 (Figure 30). Although in general this may be perceived as wasteful, it is a necessary practice to maintain well control. Although it may be possible to retrofit the well heads and seal the pump so that the artesian flow to the sewers is stopped, the Town has some concerns with potential impacts to natural springs and the possibility of increased discharge in unknown locations in Lower Gibsons. As this practice has been ongoing for over 30 years and new development has occurred it is possible that sealing the wellheads could cause new springs, blow-outs, and/or flooding in areas not previously considered. The best management practice in this case may be to capture the fresh water, and provide it to new service areas in need of a water supply. At the average daily per capita use estimated for the Town of Gibsons, this overflow from the Gibsons Aquifer could provide water supply for about 480 residents.

7.4 Community Engagement and Communication

GGC was engaged by Waterline to undertake this component of the Groundwater Management Framework as a related project. The project developed a framework for groundwater communication and engagement, and undertook several activities to be incorporated into a Gibsons Aquifer Interpretative Tour ('the Tour'). The concept of the Gibsons Aquifer Interpretive Tour was presented to the Town's Committee of the Whole on February 6, 2013 who recommended that funding from the 2013 budget be allocated. A phased approach was proposed, with a pilot and Phase 1 Tour to be conducted sometime in 2013. Additional details are provided within GGC's report which is provided in Appendix G.

7.5 Updating of Conceptual Hydrogeological and Numerical Model

The development of an accurate conceptual model is contingent on available geological and hydrogeological data. The available data for the Gibsons Aquifer has now compiled and mapping that has been completed. However, on-going long term water level monitoring is needed to continue to assess aquifer performance and long-term sustainability. Additional studies are needed to better understand the interconnections between the Gibsons Aquifer and the overlying Capilano Aquifer, creeks and mountain block all of which are thought to contribute recharge to the aquifer.

In addition, a more robust approach to numerical modelling may be required at one point in order to fully integrate groundwater and surface water flow information so that they can be managed as a single resource. This would be appropriate when new hydrometric monitoring stations have been established and long-term surface water and groundwater data becomes available.

8.0 CONCLUSIONS

Based on the aquifer mapping work completed to date, the following conclusions have been reached by Waterline:

- **Gibsons Aquifer** - The Gibsons Aquifer is composed of a sand and gravel deposit that extends beneath Gibsons Harbour and the Town of Gibsons, to the base of Mt. Elphinstone. The aquifer is capped with the low permeability Basal Capilano and Vashon Till material that creates a confining layer over the aquifer. Although the cover is extensive, it may be discontinuous in creek valleys or beneath Upper Gibsons where younger Capilano deposits may have eroded through the unit. The Gibsons Aquifer is fully confined and under artesian pressure in the vicinity of Lower Gibsons. However, monitoring data has revealed that the aquifer is only partially saturated in the area of Upper Gibsons. The presence of “blowing” wells in Upper Gibson suggests that the aquifer may be directly connected to atmosphere at some point in the system.

- **Capilano Aquifer** - A shallow unconfined aquifer has also been identified in Upper Gibsons which has been identified as the Capilano Aquifer. Historically, the Capilano Aquifer was used for domestic supply and is still being used for industrial purposes such as washing of gravel. This shallow aquifer is believed to be “perched” in some areas and not generally in direct contact with the deeper Gibsons Aquifer. Notwithstanding this, there is also some indication of leakage through what we have termed “recharge windows” which are speculated to occur in creek valleys or where Capilano Alluvium may have eroded through the Basal Capilano/Vashon Aquitard layer.

- **Average Groundwater Flow Velocity -** Estimates of groundwater flow in the Gibsons Aquifer indicate average linear groundwater velocity of 400 m/year. Based on these flow estimates, the time for groundwater to travel from the recharge area near the base of Mt. Elphinstone to the discharge area in Lower Gibsons is approximately 9 years. This is consistent with water chemistry data that suggest a short residence time of groundwater from the recharge source to the discharge area in Lower Gibsons.

- **Aquifer Response to Precipitation -** Based on these data, it appears water levels in the shallow unconfined aquifer correlate strongly to the precipitation data. Conversely, water-level data from the deeper Gibsons Aquifer wells show a reduced correlation with the precipitation record and a more muted water level response. This indicates that Gibsons Aquifer is not strongly connected to the overlying Capilano Aquifer or local creeks in the areas being monitored but some connection is thought to exist somewhere in the system (recharge windows).

- **Aquifer Response to Tidal Cycle -** Tides in the Gibsons Marina area can fluctuate by as much as five metres from the highest to the lowest tides. Water level hydrographs for WL10-02, MW06-2A, and the Georgia Mirage Strata well, all completed within the Gibsons Aquifer, showed a minor response to tidal fluctuation. The monitoring well hydrographs from MW06-1A, MW06-1B, MW06-2B and WL10-01 completed in the Capilano Aquifer showed no discernible tidal effects on the groundwater levels.

- **Aquifer Response to Pumping** - Groundwater levels in the Gibsons Aquifer appear to be influenced by the combined pumping from Town wells 1, 3 and 4. None of the other monitoring wells appeared to be affected by the Town pumping activities. Water-level fluctuations in the shallow well completed in the over lying Capilano Aquifer in same area (MW06-2B) shows no correlation with Town well pumping.

- **Water Quality -** Results from groundwater samples indicate the following:
  - Based on the data, groundwater contained in the Gibsons Aquifer is dominantly sodium-calcium-magnesium bicarbonate type water with a neutral pH and low TDS
  - Dissolved fluoride concentrations have been increasing since 2009 in groundwater samples collected from wells completed in the Capilano Aquifer near the Aquatic Centre.
  - Aluminum (total and dissolved) concentrations exceeded the GCDWQ in groundwater from WL10-01, WL10-02, MW06-01A, MW06-1B and MW06-2B.
  - Arsenic concentrations have increased over the last three sample events in groundwater from WL10-01. In 2011 and 2012, arsenic concentrations exceeded the GCDWQ in this well.
  - Iron and/or manganese concentrations have exceeded the GCDWQ in groundwater samples from WL10-01, WL10-02, School Board well, MW06-1A, MW06-1B and MW06-2B.

- **Environmental Tracer Results –** A groundwater tracer was completed using a variety of natural and human-made chemicals which become locked into the molecular structure of the water as precipitation and snowmelt to assess recharge to the Gibson Aquifer. Tritium, noble gas, and tritium/helium tracers were used to determine source and recharge conditions of the groundwater contained in the aquifer. In general, the data suggests that most samples consist of a mixture of sub-modern and modern water. The deepest wells completed in the Gibsons Aquifer indicated the oldest groundwater age, coolest recharge temperatures, and a high estimated recharge elevation. Samples from the shallow unconfined Capilano Aquifer exhibit the youngest apparent ages, the warmest recharge temperatures and the lowest estimated recharge elevations.

- **Chlorofluorocarbons -** Although the CFC data had limited utility for use in the groundwater tracer study, it was noted that Town Wells 2 and 3 contained elevated concentrations of CFC (12) above background levels (50 ppt background versus 1250 ppt at TW2 and 17,000 ppt at TW3). High levels of CFC (12) are thought to be related to sewage effluent or to a refrigerant source. It should be noted that the Town's sewage treatment plant is located only 180 m up gradient of Town Wells 2 and 3.

- **Aquifer Recharge -** Three likely significant aquifer recharge mechanisms have been recognized:

  - **Mountain Block Recharge:** Recharge from the mountain block likely moves into the aquifer through deep fractures in the bedrock that are suspected to be in contact with the Gibsons Aquifer near the base of Mt. Elphinstone. The environmental tracer study indicates that the mountain block potentially contributes 55% of the recharge to the Gibsons Aquifer.
  - **Creek Recharge:** All creeks within the study area appear to be directly connected to the shallow, unconfined Capilano Aquifer. Creek beds may also be connected to the underlying Gibsons Aquifer where the Vashon Till/Basal Capilano Aquitard cover is thin or has been eroded away.
  - **Recharge Windows through Capilano Alluvium:** It is also likely that the late-stage Capilano Alluvium found in Upper Gibsons has eroded the Basal Capilano and Vashon Till Aquitard cover and provides a direct pathway for recharge to enter the aquifer near the base of Mt. Elphinstone. These area situated in Upper Gibsons are also the site of a number of gravel pit operations.

- **Groundwater Modeling Results -** Computer model simulations indicate that the Gibsons Aquifer should be able to supply the Town's water supply needs even under moderate climate change predictions. There may be a need to eventually abandon supply wells located near the coast and replace them with wells located closer to, or in Upper Gibsons if long-term monitoring indicates that threshold limits are being approached. If a new well is added to the well field then it should be located as far away from the ocean as practicably possible. Although there are some advantages to locating a new well in Upper Gibsons, the drilling depth could exceed 100 m and the cost would increase accordingly. This would however avoid flowing artesian conditions, minimize the likelihood of inducing salt water intrusion, and allow for easy groundwater level monitoring in the absence of flow artesian conditions.

- **Climate Change** - It should be noted that climate change/variability and the effects on aquifer recharge are somewhat uncertain and can only be quantified by long-term monitoring trends and assessing cause and effect response in the aquifer. For the purposes of the predictive analysis, only the worst case climate change scenarios were considered in the model simulations completed. If the worst case is not realized, and a best case scenario occurs in which there is an increase in aquifer recharge, then results indicate no negative impacts, as the increase in recharge would likely result in higher predicted water levels in the aquifer than those predicted for no climate change assessment.

- **Aquifer Vulnerability -** BC Government aquifer vulnerability maps show discrepancies in the assessed degree of vulnerability in Lower Gibsons and do not provide the scale of resolution to be useful for the Town of Gibsons. Although not included in the provincial aquifer vulnerability assessment the geotechnical integrity of the Gibsons Aquitard needs to be considered in the Vulnerability assessment.

- **Geotechnical Integrity of Gibsons Aquitard -** The Gibsons Aquifer beneath Lower Gibsons is under artesian pressure. Historical accounts by Town staff and local contractors indicate that penetrating the Vashon Till cap in Lower Gibsons can create a high risk situation if the artesian pressure cannot be controlled. For instance, during the completion of Town Well #4, artesian flow was encountered and could only be controlled by injecting concrete in the excavation which had been dug to expose the well casing for installation of the pitless adaptor. This situation illustrates the potential vulnerability of the Gibsons Aquifer to future development within Lower Gibsons that involves excavation or intrusive.

  Recent development work initiated by the Gibsons Harbour Port Authority in the Gibsons waterfront has included driving steel pilings into the seabed and through the Gibsons Aqutard/Aquifer. Preliminary results indicate that fresh water leakage was detected both inside and outside the pile. However, no significant adverse impact to the aquitard or Gibsons Aquifer was observed. The Town's engineering department completed monitoring as additional pilings were driven through the Vashon Till Aquitard and the Gibsons Aquifer, and into the underlying bedrock. Although some indication of fresh water leakage was observed, no major uncontrolled breach of the Gibsons Aquitard was indicated during the pile driving program.

9.0 RECOMMENDATIONS

Based on the data and interpretations presented above, the following recommendations are provided regarding the Gibsons Aquifer Mapping Study:

- **Establish a Groundwater Management Zone** – A Groundwater Management Zone defines an area and depth for activities that the Town and the SCRD participate in to sustain and to protect the Gibsons Aquifer and the Town's groundwater supply. Based on Waterline's work we recommend that the interim operational management area extends from Gibsons Landing (beneath the harbour) to near the top of Mt. Elphinstone and from Chaster Creek to Gibsons Creek. In addition, the Gibsons Aquifer is defined as the depth below the Basal Capilano/Vashon Till Aquitard to the top of bedrock. It is anticipated that this boundary will be refined with time as additional data is obtained.

- **Water Management Plan and Development of Bylaws and Policies** – A Water Management Plan (WMP) is a master document that outlines the approach for a community to achieve a balance between water consumption and environmental protection, while considering economic, social and ecological objectives. The Town and SCRD should consider collaborating to develop a WMP that considers both surface water and groundwater resources in the region. Although a WMP must be customized to local conditions and needs, several components are common to all WMP's and include information ragarding the operation and maintenance (O&M) of water supply system, water accounting/monitoring and utility information, Best Management Practices (BMPs), emergency response, and water management opportunities. Operating plans, procedure and emergency response manuals is of critical importance as it provides guidance of who to contact and what to do in an emergency situation. For instance, if an uncontrolled artesian discharge caused by casing failure or a breach of the Gibsons Aquitard (either accidental or resulting from an earthquake, for example) an immediate action plan would be required to mitigate adverse impacts as quickly as possible. Drought contingency or plans for what to do in the even salt water intrusion is indicated in the monitoring data should also be considered.

As part of the WMP process, it will also be important to develop appropriate Bylaws and Policies to guide future land development that can potentially affect the long-term yield and water quality in the Gibsons Aquifer. Development planning should also be considered in conjunction with watershed(s) and aquifer management so that a proper balance can be established and maintained. For instance, establishing development permit areas within the Town and the SCRD may be needed to control the activities that may affect the sustainability and protection of the Gibsons Aquifer. Policies developed by the Town/SCRD should also be integrated with upcoming Provincial Regulations regarding groundwater licensing and use.

- **Community Engagement and Communication** – As this is a key part of maintaining public involvement in the management and protection of the Gibsons Aquifer, it is imperative that the current community engagement program be continued. Regular updates, water quality trends, and aquifer performance data should be made public so that the residents of the Gibsons and surrounding SCRD gain some understanding of the importance of the water management initiatives being undertaken by Town Planners and the engineering department. Waterline believes that the community engagement program will lead to public participation in terms of water conservation, data collection (water levels and water use), sharing of monitoring information, allowing privately owned wells to be integrated into the Gibsons Aquifer monitoring network, and community assistance in protecting the resource. Such a program will also help disseminate accurate information and hopefully discourage the distribution mis-information and misunderstandings regarding groundwater and the possible affects of certain activities on the aquifer.

- **Update Inventory of Potential Contaminant Sources and Aquifer Vulnerability** – The purpose of competing an inventory of contaminant sources situated over the Gibsons Aquifer is to assess the possible risk assciated with surface activities and vulnerability of impacting the Gibsons Aquifer. Such information also provides a basis for developing a comprehensive analytical testing program for the Town wells which should include a broader list of chemical parameters than is currently being tested. These data should be used to update the aquifer vulnerability classification completed by the Province.

- **Well Maintenance Program -** All Town supply wells need to be inspected to determine their current condition. As steel water well casings are known to have a variable servicable life which depends on well construction and corrosion potential, it is prudent to have all wells inspected regularly by a qualified well driller and/or pump installer. The main risk is of eventual casing or well seal failure which could cause uncontrolled release of groundwater from the Gibsons Aquifer due to the artesian pressure. There is also some concern with the introduction of pathogens or other contaminants into the well if the integrity of the near surface well seal becomes compromised. Town Well #1, for instance, is now over 45 years old and is showing signs of inefficiency. This is possibly due to corrosion at the well screen or near wellbore accumulation of fine material which would cause the water level inside the well to drop over time as the efficiency of passing water through the well screen is reduced. Waterline recognizes that well maintenance on the Gibsons Town Wells is complicated by the complex well head completion, flowing artesian conditions, and the need for back up supply during the well inspection/maintenance procedure. MOE guidance documents regarding well maintenance and approaches to drilling wells into artesian aquifers are provided in Appendix B.

- **Site Specific Investigations -** Additional investigation is recommended for the areas around the Aquatic Centre where elevated chloride and fluoride have been identified. In addition, further investigation is also recommended to assess the trace (but elevated) source of CFC (12) identified in Town wells 2 and 3. It should also be noted that contaminant pathways can be created by old wells that have not been properly abandoned. A number of inactive wells were identified during the field verification survey and consideration should be given to properly decommissioning and abandoning these wells as soon as practicably possible. A list of wells is provided in Appendix A.

- **Groundwater Monitoring Program -** On-going monitoring of the monitoring well network should be continued to identify long-term trends and changes in the hydrogeological regime that could influence the availability and quality of groundwater in the area. In addition to monitoring the existing well network, additional wells will likely need to be installed in advance of land development in order to understand the cumulative effects that proposed developments may have on the aquifer. Waterline also recommends that a flow meter be installed on the Eagle Crest Road Condominium well, and that the Strata Condo Association be consulted to coordinate retrieval of the existing logger (currently stuck) and installation of a drop pipe to protect the logger from getting stuck in the future.

  Climate change impacts, and changes to groundwater diversion and potential land development impacts that could reduce or increase recharge to the aquifer need to be understood. A detailed monitoring plan is provided in Appendix F. It is recommended that monitoring data be reviewed at least annually to confirm that the instrumentation remains in good working condition and for early detection of any adverse trends in the monitoring data.

- **Installation of Additional Monitoring Wells** – At least three new monitoring wells need to be in Lower Gibsons. Two of the wells will be used to measure the artesian pressure in the aquifer in Lower Gibsons in order to assess the level of risk if the Gibson Aquitard is breached, or if a well casing failure was to occur. The 3rd well is less urgent but should be installed near the water front in order to identify and locate the salt/fresh water interface. Strict drilling protocols for artesian aquifers will need to be followed as indicated in the MOE Guidance document provided in Appendix B. Additional wells are also required but may be added to monitoring well network as new developments are being considered over the long term.

- **Geotechnical/Hydrogeological Studies -** Protecting the integrity of the confining layer over the Gibsons Aquifer is imperitive. Waterline recommends that geotechnical/hydrogeological investigations be completed in advance of approving new developments in order to assess the risk associated with breaching the Gibsons Aquitard. Drilling and pile driving protocols should also be developed to avoid creating pathways for uncontrolled artesian discharges or contaminants. Geotechnical conditions in Lower Gibsons were not considered by the BC government aquifer vulnerability mapping program. Investigation and monitoring guidelines for drilling, excavation, and pile driving through the Gibsons Aquitard/Aquifer system need to be developed in order to protect the aquifer from potential adverse impact. The guidelines should consider the geotechnical stability of the aquitard confining unit, any potential for blow out and loss of control of the artesian flow from the Gibsons Aquifer during well drilling or pile driving, and the potential for creating conduit pathways for salt water intrusion or other contaminants into the Gibsons Aquifer. Although not fully defined, the most vulnerable area is identified as the aquifer discharge zone which situated beneath Middle and Lower Gibsons which also extends for some unknown distance beneath Gibsons Harbour.

  On-going monitoring of the piles installed in the near shore environment during the recent work completed by the Gibsons Port Authority is recommended to confirm the initial findings of the pile driving program.

- **Management of Storm Sewer Diversion of Artesian Flow** – Although consideration was given to sealing of Town of Gibsons well heads to prevent groundwater diversion to storm sewer, the uncertainty of raising the pressure in the aquifer and the potential for increasing spring seepage in Lower Gibsons was too risky. In the short term, the Town should consider using the 275 m^3/day that is currently being diverted to the storm sewer.

- **Water Conservation:** Several proactive groundwater conservation measures are recommended:
  - Upgrading leaky water mains – The Town of Gibsons currently loses approximately 20-30% of the water pumped from the wells;
  - Monitoring and reducing groundwater pumping and use by the Strata Condo. Much of this water is used for irrigation and the excess is directed to the storm

sewer. A water budget should be completed to determine actual water needs and groundwater extraction should be minimized wherever possible;

- Town residents should consider low volume alternatives such as low flow toilets, shower heads, and reduce water use in irrigation and watering/sprinkling. Other groundwater management measures, such as rainwater capture, managing runoff can also help to reduce the future groundwater requirements.

- **Groundwater Quantity and Quality Management Objectives** – Groundwater quality monitoring targets and thresholds need to be established for the Gibsons Aquifer. This should be completed once a comprehensive inventory of possible contaminants has been completed and baseline of water quality data is available for the specified suite of water quality parameters. Once the threhold values have been etablished, long-term water quality trends will need to be monitored and mitigation plans developed should trends in the data indicate that threshold values are being approached. This is all part of the early warning system needed to manage and protect the aquifer and ensure the long-term safe the Gibsons Aquifer groundwater supply.

- **Surface Water Monitoring** - The extent of AECOM's Integrated Stormwater Management study was limited to within the Town of Gibsons boundary. This area is insufficient coverage to fully address groundwater-surface water interactions relating to the aquifer mapping study. Installation of hydrometric and climate stations is recommended in order to more fully address groundwater-surface water interactions and aquifer recharge. This may include reactivation of former hydrometric stations or installation of new stations, reactivation of the Gower Point climate station and perhaps installation of a new hydrometric and climate stations. The results of the UBC tracer study indicates that 55% of recharge likely originates from the Mt Elphinstone Mountain Block. Therefore, consideration should be given to installing a climate station at some higher elevation than the former Environment Canada station in the Gower Point area. In addition, installation of snow gauging stations on Mt Elphinstone would allow for the monitoring of snow accumulation and water release during melt which may be critical to understanding the timing of aquifer recharge from the mountain block.

- **Mapping and Protection of Significant Recharge Areas** - Further mapping is required to identify and delineate significant recharge areas. The areas identified to date cannot be fully delineated at this time as no site specific subsurface information (borehole, wells, etc....) is available. An efficient method to obtaining land cover data is by conducting a remote sensing survey (E.g: LIDAR or Light Imaging, Detection, and Radar Technology) over the region. Such surveys would provide up-to-date information on land cover (impermeable surfaces, vegetation cover, bare land) from which to help assess areas where significant recharge to the Gibsons Aquifer may exist. If land development is undertaken in any of these areas, the proponent should be required to assess potential impacts to the Gibsons Aquifer (if any) prior to proceeding with the development. In the interim, the Town should undertake to identify the following areas as groundwater recharge areas of potential interest:

    - Mountain Recharge Area (Upper Gibsons to top of Mt. Elphinstone);

- Recharge from Creeks (150 m buffer on either side of the Creeks within the study area),
- Recharge windows in the Capilano sediments in Upper Gibsons (suspected to extend from Upper Gibsons to the base of Mt. Elphinstone.

- **Updating of Conceptual Hydrogeological and N umerical Model** – As new data comes available (new wells, long-term water level, water use, and water quality data), it will be important that it be captured electronically in a single repository/geodatabase so that the Town has up-to-date information available to allow for updating of existing conceptual and numerical models. Guideline and policies employed to protect the aquifer will also need to be reviewed to confirm that they are consistent with any new conceptual or numerical models developed.

Table 20 summarizes Waterline recommendations and implementation timeline.

Table 20: Summary of Recommendations and Implementation Timeline
Notes: Short term means 1 year, medium term means 2-5 years, long term means > 5 year

Recommendation	Timeline/Term
Community outreach	Short
Contaminant/Chemical inventory	Short
Well maintenance	Short
Site specific investigations	Short
Establish Groundwater Management Zone	Short
Groundwater Management Plan	Short to medium
Groundwater monitoring	Short to long
Installation of new monitoring wells	Short to long
Geotechnical and hydrogeology studies of Gibsons	Short to long
Manage artesian flow	Medium to long
Water conservation	Medium to long
Goundwater quality targets and thresholds	Medium to long
Hydrometric and climate stations	Medium to long
Significant recharge areas	Medium to long
Conceptual and numerical model	Long

Notes: Short term means 1 year, medium term means 2-5 years, long term means > 5 years

10.0 CLOSURE

Surface and groundwater are renewable resources but a balance must be struck between water needed to maintain healthy ecosystems and the demand for water by humans. Although the Gibsons Aquifer Mapping project sets the framework for assessing water availability versus water demand, certain data gaps exist which need to be filled in order to provide a more accurate picture of current and future conditions within the Gibsons Aquifer as the Town continue to grow. The objective in water management is to achieve “sustainability" of water resources. This is simply not possible in the absence of long-term monitoring data.

Approaches to water management are relatively well understood and not unique to the province British Columbia. Developing guidelines that lead to improved knowledge of surface water and groundwater systems has been developed by other jurisdiction across Canada and can also be applied to the Gibsons Aquifer.

The people of Gibsons are extremely fortunate to have access to such a prolific and viable fresh water aquifer and Town staff who care about its viability and protection. The Town of Gibsons has taken a proactive step with the initiation of the aquifer mapping project. The cooperation of all private landowners, drillers, water practitioners, developers, corporations, municipal/provincial/federal regulatory officials is now required to move the water management process forward to a sustainable future. It is also imperative that residents take a leadership role by providing access to existing water wells which are completed into a community resource. It is important to remember that landowners only own the surface rights and that water is a shared resource owned by the Crown. On-going land development and increasing water demand, combined with the potential effects of climate change will undoubtedly continue to place stress on groundwater resources in ways that we cannot predict or fully understand with the current datasets.

The enclosed report and the information included were compiled exclusively for the Town of Gibsons and presents results of the Aquifer Mapping study, groundwater data evaluation and monitoring plan development. The work was carried out in accordance with the scope of work for this project and accepted hydrogeological practices. No other warranty, expressed or implied, is made as to the professional services provided to the client. Any use which a third party makes of this report, or any reliance on or decisions to be made based upon it, are the responsibility of such third parties. Waterline accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

Respectfully submitted,

Waterline Resources Inc.

PROFESSIONAL GEOSCIENTIST
PROVINCE OF BRITISH COLUMBIA
D.J. DAVID
May 13, 2013

Darren David, M.Sc., P.Geo.
Principal Hydrogeologist

Jessica Doyle M.Sc. (Pending), G.I.T
Project Hydrogeologist

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