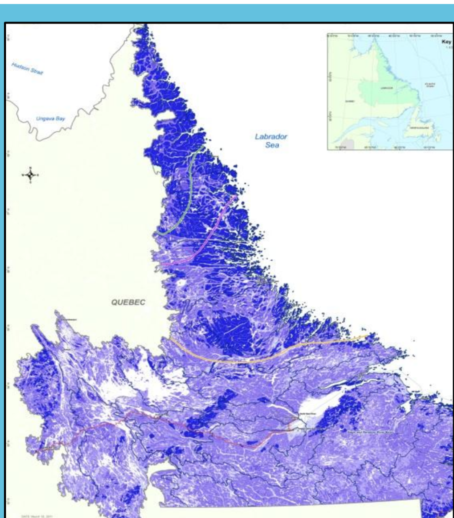
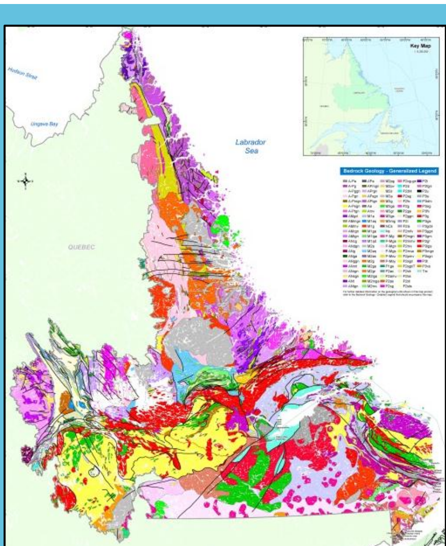
March 2013

Government of Newfoundland and Labrador,
Department of Environment and Conservation
-Water Resources Management Division

Hydrogeology of Labrador





Environment

Government of Newfoundland and Labrador
Department of Environment and Conservation – Water Resources Management Division

Hydrogeology of Labrador

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March 25, 2013

Ms. Dorothea Hanchar, M.Sc.
Groundwater Resources Manager
Department of Environment and Conservation
Government of Newfoundland and Labrador
PO Box 8700
Confederation Building, West Block 4th Floor
St. John's, NL A1B 4J6

Dear Ms. Hanchar,

Project No: 60163257

Regarding: Hydrogeology of Labrador Report

AECOM is pleased to provide the Government of Newfoundland and Labrador, Department of Environment and Conservation, Water Resources Division, with the final report on the Hydrogeology of Labrador.

AECOM would like thank you for the opportunity to work for the Water Resources Management Division. If you have any questions or comments regarding the findings herein please contact the undersigned.

Sincerely,
AECOM Canada Ltd.

Nora Doran

Nora Doran, P.Geo.
Hydrogeologist
nora.doran@aecom.com

Distribution List

# of Hard Copies	PDF Required	Association / Company Name
3	1	Newfoundland and Labrador Department of Environment and Conservation, Water Resources Management Division

Revision Log

Revision #	Revised By	Date	Issue / Revision Description
0		March 25, 2011	Draft Report (Revision 0)
1	N.Doran	March 1, 2013	Implement comments from NLDEC

AECOM Signatures

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Abstract

AECOM Canada Ltd. (AECOM) was retained by the Government of Newfoundland and Labrador, Department of Environment and Conservation, Water Resources Management Division (NLDEC) to prepare a report describing the nature, location and characteristics of groundwater resources within Labrador. This report, which is titled "Hydrogeology of Labrador", is the fourth of four hydrogeology reports that will cover all areas of the Province of Newfoundland and Labrador. The report is based on data and information obtained from NLDEC and other provincial government departments, as well as publicly available reports and data on the subject.

The main objective of this work is to describe the physical characteristics of the major geological units of Labrador. Specifically, this report establishes and describes the occurrence, availability and quality of the groundwater within specified hydrostratigraphic units and describes the aquifer potential of these units based on data obtained from the provincial well log database.

A total of 352 well logs, out of a total of 18,000 well logs available in the provincial well log database, were available for Labrador, including 47 wells completed in overburden aquifers and 305 wells completed in bedrock aquifers. Domestic water supply wells account for 55% of the total well logs in Labrador while municipal and public water supplies account for 30%.

Five surficial hydrostratigraphic units were established for Labrador by grouping lithostratigraphic units and their inferred groundwater potential. Groundwater yields in surficial aquifers of Labrador vary from zero litres per minute (Lpm) to 2,250 Lpm Unit E, consisting of glaciofluvial deposits, was identified as having the greatest groundwater development potential of any surficial material in Labrador.

Groundwater resources in the five Precambrian bedrock provinces of Labrador are highly variable with yields ranging from 0.5 to 600 Lpm. Four bedrock hydrostratigraphic units were developed for Labrador based on well construction and well yield information for areas where drilled bedrock well information was available. For areas where no information was available, well construction and well yield potential was inferred from the findings of studies conducted in other areas of Labrador. Unit 4, consisting of Labrador Trough sedimentary and volcanic rocks and metamorphic extensions in western Labrador, was identified as having the greatest bedrock well development potential in Labrador. Unit 4 has moderate groundwater development potential with mean well depths of 45.6 m and geomean well yields of 45 Lpm.

Four zones of permafrost exist within Labrador. The occurrence of groundwater in permafrost areas differs from its occurrence in warmer climates and should be considered when developing groundwater resources in northern Labrador within the zone of continuous permafrost. Groundwater movement is mildly to strongly affected by permafrost in both the discontinuous and continuous permafrost zones.

Estimated annual water surplus, groundwater recharge and surface water runoff rates were calculated for Labrador using a Geographic Information System (GIS) based analytical model. A mean normal surplus of 522 mm was estimated for Labrador. The total estimated potential annual recharge and runoff estimated for Labrador is 27.66 x 10^9 m^3 and 13.65 x 10^{10} m^3, respectively. On average, groundwater recharge accounts for approximately 17% of the total water balance of Labrador, with surface runoff accounting for the remaining 83%.

Analysis of water budget results and hydrographs from Water Survey of Canada hydrometric stations identified three general types of hydrologic systems in Labrador: regulated systems, surface water dominated (i.e. <15 % baseflow) systems, and those systems with a relatively higher baseflow component (i.e. > 15 % baseflow). Visual estimation of baseflow for select hydrographs of unregulated rivers in Labrador ranges from approximately 12% to 30% of total stream discharge. Evaluation of the regulated Churchill River hydrograph shows that the river has a very high

baseflow contribution with significant moderation of peak flows in spring summer. The artificial baseflow is maintained by slowing releasing stored surface water over time.

Surface water chemistry in Labrador reflects the composition of soils and bedrock. Higher pH, hardness, alkalinity and major ion concentrations were observed in surface waters in areas where underlying geology is composed of carbonate-rich sedimentary bedrock, whereas in areas where underlying geology consists primarily of gneiss and granite bedrock, surface water tends to be slightly acidic, coloured, highly corrosive and of low mineral content.

Groundwater quality data in Labrador are limited to sample results from only six communities with public groundwater supplies and two additional communities. In general, the chemical composition of groundwater reflects the geochemistry of the host bedrock.

There is an overall lack of information respecting groundwater quantity and groundwater quality in Labrador. Groundwater obtained from wells completed in both surficial and bedrock aquifers are utilized in Labrador to support portions of domestic, industrial and municipal requirements.

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Appendices

1. Introduction

AECOM Canada Ltd (AECOM) was retained by the Government of Newfoundland and Labrador, Department of Environment and Conservation, Water Resources Management Division (NLDEC) to prepare a report describing the nature, location and characteristics of groundwater resources within Labrador. This report, which is titled "Hydrogeology of Labrador", represents the fourth of four hydrogeology reports that will cover all areas of the Province of Newfoundland and Labrador. The report is based on data and information obtained from NLDEC and other provincial government departments, as well as publicly available reports and data on the subject.

The main objective of this work is to describe, to the extent possible using the best available data, the physical characteristics of the major geological units of Labrador. Specifically, this report establishes and describes the occurrence, availability and quality of the groundwater within specified hydrostratigraphic units and describes the aquifer potential of these units based on data obtained from the provincial well log database. The primary objective of the work is to assess the geology of the five Precambrian geological provinces and covering Quaternary deposits and correlate these findings with groundwater characteristics that are typically used to gauge the utility and vulnerability of groundwater: quality, occurrence and availability. Results of this study can be used for reference by private and public-sector groups including private industry and government officials when planning or assessing projects affecting the development and use of groundwater within Labrador.

1.1 Scope of Study

The scope of work for the project was consistent with work undertaken for the previously prepared reports in this series. The scope of work this report included the following key elements:

- Preparing a general description of the surficial and bedrock geology, physiography and hydrogeology of Labrador, with a specific focus on the hydrogeological characteristics of the principal geological units;
- Preparing compilation bedrock, surficial geological maps of Labrador on a scale of 1:1,000,000;
- Compiling existing water-well data provided by the NLDEC, including – where available – depth of well, well yield, overburden thickness, casing length, water chemistry, static water-level and; available quantitative data based on aquifer pumping tests, and field investigations;
- Preparing a hydrogeological map of Labrador divided into discrete hydrogeological units with accompanying notations and unit descriptions;
- Describing the physiography or physical geography of Labrador with a specific emphasis on the interrelationships between surface water and groundwater. This includes recharge and discharge characteristics, groundwater contribution to surface runoff, general direction of groundwater movement and seasonal fluctuations of groundwater and hydrologic budget;
- Preparing a general discussion of potential contamination problems in Labrador resulting from mining and related activities and possible contamination resulting from naturally occurring mineral concentrations within bedrock; and,
- Identifying potential areas prone to salt-water intrusion and discussing spring usage by the general public.

1.2 Overview of Labrador

Labrador forms the mainland portion of the Province of Newfoundland and Labrador and is separated from the island portion of the province by the Strait of Belle Isle (Figure 1). Labrador is the largest and northernmost geographical region in Atlantic Canada and it encompasses an area of over 294,000 square kilometres (km^2). It lies between the latitudes of 51° N and 60 ° N and between longitudes of 54° W and 65° W and because of its great size, exhibits considerable variation in climate, precipitation patterns and geology. Despite being over twice as large as the island of Newfoundland, Labrador is home to only 6% of the Province's population, approximately 27,000 people. Labrador is bordered to the west and south by the Province of Quebec and to the east by the Atlantic Ocean, specifically the Labrador Sea.

1.3 Importance of Scale in Hydrogeologic Studies

The scale of a hydrogeologic study determines the type and amount of data required, the analytical techniques used, and the accuracy of the maps produced (Singer and Cheng, 2002).

A small-scale hydrogeologic study is typically conducted at a scale of 1:5,000 or 1:10,000 to assess problems within a well-defined local area. Such problems may include provision of drinking water to new subdivisions, selection of a landfill site, decommissioning of a contaminated site, etc. The area of interest is typically a few hectares. The study is usually intensive and requires a great degree of accuracy. A small scale study may involve production of an accurate topographic map, the drilling of wells, a detailed analysis of geologic logs, pumping test analyses, and water quality tests.

A hydrogeologic study on a sub-watershed scale of 1:10,000 to 1:25,000 is typical for an area of interest in the order of 10 to 100 km^2 in size. The study may involve spot streamflow measurements, construction of cumulative stream discharge graphs, use of piezometers, continuous runoff measurements, water level measurement in wells, pumping test analyses and groundwater modelling.

On a watershed scale of 1:50,000 to 1:100,000, the objective is to describe groundwater resources within the watershed for a typical area of 100 to 1,500 km^2. The study may include compilation, analysis and interpretation of existing physical and geologic information and may include identification of major aquifers and their water-yielding capabilities, quantification of groundwater recharge and discharge, a water budget analysis and evaluation of water quality data.

For an area the size of Labrador (over 294,000 km^2), a hydrogeologic study on a regional 1:500,000 to 1:1,000,000 scale is typically conducted to assess an approximate area of 5,000 km^2 or more. The objective is to provide a general overview of the significant elements of the groundwater regime in the area. The study usually provides a general overview of the area's physical characteristics and identifies its major geologic units and their water-yielding capabilities. The study may describe groundwater flow regimes, long-term groundwater discharge and recharge, and general groundwater quality. The intent of the Hydrogeology of Labrador study is to provide basic background information that can be used to conduct future hydrogeologic studies at more detailed scales.

Map Features

- Town or Village
- Former Town or Village
- Major Road
- Secondary Road
- Ferry Route
- Watercourse
- Provincial Boundary
- Waterbody

Bathymetry

- 0 - 200m
- 200 - 1000m
- 1000 - 3000m
- > 3000m

Government of Newfoundland and Labrador
Department of Environment and Conservation

Figure 1

Labrador

Newfoundland and Labrador

Kilometres
0 25 50 100 150 200 250

FINAL

DATE: March 23, 2011
SCALE: 1:4,300,000
PROJECTION: UTM Zone 20N, NAD 83
REVISION: 6
DRAWN: HC-SEG

AECOM

1.4 Sources of Data

The primary source of data for this report is the NLDEC Water Resources Management Division (WRMD) Drilled Well Database (DWD) for wells completed between 1950 and 2009 (NLDEC, 2009). The Well Drilling Act (1982) and subsequent Regulations require all water well drillers in Newfoundland and Labrador to submit a water well record for each well drilled. The NLDEC WRMD manages this information and displays it in the Drilled Well Database where it can be accessed by the public. Since the Regulations, which describe the information that must be submitted with each drilled well, date from 1983 while many wells were installed prior to that time, much of the information within the DWD is incomplete. The DWD includes a limited amount of information such as well construction characteristics (e.g., well diameter, depth of casing, drilling method used, etc.), descriptions of rock types encountered (lithology) and pumping test results for approximately 18,000 drilled wells within Newfoundland and Labrador. The majority of wells are located on the island of Newfoundland where most of the province's population is based; fewer than 305 wells are recorded in Labrador. NLDEC WRMD in June 2010 issued a Request For Proposal to evaluate and update the database. The work is being conducted concurrently to the Hydrogeology of Labrador project and so the upgraded database was not available for use in the current report.

Historical surface water and groundwater quality data was extracted from the Community Water Resources reports available from the NLDEC WRMD Water Resources Portal (WRP) and a limited amount of data from available consultant's reports. The water quality data is based on published results of source water sampling undertaken by NLDEC for the NLDEC public water supply testing program. The WRP displays a variety of water resources data on a geographic information system (GIS)-based web portal at http://maps.gov.nl.ca/water/. Hydrometric and climate monitoring information is also available for download at the WRP; however for the purpose of this report the most recent hydrometric and climate station data was obtained through direct consultation with NLDEC WRMD staff.

The digital datasets for bedrock and surficial geology that were used for the bedrock and surficial geology maps were obtained from the Newfoundland and Labrador Department of Natural Resources (NLDNR). The base data for the maps and figures presented in this report were obtained from NLDNR / NLDEC. Geospatial data including that used in the Digital Elevation Model (DEM) and drainage area definitions of Labrador were obtained from GeoGratis, a web portal maintained by the Earth Sciences Sector of Natural Resources Canada (NRCan).

A limited number of groundwater evaluations have been conducted by consulting engineers and hydrogeologists for municipal governments and private organizations. These reports provided supplemental well information to the NLDEC Well Driller's Database, and information on physiography, hydrology, hydrogeology and water quality at specific locations within Labrador.

Climate normal data (1971-2000) obtained from Environment Canada Atmospheric Environment Service was used to describe the average climatic conditions of Labrador.

Streamflow hydrograph data was obtained from the HYDAT database maintained by Environment Canada. This database includes archived hydrometric data compiled by the Water Survey of Canada's (WSC) eight regional offices. HYDAT is a database containing data on the daily and monthly flow means from hydrometric monitoring stations operated by the WSC.

All referenced reports and other data sources used in this report are listed in Section 11.

2. Physiography

2.1 Geography

Labrador has a large, irregular, semi-triangular shape that encompasses the easternmost section of the Canadian Shield, an extensive geographical region characterised by thin soil and abundant mineral resources. Labrador is bounded by the Hudson Strait to the north, the Labrador Sea to the east, the Strait of Belle Isle to the south and the Province of Quebec to the west. Its western border with Quebec forms the drainage divide of the Labrador Peninsula. Lands drained by rivers flowing into the Atlantic Ocean are part of Labrador, while the lands drained by rivers flowing into Hudson Bay are part of Quebec.

2.1.1 Northern Region

The northern coast is largely mountainous. The long thin tip of northern Labrador holds the Torngat Mountains. The mountains stretch along the coast from Port Manvers four hundred kilometres north to Cape Chidley, the northernmost point of Labrador. The Torngat Mountain range is also home to Mount Caubvick, the highest point in the province. The deeply incised North Coast is dominated by these mountains and is characterised by steep fjords, rugged terrain and sparse population density. This area is inhabited predominantly by the Inuit, with the small Innu community of Natuashish being the exception. The north coast is the most isolated region of Labrador, with snowmobiles, boats, and planes being the most common modes of transportation. The largest community in this region is Nain, within an approximate population of 1,000 people.

2.1.2 Central Region

The most populous region of Labrador, central Labrador extends from the shores of Lake Melville in the east to the Labrador Trough area in the west. The interior averages 450 metres above sea level (masl) and is cut by large, east-flowing rivers, such as the Churchill River, the largest river in Labrador, and its tributaries. Happy Valley–Goose Bay (HVGB) is situated in eastern central Labrador and it is the largest community in Labrador, with a population of approximately 7,500 people. HVGB is situated on the shores of Lake Melville, a saltwater tidal extension of Hamilton Inlet. Both Lake Melville and Hamilton Inlet are surrounded by mountains, with population settlements at HVGB, Northwest River, and Sheshatshiu. Canadian Forces Base (CFB) 5 Wing Goose Bay is situated within HVGB. Once a refuelling point for airplane convoys to Europe in World War II, it is now a North Atlantic Treaty Organization (NATO) tactical flight training site and an alternate landing zone for the Space Shuttle.

The Trans-Labrador Highway (TLH) extends 560 kilometres (km) to the west, connecting HVGB to western Labrador including the iron mining towns of Labrador City and Wabush, and the unincorporated community of Churchill Falls. (Trans Labrador Highway, 2011). Topographic elevations in the Labrador City area range between 400 and 600 masl. The highlands above the Churchill Falls were once an ancient hunting ground for the Innu First Nations and settled trappers of Labrador. After the construction of the hydroelectric dam at Churchill Falls in 1970, the Smallwood Reservoir has flooded much of the old hunting land. The Smallwood Reservoir area is flat to gently rolling, and lakes are abundant. Drumlins and eskers are common landforms, although bedrock outcrops are widespread in western Labrador. Elevation ranges from 330 m to over 500 m, with isolated rugged hills rising approximately 150 m above the general surface (Ecological Framework of Canada, 2011). Permafrost occurs in isolated areas, primarily in wetlands.

2.1.3 Southern Region

Southern Labrador includes the coastal communities extending from L'Anse au Clair in the south to Cartwright in the east. The Labrador Straits region is across the Strait of Belle Isle from the island of Newfoundland and is approximately 10,000 km^2 in size. It includes the incorporated communities of Red Bay, Pinware, West St. Modeste, L'Anse au Loup, Forteau and L'Anse au Clair, and the unincorporated villages of Capstan Island, L'Anse Amour and

Point Amour. There is a road network connecting the Labrador Straits region to the communities to the east including the incorporated communities of Cartwright, Charlottetown, Port Hope Simpson, St. Lewis and Mary's Harbour, and the unincorporated communities of Paradise River, Black Tickle, Norman Bay, Pinsent's Arm, Williams Harbour and Lodge Bay. The road network follows the coast from L'Anse au Clair until just north of Mary's Harbour where it heads north through the interior towards Cartwright (NL Tourism, 2011).

The southern coast is rugged with varying topography including undulating hills, barren land areas, and hills with peaks up to 300 masl, which steeply decend to valleys at sea level. The coastal highways cross several large rivers, namely the Alexis and Eagle Rivers (Trans-Labrador Highway, 2011). As the road network traverses through the interior towards Cartwright, topography increases into the Mecantina Plateau (discussed in Section 2.4) to elevations in the order of 600 to 900 masl.

Fisheries, logging and tourism are the main industries of southern and southeastern Labrador. The interior areas of southern Labrador contain heavily and moderately stocked spruce and fir forest resources (NLDNR, 1990). Port Hope Simpson was founded in 1934 as a logging camp and has since become the largest community in southeastern Labrador (Our Labrador, 2011).

Mary's Harbour is a snow crab fishing village where most employment is in the fishery sector. With the opening of the new coastal Labrador highway, tourism is now providing additional employment (Our Labrador, 2011). Salmon fisheries are also common in the rivers draining into the Labrador Sea and Strait of Belle Isle.

2.2 Ecosystems

Labrador can be divided into two ecosystems or biomes with distinct climate and characteristic plants and animals (NL Heritage, 1997).

Northern Labrador is a typical part of the tundra ecosystem which is a sub-arctic zone characterized by long, cold winters and short, warm summers. Precipitation is low and occurs in the form of rain and snow. This area is sometimes referred to as a cold desert. Due to underlying permafrost, water tends to collect in shallow pools. The landscape, devoid of erect trees and tall shrubs, is dominated by low shrubs, mosses, lichens and small flowering herbaceous plants. The characteristic animals of the tundra biome include caribou, musk ox, arctic wolf, arctic fox, arctic hare, lemmings, and a variety of voles, while the polar bear is the dominant carnivore. Many birds migrate to this area in spring to lay their eggs and rear their young before flying south to warmer areas for the winter (NL Heritage, 1997).

Southern Labrador is an example of the taiga ecosystem. The taiga generally lies to the south of the tundra and is typified by very low winter temperatures, a longer growing season than the tundra, and more precipitation in the form of rain and snow. The soils are generally acidic and lack in important nutrients such as nitrogen and phosphorus. This biome is dominated by coniferous trees, especially balsam fir and black spruce, with white birch, trembling aspen and mountain ash being the most common deciduous trees. There are also large expanses of wetlands, especially bogs and fens. The characteristic animals of the taiga ecosystem include moose, black bear, Canada lynx, red fox, pine marten, short-tailed weasel, and mink. Beaver, muskrat, and river otter abound in the numerous rivers, lakes and ponds (NL Heritage, 1997).

2.3 Population

Population data for Labrador, including each of the regions and communities described above is provided in Table 1 (Statistics Canada, 2007). Information for the following communities was not available from Statistics Canada: Black Tickle, Capstan Island, Town of Churchill Falls, L'Anse Amour, Lodge Bay, Norman Bay, Pinsent's Arm, Sheshatsheits and William's Harbour.

Happy Valley-Goose Bay and Labrador City are the most populated towns of Labrador. In the north, Nain is the most populated community, followed by Natuashish. Cartwright is the most populated community in the east, while L'Anse-au-Loup is the most populated community in the Strait Region based on Census data from 2006.

Communities where public water supply is sourced from groundwater, in whole or in part, are shown in Table 1 in bold-type font.

Table 1 – Population and Dwelling Counts of Labrador Communities for 2001 and 2006

Geographic name	Population, 2006	Population, 2001	Population, growth or (decline)	Total private dwellings, 2006	Private dwellings occupied by usual residents, 2006	Land area km^2, 2006	Population density, 2006
Happy Valley-Goose Bay	7,572	7,969	(5.0)	3226	2726	306	24.8
Labrador City	7,240	7,744	(6.5)	2963	2784	39	186.5
Wabush	1,739	1,894	(8.2)	746	687	46	37.6
Nain	1,034	1,159	(10.8)	335	271	95	10.9
Natuashish	706	-	n/a	170	164	44	16.0
L'Anse-au-Loup	593	635	(6.6)	222	214	3	170.5
Cartwright	552	629	(12.2)	251	222	3	168.9
Hopedale	530	559	(29.0)	181	151	3	157.9
Port Hope Simpson	529	509	3.9	182	168	33	16.3
North West River	492	551	(10.7)	235	207	3	153.8
Forteau	448	477	(6.1)	180	162	7	60.2
Mary's Harbour	417	450	(7.3)	156	133	38	10.9
Charlottetown (Labrador)	366	346	5.8	128	112	31	12.0
Makkovik	362	384	(5.7)	130	117	2	183.4
Rigolet	269	317	(15.1)	125	90	4	74.5
St. Lewis	252	290	(13.1)	103	84	9	27.2
Red Bay	227	264	(14.0)	93	81	2	143.4
L'Anse-au-Clair	226	241	(6.2)	90	80	62	3.7
Postville	219	215	1.9	87	71	2	112.0
West St. Modeste	140	175	(20.0)	65	51	8	18.0
Pinware	114	140	(18.6)	50	45	4	26.1
Total	**24,027**	**24,948**	**-**	**9,718**	**8,620**	**744**	**1,615**

Note: Communities shown in bold-type font have public water supplies in whole or in part sourced by groundwater. Source: Statistics Canada. 2007.

2.4 Topography and Terrain

Labrador belongs to the Canadian Shield physiographic region of Canada, which consists of a core of massive, Precambrian age crystalline rocks. The Canadian Shield region is divided into five sub-regions: Kazan, Davis, Hudson, James and Laurentian regions, each with unique geological characteristics (Bostock 1967). Labrador encompasses three of the five Shield sub-regions including the Davis, James and Laurentian sub-regions. The following description is organized first by physiographic region according to Bostock (1967) and second by physiographic division according to Sandford and Grant (1976). Figure 2 shows the physiographic divisions of Labrador.

2.4.1 Davis Region

The landscape of Davis Region consists of a broad, old erosion surface almost without surficial deposits. The topographic relief along the eastern coast of the Davis physiographic region is typically high, and ranges from sea level to over 1,200 masl. Further inland, relief is less marked and elevations range from 300 masl to 600 masl.

2.4.1.1 Labrador Highlands Division

The dominant physiographic feature in the Labrador Highlands division is the Torngat Mountains that extend 400 km from Port Manvers to Cape Chidley. Topographic elevations begin at 0 masl on the coast and rise steeply to greater than 1,500 masl at Mount Caubvick, the highest point in Labrador (1,652 masl). Other high summits in the Torngat range include Mount Tetragona (1,372 masl.) and Mount Eliot (1,387 masl.). The peaks of the Torngat Mountains are separated by deep fjords and finger lakes surrounded by sheer rock walls (Parks Canada, 2010).

Parks Canada (2010) reports more than 40 small but active glaciers in the Torngat Mountains. The cirque glaciers of the Torngat Mountains are the only glaciers on mainland Canada east of the Rocky Mountains and represent the southernmost limit of glaciers in the eastern Arctic (Bell et al., 2008).

The Torngat Mountains are north of the tree line and the sparse vegetation is generally limited to mosses and lichen, low shrubs and stunted conifers. Permafrost is continuous on the Quebec side of the border, and it is extensive but discontinuous on the eastern Labrador side. The elevation of the Labrador Highlands typically exceeds 300 masl and precipitation is low, creating what is predominantly a rocky desert.

2.4.1.2 George Plateau Division

The George Plateau is a level bedrock plain cut by deep river valleys sloping gently north to Ungava Bay (Parks Canada, 2010). Elevations decrease from the Labrador Highlands to the George Plateau where relief trends northwest to southeast, parallel to the Torngat Mountains, and elevations decrease from approximately 600 masl to 300 masl. The effects of glaciation are marked by the presence of drumlin fields, kame terraces, erratics and eskers that snake over the plateau (Parks Canada, 2010).

2.4.2 James Region

The James Region includes extensive uplands and plateaus (Bostock, 1967). Topographic elevations in the central Labrador/ northern Quebec zones of the James Region range from 600 to 900 masl and generally decrease to sea level to the west and northwest towards Hudson Bay.

2.4.1 Lake Plateau

The Lake Plateau is an east-west trending interior upland area that extends from northeastern Quebec eastward into western Labrador in the vicinity of Labrador City, Wabush and the Smallwood Reservoir. The elevations on the interior plateau generally vary between 300 and 650 masl with some hills rising to 900 meters (NLDOE, 1997). Drainage on the interior plateau is poor due to relatively flat terrain and thin soils, resulting many lakes and wetlands.

2.4.2 Laurentian Region

The Laurentian Region includes uplands and highlands that rise abruptly above the St. Lawrence Lowlands along its northwestern border with the Davis and James regions (Bostock, 1967).

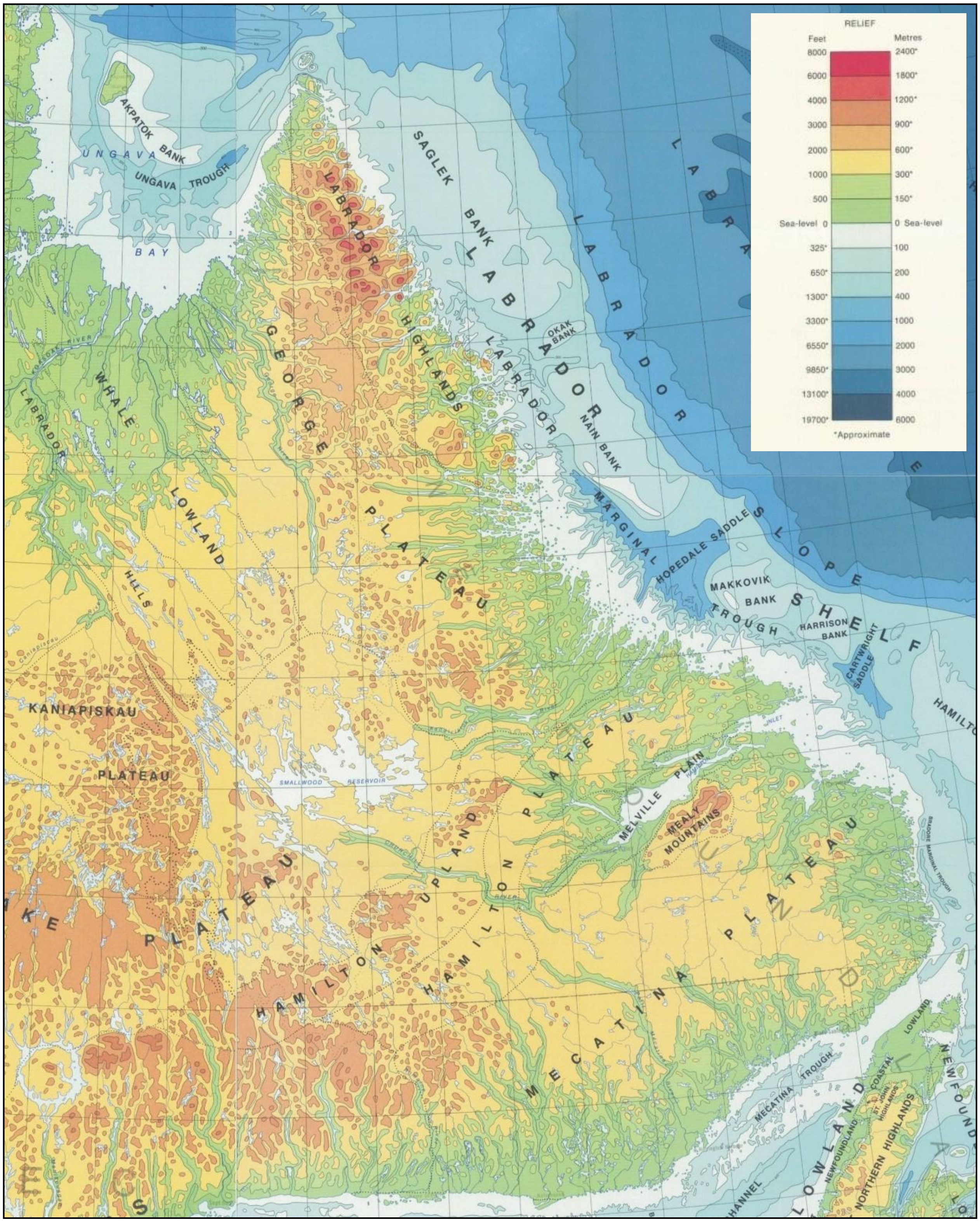

Figure 2 – Physiographic Regions of Labrador (from Sandford and Grant (1976))

2.4.2.1 Hamilton Upland

The Hamilton Upland stretches across central Labrador from west to east. Elevation typically ranges from 300 to 600 masl but the Upland is characterised by a series of hills where elevations of 900 masl are attained. Coastal regions are generally low, with elevations ranging to 300 m within approximately 200 km from the shoreline. The Upland is deeply incised by river valleys, especially in coastal areas where present watercourses once discharged huge volumes of glacial meltwater to the ocean.

2.4.3 Hamilton Plateau

The Hamilton Plateau, immediately south of the Hamilton Upland, is characterized by undulating terrain dissected by broad river valleys and rolling hills that range in elevation from 300 m to 600 masl. Peatlands are extensive in poorly drained areas, and often sites for permafrost.

2.4.3.1 Melville Plain

The Melville Plain is a broad low-lying area occupied by the Churchill River Valley and the coastal plain surrounding Lake Melville. Much of this lowland has an irregular coastline which is interrupted by numerous river valleys. Elevations range from sea level to approximately 500 masl (ESWG, 1996). Permafrost is found in isolated patches, primarily in the wetlands west of Lake Melville.

2.4.3.2 Mealy Mountains

The Mealy Mountains are an isolated west to east trending mountain range located south of Lake Melville in the southeastern portion of Labrador. The topographic elevations steeply rise from the shores of Lake Melville at sea level to over 1,000 masl. The highest peak within the Mealy Mountains has an elevation of 1,180 masl (Peakbagger, 2010).

2.4.3.3 Mecatina Plateau

The Mecantina Plateau is situated in southeastern Labrador. It has an undulating topography that rises from sea level at the south and eastern coasts of Labrador to approximately 600 masl in the central portion of the plateau (ESWG, 1996). Eskers and river terraces are common fluvioglacial features of the Plateau.

2.5 Climate

Table 2 presents a list of the 22 active climate stations in Labrador based on information obtained from the WRP. Climate monitoring in Labrador is conducted through a network of climate stations monitored by Environment Canada, the NLDEC and private companies. Climate data collected from station to station varies but typically includes air temperature, precipitation, relative humidity, wind speed and direction, atmospheric pressure, snow depth and sunshine hours. The frequency of data collection varies by station. In Labrador, climate data is most often collected on an hourly or daily basis.

Table 2 – Active Climate Stations of Labrador

Station No.	Station Name	Latitude	Longitude	Station Type	Station Date	Latest Archive
8500036	ALEXIS RIVER (AUT)	52.65	-56.86667	A1	1990	1999/2007
8500920	CAPE KAKKIVIAK	59.985	-64.165	EC	1994	2010
8500926	CAPE KIGLAPAIT	57.13583	-61.47556	EC	1994	2010
8501100	CARTWRIGHT A*	53.70833	-57.035	EC	1937	2010
8501130	CHURCHILL FALLS A*	53.55806	-64.09472	EC	1994	2010
8501547	ESKER	53.86667	-66.41667	OT	1971	
8501900	GOOSE BAY A*	53.31667	-60.43333	EC	1941	2010
8501910	GOOSE UA	53.3	-60.36667	EC		
8502400	HOPEDALE (AUT)	55.45	-60.21667	EC	1953	2010
8502485	KEPIMITS LAKE	52.7	-64.85	OT	1971	
8502561	LITTLE MECATINA RIVER (AUT)	52.23333	-61.31667	C	1994	1999
8502591	MARY'S HARBOUR A	52.30361	-55.83361	EC	1988	2010
8502799	NAIN	56.55	-61.68333	EC		
8502800	NAIN A*	56.54833	-61.68833	EC	1984	2010
8502918	ORMA LAKE	54.15	-64.16667	OT	1972	
8502NHR	MAKKOVIK A	55.08222	-59.18861	A1	1985	2010
8503249	SAGLEK	58.33333	-62.58556	EC	1989	2010
8503992	TUKIALIK BAY	54.71583	-58.35778	EC	1994	2010
8504175	WABUSH LAKE A*	52.92722	-66.87417	EC	1961	2010
8504216	WEST ST MODESTE	51.6	-56.7	OT	1984	2002
850B5R1	MARY'S HARBOUR	52.30361	-55.83361	EC	-	-
NLENCL0004	CHURCHILL RIVER AT END OF MUD LAKE ROAD	53.33775	-60.18931	ENVC	2010	2010

Source: NLDEC WRMD Water Resources Portal and Neary, P. pers. comm.

Climate normal information for at least 15 years of the 30-year period between 1971 and 2000 is available for five out of the 22 climate stations located in Labrador (Environment Canada, 2010). Climate normals (or averages) are used to summarize and describe the average climatic conditions of a particular location. At the end of each decade, Environment Canada updates its climate normals for as many locations and as many climatic characteristics as possible. Table 3 presents the climate normal data for precipitation and daily average temperature for the five climate stations in Labrador: Nain, Cartwright, Goose Bay Airport, Churchill Falls Airport and Wabush Lake Airport.

Table 3 – Climate Normal Data for Labrador

Nain	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Daily Average Temperature (°C)	-18.5	-18.3	-12.3	-4.9	1	6.2	10.1	10.7	7	1.1	-5.1	-12.8	-3
Precipitation (mm)	78.4	56.2	86.6	71.5	57.3	79.9	86.8	69.2	76.8	64.9	79	86.2	892.7
Rainfall (mm)	1.3	0.9	4.2	12.7	28.4	63.9	86.8	69.2	74.2	37.9	15.3	5.7	400.4
Snowfall (cm)	77.2	55.3	82.5	58.7	28.8	16	0	0	2.6	26.9	63.8	80.3	492.2
Cartwright	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Daily Average Temperature (°C)	-14.8	-14.1	-9	-2.3	2.9	8.2	12.1	12.1	8.2	2.9	-2.4	-9.9	-0.5
Precipitation (mm)	84	76.7	96.9	85.2	68.1	96.7	94.1	92.4	91.8	84.2	88.7	91.2	1050.1
Rainfall (mm)	3.5	4.2	10.3	23.3	43.3	92.4	94.1	92.4	89.9	68.6	36.2	14.8	573
Snowfall (cm)	84.2	75.4	86	62.1	23.9	3.3	0	0	2.1	15.9	53.8	81	487.6
GOOSE A *	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Daily Average Temperature (°C)	-18.1	-16.3	-9.6	-1.7	5.1	11	15.4	14.5	9.2	2.4	-4.5	-13.9	-0.5
Precipitation (mm)	64.6	55.1	69.6	65.4	66.2	95.8	113.8	98.8	95.2	80.1	75.6	69	949
Rainfall (mm)	1.9	3.3	5.3	19.3	47	92.1	113.8	98.8	92.3	59.6	20.3	5.7	559.5
Snowfall (cm)	80.2	62.6	75.8	52.3	19.9	3.2	0	0	2.6	22.1	62	78.3	458.8
CHURCHILL FALLS A	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Daily Average Temperature (°C)	-22.3	-20.6	-13.6	-5	2.9	9.6	13.5	12.1	6.6	-0.4	-8.6	-19.2	-3.7
Precipitation (mm)	62.1	48.5	62.2	65.8	56.7	91.2	112.3	95.8	107.2	84.6	81	59	926.4
Rainfall (mm)	0.8	1.1	3.8	10.4	37.1	84.5	112.1	95.8	96.4	40.9	8.3	2.6	493.8
Snowfall (cm)	68.3	53.1	63.5	57.7	19.6	6.3	0.2	0.1	10.6	44.6	78.2	63	465.3
WABUSH LAKE A *	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Daily Average Temperature (°C)	-22.7	-20.7	-13.5	-4.6	3.6	10.3	13.7	12.4	6.8	-0.4	-8.6	-18.6	-3.5
Precipitation (mm)	54	41.7	57.4	56.7	55.8	84.8	111.5	95.4	95.8	73.5	68.2	56.8	851.6
Rainfall (mm)	0.5	1.6	3.1	11.9	40.4	82.3	111.5	95.4	89.3	36.9	6.8	2.9	482.6
Snowfall (cm)	66.4	48.7	64.8	52.5	16.5	2.6	0	0.1	6.8	42	75.3	70.2	445.7

Source: Environment Canada (2010)

Climate normal data for the Nain area indicates the area typically receives 892.7 mm of annual precipitation, of which 400.4 mm (44.8%) occurs as rain and 492.2 mm (55.2 %) occurs as snow. The mean annual temperature in the area is - 3 °C, with mean daily extremes ranging from -18.5 °C in January to +10.7 °C in August.

Climate normal data for the Cartwright area indicates the area typically receives 1050.1 mm of annual precipitation, of which 573 mm (54.6%) occurs as rain and 487.6 mm (46.4 %) occurs as snow. The mean annual temperature in the area is - 5 °C, with mean daily extremes ranging from -14.8 °C in January to +12.1 °C in July and August.

Climate normal data for the Goose Bay Airport area indicates the area typically receives 949 mm of annual precipitation, of which 559.5 mm (53.2%) occurs as rain and 458.8 mm (48.3 %) occurs as snow. The mean annual temperature in the area is -0.5 °C, with mean daily extremes ranging from -18.1 °C in January to +15.4 °C in July.

Climate normal data for the Churchill Falls Airport area indicates the area typically receives 926.4 mm of annual precipitation, of which 493.8 mm (53.3%) occurs as rain and 465.3 mm (50.2 %) occurs as snow. The mean annual temperature in the area is -3.7 °C, with mean daily extremes ranging from -22.6 °C in January to +13.5 °C in July.

Climate normal data for the Wabush Lake Airport area indicates the area typically receives 851.6 mm of annual precipitation, of which 482.6 mm (56.6%) occurs as rain and 445.7 mm (52.3 %) occurs as snow. The mean annual temperature in the area is -0.5 °C, with mean daily extremes ranging from -22.7 °C in January to +13.7 °C in July.

3. Surficial Geology

The following sections describe the surficial geology of Labrador, based on several key information sources: regional surficial geology mapping (1:1,000,000) by Klassen et al. (1992), various geological publications, and previous experience gained through aerial photograph interpretation and fieldwork in western Labrador. A small-scale surficial geology map prepared by the Government of Newfoundland and Labrador (1997), provided in Figure 3, shows a generalized distribution of the main geological units. The more detailed mapping of Klassen et al. (1992), presented on accompanying Map 1 (Appendix A) at a scale of 1:1,200,000, provides the basis for the information presented below. A brief description of the distribution and hydrogeological implications of permafrost within Labrador follows the surficial geology sections.

The distribution and characteristics of the surficial geology of Labrador are largely the result of the last glaciation, the late Wisconsinan (25,000 – 10,000 yrs Before Present (BP)), coupled with influences from pre-existing bedrock topography and lithologies. Ice flow was generally radially outward from the ice divide, or spreading centre, situated in the vicinity of what is now the Smallwood Reservoir. During deglaciation, which was not complete in Labrador until at least 5,000 – 6,000 yrsBP (Nicholson, 1971), ice recession and disintegration occurred from the margins inward. The patterns of drumlinoid features and, to a lesser degree, eskers provide a general sense of ice dynamics during the late Wisconsinan period. The overall pattern of surface drainage, including long, ribbon lakes and irregularly configured rivers, also reflects pre-glacial drainage patterns among the many folds and fractures within underlying bedrock.

For the purposes of this report, the description of surficial geology is presented in seven sections, each of which represents a distinct origin or depositional setting:

- Exposed Bedrock and Drift-Poor Areas;
- Till;
- Ablation Drift;
- Glaciofluvial Deposits;
- Glaciolacustrine Deposits;
- Glaciomarine and Marine Deposits; and,
- Other Deposits.

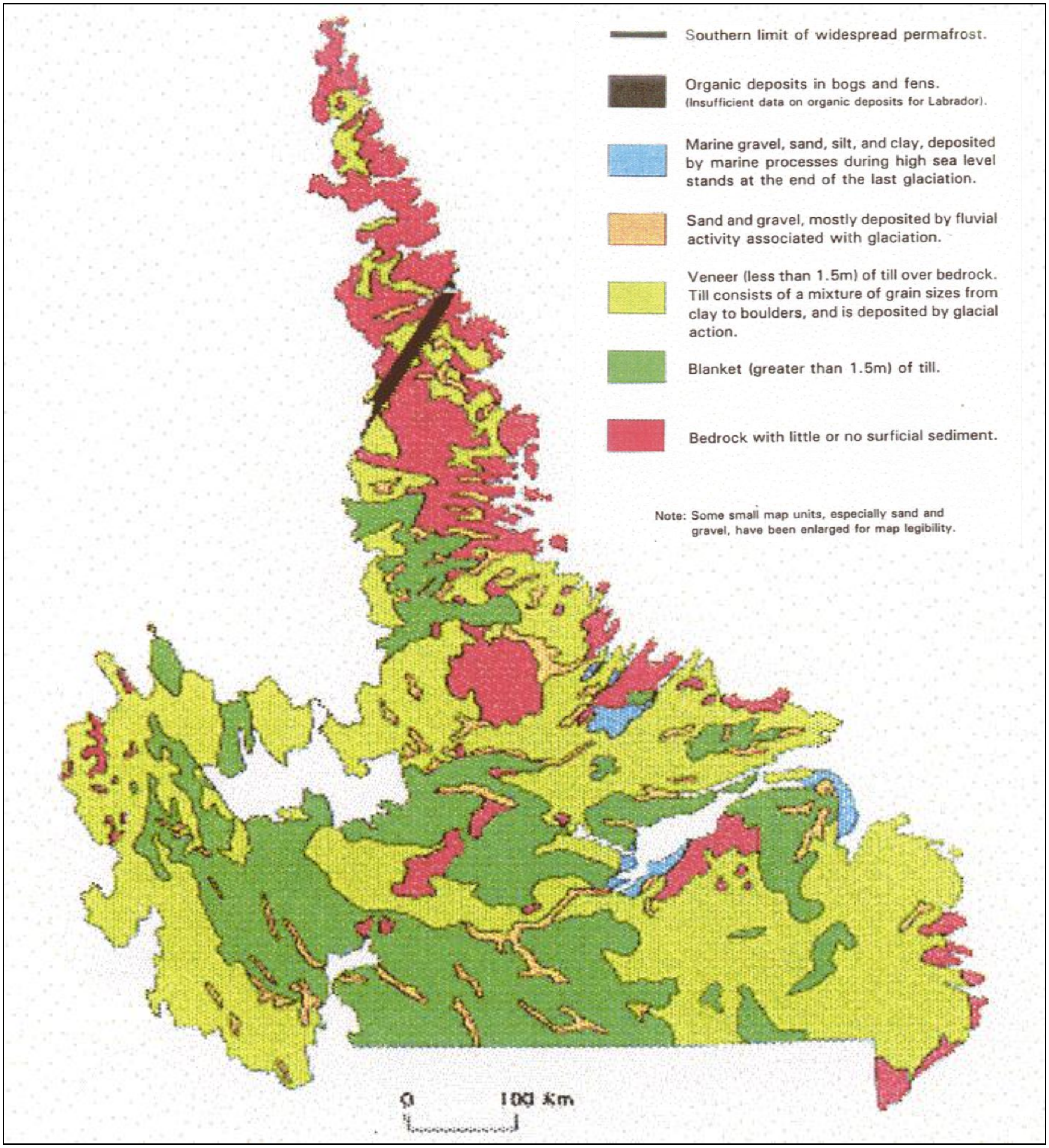

Figure 3 – Summary Surficial Geology of Labrador

(Source: Taken from the Water Resources Atlas of Newfoundland, 1992 as presented in the Report on the Hydrology of Labrador, 1997)

3.1 Exposed Bedrock and Drift-Poor Areas

Bedrock is exposed or overlain by thin, discontinuous drift within a large portion of Labrador (21%). Bedrock exposure is particularly widespread throughout northern Labrador, in the Mealy Mountains, and along much of the outer coastline. According to Klassen et al. (1992), bedrock is exposed in 80% of the area mapped as "Exposed Bedrock and Drift-Poor Areas" (Map 1, Appendix A). Thin, isolated patches of till and other surficial materials occupy the remaining 20%.

Areas of exposed bedrock generally exhibit a rugged, ridged or knobby surface expression, typical of the Canadian Shield landscape, although localized plains also exist. Through subglacial erosion, some outcrops have been striated and sculpted into roche moutonées. Local relief is typically less than 150 m across the inland plateau areas, but it reaches hundreds of metres in the Torngat Mountains of the Labrador Highlands. Localized accumulations of blocky talus line the bases of low bluffs, but with extents too small to be mapped at the provincial scale. The actual bedrock surface is commonly obscured by a thin cover of vegetation, mosses and stunted black spruce, or by peaty organic material in natural depressions. A more detailed description of bedrock within Labrador is provided in Section 4.0.

3.2 Till

Till, sediment deposited directly by glacial ice, is the most common surficial material in Labrador (64%). Given the diverse range of settings in which till can be deposited, its sedimentology and hydrogeological properties strongly depend on its origin.

The most widespread type of till in Labrador is basal till, which was deposited *beneath* moving ice. Although not specified, it is assumed that basal till is the predominant type of till mapped by Klassen et al. (1992) as "till and other surficial deposits (undifferentiated)" (64% areal coverage in Labrador). This assumption is based on the Quaternary history of the region and on field checking of aerial photograph interpretation completed in western Labrador for previous projects. It should be noted that other surficial deposits with limited areal extent, or thin (<2 m) and discontinuous coverage, are included within this map unit, due to the relatively small scale at which the surficial geology mapping was completed. The basal till blankets bedrock to depths from about one metre to locally more than 10 m. Where thickest, it exhibits a smoothly rolling or undulating surface expression.

The basal till within Labrador is derived mainly from intrusive bedrock comprising the various geological provinces of the Canadian Shield. As a result, it is predominantly non-stratified, poorly sorted, silty to sandy diamicton. From work in the Goose Bay area, Liverman (1997) reports that the tills exposed in road cuts through drumlins have sandy matrices with less than 10% silt and clay; matrix-supported clasts are predominantly pebbles and cobbles, although boulders are occasionally encountered.

Klassen et al. (1992) have also distinguished ribbed (Rogen) moraine, a unique subglacial till landform, from the more widespread areas of basal and undifferentiated tills. Ribbed, or Rogen, moraine are enigmatic subglacial landforms composed predominantly of poorly stratified, sandy diamicton (till), but commonly mixed or veneered with sandy gravel. They are commonly associated with drumlins. The term "ribbed" moraine refers to the appearance of irregular to sinuous ridges, generally less than 1 km long and 10 m high, that occupy considerable areas of Labrador (3%). They are oriented approximately perpendicular to ice flow and are commonly mantled by large boulders. In southern Labrador, ribbed moraines are most common in valleys.

3.3 Ablation Drift

Locally significant areas of ablation drift occupy inland portions of southeastern Labrador, as well as portions of the Hamilton Plateau north of Melville Lake. Pockets of ablation drift are also scattered throughout southwestern Labrador and the valleys of northern Labrador (5% total areal coverage in Labrador). Ablation drift has a variable texture depending on its depositional setting and the composition of material in the parent ice mass. Klassen et al. (1992) describe it as both massive to poorly stratified, silty to sandy diamicton and poorly sorted to well sorted sand and gravel. Ablation drift is the all-encompassing term applied to sediments and landforms that form during the disintegration of ice sheets by passive melt-out. Its association with ice melt water explains why it commonly contains significant amounts of water-sorted sediments.

Ablation drift commonly exhibits irregular hummocks and mounds 5 to 10 m high, although this is not always the case (e.g., ablation drift in the terrestrial lowlands of many fjords in northern Labrador tends to be more level, with lower relief). Klassen et al. (1992) have identified those areas of ablation drift that exhibit a hummocky surface expression. Based on previous experience in western Labrador, such hummocky landscapes have poorly integrated drainage patterns; rainfall and snowmelt are commonly forced to infiltrate or evaporate due to closed depressions among the hummocks. Combined with the granular nature of these landforms, the promotion of infiltration makes ablation moraines potentially good aquifers – although small wetlands commonly form in the poorly drained hollows.

3.4 Glaciofluvial Deposits

Glaciofluvial deposits are sediments deposited by glacial meltwater in contact with, or in front of, glacial ice. Glaciofluvial landforms within Labrador include fans and deltas, outwash plains and terraces, kames and kame terraces, and eskers. They cover 6% of Labrador. The deposits are typically clast-supported and moderately to well sorted, but the size range of the clasts depends on the depositional environment.

Eskers represent the highest energy depositional environment – most commonly forming in subglacial tunnels – so they tend to consist of rounded, cobbley sandy gravel. In contrast, outwash plains form through sedimentation in comparatively low-energy braided, proglacial streams, and are dominated by sands and smaller gravels. Sandy silt and silty sand interbeds are common due to sedimentation of fine grained material in low energy slackwater areas. Kames form in contact with glacial ice, so they tend to have a mixture of sand and gravel, as well as lenses of diamicton from sloughs off the ice surface.

Large outwash plains were deposited in the major valleys of Labrador, including the Churchill River and Goose River. Through isostatic rebound during the Holocene, the river base level and sea level has dropped significantly (>100 m), resulting in fluvial incision and the development of multi-level terraces of outwash (Liverman, 1997). Level outwash surfaces are commonly “pitted” by closed depressions known as kettles, which mark the former locations of partly buried blocks of glacial ice. Abandoned meltwater channels can also be recognized in aerial photographs covering the coastline of southern Labrador, south of Groswater Bay (Smith et al., 2003). Some outwash terraces and deltas along the coast exist well above present-day sea level, marking incremental positions of the coastline, which has risen through time due to isostatic rebound. Some of the ridge-like features originally mapped as end moraines at the entrance to the fjord in which Grand Lake is impounded are composed of stratified sand and gravel and have been re-interpreted by Liverman (1997) as ice-contact, subaqueous outwash fans.

3.5 Glaciolacustrine Deposits

Glaciolacustrine deposits occupy only 0.1% of Labrador, and no deposits exist in close proximity to communities. The few deposits that exist in Labrador are sandy and poorly sorted, and were deposited in lakes dammed by glacial ice. They are massive to laminated and may contain dropstones, fallen from calving glacier ice. Glaciolacustrine sediments blanket the underlying topography with a thickness of more than 2 m.

3.6 Glaciomarine and Marine Deposits

Glaciomarine and marine deposits occupy considerable portions of the outer coastline and the shores of Lake Melville (2% areal coverage in Labrador). The distribution of these deposits is controlled by the local amount of isostatic depression during the last glaciation and the pattern and rate of rebound. Glaciomarine deposits accumulated in shallow water along the coastline under the influence of glacial meltwater and, in some cases, direct contact with glacial ice. In contrast, marine sediments accumulated from river outflow and coastal processes without the influence of glacial processes. The thickness of these sediments varies; much of the deposits have been eroded by Holocene wave activity.

The texture of glaciomarine and marine deposits varies spatially along different areas of the outer and inner coast, and with depth. Liverman (1997) reported exposures of at least 20 m of glaciomarine fine sediments in the relatively sheltered Goose Bay area. Deposits fine upward from planar to cross-bedded sand to laminated silty clay, likely representing progressive deglaciation and a gradual transition to a lower energy setting. Dropstones are rare. Elsewhere, glaciomarine deposits are dominated by sand and gravel, in places mixed with diamictons from calving glacial ice or underflows. Remnants of gravelly cobble beaches have been observed at some locations along the southeastern Labrador coastline (Smith et al., 2003).

3.7 Other Deposits

Two other types of deposits occur throughout all regions of Labrador, but with surface areas too small to map at the provincial scale (Klassen et al., 1992).

3.7.1 Alluvial Deposits

Hundreds of creeks and rivers transporting vast amounts of silt, sand, gravel and coarser material are present in Labrador, yet their alluvial plains (active channels, side channels and floodplains) are too narrow to map at a provincial scale. The low-order, headwater tributaries tend to be steeper and flow over lag deposits from underlying till. Mid-order creeks and rivers tend to have alluvial gravel beds and discontinuous floodplains. The high-order rivers have large watersheds and relatively low gradients; typically, they transport large volumes of sand and silt through lowland areas. The modern lower Churchill River derives much of its alluvial sand from the large glaciofluvial terraces at the edges of its valley. It can be assumed that every blue line that represents a creek or river on Map 1, Appendix A has some degree of an alluvial plain, but few are likely to be useful aquifers.

3.7.2 Organic Terrain

Wetlands are scattered throughout Labrador, because the widespread low relief and poorly integrated drainage patterns impede drainage, while cool temperatures inhibit the decomposition of organic matter. Less than a metre to more than 10 m of organic material may have accumulated in these areas, yet the areal extent of the organic terrain is too small to be mapped at the regional scale.

Wetlands in Labrador commonly form in local depressions on bedrock surfaces or on till plains. Level areas of coastal lowlands may also support wetland development on fine-textured marine sediments. It is likely that development in most areas of Labrador will encounter at least small areas of poorly drained, organic soils. Organic material is not suited to groundwater taking.

4. Permafrost

Permafrost is ground that remains at or below 0°C for more than one year. Where permafrost is widespread and deep, it can significantly alter groundwater conditions and flow patterns – and thus the availability of near-surface water supply. Permafrost also affects the water balance of sites by promoting surface or near-surface runoff and inhibiting infiltration, and by altering the rate and seasonality of evapotranspiration through the maintenance of moist soils through the summer. Labrador has a sufficiently cool climate that permafrost exists, at least in small areas beneath the surface, throughout virtually all of its land area. Therefore, it is important to have a general understanding of where in Labrador permafrost is most likely to be encountered, so that the investigation, assessment and establishment of groundwater supply in areas underlain by permafrost account for its possible presence.

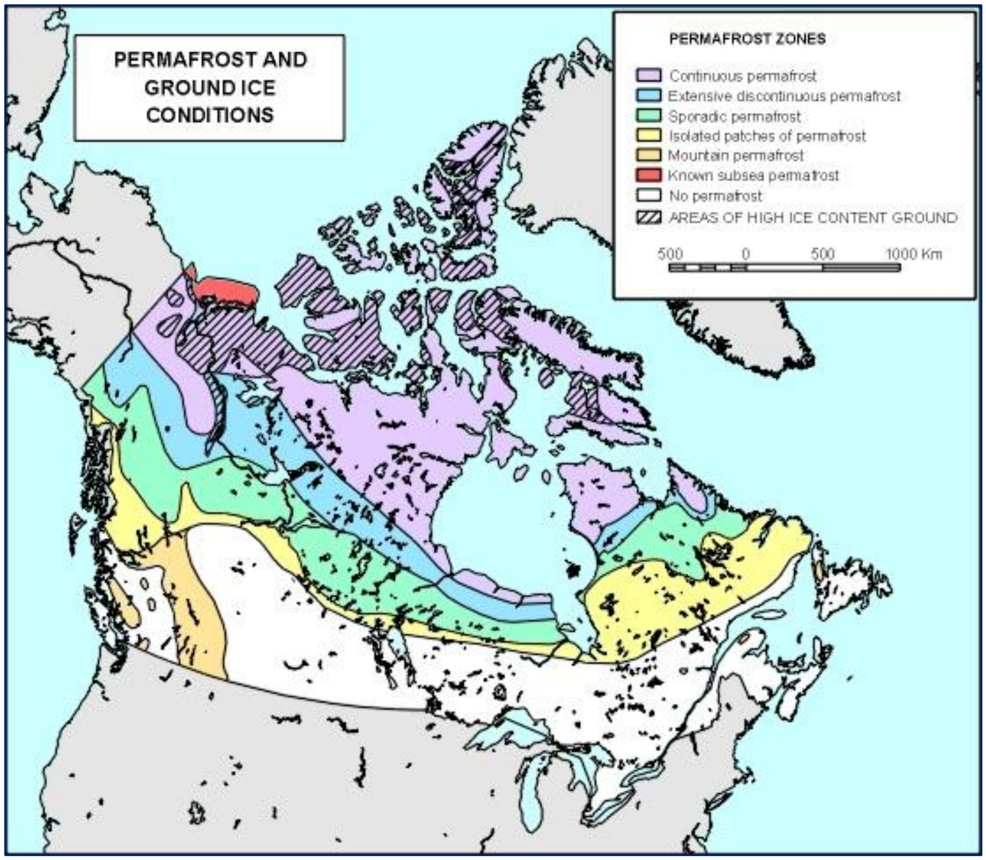

Figure 4 - Permafrost and Ground Ice Conditions of Canada

Four zones of permafrost exist within Labrador as shown in Figure 4 (Natural Resources Canada, 1993). The southern half of Labrador is characterized as having only isolated patches of permafrost, mainly in association with peaty wetlands, which insulate the subsurface. A broad band that crosses Labrador just north of the Smallwood Reservoir represents the zone of sporadic permafrost, and a narrow band immediately to its north represents the zone of discontinuous permafrost. In the zone of discontinuous permafrost, it is common to find permafrost underlying peaty wetlands, on north-facing slopes and at depth in windswept ridges. Northern Labrador is within the zone of continuous permafrost, where all ground is underlain by permafrost, except permafrost-free zones (taliks) below large water bodies. Groundwater movement is mildly to strongly affected by permafrost in both the discontinuous and continuous permafrost zones.

Overall, the continuity and thickness of permafrost increase northward through Labrador. According to data provided by Smith and Burgess (2002), permafrost in the vicinity of Labrador City ranges from less than 10 m to 50-100 m thick. In the Torngat Mountains of northern Labrador, permafrost is more than 500 m thick.

5. Bedrock Geology

The following sections describe the bedrock geology of Labrador. The work of Greene (1974) and discussions in 2010 with staff members at the NLDNR were relied upon for descriptions of the five geological provinces of Labrador and their associated rock assemblages. Bedrock geology mapping of Labrador was obtained from Newfoundland and Labrador Department of Natural Resources (2010) and is presented at a scale of 1:1,136,000 in Map 2, Appendix A. Labrador forms the eastern part of the Canadian Shield which was first sub-divided into seven provinces by Stockwell (1961, 1964), based primarily upon structural characteristics and later by radiometric age dating. For the purposes of this report, a generalized bedrock geology map was created that focuses on the generalized lithologies (Figure 6) contained in each of the five geological provinces found within Labrador (Figure 5).

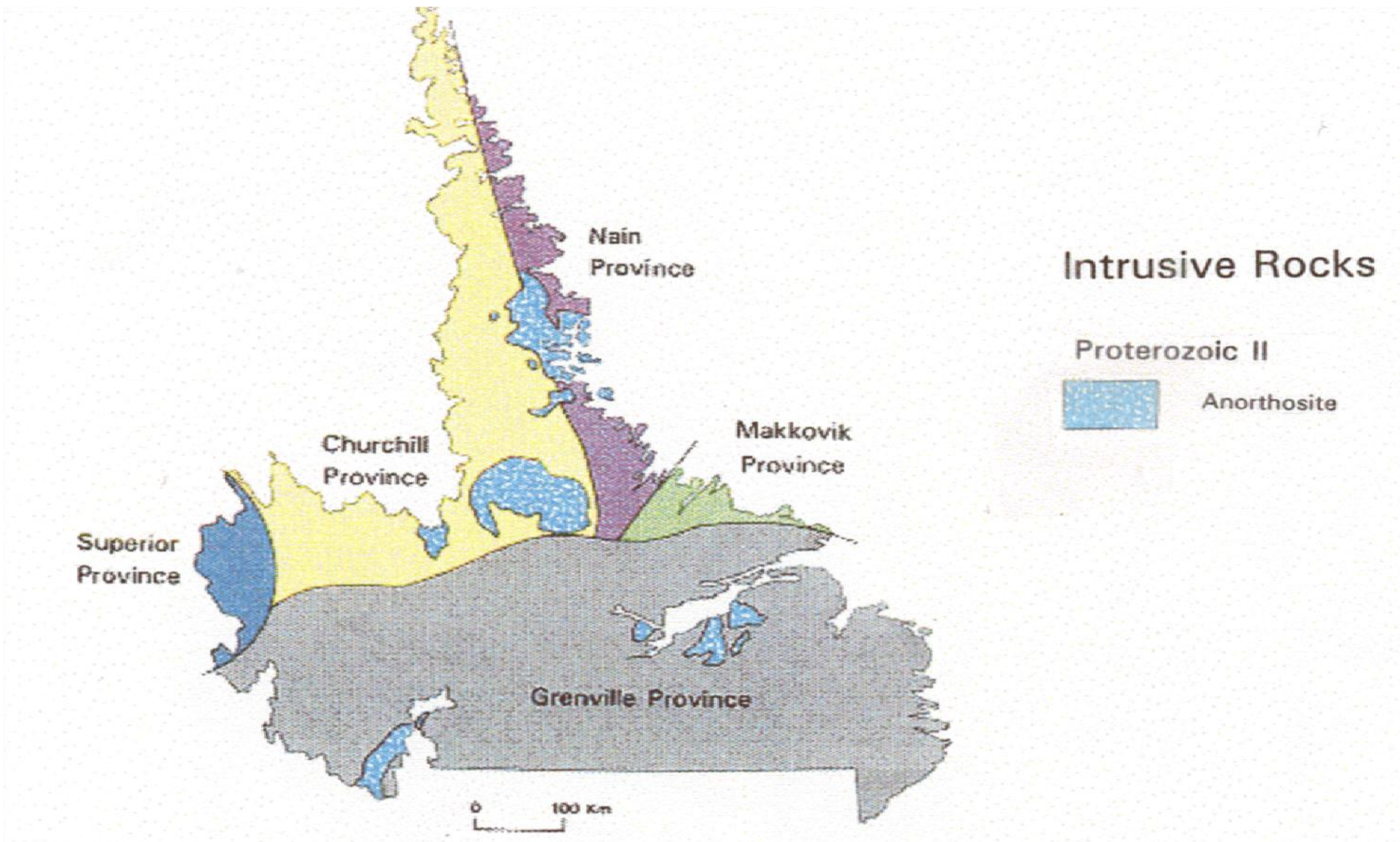

Figure 5 – Geological Provinces of Labrador

(Source: Water Resources Atlas of Newfoundland, 1992 as presented in the Report on the Hydrology of Labrador, 1997)

Labrador consists of five Pre-Cambrian age geological provinces: Superior, Nain, Churchill, Makkovik and Grenville. The Superior Province, located in the farthest western portion of Labrador and the Nain Province, located along the northeastern coast, are the two oldest rock assemblages in Canada and represent remnants of Archean age mountain complexes. Both provinces are primarily characterized by high-grade metamorphic rocks; although less deformed Proterozoic age "greenstone" or volcanic belts occur in the southern Nain Province. The Churchill Province separates the Superior and Nain provinces and contains a northward- trending assemblage of Proterozoic age rocks and reworked Archean age sedimentary rocks. The western portion of the Churchill Province is referred to as the Labrador Trough and is characterized by lightly deformed sedimentary and volcanic rocks and is an important iron ore mining area. In eastern Labrador, the Makkovik Province separates the Nain Province from the

Grenville Province. The Proterzoic age Makkovik Province contains reworked granitoid gneiss of the southern Nain Province and younger (juvenile) crust formations, including numerous granites (A. Kerr, pers. comm., 2010). Southern Labrador is dominated by the west-northeast trending Grenville Province which contains Lower to Middle Proterozoic age high-grade metamorphic and associated intrusive rocks.

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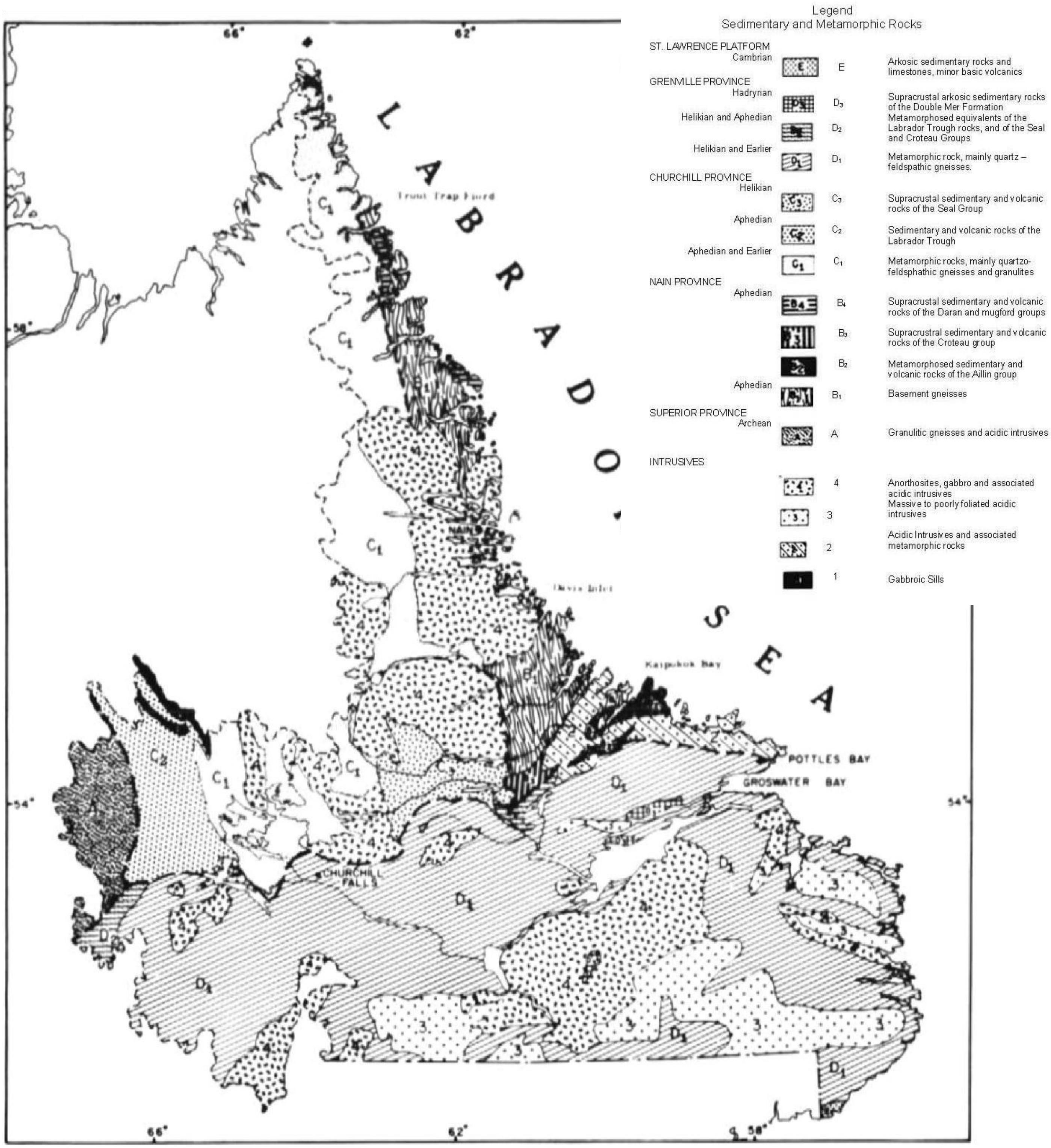
Figure 6 – Generalized Geological Map of Labrador (after Greene, 1974)



5.1 Superior Province

The Archaen age Superior Province forms the core of the North American continent, and forms the far western region of Labrador. Although it is one of the largest Canadian Shield provinces, it's exposure in the province in Labrador is small. In Labrador, the Superior Province contains high-grade metamorphic gneisses and abundant intrusive rocks. Structurally, the province trends east-west and forms an unconformity (a gap in time typically marked by an erosional surface) with the Churchill Province to the east.

5.2 Nain Province

The Nain Province is located along the northeastern coast of Labrador and is characterized by northward trending Archean age rocks consisting predominantly of high-grade basement gneisses, with overlying metasedimentary and metavolcanic rocks. Complex sequences of Archean gneiss located south of Davis Inlet are locally referred to as the Hopedale Gneiss, while two lower-grade greenstone belts occur in the southern Nain Province along the boundary with the Makkovik Province and within the Central Mineral Belt.

Intrusions of granite-type rocks partially separate the northern and southern portions of Nain Province, with the exception of some isolated patches of Archean age gneiss that provide a geological connection from north to south. The granitic intrusions have been dated at approximately 1400 m.y. old while similar intrusive rocks in the area are believed to be slightly younger.

The basement Archean age gneisses are overlain unconformably by Proterozoic age sedimentary sequences, which may be locally associated with mafic, or magnesium and iron-richvolcanic rocks. In the northern part of the province, the basement gneisses are overlain by the supracrustal Ramah and Mugford Groups. The Ramah Group is believed to be older (1750 – 2540 m.y old) and contains a lightly-metamorphosed sequence of quartizites, sandstones, and shales. The younger Mugford Group contains mafic volcanic sequences including lava flows and ash deposits, which overlie lightly deformed metasedimentary quartizites, sandstones, and shales.

The Croteau Group is found at the very southwestern tip of the Nain Province and is characterized by subaerial calc-alkaline volcanic rocks and sedimentary sequences.

5.3 Churchill Province

The Churchill Province separates the Superior and Nain provinces and is characterized by north to northwest trending Proterozoic age rocks and reworked older Archean age rocks.

The Churchill Province has two distinct lithological zones: the western and eastern zones.

The western zone in Labrador and adjacent Quebec contains low-grade metasedimentary and volcanic rocks, which have been intruded by mafic and ultra mafic gabbroic sills (linear bodies of intrusive rock, often occupying fractures) and plutons (extensive, discrete bodies of intrusive rock, often emplaced over multiple intrusive cycles). This area is better known as the Labrador Trough. The Labrador Trough contains cherty iron formations, carbonates, and quartzites along the western side and zones of copper-nickel mineralization along the eastern side. Mineralized zones are related to the gabbroic sills and other intrusive rocks. This unit is unconformably overlain by conglomerates and quartzites of the Helikian Sims Formation.

The eastern zone contains deeply-eroded, remnant mountain belt dominated by high grade metamorphic rocks, with an extensive shear zone along the boundary with Nain. In the southeastern part of the Churchill Province, the gneissic basement rocks are overlain by supracrustal plateau basalts, quartzites and shales.

The Seal Lake Group overlies the gneissic basement rocks in the southeastern portion of the Churchill Province. This group contains Proterozoic age conglomerates, arkose sandstones (James, 1994).

5.4 Makkovik Province

The Makkovik Province is wedge-shaped area, located north of the Grenville Front and southeast of the Nain Province. This area was originally grouped with the geological province of Nain, but based on structural differences between the northerly trending rocks of the Nain Province and the easterly trending rocks of the Makkovik area, Taylor (1971) proposed these rocks should form a new Precambrian Province, named the Makkovik.

The Proterozoic age Makkovik Province is predominantly underlain by the Aillik Group, which is composed of primarily granatoid rocks derived from earlier volcanics. Also contained within the Aillik Group are minor deposits of conglomerates, argillites, limestones, volcanics, metamorphic rocks and ironstone formations. The Aillik Group unconformably overlies the Hopedale Gneiss of Nain Province and grades into gneissic rocks towards the Grenville Province.

5.5 Grenville Province

Much of southern Labrador forms part of the Grenville Province, a linear Proterozoic age remnant mountain belt that extends along the east coast of North America, west of the better known and much younger Appalachian mountains. High-grade gneissic rocks comprise most of the Grenville Province in Labrador, although some metasedimentary and metavolcanic rocks are present at the south end of the Labrador Trough and along the boundary with the Makkovik Province. Similarly to the Nain Province, granite-type plutons also occur within the province.

In the southern portion of the Grenville Province, continental red-beds (iron-rich sedimentary rocks) of the Double Mer Formation are found. These rocks are believed to be related to the formation of the early Paleozoic age Iapetus Ocean, when continental rifting resulted in extensive erosion and deposition at the continental margin. Younger Cambrian age rocks occur in southernmost Labrador, near the Straight of Belle Isle, where they rest unconformably upon Grenville Province intrusive rocks and disconformably (i.e., they have the same orientation as rocks below them) upon Precambrian terrestrial sedimentary rocks and flood basalts. These rocks are characterized as platform deposits and are sedimentary in nature.

6. Hydrogeology

Groundwater is an integral component of the hydrologic cycle and originates from the percolation of rain, snowmelt, or surface water into the ground. Below ground, waters occur in two zones: the unsaturated zone and the saturated zone. In the unsaturated or upper zone (also called the vadose zone), soil pores may contain both water and air and liquid water is typically under less than atmospheric pressure. In the saturated or lower zone, all pore spaces are typically filled with water and the water is under greater than atmospheric pressure (Singer and Cheng, 2002). Water stored in the saturated zone is known as groundwater. The water table is the upper surface of the saturated zone and is the boundary between the saturated and unsaturated zones where the pressure head is equal to atmospheric pressure.

Groundwater moves continuously in the subsurface through soil and bedrock until it exits as springs, streams and lakes. An aquifer is a formation or group of formations that can store or yield useable volumes of groundwater to wells or springs (Fetter, 1994). Aquifers may be found in the bedrock or overburden (unconsolidated materials overlying bedrock). Groundwater occurs in the openings within the aquifer; these openings may consist of pores, void spaces or fractures. The ratio of the volume of the openings to the total volume of the water-bearing material is called porosity. Primary porosity refers to the main or original porosity system is associated with water-filled pore spaces between the individual grains of silt, sand, gravel. Secondary porosity occurs in bedrock and is formed as a result of secondary fractures, joints, bedding planes and faults. Groundwater can be found in fractured sedimentary rocks in the pores between grains (primary porosity) as well as in fractures (secondary porosity). Primary porosity in bedrock can also occur as a result of chemical leeching of minerals.

The ability of a formation to yield useable quantities of water depends on the inter-connectedness of the pore spaces and other voids within the aquifer. How quickly the water flows is partly dependent on how big the pores are, how interconnected the pores or fractures are, and how much energy (head or water pressure) is available to move the water through the aquifer. Groundwater flow occurs when a hydraulic gradient is present. Hydraulic gradient is defined as the change in static head (pressure) per unit of distance along the groundwater flow path (Singer and Cheng, 2002). The relative ease with which a water-bearing material can transmit water under a hydraulic gradient is a measure of the permeability or hydraulic conductivity of the material. Expressed another way, the permeability or hydraulic conductivity is a measure of the ability of the material to transmit water. Transmissivity is a measure of the amount of water that can be transmitted horizontally through a unit width of fully saturated aquifer under a hydraulic gradient of 1 (Fetter, 1994).

6.1 Summary of Water Well Records Retrieved for the Study Area

A review of all available databases, publications and unpublished consultant's reports was conducted to assess the existing groundwater resources of Labrador. Most of the water well logs available for Labrador were obtained from the NLDEC WRMD DWD for wells drilled between 1950 and 2009 (NLDEC, 2009). The data provided in the well records are organized by community and include information on well construction (e.g., well depth, casing length, screen type and setting), yield information (e.g. static water level, depths to water bearing zone(s)) and descriptions of the water quality (e.g. fresh versus salt water). The final use of the well water (e.g. domestic use versus municipal water supply) and the driller's description of the depth and lithology of the overburden and bedrock units encountered are also noted. In addition, consultant's reports on hydrogeological studies completed for various towns, communities or private organizations within Labrador were provided by NLDEC.

The information review provided a total of 352 well logs or records for Labrador, including 47 wells completed in overburden aquifers and 305 wells completed in bedrock aquifers. Table B-1 in Appendix B summarizes the records for wells completed in surficial deposits, and Table B-2, Appendix B summarizes the records for wells completed in bedrock.

The quality of information presented in the well driller's logs is variable and depends on the individual driller and/or drilling supervisor's knowledge and experience. Data and information gaps are common in the well logs obtained for Labrador. The majority of the well logs have limited location information with no location coordinates (i.e., latitude/longitude) or incomplete site addresses. Several well logs are missing well yield information while others have insufficient lithological descriptions (e.g., "grey rock") or no lithological descriptions at all.

The following section presents a summary of the information relating to wells drilled in surficial and bedrock aquifers of Labrador. The NLDEC well driller's database is limited to wells drilled between 1950 and 2009 and naturally excludes additional groundwater wells drilled where no well record was made, in addition to those wells for which the record was not submitted to NLDEC. Considering this, the following summary is based on the available information and is intended to provide a general overview of the groundwater supply well construction and aquifer characteristics in Labrador.

6.1.1 Groundwater Occurrence in Surficial Deposits

Forty-seven (47) drilled screened wells were completed in surficial aquifers. In many cases, the lithological descriptions are quite general and are of insufficient detail to define the overburden unit or type encountered in the individual wells.

Since most of the well logs could not be accurately located and since information regarding the depth of the screened interval (the depth at which the aquifer is generally located) was usually lacking, it was difficult to correlate the lithological description in the well log to a recognized map unit.

To overcome this, the well logs were sub-divided into four categories: wells completed in sandy gravel or gravel, wells completed in sand, wells completed in silty sand and wells completed in fine textured/mixture/unknown deposits. Table B-1, Appendix B lists the lithological category of each well log. Table 4 presents a summary of the well construction and well yield information for drilled screened wells in Labrador.

Table 4 – Summary of Well Records for Drilled Wells Screened in Surficial Deposits in Labrador

Lithological Sub-Category	Statistical Analysis	Static Water Level (mbTOC)	Well Depth (m)	Air Lift Yield (Lpm)	Zone 1 Depth (m)
Sandy gravel or gravel	Minimum	0.1	4.6	4.0	14.6
	Maximum	41.0	65.5	545.0	51.8
	Mean	17.0	28.0	130.5	28.5
	Geomean	8.3	22.2	55.4	25.0
	Median	9.0	24.5	45.0	22.5
	Standard Deviation	15.1	16.9	177.0	14.6
	Number of Wells	13	26	19	6
Sand	Minimum	2.6	13.2	5.0	-
	Maximum	10.9	43.5	200.0	-
	Mean	5.0	30.2	95.7	-
	Geomean	4.5	28.8	37.3	-
	Median	4.0	29.5	80.0	-
	Standard Deviation	2.6	8.5	89.2	-
	Number of Wells	7	10	6	-
Silty Sand	Min	3.4	44.2	787.5	40.2
	Max	4.6	51.5	2250.0	50.0
	Mean	3.9	47.3	1372.5	43.7
	Geomean	3.9	47.2	1235.4	43.5
	Median	3.9	47.6	990.0	42.0
	STD	0.4	2.8	632.6	3.6
	Number of Wells	5	5	5	5

Lithological Sub-Category	Statistical Analysis	Static Water Level (mbTOC)	Well Depth (m)	Air Lift Yield (Lpm)	Zone 1 Depth (m)
Fine-textured/ mixture/unknown	Minimum	26.2	21.3	14.0	13.7
	Maximum	26.2	46.0	206.0	37.0
	Mean	26.2	33.1	117.7	25.4
	Geomean	26.2	31.9	85.7	22.5
	Median	26.2	32.7	95.5	25.4
	Standard Deviation	0.0	8.6	68.6	11.7
	Number of Wells	1	6	5	2

Notes: m = metres, mbTOC = metres below top of casing, Lpm = litres per minute, Zone 1 = initial water bearing zone encountered during drilling

A total of 26 of the 47 well logs were screened in sandy gravel or gravel with reported yields ranging from 4 Lpm to 545 Lpm, with a geomean of 55.4 Lpm. For this report, where the distribution of reported values range by several orders of magnitude (e.g., from 4 Lpm to 545 Lpm), reference to the geometric mean is a useful way to present typical well construction and well yield conditions. In sandy gravel or gravel, well depths range from 4.6 m to 65.5 m, with a mean depth 28 m. Static water levels range from 0.1 metres below top of well casing (mbTOC) to 41 mbTOC, geomean of 8.3 mbTOC.

A total of 10 wells were screened in sand deposits. The reported total well depths range from 13.2 m to 43.5 m, with a mean 30.2 m. Static water levels range from 2.6 mbTOC to 10.9 mbTOC, with a mean of 5 mbTOC. The reported air lift yields range from 5 Lpm to 200 Lpm, with a mean of 37.3 Lpm. No information was available regarding the depth of Zone 1, the initial water bearing zone, for wells completed in sand deposits.

A total of five wells were completed in silty sand deposits. These wells represent the five municipal supply wells for town of HVGB. The well depths range from 44.2 to 51.5 m, with a mean depth of 47.3 m. Reported air lift yields range from 787.5 Lpm to 2,250 Lpm, with a mean air lift yield of 1,373 Lpm. The depth to Zone 1, the initial water bearing zone, ranges from 40.2 m to 50 m.

The lithological descriptions for the remaining six wells include “bog, sand, silt, clay and gravel” or “clay, sand and clay, boulders, gravel, silt” and so are grouped together as fine textured/mixture/unknown texture. These wells range in depth between 21.3 and 46 m, with a mean depth of 33.1 m. Reported air lift yields range from 14 Lpm to 206 Lpm, with a mean air lift yield of 117.7 Lpm.

6.1.2 Groundwater Occurrence in Bedrock

A total of 305 wells were completed in bedrock aquifers. The well records for 54 of these wells contained no lithological description, while the records for 35 wells contained limited or general lithological descriptions.

The well logs were sub-divided into two categories: those with and those without lithological descriptions. Of the 305 well logs, 228 (75%) had identifiable lithological descriptions while the remaining 77 (25%) did not contain lithological descriptions. The lithological descriptions were further categorized by rock type (e.g., limestone, shale, granite, ironstone, etc.) and each well log was assigned to a geologic province in Labrador (i.e., Grenville, Superior, Nain, Makkovik or Churchill) based on the name of the town documented on the well log. Table B-2, Appendix B presents the detailed well log information and sub-divisions by generalized and actual rock types. Of the 305 wells, 285 were completed in Grenville Province, 14 were completed in Nain Province, and 6 were completed in Makkovik Province. No well logs were obtained for wells completed in either the Superior or Churchill geologic provinces.

Table 5 presents a summary of select well construction parameters and well yields for drilled wells completed in bedrock. The wells are grouped by bedrock lithology to better compare hydraulic properties.

Table 5 – Summary of Available Well Records for Drilled Wells Completed in Bedrock in Labrador

Bedrock Lithology	Statistical Analysis	Total Depth (m)	Air Lift Yield (Lpm)	Zone 1 Depth	Casing Length (m)	Casing Diameter (mm)	Depth to Bedrock (m)
Granite	Minimum	13.4	0.0	5.6	2.9	150.0	at surface
	Maximum	177.0	300.0	131.0	90.0	150.0	45.0
	Mean	60.4	22.7	40.2	7.5	150.0	4.7
	Geomean	52.7	7.4	28.9	6.2	150.0	2.9
	Median	56.0	9.0	29.0	6.1	150.0	2.7
	Standard Deviation	30.8	45.4	32.0	8.3	0.0	6.1
	Number of Wells	164	151	28	162	40	128
Gneiss	Minimum	31.0	0.0	34.1	6.0	150.0	at surface
	Maximum	129.2	100.0	34.1	24.3	150.0	12.0
	Mean	77.8	11.8	34.1	7.4	150.0	4.0
	Geomean	72.8	1.7	34.1	7.0	150.0	3.2
	Median	89.5	3.5	34.1	6.5	150.0	3.0
	Standard Deviation	25.3	21.7	0.0	3.8	0.0	2.7
	Number of Wells	22	22	1	22	7	21
Sandstone	Minimum	22.8	4.0	20.0	3.9	150.0	at surface
	Maximum	91.4	600.0	53.0	17.9	152.0	21.0
	Mean	46.6	122.7	36.8	10.9	150.4	11.3
	Geomean	43.0	39.0	33.1	9.6	150.4	7.2
	Median	43.5	45.0	37.2	10.4	150.0	13.0
	Standard Deviation	19.0	174.6	16.2	5.1	0.8	7.3
	Number of Wells	12	11	4	12	5	10
Shale	Minimum	20.7	5.0	-	3.0	-	at surface
	Maximum	61.0	36.0	-	3.9	-	2.0
	Mean	33.3	7.8	-	3.1	-	at surface
	Geomean	31.9	6.0	-	3.1	-	-
	Median	30.5	5.0	-	3.0	-	-
	Standard Deviation	10.7	8.9	-	0.3	-	-
	Number of Wells	11	11	-	11	-	11
Quartzite	Minimum	15.5	4.0	35.0	3.0	152.0	1.0
	Maximum	112.0	68.0	35.0	34.8	152.0	33.5
	Mean	37.6	18.0	35.0	8.3	152.0	8.8
	Geomean	30.9	12.3	35.0	5.2	152.0	3.4
	Median	26.5	12.0	35.0	4.0	152.0	1.5
	Standard Deviation	29.1	19.5	0.0	10.9	0.0	11.1
	Number of Wells	8	8	1	7	1	8
Ironstone	Minimum	16.5	6.8	-	3.0	-	3.0
	Maximum	61.0	204.6	-	3.0	-	3.0
	Mean	32.0	50.9	-	3.0	-	3.0
	Geomean	28.8	27.7	-	3.0	-	3.0
	Median	27.5	23.9	-	3.0	-	3.0
	Standard Deviation	15.0	61.7	-	0.0	-	0.0
	Number of Wells	8	8	-	2	-	8
Limestone	Minimum	31.5	3.0	-	6.7	-	1.0
	Maximum	38.0	18.0	-	7.3	-	5.0
	Mean	33.7	8.7	-	7.1	-	2.7
	Geomean	33.5	6.5	-	7.1	-	2.2
	Median	31.5	5.0	-	7.2	-	2.0
	Standard Deviation	3.1	6.6	-	0.3	-	1.7
	Number of Wells	3	3	-	3	-	3
Unidentifiable	Minimum	8.5	0.0	2.9	1.1	150.0	at surface
	Maximum	164.9	455.0	109.7	38.7	152.0	39.0
	Mean	52.4	23.9	47.0	7.6	151.0	6.2
	Geomean	44.9	6.2	35.5	5.7	151.0	4.3
	Median	44.7	9.0	38.0	6.1	152.0	5.2
	Standard Deviation	29.6	59.4	31.6	7.2	1.0	7.3
	Number of Wells	77	61	25	69	25	51

Notes: m = metres, mbTOC = metres below top of casing, Lpm = litres per minute, Zone 1 = initial water bearing zone encountered during drilling

Most of the bedrock wells in Labrador are completed in granite (168 wells). The well logs also indicate that wells were completed in gneiss (22 wells), sandstone (12 wells), shale (11 wells), quartzite (8 wells), ironstone (8 wells) and limestone (3 wells).

Most of wells installed in granite (83%) were drilled in communities located in southern Labrador near the Straight of Belle Isle, including communities extending from English Point in the south along the coast to Charlottetown in the east. Granite wells were also noted in the communities of Cartwright, Rigolet, Makkovik, Posteville and Hopedale. The well logs indicate these wells were drilled for use as domestic wells, municipal water supply wells and "public supply".

For wells drilled in granite bedrock, well depths range from 13.4 m to 177 m, with a mean depth of 60.4 m. Reported well yields range from zero to 300 Lpm, with a geomean yield of 7.4 Lpm. Casing lengths ranged from 2.9 m to 90 m, with a geomean casing length of 6.2 m. Overburden thickness or depth to bedrock ranges from nil (i.e. no overburden cover) to 45 m, with a geomean of 2.9 m. The diameter of the steel casing was documented for 40 of the 164 well logs. The casing diameter is 150 mm (6 in.) in all 40 wells.

A total of 22 wells were completed in gneiss bedrock. The towns with these wells include William's Harbour, West St. Modeste and Charlottetown. The well logs indicate these wells were drilled for use as domestic or municipal water supply wells.

For wells drilled in gneiss bedrock, well depths range from 31 m to 129.2 m, with a mean depth of 77.8 m. Reported well yields range from zero to 100 Lpm, with a geomean yield of 1.7 Lpm. Casing lengths range from 6 m to 24.3 m, with a mean length of 7.4 m. Overburden thickness ranged from nil (i.e. no overburden cover) to 12 m, with a mean thickness of 4 m. Of the seven wells where casing diameter was given, all seven have 150 mm (6 in.) diameter casing.

A total of 12 wells were completed in sandstone bedrock. The towns with sandstone-hosted wells include Labrador City in the west and English Point, L'Anse Au Clair and West St. Modeste in the south. These wells were drilled for use as domestic, municipal, industrial or public supply wells.

For wells completed in sandstone, well depths range from 22.6 m to 91.4 m, with a mean depth of 46.6 m. Reported well yields range from 4 Lpm to 600 Lpm, with a geomean yield of 39 Lpm. Casing lengths range from 3.9 m to 17.9 m, with a mean length of 10.9 m. Overburden thickness ranged from nil (i.e. no overburden cover) to 21 m, with a mean thickness of 11.3 m. The diameter of the steel casing was documented for five of the twelve well logs: all five wells have 150 mm (6 in.) diameter casings.

6.2 Aquifer Tests

Reported well yields in well drillers' logs do not necessarily represent the short term or long term safe yield of the well, and by extension, the groundwater characteristics of the host aquifer. Well pumping and recovery tests are generally the most reliable methods for determining hydraulic constants of materials surrounding a well (Singer and Cheng, 2002). To determine these values, a program of variable rate step drawdown testing followed by a constant rate pumping test should be conducted. Water level drawdown and recovery responses are measured in the pumping well to determine the hydraulic properties of the pumping well and water level drawdown and recovery responses in observation wells are used to assess the hydraulic properties of the host aquifer. The pumping test data is typically processed and analyzed using computer-based software program such as AquiferTest Pro or AQTESOLV Pro that automates aquifer analysis using well established analytical solutions. The results of these tests are used to estimate the safe yield of individual wells and the aquifer, to size appropriate pumping equipment, and to predict interference between adjacent pumping wells or with off-site domestic wells.

Evaluation of groundwater resources requires knowledge of the capacity of aquifers to store and transmit ground water. This requires estimates of key hydraulic parameters, such as the transmissivity and specific capacity. Transmissivity is a measure of the amount of water that can be transmitted horizontally through a unit width of the aquifer by full saturated thickness of the aquifer under a hydraulic gradient of 1 (Fetter, 1994). The specific capacity of a well is its yield per unit of drawdown, expressed as cubic metre per day per metre of drawdown (i.e. L/min/m or m^3/d/m). Dividing the yield of the well by the drawdown, for a specific length of time during a pump test gives the value of specific capacity.

The specific capacity of a well depends on the type of aquifer, well diameter, pumping time, partial penetration, hydrogeologic boundaries and well construction characteristics (Singer and Cheng, 2002). Because of these constraints, the specific capacity is not an exact criterion with which to calculate transmissivity, however it is a useful index to describe the water-yielding characteristics of the well and the formation(s) the well intercepts. Overall, high specific capacities show high transmissivities and, consequently, high water-yielding capabilities.

Pumping test information is generally lacking for wells in Labrador. Limited information in the form of pumping test duration and pumping test rate is provided in the NLDEC well drillers' database for 13 wells completed in surficial aquifers and 53 wells completed in bedrock aquifers. This information is of limited use because no other data is reported with the pumping test rates and durations. Tables C-1 and C-2 in Appendix C present a summary of pumping test information from the NLDEC well drillers' database for wells completed in surficial deposits (Table C-1) and bedrock aquifers (Table C-2).

Pumping test information is also available from several consultant's reports for wells completed in surficial aquifers. These wells include one municipal well in the Town of Sheshatshiu, three municipal wells in the Town of North West River and the five production wells comprising the Happy Valley – Goose Bay well field. The results of these pumping tests are discussed in greater detail in the report section below.

6.2.1 Surficial Aquifer

This section summarizes the available pumping test information retrieved from consultant's reports for the Town of Shetshatshiu, Town of North West River and Happy Valley – Goose Bay.

Results of a 72-hour constant rate pumping test for a third production well in the Town of Sheshatsheits are presented in SGE Group (1998). The reported maximum observed drawdown in the pumping well after 72 hours of pumping at 210 igpm (954 Lpm) was 0.84 m. The report concludes the well is capable of yielding in excess of 210 igpm (954 Lpm), however SGE Group (1998) indicated there was insufficient information to provide detailed analysis and calculation of aquifer transmissivity and storativity. Based on the data given in SGE Group (1998), AECOM calculates a 72-hour specific capacity of 1136 L/min/m for this well.

Results of three constant rate pumping tests conducted for the Town of North West River on Well No.'s 1, 2 and 3 are presented in Terpstra (2004). The results indicate:

- Well No. 1 was pumped at a rate of 206 Lpm for 72 hours and exhibited 2.19 m of drawdown. Terpstra (2004) estimated that Well No. 1 has a capacity in the 681 Lpm range. No information was presented on interpreted hydraulic properties of Well No. 1; however, AECOM calculates a 72-hour specific capacity of 94.1 L/min/m for Well No. 1 based on the drawdown and pumping data presented above.

- Well No. 2 was pumped at a rate of 206 Lpm for 72 hours and exhibited 0.98 m of drawdown. Terpstra (2004) estimated the capacity of Well No. 2 of 1500 Lpm, but in order to prevent seawater intrusion a maximum pumping rate of 273 Lpm was recommended for this well. No interpreted hydraulic parameters were presented in Terpstra (2004); however, AECOM calculates a 72-hour specific capacity of 210.2 L/min/m based on the data presented in Terpstra (2004).

- Well No. 3 was pumped at a rate of 93 Lpm for only 25 hours due to equipment malfunctions. The maximum drawdown after 25 hours was 0.88 m. Terpstra (2004) reported a maximum pumping capacity of 454 Lpm for Well No. 3. AECOM calculates a 25-hour specific capacity of 109.1 L/min/m for Well No.3, based on the information presented in Terpstra (2004).

Results of five pumping tests conducted for HVGB are reported in Fracflow and HCL (1996). A step testing program followed by 72-hour constant rate pumping tests was completed for Well No.'s FFW-1 to FFW-5. A summary of the maximum and recommended pumping rates for each well from Fracflow and HCL (1996) and Fracflow (2004) is provided in Table 6 below.

Table 6- Summary of 72 hour aquifer test results for each of the Happy Valley-Goose Bay Production Wells

Well Reference No.	Available Drawdown (m)	Specific Capacity (L/min/m)	Recommended Pumping Rate (L/min)	Maximum Pumping Rate (L/min)	Average Transmissivity (m^2/s)[1]	Average Storage Value
FFW-1 (Well No. 2)	21.8	110.4	2075	2407	1.2×10^{-3}	2.2×10^{-3}
FFW-2 (Well No. 3)	20.9	45.2	809	947	5.7×10^{-2}	2.2×10^{-5}
FFW-3 (Well No. 4)	24.9	39.2	858	976	5.9×10^{-2}	3.8×10^{-6}
FFW-4 (Well No. 1)	29.7	72.2	1928	2144	7.7×10^{-3}	4.8×10^{-4}
FFW-5 (Well No. 5)	20.0	37.6	638	752	3.4×10^{-2}	3.2×10^{-5}

Note: 1. Source: Fracflow and HCL, 1996; Fracflow, 2004

2. Average transmissivity presented based on Fracflow, 2004 calculated from Theis solutions reported in Table 4.7 of Fracflow/ HCL, 1996.

Based on the pumping test results described above, the specific capacities for wells completed in surficial glaciofluvial deposits of the Town's of Shetshatshiu, North West River and Happy Valley-Goose Bay ranged from 37.6 L/min/m to 1,136 L/min/m. Due to data limitations associated with pumping test data available for wells completed in surficial aquifers; it is not possible to form additional conclusions regarding the hydraulic properties of the surficial aquifers.

6.2.2 Bedrock Aquifer

Table C-2 in Appendix C provides a summary of the pumping test information from the NLDEC DWD for wells completed in bedrock aquifers. Only those well logs with data regarding the pumping test rate and pumping test duration are shown. No consultant's reports with pumping test data in bedrock aquifers were available for review. The pumping test results presented in Table C-2, Appendix C generally represent short duration (average 180 min.) tests completed by the well drillers upon well completion. Step drawdown tests were not conducted for any of the pumping tests shown in Table C-2. These data limitations prevent an accurate assessment of aquifer characteristics.

Pumping test information was available for seven wells completed in gneiss bedrock. Pumping tests ranged from 60 minutes to 240 minutes in duration and pumping rates ranged from 2 Lpm to 18 Lpm, with an average pumping rate of 6 Lpm.

Pumping test information was available for a total of 33 wells completed in granite bedrock. The duration of the pumping tests ranged from 30 minutes to 900 minutes, with a mean duration of 149 minutes. Pumping test rates ranged from 1 Lpm to 315 Lpm, with a geomean pumping rate of 10 Lpm.

Pumping test information was available for a total of five wells completed in sedimentary bedrock aquifers. The pumping tests ranged from 50 minutes to 360 minutes in duration and pumping rates ranged from 9 Lpm to 600 Lpm, with geomean pumping rate of 63 Lpm.

Finally, pumping test information was available for eight wells where the bedrock aquifer lithology could not be identified. The pumping tests ranged from 50 minutes to 2,880 minutes in duration at pumping rates ranging from 18 Lpm to 68 Lpm.

6.3 Hydrostratigraphic Units

Hydrostratigraphic units were originally defined by Maxey (1964) as presented in Seaber (1988) as “bodies of rock with considerable lateral extent that compose a geologic framework for a reasonably distinct hydrologic system”. It was intended to serve as a “fundamental unit for describing hydrogeologic systems in the field based on properties of the rock that affect groundwater conditions and would be of tested map ability” (Seaber, 1988).

6.3.1 Surficial Hydrostratigraphic Units

Considering the geographic extent of Labrador and the lack of detailed well information, surficial hydrostratigraphic units for Labrador were developed based on grouping lithostratigraphic units mapped by Klassen (1992) and the inferred groundwater potential based on the professional expertise of the report authors.

A lithostratigraphic unit consists of a group of rock formations or surficial deposits having characteristic physical properties which can be identified and mapped in the field. A range of typical hydraulic conductivity values from published sources is presented with each hydrostratigraphic unit to provide context for the quantification of relative estimated water transmission potential of each unit. Ranges of well yields and well depths based on the 47 existing well logs in Labrador are not presented because in most cases the yields, depths and lithologic descriptions recorded in the well logs could not be correlated to specific formations or groups of formations. For example, Klassen (1992) indicates that the five Happy Valley- Goose Bay municipal wells are located in a glaciofluvial map unit. However, the lithological description in the well logs record the wells are screened in a silty sand, which does not correlate with the expected coarse deposits of a typical glaciofluvial deposit.

A description of groundwater occurrence in surficial deposits has been presented above to provide an overview of the surficial aquifer potential in areas of Labrador where wells have been installed. The available data indicate that the groundwater potential of surficial deposits in Labrador is highly variable, with reported well yields ranging from 0 to 2,250 Lpm (with a mean yield of 283 Lpm, and a geomean yield of 36.22 Lpm), and depths ranging from 4.6 m to 65.5 m (with a mean depth of 31.2 m). Although hydraulic conductivity is considered a characteristic physical property, the “true” hydraulic conductivity of saturated near-surface materials is difficult to define (Bradbury and Muldoon1990). The physical characteristics of geologic materials (i.e. particle size, roundness, sorting, etc.) vary spatially, and this variation can be large in glacial and fluvial deposits, where significant changes in the depositional environment can often occur over short distances. This variation is physical characteristics, combined with poor well data coverage, may account for the highly variable groundwater potential observed in surficial aquifers in Labrador.

Five surficial hydrostratigraphic units have been developed for Labrador, and are shown in Table 7 and depicted graphically on Map 3, Appendix C. The following qualitative discussion of the relative groundwater potential of each surficial hydrostratigraphic unit is presented in order of lowest to highest interpreted potential.

Table 7 - Surficial Hydrostratigraphic Units - Labrador

Hydrostratigraphic Unit	Interpreted Relative Groundwater Development Potential	Typical Hydraulic Conductivity Range (m/d)[1]
Unit A Exposed Bedrock and Drift-Poor Areas	Very Low Yield	-
Unit B Till and Ribbed (Rogen) Moraine Deposits	Low to Moderate Yield	Glacial till (10 to 10^{-7} m/d)
Unit C Ablation Drift Deposits	Moderate Yield	Coarse gravel (10^{5} to 10^{3} m/d) to fine to coarse sand (10^{3} to 10^{-2} m/d)
Unit D Glaciomarine and Marine Deposits and glaciolacustrine deposits	Low to Moderate to High Yield	Coarse gravel (10^{5} to 10^{3} m/d) to fine to coarse sand (10^{3} to 10^{-2} m/d) to silt (1 to 10^{-4})
Unit E - Glaciofluvial Deposits	High Yield	Coarse gravel (10^{5} to 10^{3} m/d) to fine to coarse sand (10^{3} to 10^{-2} m/d)

Reference: 1. Typical hydraulic conductivity values for consolidated and unconsolidated aquifers as presented in Driscoll (1986) after Davis, 1969; Dunn and Leopold, 1978; Freeze and Cherry, 1979.

6.3.1.1 Unit A - Exposed Bedrock and Drift-Poor Areas

Unit A is composed of localized deposits of surficial material in the vicinity of exposed bedrock and drift-poor areas. Isolated deposits of water-sorted sediment or sandy till may exist within hollows and other topographically sheltered/low areas. These deposits may contain enough water for local or domestic use, but overall these areas are not reliable sources of groundwater. Felsenmeer (frost-shattered weathered bedrock) is quite extensive in alpine or subalpine regions of Labrador, and especially common in the far north. These areas allow infiltration of water into underlying zones of intact bedrock more effectively than areas with smooth, less actively weathered bedrock surfaces. Despite this, the interpreted relative groundwater potential within surficial deposits in areas of exposed bedrock and drift-poor areas is considered to be very low.

6.3.1.2 Unit B - Till and Rogen Moraine Deposits

Unit B comprises till blanket and Rogen moraine deposits. Unit B is considered to have a low to moderate aquifer development potential. The hydrogeological properties of till depend on the dominant matrix composition, density (stress history), and degree of weathering. Tills in Labrador typically have low to moderate permeabilities, although granular lenses within the till may have useful yields for local groundwater supply.

It is common to find pockets and thin drapes of water-sorted sediment on or between “ribs” of Rogen moraines, but generally speaking these are just a surface expression of the underlying (basal) till. Sandy tills – i.e., those derived directly from granitic/gneissic bedrock and with short travel/deposition distances – can be quite good local aquifers. These tills occasionally contain lenses of water-deposited sediments, which can also be sufficient for small water supply needs.

6.3.1.3 Unit C- Ablation Drift Deposits

Ablation drift (Unit C) exhibits a wide range of hydrogeological properties and is considered to have a moderate groundwater potential. Its association with melting glacial ice and deposition with water results in heterogeneous mixtures of sediments with pockets of high and low permeabilities. Thus, overall, ablation drift tends to have a moderate ‘composite’ permeability. Areas of extensive ablation drift may be potentially useful aquifers, because the size of lenses of water-bearing, granular materials may be correspondingly large. Hydraulic conductivities may be locally high, but connectivity of water bearing zones and the lateral extent of porous granular materials may be limited due to the complex, heterogeneous depositional environment that forms these deposits.

6.3.1.4 *Unit D- Glaciomarine, Marine and Glaciolacustrine Deposits*

Unit D includes glaciomarine, marine and glaciolacustrine deposits and is considered to have a moderate to high groundwater development potential. The hydrogeological properties of glaciomarine and marine deposits depend largely on the depositional setting. The sandy to gravelly deposits of high-energy environments may provide excellent aquifer potential, while the finer-textured deposits of low-energy environments may result in poorly productive aquifers suitable for limited local groundwater supply. The surfaces of glaciomarine and marine deposits are commonly level and, if relatively silty or clayey, may be poorly drained. Organic material commonly accumulates in such areas, so drilling on these unstable organic deposits may be difficult and water quality may be impaired.

The hydrogeological importance of glaciolacustrine deposits in Labrador is relatively low, given their limited lateral extent and remote locations. However, any developments in close proximity to such deposits should consider them as a potential source of groundwater due to their dominantly sandy texture.

6.3.1.5 *Unit E- Glaciofluvial Deposits*

Glaciofluvial deposits (Unit E) have the greatest potential yields of any surficial material in Labrador. These deposits are commonly composed of relatively well sorted, coarse sediment which exhibits a high permeability. Large outwash deposits are usually well suited to groundwater taking because of their extent, relatively consistent permeability and their well drained, dry surfaces.

Eskers may be the coarsest and exhibit the highest hydraulic conductivity, but they are typically elevated above the surrounding ground level, and so are well drained with relatively little water. Exceptions may be found in larger esker complexes with substantial breadth and relief and in partially buried eskers that may extend below the water table. Outwash deposits typically contain high quality aquifers because of their porous sand to gravel composition, their lateral extent and their local thickness.

6.3.2 Bedrock Hydrostratigraphic Units

Groundwater resources in the five Precambrian bedrock provinces of Labrador are highly variable. In the Canadian Shield where mixed igneous and metamorphic crystalline rocks, as well as sedimentary rocks are found, groundwater flow occurs along faults, fractures and joints. Sedimentary rocks typically have a much greater aquifer potential than other bedrock types mainly because their variable composition allows for more void space. Sedimentary rocks such as sandstone and limestone may also derive groundwater storage from both primary and secondary porosity, thus increasing the potential production capacity of a well installed in these rocks. The hydrogeological properties of bedrock in Labrador vary with lithology, stress history and the degree of weathering. Permeability is largely a function of the size, orientation and connectivity of fractures or cavities.

Groundwater production in metamorphic and igneous rocks is generally low, but groundwater can be derived from fractures, which are more likely to present closer to surface or along shear zones. In these rock types, secondary porosity resulting from folding, faulting and weathering will dominate over primary porosity present when the rock was formed. Hydraulic conductivity may vary drastically in rocks with fractures and joint systems, and will depend on the openness, connectivity and lateral extent of these flow pathways. Fracture and joint systems become tighter with depth so as the depth of well increases it becomes less likely that adequate water sources will be encountered (Driscoll 1988).

Population growth and community development in Labrador is generally confined to certain coastal areas and several interior towns and villages. The water wells installed by residents and municipal governments within these communities constitute the primary source of groundwater information in Labrador. This development pattern has naturally left most of Labrador unexplored in terms of groundwater potential. The bedrock hydrostratigraphic units defined in the sections below are based on information that is spatially limited to those population centres, and when applied to greater Labrador, should be cautiously considered as units of inferred groundwater development potential.

Bedrock lithologies were grouped together based on the lithological interpretations presented in the Generalized Geological Map of Labrador by Greene (1974) and are mapped according to the detailed lithologies of Wardle *et al.* (1997). In general, where drilled bedrock well information was available, information respecting well construction and well yields were used for interpretation. For areas where no bedrock well information was available, well construction and well yield potential was inferred based on the findings from studies conducted in other areas of the region.

Four bedrock hydrostratigraphic units are proposed (Table 8):

- Unit 1 – Mafic Intrusives and All Extrusive Igneous Rocks;
- Unit 2 – Granitic and Gneissic Rocks;
- Unit 3 – Sedimentary and Low-Grade Metasedimentary Rocks;
- Unit 4 – Sedimentary and Volcanic Rocks of the Labrador Trough and Seal Lake Group; and,
- Metamorphosed Equivalents.

The four bedrock hydrostratigraphic units are presented graphically on Map 4, Appendix D (geologic contacts are shown as thick dashed lines).

Table 8 – Bedrock Hydrostratigraphic Units - Labrador

Hydrostratigraphic Unit	Interpreted Relative Groundwater Development Potential	Example Lithology	Well Characteristics Based on Available Well Logs in Labrador			
			Statistical Parameter	**Total Depth (m)**	**Air Lift Yield (Lpm)**	**Pumping Test Rates (Lpm)**
Unit 1 – Mafic Intrusives and All Extrusive Igneous Rocks	Low Yield	Gabbro, basalt, rhyolite	Minimum	13.4	0.1	-
			Maximum	118.5	204.6	-
			Mean	51.0	16.7	**-**
			Geomean	**43.0**	**6.8**	**-**
			Median	**37.8**	**6.8**	**-**
			STD	28.9	28.9	**-**
			No. of Wells	103	99	-
Unit 2 – Granitic and Gneissic Rocks	Low to moderate Yield	Granite, gneiss	Minimum	13.4	0.0	0.6
			Maximum	177.0	300.0	315
			Mean	62.4	21.5	28.7
			Geomean	-	**7.2**	**8.6**
			Median	57.9	9.0	**6.5**
			STD	30.7	43.5	60.6
			No. of Wells	186	171	40
Unit 3 – Sedimentary and Low-Grade Metasedimentary Extensions	Moderate Yield	Sandstone, limestone, conglomerate, quartzite, shale, ironstone	Minimum	15.5	3.0	9
			Maximum	112	600	600
			Mean	38.2	50.1	179
			Geomean	**34.5**	**16.1**	63
			Median	**31.0**	**11.0**	**35**
			STD	19.4	104.9	225
			No. of Wells	43	42	5
Unit 4– Sedimentary and Volcanic Rocks of the Labrador Trough and Metamorphosed Equivalents of the Labrador Trough and Seal Lake Group	Moderate to High Yield	Siltstone and shale sequences of deep water, turbiditic origin including schistose equivalents, dolomitic marbe, shale and sandstone of shallow to deep water origin	Minimum	22.8	9	10
			Maximum	91.4	600	600
			Mean	**45.6**	116.3	120
			Geomean	**41.2**	**44.7**	**50**
			Median	**41.2**	**20**	**23**
			STD	22.2	182.7	181
			No. of Wells	10	9	9

Notes: Mean = arithmetic average; STD = standard deviation of the population; Lpm = litres per minute; m = metres; ***Bold and underlined*** *values are considered to be representative for each hydrostratigraphic unit shown.*

6.3.2.1 Unit 1 – Mafic Intrusives and All Extrusive Igneous Rocks

Mafic intrusive igneous rocks such as gabbronorite, gabbro sills, troctolite, norite and all extrusive igneous rocks such as basalt, rhyolite, ash-flow tuff, are categorized as Unit 1 and have the expected lowest groundwater development potential as they are less likely to be fractured than rocks in Unit 2 and will have virtually have no primary porosity.

Well construction and well yield information for Unit 1 is based on information documented for 103 well logs from the Towns of Charlottetown and Port Hope Simpson located in southeastern Labradror. According to bedrock geology compiled by Wardle *et al.* (1997) as shown in Map 4, Appendix D, the bedrock geology underlying Charlottetown is composed of mafic intrusive rocks such as gabbronorite, diorite and amphibolites metamorphosed to granulite facies. Similarly, the bedrock geology underlying Port Hope Simpson is shown by Wardle *et al.* (1997) as anorthosite and with layered mafic components. In the absence of additional sources of information respecting well construction and well yields completed in mafic intrusive rocks for Labrador, Charlottetown and Port Hope Simpson wells are considered to be representative of potential yields for wells completed in mafic intrusive rocks of other areas of Labrador.

Table 8 shows that wells completed in the mafic intrusive rocks in southeastern Labrador (Unit 1), ranged in depth between 13.4 m and 118.5 m with a mean depth of 51 m. Well yields ranged from 0.1 Lpm to 204.6 Lpm, and have low potential yields with geomean and median yields of 6.8 Lpm. No pumping test information is available for this map unit.

Map 4, Appendix D shows these areas and represents areas of Labrador that have interpreted underlying bedrock geology composed of mafic intrusive rocks that are inferred to be comparable in structure and water bearing potential to the bedrock underlying Charlottetown and Port Hope Simpson.

6.3.2.2 Unit 2 – Granitic and Gneissic Rocks

Granites and gneisses will have the next highest permeability, although (as with Unit 1) it will be very low unless fractures are encountered. Unit 2 includes metamorphic rocks consisting mainly of quartz-feldspathic gneisses, basement gneisses, granulitic gneisses and acidic intrusives.

Well construction and well yield information for Unit 2 is based on information documented for 186 well logs completed in granite or gneiss bedrock within Labrador. Table 8 shows that wells completed in granite and gneiss bedrock exhibit variable well construction and well yield information. These wells are installed to depths ranging from 13.4 m to 177 m and have well yields ranging from 0 Lpm to 300 Lpm, with a geomean yield of 7.2 Lpm and a median yield of 9.0 Lpm. Pumping test information for 40 short duration pumping tests completed on Unit 2 wells reveal variable yields, similar to the variable distribution of air lift yields. Although the well yield information for Unit 2 wells in Labrador suggest low well yield potential, Unit 2 is defined as having low to moderate well yield potential due to the anticipated greater potential to encounter secondary permeability in the form of fractures when compared to wells completed in slightly younger mafic intrusive rocks.

Map 4, Appendix D and shows areas of Labrador representing Unit 2 that have interpreted underlying bedrock geology comprising granitic or gneissic bedrock. Groundwater supply wells completed in Unit 2 are inferred to be comparable in water bearing potential to the 186 well logs retrieved for wells completed in granite or gneiss bedrock in other areas of Labrador, mainly the Strait of Belle Isle region of southeastern Labrador, western Labrador and coastal northeastern Labrador.

6.3.2.3 Unit 3 – Sedimentary and Low-Grade Metasedimentary Rocks

Sedimentary (sandstone, limestone, conglomerates) and meta-sedimentary (quartzite, ironstone) rocks will likely have the highest permeability because both primary and secondary porosities may both contribute to flow.

Well construction and well yield information for Unit 3 is based on information documented for 43 well logs completed in sedimentary bedrock within Labrador. This bedrock includes sandstone, limestone, conglomerate, ironstone, shale and quartzite. Table 8 shows wells completed in sedimentary and low-grade metasedimentary rocks have variable well construction and well yield information. These wells are drilled to depths ranging from 15.5 m to 112 m and have well yields ranging from 3 Lpm to 600 Lpm, with geomean yield of 16 Lpm. Pumping test information for five short duration pumping tests completed on Unit 3 wells revealed yields ranging from 9 Lpm to 600 Lpm (geomean yield of 63 Lpm), which is generally higher than yields reported for Unit 1 and Unit 2 wells.

The younger platform deposits consisting of sandstone and nodular limestone in the southern tip of Labrador near the Straight of Belle Isle area (map unit NCs on Map 2, Appendix A) are representative of Unit 3. Well yields for the sandstone and nodular limestone of English Point, Forteau, L'Anse-Amour, L'anse-au-Loup are slightly higher than the mean well yields in the sedimentary bedrock elsewhere in Labrador. Here, well depths range from 25.6 m to 61.7 m, with a mean depth of 41.9 m and air lift yields range from 3 Lpm to 273 Lpm, with a geomean of 24 Lpm.

Map 4, Appendix D shows areas of Labrador representing Unit 3 having interpreted underlying bedrock geology comprising sedimentary or low-grade meta-sedimentary rocks. Wells completed in Unit 3 are inferred to be comparable in water bearing potential to the 43 well logs retrieved for wells completed in sedimentary bedrock in other areas of Labrador, mainly the Strait of Belle Isle region in southeastern Labrador and Labrador City in western Labrador.

6.3.2.4 Unit 4 – Sedimentary and Volcanic Rocks of the Labrador Trough and Seal Lake Group and Metamorphosed Equivalents

A fourth bedrock hydrostratigraphic unit, Unit 4 is defined for the sedimentary and volcanic rocks of the Labrador Trough and metamorphic extensions of the Labrador Trough and Seal Lake Groups. Unit 4 rocks are considered to have moderate groundwater development potential.

Well construction and well yield information for Unit 4 is based on information from 10 well logs completed in sedimentary or unidentifiable bedrock units in Labrador City. Table 8 shows these wells have distinctly higher mean well yields than wells completed in other sedimentary bedrock in other areas of Labrador. Unit 4 has well depths ranging from 22 m to 91.4 m, with a mean depth of 45.6 m. Well yields range from 9 Lpm to 600 Lpm, with a geomean of 44.7 Lpm. Pumping test information from nine short duration tests revealed yields ranging from 10 Lpm to 600 Lpm, with geomean yield of 50 Lpm. The well yield potential of Unit 4 is consistent with the well yield potential of the Seal Lake Group sandstones presented by Herr *et al.* (1978), which are in the range of 0.5-2 L/s (30 – 120 L/min) and are higher than those of Units 1-3.

Map 4, Appendix D and shows areas of Labrador representing Unit 4 having bedrock geology composed of shale and sandstone of shallow to deep water origin (P2ss, P2st map units), schistose to gneissic equivalent rocks of Knob Lake, Grenville Province (P2is) and dolomite, chert breccia and equivalent dolomitic marble (P2d/P2dm).

6.3.3 Groundwater Occurrence in Permafrost Areas

The occurrence of groundwater in permafrost areas differs from its occurrence in warmer climates (Driscoll, 1986) since permafrost restricts the groundwater movement, especially infiltration. In areas of low relief, this results in numerous lakes or wetlands whereas in areas of higher relief, restricted infiltration results in rapid overland runoff. In both areas, aquifer recharge is slower than comparable permafrost-free zones.

In permafrost areas groundwater may occur as supra-permafrost water, intra-permafrost water, or sub-permafrost water (Driscoll, 1986). Supra-permafrost water is found in the top of the permafrost layer and is widespread in permafrost regions during the summer. If thawing extends deep enough, it can create an appreciable reservoir of groundwater perched upon the underlying permanently frozen soil or bedrock. In regions of thick, continuous permafrost, the supra-permafrost zone beneath rivers and lakes is often the only supply of groundwater available at a minimal cost (Williams and Waller, 1963). Intra-permafrost water exists within the thawed zones of frozen ground between islands of permafrost. It commonly occurs in alluvium near rivers or in abandoned river channels and in glaciofluvial material covering wide river valleys. However, intra-permafrost is considered to be uncommon and, if water obtained from these zones is potable, it is generally connected to an aquifer above or below the permafrost (Williams and Waller, 1963). Sub-permafrost water occurs beneath large areas of permafrost in permeable unconsolidated deposits and in fractured zones in the shallow bedrock. Recharge of aquifers is either from distant sources or from downward percolation of water through unfrozen zones that perforate the permafrost (Williams and Waller, 1963). Sub-permafrost water is commonly artesian. Flowing artesian wells are common on the slopes of uplands where water in alluvium or bedrock is confined beneath silt or permafrost.

Canadian communities in areas of continuous permafrost do not obtain permanent water supplies from groundwater, but communities in the discontinuous permafrost zone situated next to large streams or lakes may obtain their water from wells in unfrozen material close to the surface water.

Mineral content of groundwater varies greatly in permafrost zones. Water in rocks beneath the permafrost may be highly mineralized (Driscoll, 1986).

Available research on groundwater availability in permafrost is limited to Western Canada and Alaska. There are no known studies on groundwater resource development in the continuous permafrost zone of Labrador.

6.4 Groundwater Usage

Table 9 presents a summary of the water use by well type, as documented in the water well records of Labrador. Domestic water supply wells account for 55% (192 well logs) of the total well logs (352 well logs) in Labrador while municipal and public water supplies account for 30% (107 well logs). Several well logs appear to have been incorrectly coded: "water use" of the well is reported as "abandoned", "observation hole" or "water supply". These descriptions are applicable to the category of "final use" of the well, rather than "water use" (Appendix A).

Table 9 – Summary of Water Use by Well Type

Water Use	No. of Wells Completed in Surficial Aquifers	No. of Wells Completed in Bedrock Aquifers	Total
Domestic	10	182	192
Municipal	16	40	56
Public Supply	8	43	51
Commercial	-	8	8
Industrial	-	7	7
Unknown	8	25	33
Abandoned	1	-	1
Observation Hole	3	-	3
Water Supply	1	-	1
Total	47	305	352

Tables B-1 and B-2 in Appendix B provide lists of communities and water well data for all communities reporting groundwater use in Labrador. Maps No. 3 and 4 (Appendix C) show areas of concentrated groundwater use.

In Labrador communities without a surface or groundwater municipal water supply, there is a significant dependence on groundwater for domestic water supplies. Several communities within Labrador rely entirely on private wells for potable water (Gillis, G. pers. comm. 2010), including:

- Capstan Island;
- L'Anse Amour;
- Lodge Bay;
- Norman Bay;
- Paradise River;
- Pinsent's Arm;
- Pinware; and,
- West St. Modeste.

6.4.1 Municipal Uses

There are three major population centres in Labrador with municipal water supplies that rely primarily on groundwater. They include Happy Valley-Goose Bay, North West River and Sheshatsheits.

Water for the Town of HVGB is obtained from two sources: Spring Gulch (a spring-fed surface water source) and the Town of HVGB well field. Each of these water sources feed reservoirs managed by the town. The Spring Gulch reservoir is located on Department of National Defence (DND) land and is maintained by the DND. It provides water to Canadian Forces Base (CFB) 5 Wing Goose Bay and also supplies three municipal reservoirs. The two smaller reservoirs are sourced 100% by Spring Gulch while the third reservoir is supplied by water from Spring Gulch and the Town of HVGB well field (Gillis, G. pers comm. 2010). The well field consists of five drilled wells screened in surficial deposits and is located between the Trans Labrador Highway and the Churchill River (HVGB, 2008). The municipal water treatment plant supplies approximately 65% of the water to the Town of HVGB and Spring Gulch, with its own chlorination system, makes up the remaining 35% (HVGB, 2011).

The towns of North West River and Sheshatsheits are entirely dependent on groundwater for their water supplies. Each town has three drilled wells screened in glaciofluvial deposits as their municipal water supply source.
The community of West St. Modeste reportedly has an unknown number of artesian wells providing its municipal water supply.

The community of Natuashish, built in early 2000 after relocation of the community of Davis Inlet, was entirely dependent on a groundwater sourced municipal supply consisting of five wells until November, 2010. At that time, the municipal water supply was converted to a mixture of a ground and surface water due to persistent water quality issues, particularly elevated fluoride concentrations. The current supply consists of one groundwater well supplemented by surface water from Sango Brook (Gillis, G. pers comm. 2010).

6.4.2 Industrial Uses

Non-municipal industrial use of groundwater in Labrador is quite limited since most industrial water users are located in communities where a municipal water supply is available. In more remote areas, mining companies, the provincial electrical utility and the public works department are the main groundwater users. There are seven wells categorized as industrial wells in Table B-2, Appendix B. Owners of these wells include the Iron Ore Company of Canada (2 wells), NL Hydro (2 wells), NL Department of Works , Services and Transportation (2 wells) and the Gull Island (hydroelectric) Project (1 well).

Industrial wells in Labrador have depths ranging from 22.8 m to 129.2 m with a mean depth of 72.2 m and yields ranging from 4 Lpm to 600 Lpm with a mean yield of 157.4 Lpm. The industrial groundwater withdrawals make up a small proportion of the overall groundwater takings in Labrador. However, due to the relatively high reported yields, proportionally, industrial users are considered to be among the highest groundwater consumers in Labrador.

7. Hydrologic Cycle

Flow within the streams and rivers consist of direct overland surface water runoff combined with a groundwater contribution referred to as baseflow. The baseflow component can be further subdivided into i) shallow groundwater flow that occurs near surface within thin overburden units and alluvial sediments within the river valleys, and ii) flow from the deeper groundwater system derived from aquifer discharge into the streams and rivers. Contribution to and from groundwater generally accounts for a small amount the total water budget in the Labrador. Much of the baseflow in Labrador, and other areas with similar geological and climatic settings, originates from the shallow groundwater flow system where precipitation is held in shallow sediments (drift, till, alluvial deposits) which prevent rapid runoff. These sediments release water slowly over days and weeks. With the exception of those locations with substantial overburden thickness, only a small proportion of water from shallow sediments recharges into deeper aquifer systems. The scarcity of groundwater resources in Labrador is the result of the thin surficial deposits over the bedrock surfaces, steep exposed bedrock terrain and permafrost. Although groundwater recharge can also occur by direct infiltration of precipitation into the bedrock, this type of recharge is a very small component of the overall water budget. For the most part, surface water features such as lakes and streams are derived from overland surface runoff with a minor groundwater component.

7.1 Drainage Areas of Labrador

Figure 7 presents the drainage areas of Labrador according to the Atlas of Canada 1,000,000 National Frameworks Hydrology Data (Natural Resources Canada, 2010). The drainage areas shown are representative of the Atlas of Canada drainage boundaries. Areas comprising sub-component and sub-sub component basins are further divided into watersheds, as shown on Figure 7. The drainage divisions of Labrador are divided into a total of nine sub and sub-sub component basins, as shown by the areas delineated in blue coloured lines in Figure 7. There are a total of 29 watersheds within the sub and sub-sub component basins, as shown by the areas delineated by purple coloured lines.

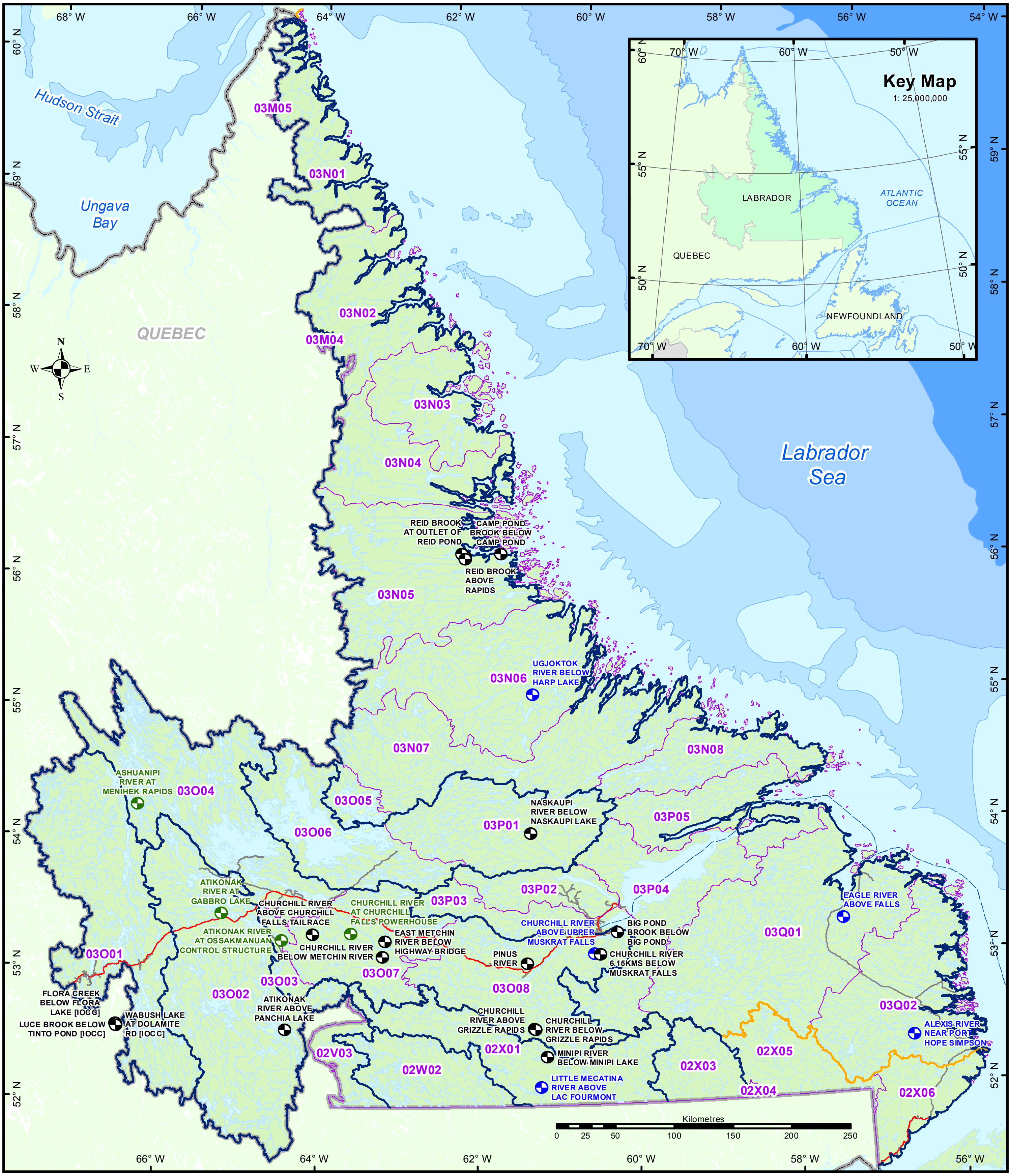
According to Natural Resources Canada (2010), the National Atlas Drainage Basin scheme, delineated on a paper map in 1980, was based on classic drainage basins having certain minimum volume of mean annual discharge. (A classic drainage basin is a land area for which all the surface drainage with its boundary converges and exits at a single point.) The National Atlas Drainage Basin scheme effectively excludes coastal drainage areas whose discharge volume does not meet its criterion for inclusion.

Stream flow monitoring in Labrador is monitored at a network of gauges maintained under the Canada-Newfoundland Hydrometric Monitoring Agreement. The operation of the network is cost-shared between federal and provincial government departments and private companies. Table 10 includes a summary of the active hydrometric monitoring stations in Labrador. Stations are organized in Table 10 by contributing/managing organization. The first three digits of the Station No. correspond to the applicable sub and sub-sub component basin where the hydrometric monitoring location resides. For example, the monitoring station for the ”Alexis River Near Port Hope Simpson” has a station reference number of 03QC002 and is located within the sub/sub-sub component basin labelled as 03Q02. Please refer to Figure 7 for the locations of each of the hydrometric monitoring locations included in Table 10.

Table 10 – Summary of Active Hydrometric Monitoring Stations of Labrador

Station No.	Station Name	Latitude	Longitude
FEDERAL			
03QC002	ALEXIS RIVER NEAR PORT HOPE SIMPSON	52 38 57	56 52 17
03OE001	CHURCHILL RIVER ABOVE UPPER MUSKRAT FALLS	53 14 52	60 47 21
03QC001	EAGLE RIVER ABOVE FALLS	53 32 03	57 29 42
02XA003	LITTLE MECATINA RIVER ABOVE LAC FOURMONT	52 13 42	61 19 21
03NF001	UGJOKTOK RIVER BELOW HARP LAKE	55 14 00	61 17 57
PROVINCIAL			
03OC003	ATIKONAK RIVER ABOVE PANCHIA LAKE	52 58 10	64 39 44
03OE010	BIG POND BROOK BELOW BIG POND	53 30 43	60 17 31
03NE003	CAMP POND AT S/W END	56 20 02	62 05 39
03NE002	CAMP POND BROOK BELOW CAMP POND	56 21 41	61 56 23
03OD007	EAST METCHIN RIVER BELOW HIGHWAY BRIDGE	53 26 07	63 14 03
03OA010	Flora Creek below Flora Lake [IOCC]	52 59 12	66 52 19
03OA012	Luce Brook below Tinto Pond {IOCC]	52 59 16	66 52 37
03OA014	Wabush Lake at Dolamite Rd [IOCC]	52 58 00	66 51 33
03OE003	MINIPI RIVER BELOW MINIPI LAKE	52 36 53	61 11 11
03PB002	NASKAUPI RIVER BELOW NASKAUPI LAKE	54 07 54	61 25 45
03OE011	PINUS RIVER	53 08 52	61 33 31
03NE011	REID BROOK ABOVE RAPIDS	56 18 18	62 05 34
03NE001	REID BROOK AT OUTLET OF REID POND	56 22 22	62 09 43
03NE012	TRIBUTARY ABOVE RAPIDS	56 18 22	62 05 40
02ZC003	WHITE BEAR RIVER ABOVE BIG INDIAN BROOK	48 04 50	57 22 06
03OD008	CHURCHILL RIVER ABOVE CHURCHILL FALLS TAILRACE	53 31 29	64 06 54
03OD009	CHURCHILL RIVER BELOW METCHIN RIVER	53 14 22	63 17 06
03OE013	CHURCHILL RIVER ABOVE GRIZZLE RAPIDS	52 58 12	61 26 43
03OE012	CHURCHILL RIVER BELOW GRIZZLE RAPIDS	52 57 53	61 24 44
03OE014	CHURCHILL RIVER 6.15KMS BELOW MUSKRAT FALLS	53 14 15	60 40 31
**	Churchill River Lake Melville		
**	Churchill River near Mud Lake		
CONTRIBUTED			
03OA001	ASHUANIPI RIVER AT MENIHEK RAPIDS	54 27 18	66 37 30
03OC006	ATIKONAK RIVER AT GABBRO LAKE	53 46 20	65 23 47
03OD006	ATIKONAK RIVER AT OSSAKMANUAN CONTROL STRUCTURE	53 26 53	64 46 09
03OD005	CHURCHILL RIVER AT CHURCHILL FALLS POWERHOUSE	53 32 10	63 57 51

*Note: 1. ** The un-assigned stations for Churchill River Lake Melville and Churchill River near Mud Lake are newly created stations as of December, 2010 and are not yet fully functional according to the Surface Water Manager for the NL Gov Department of Environment and Conservation, Water Resources Management Division.*



Map Features

Hydrometric Station
- Contributed
- Federal
- Provincial
- Watershed Boundary
- Areas of Overlap of Sub, Sub-Sub Component Basin
- Drainage Basin
- Major Road
- Secondary Road
- Ferry Route
- Watercourse
- Provincial Boundary
- Waterbody

Bathymetry
- 0 - 200m
- 200 - 1000m
- 1000 - 3000m
- > 3000m

Newfoundland Labrador

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Figure 7

Drainage Areas and Hydrometric Monitoring Station Locations

Labrador Region, NL

References

Drainage area definitions comprising Sub-Component Basins and Sub-Sub Component basins data based on the National Scale Frameworks Hydrology data according to the Atlas of Canada 1,000,000 National Frameworks Data, Hydrology – Drainage Areas downloaded from www.geogratis.ca.

FINAL

DATE: March 18, 2011
SCALE 1:4,300,000
PROJECTION: UTM Zone 20N, NAD 83
REVISION: 8
DRAWN: HC-SEG

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7.2 Water Budget

The following section summarizes the results of the regional water budget assessment. The purpose of the water budget is to provide a general overview of the hydrologic cycle, and describe the proportion of precipitation that is divided into evaporation, transpiration, runoff, and recharge. A number of assumptions and professional judgements are made in order to conduct a water budget across Labrador. Key assumptions and judgements include soil moisture values, representativeness of temperature and climate data between stations, distribution and nature of surficial geology and soils, and the influence of permafrost. Actual water budget values are highly dependent on site conditions and cannot be accurately predicted at the regional scale using the methods described in this report. The water budget and simulated runoff and recharge maps should be considered approximate, and are meant to illustrate the relative magnitude of the hydrologic processes across Labrador.

A *water budget* is used to describe the movement of water in a basin. In this report, it is assumed that the political boundaries of Labrador are representative of a basin. The total *precipitation* (P) accounts for the water that falls both as rainfall and as snow and constitutes the total amount of water available for hydrological processes such as stream flow and groundwater recharge. A water budget also considers the amount of water that is returned back to the atmosphere by both *evaporation* and plant *transpiration* in the combined process called *evapotranspiration (ET)*.

The water budget equation is not complicated. For a given time period (often one year), the water budget balances the gains and losses of water with the quantities of water stored in the basin. The water budget equation is expressed as follows:

$$P = RO + R + ET + \Delta S_s + \Delta G_s$$

Where:

P = Precipitation (mm/yr);
RO = Runoff (mm/yr);
R = Groundwater Recharge (mm/yr)
ET = Evapotranspiration (mm/yr);
ΔS_s = Change in soil moisture storage (mm/yr); and,
ΔG_s = Change in groundwater storage (mm/yr).

In a large watershed or basin where the groundwater system boundaries coincide with surface water divides, the change in groundwater storage can be assumed to equal zero ($\Delta G_s = 0$). However, the political boundaries of Labrador do not coincide with the exact watershed boundaries of all surface water divides in the area. It is therefore recognized that by assuming that the change in groundwater storage equals zero, this adds a source of error into the calculations. Given the size and scale of this analysis, this error is expected to be small.

Within a large drainage basin, precipitation rates can be spatially and temporally variable. Therefore, it is important to obtain precipitation estimates from multiple points within a basin that have been averaged over a long period of time. Long term meteorological data from the 1971 – 2000 average was obtained from Environment Canada for the following five weather stations in Labrador:

- Cartwright A (Station ID: 8501100);
- Churchill Falls A (Station ID: 8501130);
- Goose Bay A (Station ID: 8501900);
- Nain A (Station ID: 8502800); and,
- Wasbush Lake A (Station ID: 8504175).

Evapotranspiration can be defined as potential evapotranspiration or actual evapotranspiration. Potential evapotranspiration can be estimated using temperature data and incoming solar radiation (often referred to as the daylight correction factors) from data measured within the basin. The daylight correction factors are dependent upon the latitude of the basin or meteorological station; with the understanding the areas closest to the equator will have the most daily sunlight and therefore, the highest potential evapotranspiration rates. Actual evapotranspiration expands upon potential evapotranspiration to include changes in soil moisture and monthly precipitation rates.

Soil moisture storage was estimated for the various surficial geological units in Labrador and was designed to be consistent with the values proposed by Singer and Cheng (2002) in their hydrogeology study of Northern Ontario. Special consideration for soil moisture storage was given to areas covered by continuous or extensive permafrost. It was shown by Quinton *et al.* (2005) that soil moisture storage in organic covered permafrost terrains varies between a winter period value of approximately 50 mm and a summer period value of 100 mm. Overall, it was assumed that the average soil moisture storage in Labrador was 50 mm. This low value reflects the extensive areas of shallow or exposed bedrock, permafrost, sandy till deposits and a lack of lacustrine or glaciolacustrine clay soils.

The process of sublimation is the phase transition from a solid substance to vapour without passing through the intermediate liquid stage. This process removes a portion of the snow pack in Labrador and prevents it from contributing to spring stream flow or groundwater recharge. Literature values for sublimation rates vary significantly. For instance, Hood *et al.* (1999) estimate that the water equivalent of the total net sublimation could be 15 % of maximum snow accumulation. Fassnacht (2004) estimates that between 7 mm to over 20 mm per month could be lost to sublimation depending upon environmental factors such as wind speed, humidity and precipitation. It was clear from both studies that the process of sublimation is based on site specific conditions and for best results should be measured in-situ, which is beyond the scope of this report. Therefore, the potential loss of water from sublimation was not taken into account for the water budget analysis, but it was considered in the interpretation of the results.

7.3 Labrador Water Surplus

Assuming that changes in soil moisture storage (ΔS_s) are negligible and that there is no change in groundwater storage (ΔG_s) in the basin, the total *water surplus* that is available for *surface runoff* to the surface water system and *infiltration* as groundwater recharge, can be determined. The water surplus (mm/yr) is expressed as follows:

$$Surplus = P - ET$$

The proportion of the water surplus that is infiltrated or runoff depends primarily upon the characteristics of the soils, the topography, the land use and the vegetative cover present. This concept is based upon the fact that water will infiltrate more easily through flat lying, high permeability soils than it will though steep slopes or low permeability soils. Water that infiltrates to the ground recharges the water shallow water table flowing laterally towards rivers and streams. In locations with significant overburden, this recharge may migrate into deeper groundwater aquifer systems and eventually discharge into surface water systems.

Surface runoff, on the other hand, generally coincides with rainfall events. As the surficial soil layers become saturated by rainfall, water may runoff to low lying areas. This process is especially pronounced during the spring snow melt where the melting snowpack is forced to runoff because the upper soil layers are still frozen and do not accept infiltration.

The actual evapotranspiration was calculated using the method described in Thornthwaite and Mather (1957), using a monthly time step and assuming a soil moisture of 50 mm. A daylight correction factor for 50 degrees latitude was applied to the southernmost weather stations. A daylight correction factor for 60 degrees latitude was applied for the Nain station in the north. The overall water surplus was determined for each of the five meteorological stations by the difference between the mean annual precipitation (P) and the actual evapotranspiration (ET) and is presented in Table 11.

Table 11– Yearly Water Surplus by Meteorological Station

Meteorological Station	Total Precipitation (mm)	Actual Evapotranspiration (mm)	Water Surplus (mm)
Cartwright A	**1,050**	**416**	**634**
Churchill Falls A	**926**	**403**	**523**
Goose Bay A	**949**	**452**	**497**
Nain A	**893**	**381**	**511**
Wabush Lake A	**852**	**408**	**443**
Average	**934**	**412**	**522**

Notes:
1. *Data obtained from the 1971 – 2000 average at each meteorological station*
2. *Actual Evapotranspiration calculated using the Thornthwaite and Mather (1957) method.*

In summary, based on the meteorological data from Cartwright, Churchill Falls, Goose Bay, Nain and Wabush Lake collected from 1971-2000, the mean long-term or mean normal annual precipitation throughout Labrador is 934 mm. The water balance prepared using the method described in Thornthwaite and Mather (1957) indicated that the mean normal evapotranspiration is 412 mm, based on a soil moisture storage of 50 mm. By taking the difference between total precipitation and evapotranspiration, an average normal water surplus of 522 mm/yr was determined for Labrador.

The relatively high rates of precipitation, especially in the southern part of the Province, and low amounts of solar energy, due to the high latitude position results in significant water surpluses. This conclusion is supported by the observation of abundant surface water in Labrador.

According to Christopherson (2000), the evapotranspiration calculated using the Thornthwaite and Mather (1957) method for the northern regions of Canada including Labrador, should be less than 460 mm/yr, which fits within the range of values obtained for this report.

The calculation of the annual water budget and water surplus for Labrador requires that a number of assumptions be made, including:

- The political boundaries of Labrador are representative of a closed basin with no groundwater or surface water flow into or out of the basin;
- Temperature and precipitation data measured at the Cartwright, Churchill Falls, Goose Bay, Nain and Wabush Lake from 1971-2000 are representative the conditions in the vicinity of the stations;
- Temperature and precipitation data can be extrapolated for a large area outside of the watershed containing the meteorological station;
- Soil moisture storage remains relatively constant at 50 mm annually and is representative of conditions throughout Labrador; and,
- The effects of permafrost were not directly considered as part of the water balance and are considered negligible when all of Labrador is assessed.

With these assumptions expressed, the precipitation, evapotranspiration, and water surplus results should be considered estimates for areas beyond the specific locations of Cartwright, Churchill Falls, Goose Bay, Nain and Wabush Lake meteorological stations.

7.4 Recharge and Runoff Modelling

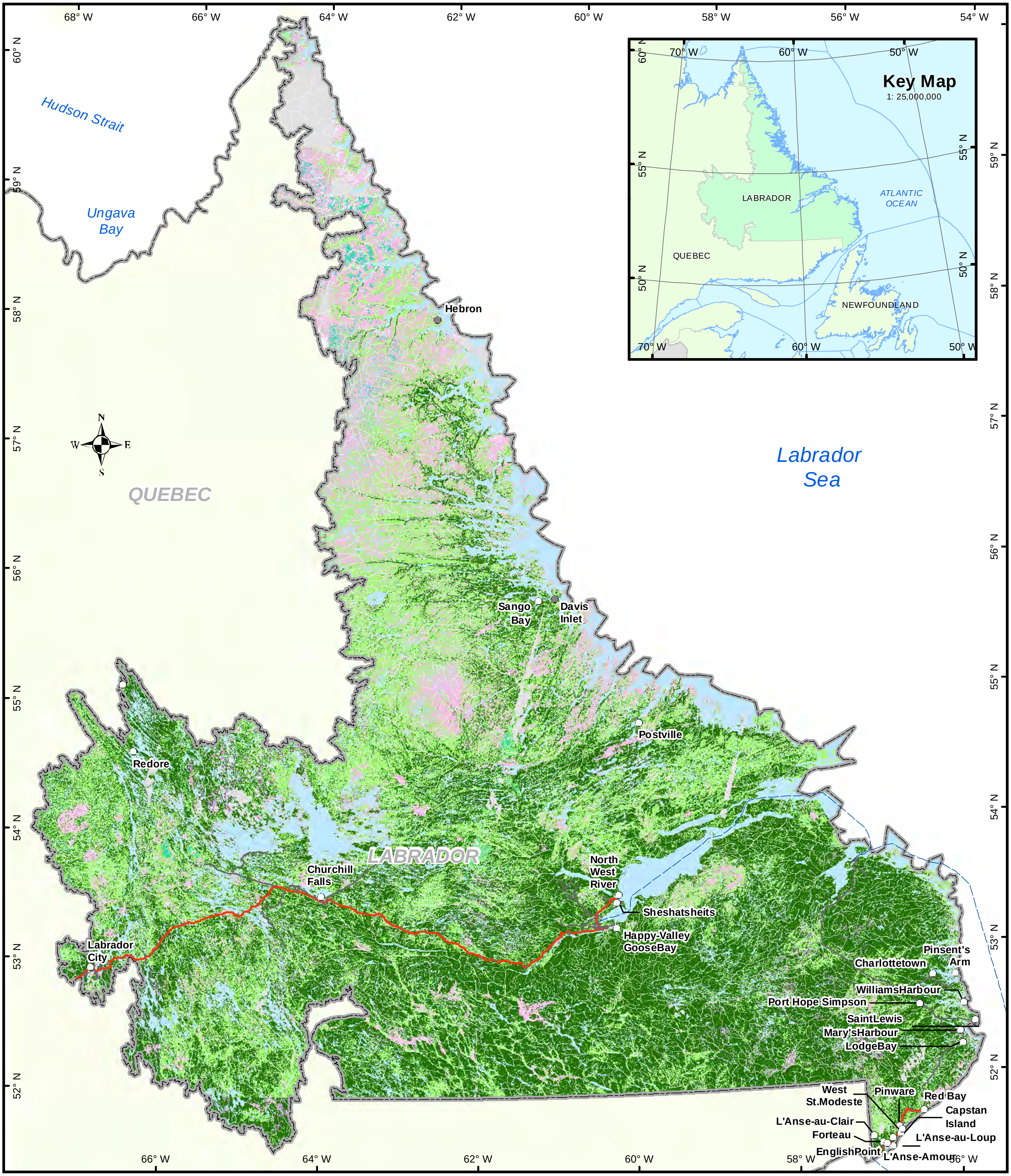
Based upon the estimated annual water surplus, groundwater recharge and surface water runoff rates were calculated for Labrador using a Geographic Information System (GIS) based analytical model. This model assumes that volumes of domestic and municipal groundwater taking are negligible, and that groundwater and/ or surface water inflow from outside the basin is also negligible. The model integrates slope, land use (vegetative cover), and geology over a 1000 x 1000 m grid to estimate potential groundwater recharge rates and runoff volumes for the area of Labrador.

The first step in this GIS model was to calculate the quantity of surplus water available for infiltration and runoff, which is the difference between precipitation and evapotranspiration. Evapotranspiration was determined using the method developed by Thornthwaite and Mather (1957).

The second step was to partition the surplus water into runoff and infiltration. A distribution of infiltration weights was determined for each of the different geologic, vegetative and topographic units within the study area. Infiltration factors were calculated using a method developed by the Ontario Ministry of the Environment (formerly the Ministry of Environment and Energy) (MOEE, 1995), and through professional judgment to incorporate the unique hydrological conditions of Labrador. The total infiltration factors are calculated by summing the individual subfactors that are dependent upon the topography, soil, and cover at the site.

The land use mapping and digital elevation model (DEM) used to assign values for slope and vegetative cover are provided in Figures 8 and 9, respectively. The surficial geology map shown in Map 1, Appendix A provides the data for infiltration value weighting within the model. Once weights are applied to all layers they were combined within the GIS to create a layer of infiltration distribution.

The infiltration distribution, in combination with the distribution of water surpluses, produced a model of the spatial variability of groundwater recharge across Labrador, from which the estimated recharge and runoff distribution mapping was produced (Map 5 and Map 6, Appendix E). Recharge and runoff estimates for each 1000 m x 1000 m grid cell were grouped to present a range of values reflective of the general geological and hydrological conditions of the area.



Map Features

- Town or Village
- Former Town or Village
- Major Road
- Secondary Road
- Ferry Route
- Provincial Boundary

Land Cover

- No Data
- Water
- Bedrock/Bare soils
- Snow/Ice
- Developed
- Shrubland
- Wetland
- Tundra
- Grassland
- Forest

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Department of Environment and Conservation

Figure 8

Vegetative Cover

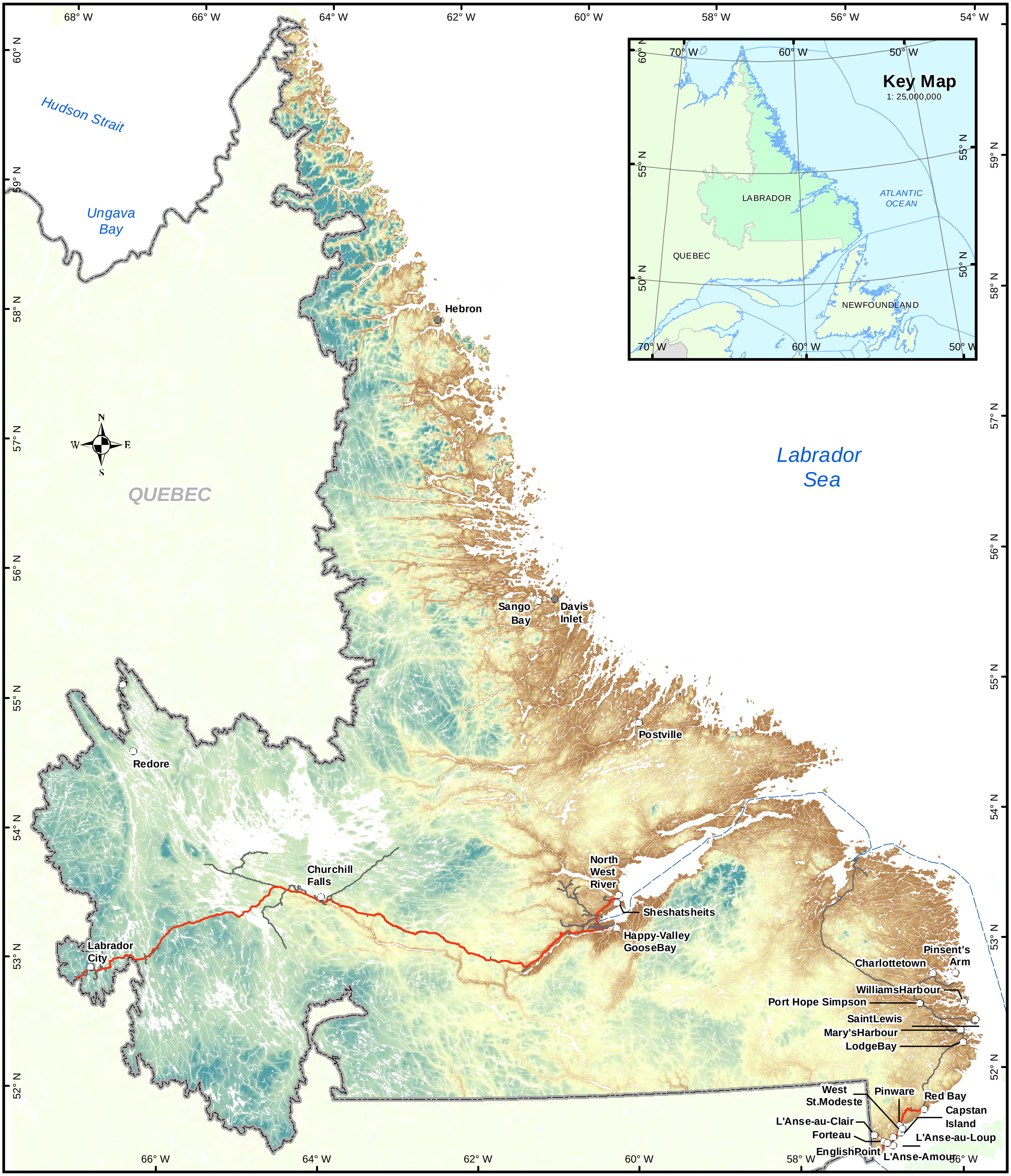
Labrador Region, NL

Kilometres
0 25 50 100 150 200 250

FINAL

DATE: March 2013
SCALE: 1:4,400,000
PROJECTION: UTM Zone 20N, NAD 83
JOB NO.: 60163257
REVISION:
DRAWN: BKV

AECOM



Map Features

- Town or Village
- Former Town or Village
- Major Road
- Secondary Road
- Ferry Route
- Provincial Boundary

Elevation (mASL)

1508 m

1 m

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Figure 9

Digital Elevation Model

Labrador Region, NL

Kilometres

0 25 50 100 150 200 250

FINAL

DATE: March 2013
SCALE: 1:4,400,000
PROJECTION: UTM Zone 20N, NAD 83
JOB NO.: 60163257
REVISION: 1
DRAWN: BKV

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7.5 Results of the Water Budget Calculations and Modelling

The results of the water budget calculations and modelling are presented on Maps 5 and 6, Appendix E as the potential estimated groundwater recharge and potential surface runoff for Labrador. The purpose of these maps is to highlight areas where there is a greater estimated potential for groundwater recharge, which should correspond to more productive hydrostratigraphic units as well as stream and river systems with a higher relative proportion of baseflow. The opposite is true for surface runoff. Areas where there is a greater potential for surface runoff should correspond to poorly developed groundwater resource areas and higher peak flows in streams. As previously described, the results presented should be considered approximate, and are meant to illustrate the relative magnitude of the hydrologic processes across Labrador

The total estimated potential annual recharge and runoff for Labrador is $27.66x10^{9}$ m^{3} and $13.65x10^{10}$ m^{3}, respectively. This means that on average, recharge accounts for approximately 17% of the total water balance in Labrador, with surface runoff accounting for the remaining 83%. These divisions between recharge and runoff seem reasonable given the predominance of low permeability soils at surface, the abundance of surface water features, and the strong event-based flows recorded in most river basins. As previously described, much of the recharge would involve shallow infiltration and lateral migration into stream systems.

7.5.1 Groundwater Recharge

The permeability (i.e., the ability of soils to convey groundwater flow) of surficial geological formations is the most important factor influencing groundwater recharge rates across most Labrador. Although groundwater recharge will occur everywhere within a basin, from a practical point of view, only higher permeability soils can transmit enough recharge to support a groundwater resource. High permeability units are generally limited to glacial fluvial and glacial marine sedimentary deposits (Map 5, Appendix E). Glacial till is the most common surficial sediments over the bedrock. In general, glacial tills are considered aquitards, inhibiting significant infiltration. As such, most of Labrador shows infiltration rates of 100 mm or less, with the main component of groundwater movement occurring as shallow lateral flow toward stream systems. In areas with very thin overburden or drift, recharge is controlled by the underlying very low permeability bedrock geology. The main function of the surficial till and drift units will be to hold precipitation near surface long enough to prevent rapid runoff.

Areas where bedrock is exposed at surface or covered by thin drift have the lowest potential recharge rates at less than 10 mm/yr. The glaciofluvial and glaciomarine deposits have the highest potential for groundwater resource development. Potential recharge in these soils can range from approximately 150 mm/yr to greater than 225 mm/yr. Recharge through till deposits, which are the most common surficial soils in Labrador, generally range from 75 – 150 mm/yr, depending upon site specific conditions of land-use and topography. Jacques Whitford (2008) predicts an average recharge value of 95 mm within the Goose Bay Agricultural Development Area which is consistent with the estimated values presented in Map 5, Appendix E.

Groundwater recharge in general varies seasonally, with the highest rates occurring in the spring (May to early July) during snow melt and spring rainfall events and the lowest rates occurring in the winter months (November to April) when most precipitation falls as snow. Areas that are covered by continuous or extensive permafrost (shown on Map 5, Appendix E) have continuously low groundwater recharge rates because saturated permafrost soils encourage runoff and limit infiltration. The effect of permafrost soils were not considered in generating the potential recharge mapping, but must be considered when developing groundwater resources in permafrost areas. As such, recharge is likely overestimated in permafrost zones in Map 5, Appendix E.

Deep groundwater recharge is controlled by the low permeability of the bedrock. Thick sequences of glacial materials that can host extensive and productive confined aquifers are generally not present in Labrador. It is expected that the percentage of groundwater recharge that reaches deep geological units is very low.

7.5.2 Surface Runoff

When rainfall or snow melt encounters a saturated or low permeability surficial soil, rather than infiltrating into the ground, the majority of the precipitation runs off via overland flow into the surface water system. Part of this runoff water is responsible for causing peak flows and flood conditions in surface watercourses. In Labrador, peak flows are especially pronounced during the melting snow pack. When the snow first begins to melt, the surface soil is either frozen or saturated, so the majority of the water held in storage within the snowpack is suddenly available.

As with groundwater recharge, some soil types are more conducive to surface runoff than others. Bedrock surfaces were shown to allow less than 10 mm/yr of infiltration, resulting in high runoff rates that can exceed 500 mm/yr (Map 6, Appendix E). Areas where bedrock is exposed at surface or where it is only covered by a thin drift have the highest runoff rates in Labrador. Obviously, watercourses in these areas are more prone to peak flows and flood conditions than watercourses in areas when more infiltration can occur.

Areas covered by permafrost are also expected to be dominated by surface runoff as infiltration into saturated and frozen soils is very limited. Some shallow recharge and discharge may occur during summer when upper portions of the permafrost melt.

7.6 Hydrology

Based on an analysis of the water budget results and hydrographs from select Water Survey of Canada hydrometric stations, there are three general types of hydrologic systems. These include:

1) Regulated;
2) Surface water dominated (i.e. <15 % baseflow); and,
3) Those systems with a relatively higher baseflow component (i.e. > 15 % baseflow).

The relative importance of baseflow can be predicted using the recharge mapping shown in Map 5, Appendix E. Figure 10 shows hydrographs for Eagle River, Atikonak River, Reid Brook and Churchill River (hydrometric station locations are shown on Figure 7). Along with 2009 data, the minimum, maximum and mean hydrographs are presented in Figure 10. The four hydrographs were selected to illustrate typical hydrologic systems within Labrador.

In general, all hydrographs show peak flow during spring and summer related to thawing and snow melt. These flows decrease through late summer and fall as evapotranspiration increases and precipitation decreases. Visual estimation of baseflow for each of the unregulated hydrographs range from approximately 12% to 30% of total stream discharge. The higher baseflow estimate for the Eagle River corresponds to a greater recharge potential as estimated in Map 5, Appendix E. The lower estimated baseflow for Reid Brook is predicted by the predominance of low permeability bedrock at surface and potential for permafrost. The Atikonak River located in Western Labrador is considered to be similar to the Eagle River with respect percentage baseflow due to its similar recharge potential setting as shown in Map 5, Appendix E.

The regulated hydrograph example in Figure 10 is from the Churchill River. The data show that the river has a very high baseflow contribution with significant moderation of peak flows in spring summer. The artificial baseflow is maintained by slowing releasing stored surface water over time. During spring and summer melts, much of the flow is used to refill reservoirs above dam structures.

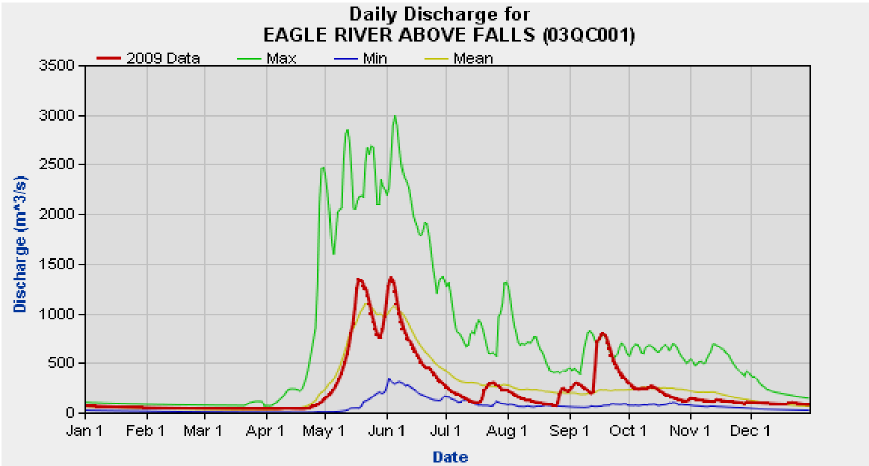
The Eagle River watershed was selected to compare estimated volumes of recharge and runoff to known stream flow values at the Eagle River Surface Water Monitoring Station (Station ID: 03QC001). The total potential volumetric flow rate (in m^3/s) was determined for recharge and runoff values in the watershed and compared to the mean annual flow (m^3/s). The results of this comparison are presented in Table 12 for both recharge and runoff.

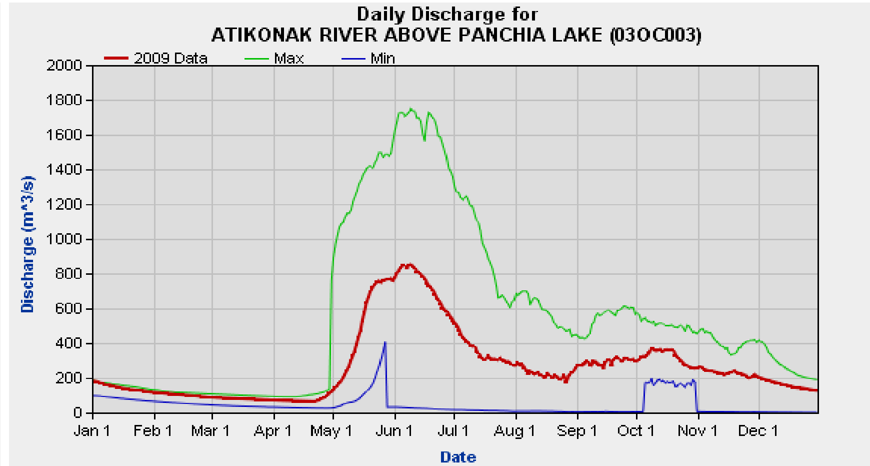
Table 12 – Stream Flow Estimation from Water Surplus in the Eagle River Basin

Watershed	Area (km^2)	Water Surplus (mm/yr)	Recharge (mm/yr)	Runoff (mm/yr)	Contribution to Stream Flow from Recharge (m^3/s)	Contribution to Stream Flow from Runoff (m^3/s)	Total Estimated Stream Flow (m^3/s)
Eagle River Watershed	10,900	634	114	520	40	179	219

Notes: 1. Water Surplus value obtained from Cartwright Meteorological Station.

The mean yearly discharge for the Eagle River measured between 1966 and 2009 is 252 m^3/s. The similarity of this value to the total estimated stream flow from the water surplus calculations of 219 m^3/s provides some confidence in the water surplus value. The estimated baseflow for the Eagle River based on visual hydrograph comparison is up to approximately 30% of stream flow. The contribution to stream flow from recharge as estimated from the GIS-based model is 40 m^3/s or approximately 18% of total stream flow. Given the limitations of the large scale water budget analysis, the results are relatively consistent. The water budget estimates could be improved by using individual hydrometric stations data with larger scale geological mapping to improve the resolution of the model. This level of detail was outside the scope of the current project, however the results of the water budget do allow for estimation of the relative importance of hydrologic processes across Labrador.





Statistics corresponding to 43 years of data recorded from 1966 to 2009.*

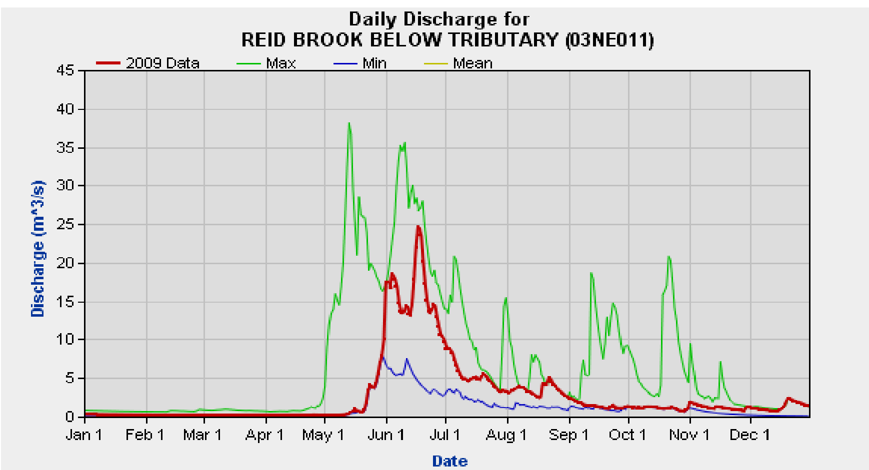
Drainage area = 10,900 km2 **"Natural Drainage Area - Coastal Labrador"**

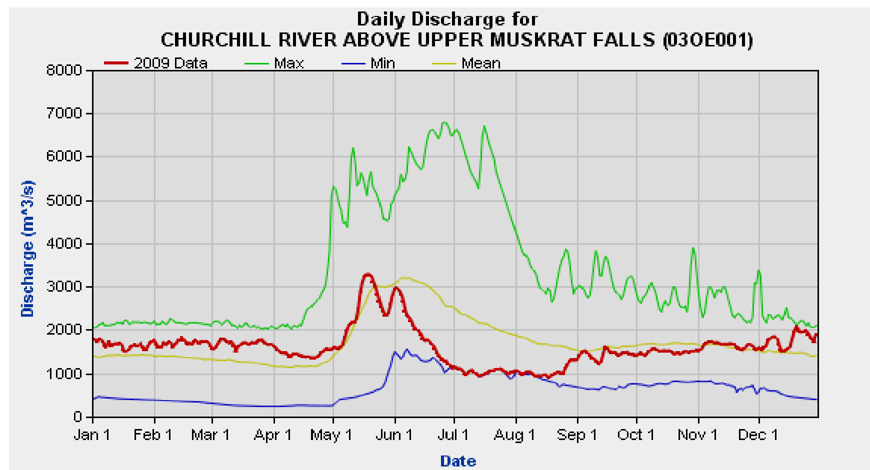
Regulation Type = Natural Approx. Baseflow - 30%

Statistics corresponding to 22 years of data recorded from 1972 to 2009

Drainage Area = 15100 km2 **"Natural Drainage Area - Western Labrador"**

Regulation Type = Natural Approx. Baseflow - 20-30%





Statistics corresponding to 7 years of data recorded from 2003 to 2009

Drainage Area is unknown Approx. Baseflow - 10-15%

Regulation Type = Natural **"Northern (Permafrost Area) Hydrograph"**

Statistics corresponding to 58 years of data recorded from 1948 to 2009

Gross drainage area = 92500 km2

Regulation type = regulated **"Regulated Drainage Area"**

Figure 10 - Sample Hydrographs of Representative Hydrologic Systems of Labrador

(Source: Environment Canada, HYDAT Database, archived hydrometric data through the National Hydrometric Program.

8. Water Quality

A review of NLDEC Water Resources Portal (WRP) database and unpublished consultant's reports was conducted to assess the surface water and groundwater quality of Labrador.

The NLDEC WRP contains results of public water supply testing programs from communities within Labrador. A summary of the source water nutrient, metal and major ion (except bicarbonate) concentrations, as well as physical parameters such as colour is presented in Appendix F (surface water) and Appendix G (groundwater).

The water quality results are compared to the Health Canada (2010) *Guidelines for Canadian Drinking Water Quality* (GCDWQ). Parameters are compared on the basis of Maximum Acceptable Concentrations (MAC), Interim Maximum Acceptable Concentration (IMAC) or Aesthetic Objectives (AO). MAC and IMACs have been established for certain substances that are known or suspected to cause adverse effects on human health. Aesthetic parameters reflect substances or characteristics of drinking water that can affect its acceptance by consumers but which usually do not pose any health effects.

The Water Quality Index (WQI) was developed by the Canadian Council of the Ministers of the Environment in 2001 to provide a tool for simplifying the reporting of water quality data. It is used by NLDEC as a means by which water quality data are summarized for reporting to the public in a consistent manner. It is calculated by comparing the water quality data to the GCDWQ.

8.1 Surface Water

A total of 175 water quality samples from 16 public surface water supplies are available for Labrador. Parameters that typically exceed the GCDWQ criteria include colour, pH, turbidity, iron and manganese. Tables F-1 and F-2 in Appendix F include the tabulated surface water quality results. Table 13 presents a summary of mean concentrations of select parameters for regions of Labrador where public supplies are obtained from surface water sources. The mean concentrations presented in Table 13 are used to support the written description of the surface water conditions of each region that follows.

Table 13 - Summary of Select Parameters - Surface Water Quality

Region of Labrador	Towns/ Communities	No. of Samples	Mean Concentrations						Exceedances to GCDWQ
			Hardness (mg/L)	pH	Alkalinity (mg/L)	TDS (mg/L)	Turbidity (NTU)	Langelier Index	
Western Labrador	Labrador City, Wabush, Churchill Falls	54	33.8	7.2	32.3	42.0	0.5	- 1.86 to - 3.95	Manganese (6 of 54 samples)
Northern and Northeastern	Nain, Hopedale, Makkovik, Postville and Rigolet	49	5.0	6.3	5.7	15.0	1.0	-4.08	ph (37 of 53 samples) Colour (44 of 53 samples) Turbidity (19 of 53 samples) Iron (9 of 10 samples at Rigolet only)
Southeast Region	Cartwright, Charlottetown, William's Harbou, Mary's Harbour, St. Lewis	49	6.4	5.9	6.6	18.0	0.7	-4.86	Colour (all 49 samples) pH (all 49 samples) Iron (18 of 49 samples)
Southern	L'Anse au Loup and Red Bay	22	8.0	6.6	10.6	17.0	0.5	- 3.08 to - 5.25	Colour (18 of 22 samples) pH (10 of 22 samples)
	Forteau and L'Anse au Clair	22	94.0	8.1	115.5	142.0	0.4	-0.10	Iron (2 of 22 samples)

Based on 53 samples collected between 2001 and 2009 from surface waters in western Labrador (Churchill Falls, Labrador City and Wabush) water quality is “soft”, near neutral, contains low concentrations of total dissolved solids, and has low turbidity. Manganese exceeded the aesthetic objective (AO) guideline of 0.05 mg/L in 6 out of 54 samples. Calcium is the dominant cation and bicarbonate is inferred to be the dominant anion based on relatively low concentrations of chloride, sulphate and bromide. Surface water in Labrador City and Wabush is slightly corrosive (slightly under saturated with calcium carbonate), while the water in Churchill Falls is moderately corrosive, suggesting it may affect pipes within the water distribution system.

Based on 49 samples collected between 2001 and 2009 from surface waters serving communities in northern and northeastern Labrador (Nain, Hopedale, Makkovik, Postville and Rigolet), water quality is “very soft” and slightly acidic with pH values less than the 6.5 GCDWQ criteria in all 49 samples. Colour exceeded the 15 total colour units (TCU) AO in 44 of 53 samples. Turbidity marginally exceeded the MAC in 19 of 53 samples. Iron exceeded the AO in 9 of 10 samples taken at Rigolet. Water from the Nain-Hopedale-Makkovik-Postville-Rigolet area is naturally very corrosive indicating it is under saturated with respect to calcium carbonate.

Based on 49 samples collected between 2000 and 2009 from surface waters serving communities in southeastern Labrador (Cartwright, Charlottetown, William’s Harbour, Mary’s Harbour and St. Lewis), water quality is “very soft” and slightly acidic with pH values less than the 6.5 GCDWQ criteria in 37 of 53 samples. Colour exceeded the 15 total colour units (TCU) AO in all 49 samples. Turbidity exceeded the MAC in 8 of 49 samples. Iron exceeded the AO in 18 of 49 samples. Water from the Cartwright-Charlottetown-William’s Harbour-Mary’s Harbour and St. Lewis area is naturally very corrosive indicating it is under saturated with respect to calcium carbonate.

Based on 22 samples collected between 2000 and 2010 from surface waters in communities of L’Anse Au Loup and Red Bay, water quality is “very soft”, slightly acidic and has a pH less than the 6.5 GCDWQ criteria in 10 of 22 samples available. Colour exceeded the 15 TCU AO in 18 of 22 samples. Surface water in this area has low TDS and turbidity. Surface water is classified as corrosive in L’Anse Au Loup and very corrosive in Red Bay.

Lastly, surface water quality in Forteau and L’Anse Au Clair in southern Labrador is “moderately hard”, alkaline and contains moderate TDS and moderate conductivity (mean conductivity = 226.6 µS/cm), and is enriched in calcium (mean calcium = 30.9 mg/L). The near-neutral Langelier Index indicates the water is in equilibrium with carbonate and a scale layer is neither dissolved (i.e. corrosion) or precipitated (i.e. scale forming).

In summary, higher pH, hardness, alkalinity and major ion concentrations are notable in the surface waters of Forteau and L’Anse au Clair and to a slightly lesser degree in Labrador City and Wabush where underlying geology is composed of carbonate-rich sedimentary bedrock common to the areas of southern (Strait of Belle Isle area) and western Labrador (Labrador City and Wabush). Conversely, in other areas of Labrador where underlying geology is composed primarily of gneiss and granite bedrock, surface water tends to be slightly acidic, coloured, highly corrosive and of low mineral content.

8.2 Groundwater

Groundwater quality data are limited for Labrador: only 63 samples from 6 different communities with public groundwater supplies are contained in the WRP database. Parameters exceeding the GCDWQ criteria included colour, pH, TDS, turbidity, chloride, fluoride, sodium, copper, iron and manganese. Tables G-1 and G-2 in Appendix G present the tabulated groundwater water quality data obtained from the WRP. Table G-3 in Appendix G presents a summary of available groundwater chemistry obtained from NLDEC and from available consultant’s reports provided by NLDEC. Results for a tap water sampling program conducted in May, 2010 were provided by NLDEC for the HVGB area and are included in Table G-3, however, because these data represent treated water samples, they are not included in the groundwater quality evaluation.

Table 14 presents a summary of mean concentrations of select parameters for regions of Labrador where public supplies are obtained from groundwater and select results obtained from the NLDEC chemistry database. The mean concentrations presented in Table 14 are used to support the written description of the groundwater quality of each region that follows.

Based on one sample from the Charlottetown Recreation Centre well in August 2010 and eight samples from an unknown source in Hopedale, groundwater quality in south-eastern Labrador is near neutral to alkaline and is a sodium dominated, with moderate TDS and moderate specific conductivity. The near-neutral LI indicates the water is in equilibrium with carbonate, suggesting that this water will cause neither corrosion nor carbonate scale formation in system piping. The Charlottetown Recreation Centre well has been on a boil water advisory since July, 2010 due to insufficient free chlorine residual concentrations in the water after chlorination.

Based on two samples from unknown wells in Forteau and L’Anse au Loup, groundwater is “soft”, near-neutral, contains moderate TDS and specific conductivity and is dominated by calcium. There were no exceedances of the GCDWQ in the parameters analyzed in the two available samples.

Groundwater from the West St. Modeste well field in south-eastern Labrador, is “soft”, near neutral, contains moderate TDS and specific conductivity, and is highly coloured and enriched in iron and manganese at concentrations that exceed the GCDWQ criteria for these parameters. Groundwater in West St. Modeste is slightly corrosive and is under saturated in calcium carbonate. The water quality from the West St. Modeste well field is classified as fair to good with WQI ranging from 79 to 82. A boil water advisory has been issued for West St. Modeste since November, 2010 due to detections of total coliform bacteria in treated water.

Elevated sodium chloride (salt) concentrations have been observed in Well No. 2 at the HVGB well field. The salt source is believed to be brackish groundwater at depth, derived from meteoric (atmospheric) water contaminated by rock-water interactions (Fracflow Consultants 2003). The water quality from the HVGB well field is classified as very good to excellent with WQI ranging from 92 to 100 for the period of July, 2006 to August, 2010.

Groundwater in North West River is “moderately hard”, near-neutral, and moderate in TDS content. Groundwater from Sheshatsheits is also “moderately hard” and near-neutral but contains higher TDS and is enriched in iron and manganese in excess of GCDWQ criteria. According to the dissolved solids and specific conductance, water quality from North West River is generally indicative of fresh (as opposed to saline) conditions, although relatively higher specific conductance and TDS in the Sheshatsheits supply may be indicative of slightly saline conditions. The water quality from the North West River well field is classified as excellent, with a WQI of 100 for the period of July, 2006 to August, 2010. The water quality from Shetshatsheits well field is classified very good to excellent having WQI ranging from 92 to 100 for the period of July, 2006 to August, 2010.

In summary, groundwater quality data are limited for Labrador with sample results from only six communities with public groundwater supplies and two additional communities. In general, the chemical composition of groundwater reflects the geochemistry of the adjacent bedrock or unconsolidated sediments.

Table 14 – Summary of Select Parameters – Groundwater Quality

Region of Labrador	Towns/ Communities	No. of Samples[1]	Mean Concentrations[2]													# Exceedances of GCDWQ out of # samples analyzed
			Hardness (mg/L)	pH	Alk. (mg/L)	TDS (mg/L)	Cond. (µS/cm)	Turb. (NTU)	Na (mg/L)	Ca (mg/L)	Cl (mg/L)	LI	Colour	Fe (mg/L)	Mn (mg/L)	
GCDWQ			-	6.5-8.5	-	500	-	5	200	-	250	-	15	0.3	0.05	
Northern	Natuashish	10/38	179.3	7.6	60.0	367	608	0.3	107	53.9	134	-2.8	-	0.1	0.03	TDS (3 of 10), Chloride (3 of 10), Fluoride (3 of 10), Sodium (2 of 9), Iron (2 of 9).
Central	HVGB Well Field	10/53	68.8	7.3	44.9	215	106	14.3	42	8.0	71	-2.06	50	5.1	0.45	Iron (49 of 52) Manganese (48 of 53) Colour (8 of 9) Copper (1 of 53)
	Spring Gulch	9/9	22.2	6.9	18.3	75	374	2.6	10	4.0	42	-3.22	8.7	2.0	0.16	TDS (1 of 10) Iron (1 of 10) Manganese (1 of 10)
	North West River	11/28	68.5	7.7	51.9	98	156	0.7	2	21.4	2	-0.99	-	0.1	0.02	Iron (1 of 28) Manganese (1 of 28)
	Sheshatsheits	11/26	88.5	7.9	116.7	346	580	0.4	83	19.6	88	-0.67	8	0.2	0.06	Iron (4 of 26) Manganese (8 of 26)
South Eastern	Charlottetown, Hopedale	8/8	129.2	8.0	109.7	-	414	3.0	97	-	4	-0.47	36	0.5	0.20	Iron (4 of 9), Manganese (5 of 8), Colour (6 of 8)
Southern	Forteau, L'Anse au Loup	2/2	77.8	7.4	95.4	142	181	-	3	22.3	5	-	5	0.0	0.03	-
	West St. Modeste	11/21	46.3	7.4	75.8	128	201	1.2	24	11.6	13	-1.6	57.5	1.8	0.66	Iron (21 of 21), Manganese (21 of 21), Colour (11 of 11)

Notes: 1. Number of samples includes (number of physical parameter and major ion samples / number of nutrient and metals samples).

2. Alk. = alkalinity, TDS = total dissolved solids; Cond. = conductivity, Turb. = turibidity, Na = sodium, Ca = calicium; LI = Langelier Index; Fe = Iron, Mn = manganese

8.3 Potential and Existing Groundwater Quality Concerns

In addition to naturally-occurring impacts to water quality, water pollutants associated with anthropogenic sources may affect groundwater quality in Labrador. Potential causes of groundwater quality degradation include: poorly constructed dug or drilled wells that permit contamination by coliform bacteria, poorly managed sewage effluent, seawater intrusion, accidental releases of petroleum products or industrial chemicals, contamination associated with historical site activities and historical waste disposal practices, the use of road salt, and potential groundwater quality concerns associated with mining operations.

In general, dug wells or screened wells completed in shallow sandy till overburden are more susceptible to seasonal water level declines, and are more at risk to surface sources of pollution than deeper drilled bedrock wells.

8.3.1 Sewage Effluent

Groundwater quality can be adversely affected if sewage effluent is released into the groundwater aquifer from near-by septic systems or sewage disposal areas. Poorly constructed drilled wells or shallow screened wells are more susceptible to such impacts than deep bedrock wells or properly constructed wells with grouted steel casings and set into competent bedrock.

Bacteria from human waste in septic systems and outhouses, as well as animal waste, can be introduced into shallow wells either through surface runoff or direct infiltration through the screened interval. Infiltration is most commonly encountered where a shallow well is located in close proximity to a contaminant source (Golder Associates, 1985). In addition, poorly constructed drilled wells with short casings (i.e., less than 6.1 m in length) that are not adequately set a minimum of three meters into competent bedrock are common in rural Labrador (Hanchar, D. pers comm. 2010). The casing provides initial protection from contaminated surface water or shallow groundwater in direct communication with contaminated surface water.

Establishing the casing seal and maintaining its integrity is critical to ensuring long-term water quality. Grouting involves the placement of a water-tight seal between the outer well casing and the borehole wall to prevent vertical movement of groundwater along a well casing. Injection of bentonite grout between the annulus of the exterior well casing and borehole wall is not typically practiced when constructing bedrock domestic wells in Labrador but is common when installing commercial and industrial wells (D. Hanchar, pers comm.2010).

In accordance with information presented in Section 9 of the Government of Newfoundland and Labrador Regulation 63/04, *Well Drilling Regulations* (2003) under the *Water Resources Act*, a well driller is not permitted to install a well within the distances specified in Table 13 below from the sources of pollution named below.

Table 15 – Sources of Pollution and Well Separation Distance Requirements

Source of Pollution	Distance (m)
Cesspool (receiving raw sewage)	30 m
Seepage (leaching) pit, filter bed, soil absorption field, earth pit privy, or similar disposal unit. Septic tank, concrete vault privy, sewer of tightly jointed tile or equivalent material, or sewer connected foundation drain	16 m
Sewer of cast iron with leaded or approved mechanical joints, independent clean water drain, or cistern	3 m
Pumphouse floor drain, cast iron with leaded joints, draining to ground surface	1 m

8.3.2 Seawater Intrusion

Seawater intrusion occurs in coastal aquifers due to the natural flow paths that allow seawater to migrate landward or because of pressure gradients induced by extensive freshwater withdrawals that allow seawater to move into void space previously occupied by freshwater (Bear et al., 1999). Seawater can also contaminate coastal aquifers following extreme storm surges.

Seawater has a higher density than freshwater due to its higher concentration of dissolved ions. The density difference means that the pressure under a seawater column is greater than the pressure under a freshwater column of the same height. If the two columns are connected through groundwater flow pathways, then the pressure difference would cause a flow from the seawater column to the freshwater column until the pressure equalizes. Further inland, the freshwater column is higher due to the increasing elevation of the land and so is able to equalize the pressure from the seawater, stopping the seawater intrusion. The higher water inland also causes fresh water to flow seaward. At the sea-land boundary, at the high part of the aquifer, freshwater flows out. In the lower part of the aquifer, seawater flows in, forming a seawater wedge at the bottom of the aquifer. The intrusion of seawater into a freshwater aquifer occurs when the freshwater is pumped out of the aquifer faster than it is replenished, thereby reducing the water pressure, and drawing seawater into new areas (Delleur, 2007). Commonly referred to as 'salt water intrusion' the impact of seawater on the fresh groundwater resources can be a major factor in limiting groundwater use in coastal environments.

In Labrador, recent seawater intrusion studies have been completed for the communities of Mud Lake and HVGB.In the community of Mud Lake, where residents use a shallow aquifer as their water source, the results of the 1980 Environmental Impact Statement for the Lower Churchill Project (LCDC, 1980) identified the Churchill River below Muskrat Falls as potentially susceptible to salt water intrusion from Goose Bay during the temporary reduction in river flows that would occur during the process of reservoir impoundment. Hatch (2008) completed a three-dimensional numerical model of the Churchill River and Goose Bay estuary in 2008 to estimate the amount of salt water intrusion that could occur. The results of later modelling by AMEC (2008) indicated a potential for temporary salt water intrusion up the Churchill River, to a maximum point approximately 2 km upriver of the confluence of the Channel from Mud Lake during impoundment of the Gull Island Reservoir. A potential implication of this temporary salt water intrusion was identified to be water quality degradation of the shallow aquifer used for potable water by residents of Mud Lake. In a subsequent study by AMEC (2010) who undertook a water well inventory, groundwater sampling and analysis, and water level monitoring, it was concluded that "during reservoir impoundment, any potential intrusion of a salt water lens in the Channel under storm conditions is not expected to significantly alter the groundwater regime from current conditions."

A study conducted by FracFlow (2003) involved a Phase I water quality assessment of the HVGB wellfield to investigate the occurrence of elevated sodium and chloride concentrations in HVGB's groundwater supply. The scope of work consisted of an information review, groundwater sampling and analysis and well inspections with the objective of identifying the source of salt in the HVGB wellfield. Ultimately, the objective of the work was to recommend mitigation measures to manage the problem and allow continual operation of the well field, and to outline action steps for the Town of HVGB to resolve the problem of elevated sodium chloride. FracFlow (2003) tentatively concluded the source of brackish water was natural groundwater existing below the depth of the wells. This brackish groundwater was derived from atmospheric water that evolved in the groundwater flow system by rock-water interactions (FracFlow, 2003). Recommendations included shutting down Production Well 2 and reducing the discharge from the remaining four wells to 75% of their normal capacity. Future work programs were recommended by FracFlow (2003) consisting of Phases 2 and 3, however it is not known whether this additional work has been completed at the HVGB wellfield.

Municipal groundwater supply wells in coastal areas of Labrador could be at potential risk to seawater intrusion due to inferred higher withdrawal volumes. The communities of North West River, Sheshatsheits and West St. Modeste use groundwater supplies as their potable municipal supply. Groundwater quality information reviewed for these communities in the section 8.2 suggest that groundwater from North West River and West St. Modeste are generally indicative of fresh (as opposed to saline) conditions, however, relatively higher specific conductance and TDS in the Sheshatsheits supply may be indicative of slightly saline conditions. There are no known additional studies relating to seawater intrusion in these communities for inclusion into this report.

Presumably domestic well users along coastal Labrador are also susceptible to seawater intrusion; however there is no data available on the water quality conditions from coastal domestic wells.

Factors affecting seawater intrusion in groundwater supply wells include the proximity to the sea, well depth, dip of the water bearing geological formation, the depth and orientation of water-bearing fractures intercepted by the well, aquifer characteristics such as void type and connectivity, and the number and pumping rates of the wells.

Chemical indicators for that can be used to evaluate seawater intrusion include elevated concentrations sodium, chloride, hardness, total dissolved solids, conductivity and associated elevated of metals. Magnesium is proportionally higher in seawater than calcium (Hem, 1992) and can be used to distinguish elevated sodium and chloride concentrations caused by seawater intrusion from increases associated with the use of road salt or natural groundwater from salt-bearing geological formations (i.e., formation brines). Barium and strontium are also proportionally high in seawater (Hem, 1992) and are often useful indicators of seawater intrusion.

In areas prone to seawater intrusion, aquifer managers typically limit the overall pumping stresses of an aquifer to mitigate the potential for seawater intrusion. Future groundwater supply in such areas should be evaluated on a site-specific basis. A program of hydrogeological investigation, including drilling and testing, would be required to assess future water supplies in these areas. Shallow well field development options that could be considered, in consultation with a professional Hydrogeologist; multiple shallow wells spaced throughout a protected area and pumped at relatively low rates will intercept the shallow aquifer flow regime and may prevent or limit seawater intrustion.

8.3.3 Petroleum Products

Petroleum products have long been a concern to residential and municipal well owners, due to their widespread use in modern society, relative mobility and persistence in groundwater systems, the carcinogenic properties of most petroleum products, and the fact that these products can typically be detected by smell or taste at extremely low concentrations.

Spills and leaks associated with both aboveground and underground petroleum product reservoirs are a major source of groundwater contamination in both urban and rural settings. While most residential tanks are typically installed aboveground where they are more easily monitored for accidental events, both active and abandoned underground reservoirs and piping associated with service stations, schools, hospitals, government buildings and industrial installations remain significant potential sources of groundwater contamination.

In Newfoundland and Labrador, petroleum storage tanks for both residential and industrial must be built according to specifications defined by the Underwriters Laboratories of Canada (ULC), installed by licensed practitioners and, depending on their use and volume, must be registered with the province. Abandoned reservoirs must be removed and contaminated soil or groundwater associated with these reservoirs, or resulting from an accidental spill, must be remediated according to provincial guidelines. Despite these measures, petroleum contaminated soil and groundwater continue to pose a challenge to water well users.

8.3.3.1 Canadian Forces Base 5 Wing Goose Bay

Past fuel storage and handling operations and historical waste disposal activities conducted at the Canadian Forces Base (CFB) 5 Wing have negatively affected soil and local groundwater quality and should be considered if groundwater resources will be developed in this area in the future. While 5 Wing Goose Bay is not considered to be the only petroleum impacted site in Labrador, due to the magnitude of the impacts and its proximal location to municipal groundwater supplies it is considered to be significant and a notable impacted site in Labrador.

CFB 5 Wing Goose Bay is located in central Labrador at the southwestern limit of Hamilton Inlet, approximately 200 kilometres inland from the Labrador coast. CFB 5 Wing is situated on a flat-lying terrace plateau at an average elevation of 40 metres above sea level (masl). The Goose River is situated approximately 10 km northwest of the site, while the Churchill River is located approximately 5 km to the south. Terrington Basin (an extension of Hamilton Inlet) borders a portion of the Base to the north-northeast.

The following summary of the contaminants of concern, impacts to soil and groundwater and the status of remedial efforts is based on the Project Description in the Canadian Environmental Assessment Registry (DND 2007).

Most of the waste materials generated at the remote site were disposed of on the property until the 1990's. These waste disposal activities, combined with releases of a variety of contaminants (but mainly from spills and leaks of petroleum products) over the last 60+ years, have resulted in environmental contamination that is currently the subject of long-term cleanup effort. These issues are currently being addressed by the Department of National Defence (DND) through investigation, mitigation and risk management activities within the Goose Bay Remediation Project (GBRP).

Contamination is present in soil, sediment, surface water, groundwater, and local biota. Effects have been documented both on the plateau where the main base was located, as well as in the surrounding environment, at the toe of the escarpment and at remote locations removed from the base. The majority of contamination at the CFB 5 Wing can be attributed to several sources. Major subsurface hydrocarbon plumes are attributed to leaking underground and aboveground tanks, leaking or ruptured pipelines, and inadequate management and containment practices. Heavy metals and other chemical contaminants (e.g. polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs)) are due to historical waste disposal practices and originate from numerous dumpsites. While contamination at several of the sites is well documented (i.e., type, location and volume of impacted media), the scope of the environmental problems at most of the sites remain unknown, as evidenced by the preliminary nature of the investigations at these sites

The remediation of contaminated soils, sediments, groundwater and surface water will occur on federally owned land at CFB 5 Wing Goose Bay. In some instances, contamination has crossed the DND boundary onto provincial and private lands, and it is possible that more off-site contamination will be identified as the GBRP proceeds. Remediation criteria will be set in accordance with federal and provincial regulatory authorities. It is anticipated that remediation will be completed 2019.

8.3.4 Solid Waste Disposal Leachate

There are four waste management regions in Labrador that are managed in accordance with the Newfoundland and Labrador Waste Management Strategy (NLDEC, 2002). The waste management regions and existing waste disposal sites for all areas of Labrador are shown in Figure 11. Groundwater use is expected in these areas for domestic, industrial or municipal purposes. Due to provincial design and environmental monitoring requirements for landfill construction and operation, groundwater quality in these regions is not considered to be a major issue for nearby well users.

Landfill operators are required to conduct environmental compliance monitoring of groundwater, surface water and leachate quality in accordance with the Guidance Document on the Environmental Standards for Municipal Solid Waste Landfill Sites (NLDEC, 2010).

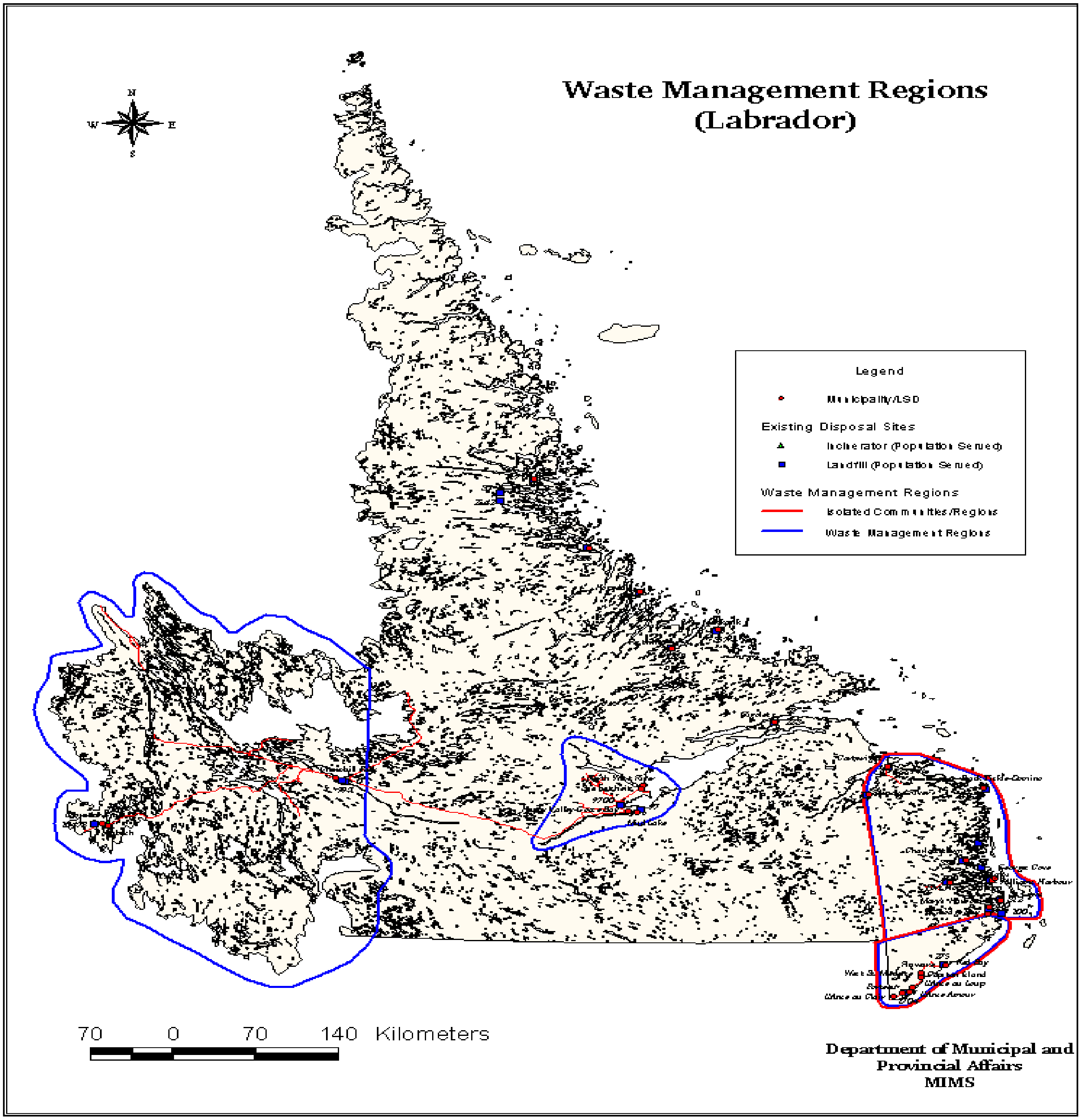


Figure 11 – Waste Management Regions of Labrador

8.3.5 Road Salt

Road de-icing typically requires the application of large quantities of road salt to roads. According to Seawell and Agbenowosi (1996) salt from the highway is introduced into the groundwater through 1) overland flow of highway runoff to ditches which allow water infiltration into the soil and eventually into groundwater; and, 2) infiltration of water from the melting salt-rich snow cleared from paved surfaces.

Groundwater users located hydraulically downgradient of highways where salt is used for road de-icing are at risk from groundwater quality impacts due to increases in sodium and/or chloride concentrations. Factors affecting the potential water quality effects include amount and duration of road salt applications, relative location of the groundwater supply well in relation to the road-way, permeability of the overburden soils (i.e. permeable sand and gravel deposits versus low-permeability clay till overburden soils) and well construction characteristics.

According to the Road Maintenance Supervisor for Labrador for Newfoundland and Labrador Transportation and Works, sand is usually applied. Where required, less than 5% by volume of road salt is used in the sand mixture that is applied to roads in Labrador. Road salt is typically added to prevent the road sand from freezing. Considering this and the limited road network within Labrador, the potential risk for road salt effects to Labrador well users is low.

8.3.6 Mining

Labrador is home to several producing mines, while other projects, particularly in the iron-rich Labrador Trough, will begin shipping ore to market over the next two to three years. Iron is Labrador's most active mining sector with operating mines in Labrador City (Iron Ore Company of Canada who also mines dolomite in the area) and Wabush (Wabush Mines), and near-production projects in the Howells River Valley (New Millennium Capital Corp. and Labrador Iron Mines).

Each of these projects uses open pit mining methods to extract the ore. Open pit mining typically employs groundwater pumping to depress the water table elevation to accomplish pit dewatering. Since the deposits in Labrador consist of oxidized forms of iron (sulphide minerals are uncommon), acid rock drainage and heavy metal enriched tailings are largely non-existent. Water quality impacts to surface water are associated with total suspended solids and iron while water quality impacts to groundwater are minimal.

Labrador also hosts the Voisey's Bay deposit, a large nickel, copper and cobalt open pit mine and processing facility operated by Vale Newfoundland and Labrador near the town of Nain. In contrast to iron mines, these metal suphide minerals have more potential to affect groundwater quality through tailings pond seepage of metal contaminated effluent and acid rock drainage. The Voisey's Bay deposit is remote from most settlement in Labrador and effects to groundwater water will be isolated from aquifers used for potable water.

Finally, the building stone anorthosite is quarried by the Torngait Ujaganniavingit Corporation at a site near Nain. No regional effects to groundwater quality or quantity are expected from this modest size geochemically inert mining operation.

All operating mines within the province are required to participate and fund a Real Time Water Monitoring Program (RTWMP) to help assess the effects of their operations, if any, on local surface and groundwater resources. The RTWMP is a data gathering exercise shared between the mine proponent, the Newfoundland Department of Environment and Conservation Water Management Branch and Environment Canada. The objective is to obtain near real time water quality and quantity data that can be used to establish trends, assess ecosystem health, and detect point sources of pollutants. In addition, each mine may be subject to quarterly water quality monitoring requirements listed in their operating permits, while discharges may necessitate Environmental Effect Monitoring as required by the federal Metal Mining Effluent Regulations.

9. Spring Usage

Springs are locations where the piezometric surface (the water table) intersects the ground level, resulting is discharges of groundwater at the surface. They are equally vulnerable to surface sources of pollution as surface and groundwater resources. There are six types of springs (Fetter, 1994):

- Depression springs, formed when the water table intersects the ground surface at topographic low spots;
- Contact springs, formed at a lithologic contact where permeable rock units overly rocks of much lower permeable units;
- Fault springs, where a faulted rock unit that is impermeable may be placed adjacent to an aquifer;
- Sinkhole springs, formed under artesian pressures; and,
- Joint or fracture springs, formed from existence of jointed or permeable fault zones in lower permeability rock.

As previously noted, the Spring Gulch source in HVGB is a groundwater-fed surface water source. According to NLDEC, it has historically been referenced as a groundwater source, however, its status as a groundwater vs surface water source has recently been a discussion point between the Surface Water Section and the Groundwater Section with respect to which should monitor its quality.

In an interview with the NLDEV WRMD personnel responsible for sampling source water supplies in Labrador, NLDEV indicated that information on spring usage in Labrador is largely held within the communities themselves (Gillis, G. pers. comm.). Representatives of several communities have indicated to NLDEV that members of their community obtain potable water from road-side springs and do not use the municipal supply source for consumption. The number of people using springs, or the number of springs used for potable water in Labrador cannot be estimated based on this information.

No other information was available regarding spring usage in Labrador.

10. Conclusions

The groundwater potential of **surficial deposits** in Labrador is highly variable, with reported well yields ranging from 0 to 2,250 Lpm and aquifer depths ranging from less than five meters to greater than 65 meters below ground surface. As with aquifers elsewhere, the variation in physical characteristics of geologic materials making up the aquifer (particle size, rounding, sorting, etc.) may account for the variability in groundwater potential observed in surficial aquifers in Labrador, but relative lack of data available for most aquifers (only 47 surface aquifer wells are recorded over a surface area of 294,000 km^2), combined with the absence of lithologic detail contained in the available well records, makes it difficult to form specific conclusions regarding individual aquifers.

Five surficial hydrostratigraphic units were established for Labrador. Unit E, consisting glaciofluvial deposits composed of coarse gravel and sand, has the greatest groundwater storage and yield potential while Unit A, consisting of exposed bedrock and drift-poor areas has the lower groundwater development potential. The two most promising units (Unit D and Unit E), together cover an area of nearly 24,000 km^2, or approximately 8% of Labrador's surface area.

Groundwater resources in the five Precambrian provinces of Labrador are similarly variable with **bedrock aquifer** yields ranging from 0.5 to 600 Lpm. Data limitations again prevent definitive conclusions: only 251 of 308 bedrock wells contain information on lithology, and these wells tend to be concentrated near population centres where the stratigraphy is relatively well known.

Four bedrock hydrostratigraphic units were developed for the province. Unit 4, the sedimentary and volcanic rocks of the Labrador Trough and their metamorphic extensions in western Labrador, has the greatest potential for useable water resources, due to an apparent combination of both primary and secondary porosity. In contrast, the mafic intrusive rocks plus all extrusive volcanics of Unit 1 hold the lowest potential for new supplies, likely because of their limited geographical extent and relative lack of void space in the form of fractures. Unit 3, consisting of sedimentary of low-grade metamorphic rock has a moderate yield, and together with Unit 4, underlie a surface area of less than 5% of Labrador.

Surface water chemistry was assessed from 175 samples from 16 public water supplies and tends to reflect the composition of soils and bedrock. Higher pH, hardness, alkalinity and major ion concentrations were observed in surface waters in areas where underlying geology is composed of carbonate-rich sedimentary bedrock, such as the Strait of Belle Isle area, while surface water quality in areas underlain by gneiss and granite such as southeastern Labrador tends to be slightly acidic, coloured, highly corrosive and of low mineral content.

Groundwater quality data are also limited: only 63 sample results from a total six communities with public groundwater supplies and two additional communities were assessed, and again the results are generally reflective the geochemistry of the host bedrock. Water quality prior to treatment in these communities is generally good although coliform has recently been detected in treated water in West St. Modeste. More generally, there are inadequate data available to characterise the groundwater water quality in either bedrock or surficial aquifers of Labrador.

Four zones of **permafrost** exist within Labrador. The occurrence of groundwater in permafrost areas differs from its occurrence in warmer climates and should be considered for developing groundwater resources in northern Labrador with the zone of continuous permafrost. Groundwater movement is mildly to strongly affected by permafrost in both the discontinuous and continuous permafrost zones.

A **water budget** exercise provided estimated annual water surplus, groundwater recharge and surface water runoff rates were calculated for Labrador. The mean normal surplus is 522 mm while the total estimated potential annual recharge and runoff for Labrador is 27.66 x 10^9 m^3 and 13.65 x 10^{10} m^3, respectively. On average, groundwater recharge accounts for approximately 17% of the total water balance for Labrador, with surface runoff accounting for the remaining 83%. Areas where bedrock is exposed at surface or covered by thin drift have the lowest potential groundwater recharge rates at less than 10 mm/year, whereas the glacialfluvial and glaciomarine deposits have the highest potential for groundwater recharge, with recharge estimates ranging 150 mm/year to greater than 225 mm/year.

Visual estimation of **baseflow** for several unregulated rivers in Labrador ranged from approximately 12% to 30% of total stream discharge. Evaluation of the regulated hydrograph of the Churchill River shows that the river has a very high baseflow contribution with significant moderation of peak flows in spring summer. The artificial baseflow is maintained by slowing releasing stored surface water over time.

Seawater intrusion and aquifer contamination by industrial use, military occupation and mineral exploitation appear to have resulted in localized instances of **groundwater contamination**, but these sites appear to be spatially limited and do not represent a significant threat to groundwater quality in Labrador. Very little data on contaminated sites was collected during this study so few general conclusion can be drawn. Area prone to seawater intrusion and historically contaminated sites must be assessed on a case-by-case basis so that site-specific mitigative or restorative actions can be taken.

11. References

11.1 Literature Cited

AMEC. 2010. Report on the Lower Churchill Project Baseline Water Quality and Salt Water Intrusion Study, Mud Lake, Newfoundland and Labrador. Prepared for Nalcor Energy. Dated March, 2010.

Bear, J., Cheng, A.H.-D., Sorek, S., Ouazar, D., and Herrera, I. (Eds). Theory and Applications of Transport in Porous Media. Seawater intrusion in coastal aquifers: concepts, methods, and practices. Accessed from: http://books.google.ca/

Bell,T., Barrand,N, Leblanc, P., and Sharp, M. (2008). *Glacier observations in the Torngat Mountains, Northern Labrador*. International Arctic Change 2008 Conference. December 9-12, 2008. Quebec City, Quebec.

Bradbury, K.R. and Muldoon, M.A.. 1990. "Hydraulic Conductivity Determinations in Unlithified Glacial and Fluvial Materials", *Ground Water and Vadose Zone Monitoring ASTM STP 1053,* D.M. Nielsen and A.I. Johnson, Eds. American Society of Testing and Materials, 1990, pp.138-151.

Christopherson, R.W. (2000), Geo-systems. Prentice-Hall, Inc, USA. Fig. 9-8

Delleur, J.W., 2007. *The Handbook of Groundwater Engineering - 2nd Edition*. Florida: CRC Press.

Department of National Defence (DND).2007. Project Description for 5 Wing Goose Bay Remediation Project (CEAR 07-01-26393). Accessed from: http://www.ceaa.gc.ca/052/details-eng.cfm?pid=26393#desc

Driscoll F.G. (1986). Groundwater and Wells. Third Edition, published byU.S Filter/Johnson Screens, St Paul, Minnesota, USA.

Ecological Stratification Working Group (ESWG) 1996. Ecoregions of Labrador. Accessed from : http://www.heritage.nf.ca/environment/ecoregions_lab.html#maplab

Ecological Framework of Canada, 2011. Taiga Shield Ecozones. Accessed from: http://ecozones.ca/english/.

Environment Canada Atmospheric Environment Service (Environment Canada) 2010. Canadian Climate Normals 1971-2000. Atlantic Provinces. http://climate.weatheroffice.gc.ca/climate_normals/index_e.html

Fassnacht, S.R. (2004). Estimating Alter-shielded gauge snowfall undercatch, snowpack sublimation, and blowing snow transport at six sites in the conterminous USA. Hydrol. Process, **18**: 3481-3492.

Fetter, C.W. 1994. Applied Hydrogeology. Third Edition. Prentice-Hall, Inc. New Jersey.

Fracflow Consultants Inc. 2004. Well Field Remediation and Wellhead Protection Project Interim Report. Prepared for the Town of Happy Valley – Goose Bay. March 15, 2004.

Fracflow Consultants Inc. and Hydrologic Consultants Inc. (Fracflow/ HCL). 1996. Happy Valley – Goose Bay Well Field Completion Report. Prepared for the Town of Happy Valley – Goose Bay. February 20, 1996.

Freeze, R.A. and Cherry, J.A. 1970. Groundwater. Prentice-Hall Inc.: Englewood Cliffs, NJ.

Golder Associates. 1985. Hydrogeology of the St. George's Bay Area. Government of Newfoundland and Labrador, Department of Environment, Water Resources Division,Groundwater Branch, Report 2-8.

Government of Newfoundland and Labrador. 1997. Report on the Hydrology of Labrador.

Greene, B.A. (1974). An Outline of the Geology of Labrador. Mineral Development Division, Newfoundland Department of Mines and Energy. Geoscience Canada, Volume 1, Number 3, pg. 36-40.

Happy Valley-Goose Bay, Town of. 2008. Town of Happy Valley- Goose Bay Municipal Plan 2008 – 2018. Accessed from www.happyvalley-goosebay.com/home/files/.../municipal_plan.doc

Hem, J.D. (1992). Study and Interpretation of the Chemical Characteristics of Natural Water. USGS Water Supply Paper 2254. 3rd Edition.

Herr, R.L., Ward, G. and L.Hope. 1978. Plate 31 Bedrock Hydrogeology of Canada.Inland Waters Directorate, Department of Fisheries and the Environment in cooperation with provincial groundwater agencies. Scale 1:10,000,000.

Hood, E., M. Williams, and D. Cline 1999. Sublimation from a seasonal snowpack at a continental, mid-latitude alpine site. Hydrol. Process, **13**: 1781-1797.

Jacques Whitford Limited. 2008. Hydrogeology of Agricultural Development Areas Newfoundland and Labrador. Chapter 18 – Goose Bay ADA. June, 2008.

James, D.T. 1994. Geology of the Woods Lake area (NTS area 231), western Labrador. Geological Survey Branch, Department of Mines and Energy, open File Map 94-239, scale 1:200,000.

Klassen, R.A., S. Paradis, A.M. Bolduc and R.D. Thomas. 1992. Glacial Landforms and Deposits, Labrador, Newfoundland and Quebec. Geological Survey of Canada, Map 1814A, Scale 1:1,000,000.

Liverman, D.G.E. 1997. Quaternary Geology of the Goose Bay Area. In: Current Research. Newfoundland and Labrador Department of Mines and Energy, Geological Survey, Report 97-1, pages 173 – 182.

Ministry of Environment and Energy (MOEE), 1995. Hydrogeological Technical Information Requirements for Land Development Applications. April, 1995.

Natural Resources Canada. 1993. Canada-Permafrost [map]. Fifth Edition, National Atlas of Canada. http://gsc.nrcan.gc.ca/permafrost/wheredoes_e.php

Newfoundland and Labrador Department of Environment and Conservation (NLDEC) 2009. Water Resources Management Division Drilled Water Well Database for wells drilled between 1950 and 2009.

Newfoundland and Labrador Department of Environment (NLDOE) 1997. The Hydrology of Labrador. Hydrologic Modelling Section.

Newfoundland and Labrador Department of Environment (NLDOE). 2002. Waste Management Strategy

Newfoundland and Labrador Heritage . 1997. Newfoundland and Labrador Biosphere. Newfoundland and Labrador Heritage Web Site Project. Accessed from http://www.heritage.nf.ca/environment/biosphere.html

Newfoundland and Labrador Department of Natural Resources (NLDNR). 1990. Map of the Forest Resource of Labrador. Accessed from: http://www.nr.gov.nl.ca/nr/forestry/maps/res_lab.html

Newfoundland and Labrador Tourism . 2011. Labrador Coastal Drive. Newfoundland and Labrador Tourism. Accessed from: http://www.explorenewfoundlandandlabrador.com/scenic-routes-labrador-region/labrador-coastal-drive.htm

Nicholson, F.H., 1971: Evolution of the Landscape of the Schefferville area. *In* The Physical Environment of the Schefferville Area, McGill Sub-Arctic Research Laboratory, McGill University, 2 pp.

Quinton, W.L., T. Shirazi, S.K. Carey, and J.W. Pomeroy (2005). Soil Water Storage and Active-layer Development in a sub-alpine Tundra Hillslope, Southern Yukon Territory, Canada. Permafrost and Periglac. Process. **16**: 369-382.

Our Labrador, 2011. Online Reference http://www.ourlabrador.ca/member.php?id=14

Parks Canada, 2010. Torngat Mountains National Park. Accessed from: http://www.pc.gc.ca

Peakbagger Online Reference. 2010. Mealy Mountains. Accessed from: http://www.peakbagger.com/range.aspx?rid=15055

Sandford, B.V., Grant, G.M. 1976. Physiography, Eastern Canada and Adjacent Areas, Geological Survey, Map 1399A. Geological Survey of Canada. Scale: 1:2,000,000

Seaber, P.R. 1988. Hydrostratigraphic Units in Back, W., Rosenshein, J.S., and Seaber, P.R., eds., Hydrogeology : Boulder, Colorado, Geological Society of America, The Geology of North America, v. O-2.

Seawell, C and Agbenowosi, N. (1998)."Effects of Road Deicing Salts on Groundwater Systems." Virginia Polytechnic Institute, Department of Civil Engineering. Accessed from :http://www.cee.vt.edu/ewr/environmental/teach/gwprimer/roadsalt/roadsalt.html

Singer, S.N. and Cheng, C.K. 2002. An Assessment of the Groundwater Resources of Northern Ontario. Ministry of the Environment, Environmental Monitoring and Reporting Branch. Hydrogeology of Ontario Series (Report 2). Toronto, Ontario.

SGE Group Inc. 1998. Well Testing Report Sheshatsheits New Production Well (1998). Prepared for Groundwater Division, Department of Environment and Labour. 1998.

Smith and Burgess (2002).A digital database of permafrost thickness in Canada;. Geological Survey of Canada, Open File 4173, 2002; 38 pages. 2002

Smith, J.S., Bell, T. and Rankin, L., 2003: Quaternary geology and landscape change, Porcupine Strand, Labrador. Current Research (2003), Newfoundland Department of Mines and Energy Geological Survey, Report 03-1, pp. 293-305

Stockwell, C.H. 1961. Structural provinces, orogenies, and time classification of rocks of the Canadian Precambrian Shield. Geological Survey of Canada, Paper 61-17, p. 108-127.

Stockwell, C.H. 1961. Fourth report on structural provinces, orogenies, and time classification of rocks of the Canadian Precambrian Shield. Geological Survey of Canada, Paper 64-17, Part II, p. 1-21.

Statistics Canada. 2007. Population and dwelling counts, for Canada, provinces and territories, and census subdivisions (municipalities), 2006 and 2001 censuses - 100% data (table). Population and Dwelling Count

Highlight Tables. 2006 Census. Statistics Canada Catalogue no. 97-550-XWE2006002. Ottawa. Released March 13, 2007.

Stephenson, D.A., Fleming, A.H., and Mickelson, D.M., 1988. Glacial deposits. In: Black, W., Rosenhein, J.S., and Seaber, P.R. (Eds.), Hydrogeology: Boulder, Colorado, Geological Society of America, The Geology of North America, v. O-2, p. 301-314.

Taylor, F.C. (1971). A revision of Precambrian structural provinces in northeastern Quebec and northern Labrador. Canadian Journal of Earth Sciences, vol. 8, p. 579-584.

Terpstra Engineering Limited (Terpstra). 2004. Wellhead Protected Water Supply Area WS-G-0513. Town of North West River Labrador Region. Prepared for Department of Environment, Water Resources Management Division. February 16, 2004.

Thornthwaite, C.W. and J.R. Mather. 1957. Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance. Publ. in Climatology, vol.10, no.3, C,W. Thornthwaite & Associates, Centerton, New Jersey.

Trans Labrador Highway, 2011. Online Reference http://www.tlhwy.com/south/index.html

Williams and Waller, 1963. Permafrost International Conference, Layfeyette, Indiana. Groundwater Occurence in Permafrost Regions of Alaska. National Academy of Sciences – National Research Council, Washington, D.C. Publication No. 1287

11.2 Personal Communications

Gillis, G. 2011. Personal Contact. Environmental Scientist. Newfoundland and Labrador Department of Environment and Conservation, Water Resources Management Division, Labrador Region.

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