HYDROGEOLOGY OF EASTERN NEWFOUNDLAND

Submitted to:

Water Resources Management Division

Department of Environment and Conservation

Government of Newfoundland & Labrador

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ABSTRACT

AMEC Environment & Infrastructure (formerly AMEC Earth and Environmental), a Division of AMEC Americas Limited (AMEC), was retained by the Government of Newfoundland and Labrador, and the Department of Environment and Conservation, Water Resources Management Division (the Department) to conduct and report on a desktop study relating to key aspects of groundwater resources for the eastern zone of Newfoundland. The main objective of this study is to determine the physical characteristics of the major geological units in relation to the occurrence, availability, and quality of the constituent groundwater and to define in latter terms the aquifer potential. This study is based entirely on available data sources for the groundwater resources of the eastern Newfoundland region. Three accompanying maps outline the hydrogeological resources.

A total of 11,966 individual provincial water well records of drilled wells were obtained for the study area. Water well records were used to subdivide the overburden deposits into two overburden hydrostratigraphic units and to identify six bedrock hydrostratigraphic units. Groundwater yields vary from low (<1 L/min) to high (>550 L/min). The variance in yields shows correlation with the various overburden deposits and bedrock types encountered.

The majority of the wells within the study area are drilled into bedrock at an average depth of approximately 65 meters. The Late Neoproterozoic siltstone and shale rock units are the most widely used aquifer units and offer potential to meet any domestic groundwater needs. The highest well yields within the study area are associated with overburden deposits of outwash sands and gravels and offers potential to meet any domestic or commercial groundwater needs. However, sand and gravel deposits are also most susceptible to contaminants originating from surface water conditions due to high permeabilites.

Streamflow data were analyzed to estimate the annual baseflow component of total streamflow for given drainage divisions, which would include groundwater contributions and water released from storage in lakes, ponds and bogs. Considering the drainage divisions developed by Environment Canada, the topographic features, and annual precipitation distribution, the study area was divided into three sub-regions for the purposes of this study. The annual runoff depth for the three sub-regions ranges from 1013.4 mm for Sub-region 3 to 1415.1 mm for Sub-region 1. On an annual basis, the baseflow component of runoff is estimated to range from 425.3 mm for Sub-region 3 to 705.7 mm for Sub-region 1, representing 37 to 50 % of flow, which would include water released from storage in lakes, ponds, bogs and groundwater. During the summer, streamflows decrease in response to increased evapotranspiration and a decrease in the amount of water released from bogs. During these periods, groundwater would make up a larger component of streamflow, but would be expected to be significantly less than the annual baseflow.

The chemical quality of the groundwater from wells is generally quite acceptable, and in most cases falls within the criteria established for drinking water purposes. For the most part, the chemical composition of the groundwater reflects the geochemistry of the adjacent bedrock or unconsolidated sediments. Three groundwater quality types were identified from the

groundwater chemistry data. These include calcium bicarbonate, sodium bicarbonate, and sodium chloride types.

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1.0 INTRODUCTION

AMEC Environment & Infrastructure, a Division of AMEC Americas Limited (AMEC), was retained by the Government of Newfoundland and Labrador, through the Department of Environment and Conservation, Water Resources Management Division (the Department) to conduct and report on a desktop study relating to key aspects of groundwater resources for the eastern zone of Newfoundland. This is the third of four hydrogeology reports that will cover all areas of the province. A map showing the study area is presented as Figure 1-1.

The main objective of this study was to determine the physical characteristics of the major geological units in relation to the occurrence, availability, and quality of the constituent groundwater and to define the latter in terms of aquifer potential. Findings of the study will be used as a future reference for consultants, town officials, government, and the general public when making decisions concerning the development and use of groundwater in the region of eastern Newfoundland.

1.1 SCOPE OF STUDY

Based on a review of the Request for Proposal (RFP) and in consultation with the Department of Environment and Conservation (Water Resources Division), and the Department of Natural Resources (Geological Survey), the scope of work developed for the Hydrogeology of Eastern Newfoundland study included the following activities:

- Describe the physiography, the surficial and bedrock geology, and the hydrogeological properties of the overburden deposits and bedrock lithofacies present within the study area.
- Prepare three sets of maps at a scale of 1:250,000. These maps display bedrock geology, surficial geology, and hydrogeology with accompanying notations and unit descriptions.
- Compile existing water well data and include, in so far as possible, depth, production, chemistry, static water level, and available quantitative data based on pumping test, observation well, and field investigations.
- Describe the interrelationships between surface water and groundwater of the region. This includes recharge and discharge characteristics, groundwater contribution to surface runoff, general direction of groundwater movement, seasonal fluctuations of groundwater and hydrologic budget; and,
- Compile and evaluate water quality data and discuss existing and potential pollution problems, salt water intrusion and spring usage.

1.2 STUDY AREA

The location of the study area is shown in Figure 1-1. The eastern boundary extends from Fortune Bay in the south to Bonavista Bay in the north and the entire Avalon Peninsula.

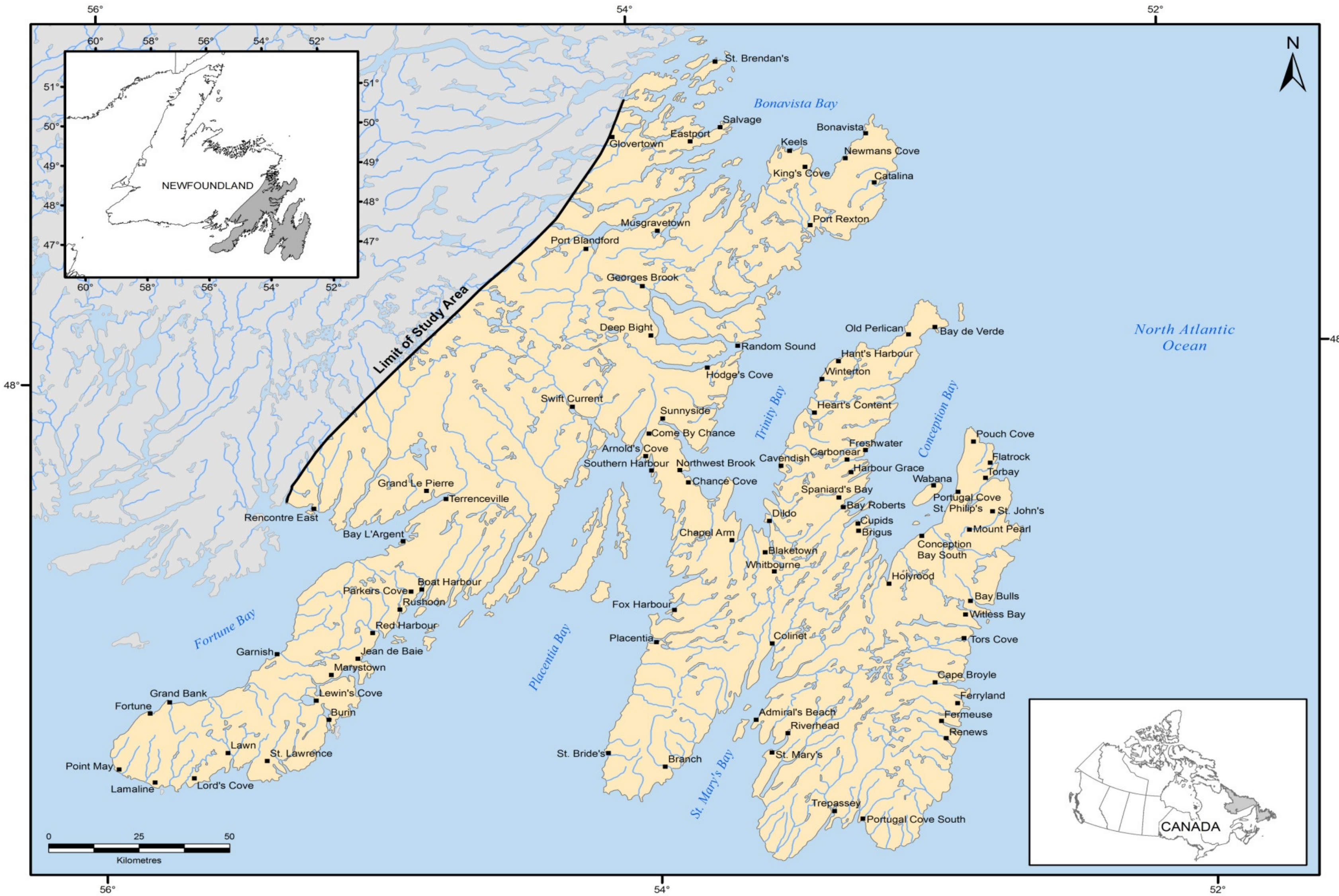

Figure 1-1: Study Area and Places Mentioned in Text

1.3 SOURCES OF DATA

The primary source of hydrogeological data for the study area is contained in "Water Well Data for Newfoundland and Labrador 1950 - 2001". This is an extensive database containing information on 17,000 drilled wells in the province, pump tests, and some material on previous well simulations provided by the Groundwater Section of Water Resources Management Division. However, regulations regarding the submission of detailed data by drilling contractors did not exist until 1983; therefore these data are commonly incomplete. Available data since 2001 were obtained from open file records at the Department of Environment and Conservation.

A number of geological, environmental and geotechnical studies have been conducted by consulting engineers for government and private agencies. These reports provided background information on bedrock geology, surficial geology, hydrogeology, physiography, hydrology, water quality, and spring usage throughout the study area.

Climate normals were used to summarize the average climatic conditions of the study area. They were obtained from the National Climate Data and Information Archive website (http://climate.weatheroffice.ec.gc.ca, accessed 2010) operated and maintained by Environment Canada. At the completion of each decade, Environment Canada updates its climate normals for as many locations and as many climate characteristics as possible. The climate normals used in this study are based on climate stations with at least 15 years of data between 1971 and 2000.

Streamflow records were obtained from the National Water Data Archive provided by Environment Canada, Water Survey Branch. The data from existing gauging stations in the study area were used to assist in interpreting the groundwater contribution to stream flow and the annual rate of groundwater recharge from precipitation.

Existing water quality data used for assessing the chemical character of groundwater resources were extracted from public water supply testing results provided by the Department of Environment and Conservation. These data were also used to help identify areas that are potentially prone to salt water intrusion and other potential pollution problems throughout the study area.

All referenced reports and other sources of data used in this study are documented in the List of References in Section 9.0 of this report.

1.4 CLIMATE

Data on climate normals including temperature and precipitation were obtained from Environment Canada (Environment Canada, 2010). There are 19 climate station locations within the study area which are shown in Figure 1-2.

It is recognized that the availability of data does not permit a thorough evaluation of the climatic conditions throughout the study area. The climate stations are typically located along the coast at low elevations; therefore the values presented in this section are more representative of these areas. It is possible that areas with high topography which are further inland may exhibit somewhat different climatic characteristics from locations along the coast at low elevations.

1.4.1 Temperature

Air temperature varies across the study area and is influenced by latitude, distance from the ocean, prevailing winds, and season. The monthly and annual mean daily temperatures for the 19 climate stations in the study area are provided in Table 1.1.

The climate of Newfoundland is dominated by the ocean and, to a much lesser extent, by the North American continent. The Labrador current, which consists partly of arctic water, encircles the study area with cold water in spring and summer, but with warmer water in winter.

In spring, sea ice along the coast often keeps water temperatures close to freezing. The pack ice is at its peak in March. The warm air masses approaching the island are chilled by the ice. The sea ice begins to break up in April, but disintegrating parts of the pack ice may lie off the northeast coast until June or even July. These ice conditions vary, but mild winters with no sea ice are not uncommon.

The summers are short but pleasant with much cooler temperatures prevailing along the coast than farther inland. The average air temperature in July is 15℃, with an average of slightly above 16℃ in Holyrood, Lethbridge and Terra Nova and 13℃ in St. Lawrence. The winters are mild, and the average monthly temperatures from December to February are between -1.6℃ and -5℃. Extremely cold periods seldom occur and temperatures near -20℃ are an exception.

Winds are predominantly from the west year-round, but variations are common both from location to location and from month to month. Prevailing wind directions are west in winter and west-southwest in summer. Calm or light and variable conditions occur about 2% to 3% of the time along the coast but more than 10% of the time at inland stations.

1.4.2 Precipitation

The monthly mean precipitation normals for the 19 climate stations in the study area are provided in Table 1.2. The area receives an average annual precipitation of 1,376 mm, ranging from approximately 1,072 mm at Bonavista to 1,640 mm at Boat Harbour, Placentia Bay.

The precipitation is fairly evenly distributed throughout the year, but is usually heaviest in winter, with a decline during the late winter and early spring. Summer is the driest period. Summer rains are usually heavier, of shorter duration, and less frequent than during the remainder of the year. The precipitation increases in the fall and in the early winter. Snowfall is heavy in the latter part of December and lasts until early April.

Precipitation is discussed in further detail in Section 6.0.

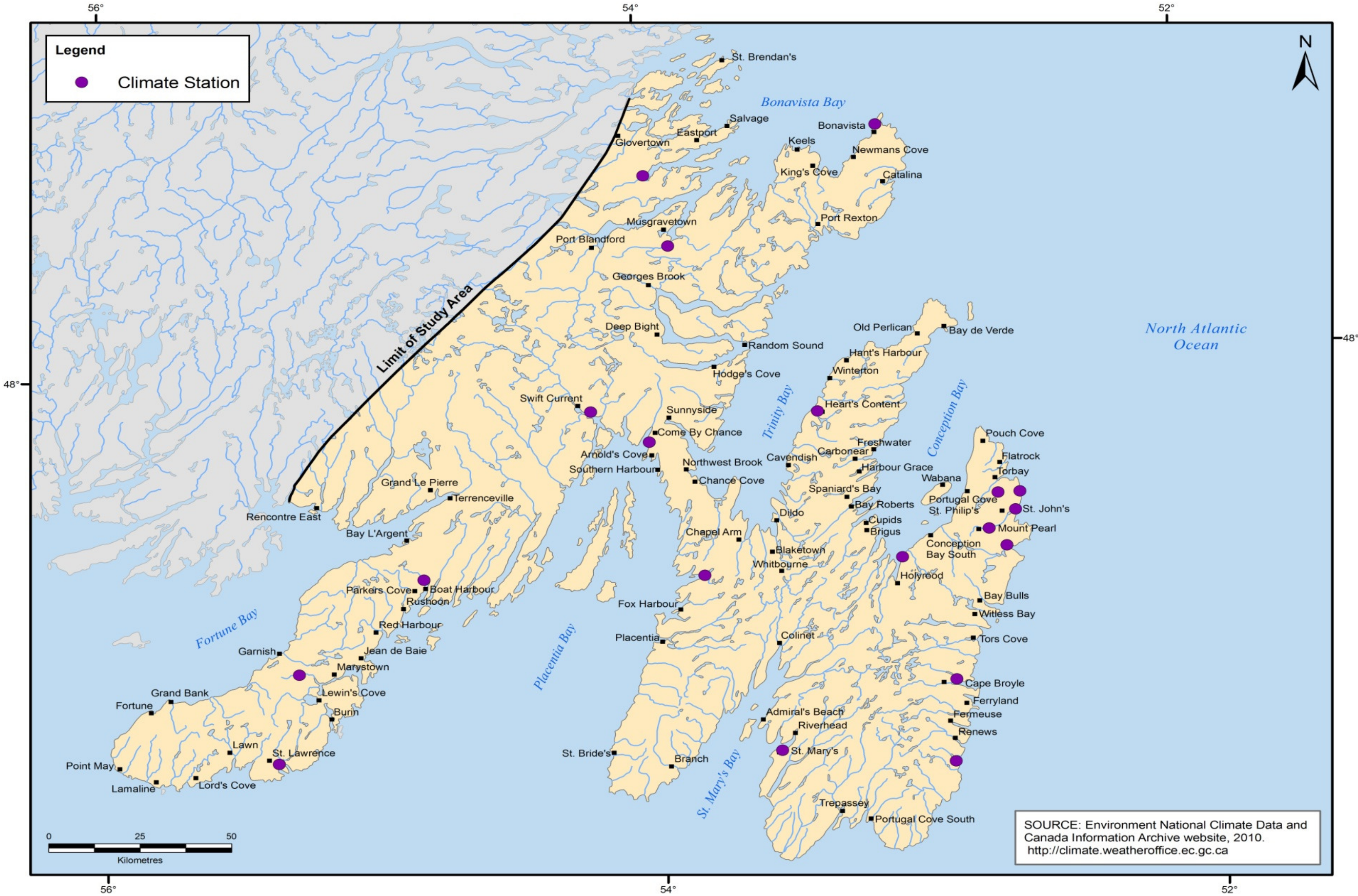

Figure 1-2: Locations of Climate Stations within the Study Area

1.4.3 Evapotranspiration

Evapotranspiration is broadly divided into two main categories: evaporation and transpiration. Evaporation is the water that evaporates due to solar radiation, mild to hot temperatures, and wind. Transpiration is the loss of water from plants through the leaves, stems, flowers or roots. Evapotranspiration is the combination of evaporation and the transpiration. The proportion of precipitation that is available for direct runoff or recharge is dependent on the amount of evapotranspiration.

Calculations have been made by Environment Canada for 9 climate stations throughout the study area to evaluate potential and actual evapotranspiration. Potential evapotranspiration is the amount of water that would evaporate and transpire with optimum water availability, whereas actual evapotranspiration is the amount of water that evaporated and transpired, which is dependent on the seasonal availability of precipitation and soil moisture. Monthly potential and actual evapotranspiration data for the 9 climate stations throughout the study area are shown in Table 1-3. The calculations assume 100 mm of soil moisture, which is defined as the amount of water held in place after excess gravitational water has drained.

These data illustrate the abundant seasonal availability of water, with soil moisture depletion occurring only during the period extending from July to September. In total, potential evapotranspiration ranged from an average of 485 mm per year (Bonavista) to 525 mm per year (St. Mary’s and Winterland) while actual evapotranspiration ranged from an average of 458 mm per year (Bonavista) to 524 mm per year (St. Mary’s).

Table 1-1: Monthly Mean Daily Temperatures (ºC) for Climate Stations within the Study Area

Station	Code[1]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Boat Harbour	D	-4.8	-5.0	-2.2	2.8	7.2	11.3	15.3	15.9	12.2	7/4	2.7	-1.7	5.1
Bonavista	A	-5.0	-6.0	-3.0	1.1	5.2	9.7	14.6	15.3	11.8	7.1	2.7	-2.0	4.3
Cape Broyle	A	-	-	-	-	-	-	-	-	-	-	-	-	-
Cappahayden	D	-4.1	-4.2	-1.8	1.9	6.0	9.8	14.3	15.2	12	7.3	3.1	-1.2	4.9
Come By Chance	C	-4.6	-5.7	-2.3	2.2	6.1	9.9	14.1	15.4	12.3	7.5	2.9	-1.9	4.7
Hearts Content	D	-4.3	-4.8	-1.6	2.4	6.4	11.0	15.5	16.2	12.5	7.5	3.3	-1.5	5.2
Holyrood	C	-3.2	-3.9	-0.9	3.1	7.4	11.9	16.3	16.8	13.1	8.5	4.0	-0.4	6.1
Lethbridge	D	-6.5	-6.4	-2.8	2.5	7.6	11.8	16.1	16.3	11.9	6.7	2.0	-3.1	4.7
Logy Bay	A	-3.7	-4.3	-1.5	2.2	6.4	11.1	15.5	16.1	12.6	7.7	3.5	-1.1	5.4
Long Harbour	C	-3.5	-4.0	-1.1	3.0	6.8	10.8	14.9	15.9	12.9	8.2	4.0	-0.7	5.6
Petty Harbour	A	-	-	-	-	-	-	-	-	-	-	-	-	-
Signal Hill	D	-4.2	-4.7	-2.0	2.0	6.4	10.9	15.3	16.2	12.5	7.5	3.1	-1.5	5.1
St. John's W	C	-4.5	-5.2	-2.1	2.0	6.5	11.4	15.7	15.7	12	7.3	2.9	-2.0	5.0
St. John's Airport	A	-4.8	-5.4	-2.5	1.6	6.2	10.9	15.4	15.5	11.8	6.9	2.6	-2.2	4.7
St. Lawrence	A	-4.3	-5.0	-2.4	1.6	5.5	9.2	13.2	14.7	11.9	7.3	3.1	-1.5	4.4
St. Mary's	D	-2.9	-2.9	-0.6	3.2	6.6	10.5	14.3	15.8	12.9	8.4	4.0	0.0	5.8
Swift Current	D	-5.4	-5.6	-2.4	2.9	7.2	11.2	15.4	16.4	12.4	7.2	2.4	-2.3	5.0
Terra Nova	C	-6.8	-7.2	-3.0	2.0	7.0	11.8	16.1	16.1	12.0	6.5	1.6	-3.7	4.4
Winterland	D	-4.1	-4.4	-1.7	2.7	7.4	11.4	15.8	16.6	13.1	7.9	3.5	-1.1	5.6

Notes:

1. The minimum number of years used to calculate normals are indicated by a "code" defined as:
   - "A": No more than 3 consecutive or 5 total missing years between 1971 to 2000.
   - "B": At least 25 years of record between 1971 and 2000.
   - "C": At least 20 years of record between 1971 and 2000.
   - "D": At least 15 years of record between 1971 and 2000.
2. Data obtained from National Climate Data and Information Archive website operated and maintained by Environment Canada (Environment Canada, 2010).
3. -: No data available

Table 1-2: Monthly Mean Total Precipitation (mm) for Climate Stations within the Study Area

Station	Code[1]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Boat Harbour	D	135	117	121.8	142.9	118.1	130.8	122.1	101.6	161	172.1	171.6	145.3	1639.2
Bonavista	A	93.6	86.2	92.7	76.0	72.5	79.3	74.3	80.2	100.8	113.7	100.3	102.4	1072.0
Cape Broyle	A	159.7	130.7	143.2	131.9	116.4	105.5	99.9	105.4	146.4	158	153.1	158.8	1608.9
Cappahayden	D	152.6	126.6	140.2	124.1	111.1	112.3	115.0	112.7	134.7	144.2	158.5	151.4	1583.2
Come By Chance	C	127.7	102.2	104.6	93.2	88.0	119.7	86.1	88.0	107.9	128.4	108.8	115.0	1269.9
Hearts Content	D	114.7	89.0	99.1	87.8	79.4	75	80.1	100.4	103.8	127.4	108.8	102.3	1167.7
Holyrood	C	111.4	82.0	92.3	87.8	74.1	81.3	80.8	82.3	102.0	117.4	107.8	107.9	1127.2
Lethbridge	D	103.1	97.2	100.8	100.3	87.9	98.7	97.0	85.3	114.8	121.5	98.3	106.9	1211.8
Logy Bay	A	106.1	95.4	97.0	89.4	79.5	90.7	80.9	94.0	99.0	128.7	117.7	118.0	1196.4
Long Harbour	C	130.5	108.1	110.9	102.3	91.5	112.0	93.5	102.4	123.8	105.2	125.2	116.2	1366.3
Petty Harbour	A	128.9	108.8	115.4	116.1	90.6	89.6	79.0	93.7	124.8	145.4	135.6	135.3	1363.0
Signal Hill	D	109.7	106.8	98.0	104.1	88.4	83.3	82.7	84.4	101.4	133.0	126.7	123.2	1241.7
St. John's W	C	107.7	144.6	146.5	117.9	103.9	101.9	84.1	103.7	130.6	157.8	145.5	164.8	1571.9
St. John's Airport	A	150.0	125.2	130.8	121.8	100.9	101.9	89.4	108.1	130.9	161.9	144.0	148.8	1513.7
St. Lawrence	A	140.2	121.6	122.7	118.9	118.5	133.1	109.4	106.1	157.4	157.4	146.4	132.4	1564.0
St. Mary's	D	131.7	130.3	134.9	115.7	109.9	117.8	120.4	103.9	124.3	134.3	146.6	141.0	1510.8
Swift Current	D	139.6	133.2	125.0	117.9	93.8	110.8	108.6	101.3	133.7	150.6	140.2	139.2	1493.8
Terra Nova	C	105.7	107.3	99.7	82.3	87.6	88.2	88.3	88.7	108.6	110.6	105.9	110.9	1183.7
Winterland	D	127.4	122.7	117.1	124.8	112.5	112.1	92.3	87.3	143.5	153.0	140.1	128.2	1461.1

Notes:
1. The minimum number of years used to calculate normals are indicated by a "code" defined as:
- "A": No more than 3 consecutive or 5 total missing years between 1971 to 2000.
- "B": At least 25 years of record between 1971 and 2000.
- "C": At least 20 years of record between 1971 and 2000.
- "D": At least 15 years of record between 1971 and 2000.

2. Data obtained from National Climate Data and Information Archive website operated and maintained by Environment Canada (Environment Canada, 2010).

Table 1-3: Mean Monthly Evapotranspiration (mm) for Climate Stations within the Study Area

Station and Years	Potential vs. Actual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Boat Harbour (1983-2005)	Potential	1	2	6	21	55	83	111	106	72	42	16	5	520
	Actual	1	2	6	21	55	83	111	104	72	42	16	5	518
Bonavista (1957-1996)	Potential	1	1	3	13	42	76	109	104	72	42	18	4	485
	Actual	1	1	3	13	42	76	104	87	67	42	18	4	458
Come By Chance (1974-1994)	Potential	2	1	6	20	50	77	105	104	74	43	17	5	504
	Actual	2	1	6	20	50	77	105	92	72	43	17	5	493
Hearts Content (1963-1979)	Potential	2	2	7	18	49	84	114	105	72	43	19	6	521
	Actual	2	2	7	18	49	84	110	92	69	43	10	6	501
Long Harbour (1970-1999)	Potential	3	3	8	22	52	79	107	105	74	45	20	6	524
	Actual	3	3	8	22	52	79	105	102	73	45	20	6	518
St. John’s W (1874-1921)	Potential	3	2	5	18	49	81	110	103	72	42	17	5	507
	Actual	3	2	5	18	49	81	109	97	69	41	17	5	496
St. Mary’s (1983-1999)	Potential	3	4	9	24	52	78	104	104	75	45	20	7	525
	Actual	3	4	9	24	52	78	104	104	74	45	20	7	524
Terra Nova (1979-1996)	Potential	1	2	5	20	56	87	115	106	70	37	13	3	515
	Actual	1	2	5	20	56	87	111	98	68	37	13	3	501
Winterland (1981-2005)	Potential	1	2	6	21	54	81	111	108	75	43	18	5	525
	Actual	1	2	6	21	54	81	111	104	74	43	18	5	520

Notes:
1. Data obtained from Meteorological Service of Canada operated and maintained by Environment Canada.
2. Calculations assume 100mm soil moisture

2.0 POPULATION

Census data for 2001 and 2006 (Statistics Canada, 2010) are included in Appendix I for those communities within the study area. The data indicate a population of approximately 288,358 in 2006 compared to a population of 279,488 in 2001. The majority of the population is distributed in the centers of St. John's (100,646), Mount Pearl (24,671), Conception Bay South (21,966), Paradise (12, 584), Portugal Cove-St. Phillips (6,575) and Torbay (6,281). The remainder of the population is distributed in smaller communities which range in population from 68 (Terra Nova) to 5,436 (Marystown).

3.0 PHYSIOGRAPHY

The physiography of the island of Newfoundland is controlled by the underling geology and consists of a broad plateau sloping from the west (700+ m above sea level (asl)) to the northeast and southeast. The most distinctive feature is the dissected nature of the plateau itself. Deep valleys alternate with long high ridges resulting in a coastline that has numerous fiords, bays, many islands, peninsulas and small harbours. Average elevation of the plateau which includes the major part of Newfoundland is about 350-400 m asl (South, 1983).

The island of Newfoundland can be divided into 12 physiographic regions (South, 1983). These regions have been modified after Twenhofel and MacClintock (1940). Three of these regions are contained in the Eastern Newfoundland study area and are presented in Figure 3-1, along with the shaded relief.

3.1 CENTRAL PLATEAU

A small portion of the Central Plateau physiographic region is located along the western boundary of the study area (refer to Figure 3-1). The Central Plateau is an area that is dominated by rolling topography with an average elevation of about 250 m on a wide variety of bedrock types (South, 1983). Local variations in relief are caused by ice scour and deposits of glacial material. It is an area of poor drainage with many small lakes. The rivers meander in broad shallow valleys.

The drainage pattern was originally influenced by the geological structure, which trends southwest to northeast. The original drainage pattern was extensively modified by glaciation which over-deepened some of the valleys and interrupted the drainage network on the plateaus by deposition of drift. As a result of the modification of the drainage pattern, the plateaus are now largely covered with extensive bogs and fens (South, 1983).

The north coast is irregular with many bays and inlets extending far inland in a southwesterly direction. The area is mostly forest covered, but it includes some barren areas especially in coastal localities. The quality and height of the forests diminishes towards the coast due to increased wind exposure. There are numerous bogs, ponds and lakes that have drainage patterns reflecting glacial as well as strong structural and lithological controls.

3.2 SOUTH COAST HIGHLANDS

Within the study area, the South Coast Highlands physiographic region is located to the north of the Burin peninsula (refer to Figure 3-1). This is an area characterized by deep fiords, shallow till and numerous rock outcrops. Along the coast, some cliffs rise vertically over 300 m asl. The major height of land occurs within the area bordering Fortune Bay near Terrenceville where several bedrock ridges attain elevations of 300 m to 375 m. The area is characterized by extensive barrens, open peatlands and a fragmented forest landscape that has been decimated by fire.

3.3 EASTERN UPLANDS

The majority of the study area is located within the Eastern Uplands physiographic region (Avalon Peninsula, Bonavista Peninsula and the southern portion of the Burin Peninsula; refer to Figure 3-1). The landscape consists generally of a hummocky to rolling plateau, 75 to 250 m asl, with isolated hills rising above the general level. Drainage is variable but flows mainly in short swift streams.

The Burin Peninsula extends approximately 140 km southwest from the main body of the Island of Newfoundland separating Placentia Bay to the east from Fortune Bay to the west. The width of the peninsula varies from 15 km to 25 km. The peninsula has a rolling, rugged topography controlled by northeast-southwest trending bedrock ridges that vary in elevation from approximately 50 m to 374 m asl. The area is drained by several small rivers, the largest being the Garnish River. The ground surface throughout the peninsula is predominately barren, with exposed bedrock or thin surficial deposits and large areas of bog. The vegetative cover mainly consists of low grasses, sedges and lichen. Forested areas of spruce and alder are restricted to the more sheltered valleys within the area.

The Bonavista Peninsula generally lies below an elevation of 80 m. Higher hills occur along two subparallel south-southwest trending ridges between Freshwater Bay and the Community of North West Brook and between Keels and the east end of Random Sound. Ground moraine is common throughout the Bonavista Peninsula, but is typically less than 5 m thick. Almost the entire coastline exhibits bare rock outcrop and supports little vegetation. Extensive areas of barren and boggy terrain exist, with evergreen growth thickening inland. The Bonavista Peninsula is drained to the north and east by numerous streams and rivers. The most readily drained land exists near the coast due to the thinner overburden and the rugged relief, especially where bedrock is exposed. The largest river draining the area is the Terra Nova River.

The Avalon Peninsula may be regarded as a highland area surrounding a central lowland. In a few locations the uplands are rocky and rugged, but generally the uplands are a rolling plain of low relief. Hills that are 300 m high are found between Placentia and Markland. The southwestern shore of Conception Bay is broken by many inlets and bays. Some of these inlets extend inland to form prominent valleys in a rolling, rugged plateau. The central part of the Peninsula between Conception Bay and St. Mary's Bay is a lowland composed of a series of rounded hills. Rock outcrops are common throughout the Peninsula and many large bogs and fen deposits are interspersed with numerous lakes. Extensive areas of organic soils occur in the south and southwestern parts of the Peninsula, and along the western shore of St. Mary's Bay. A few large and many small streams drain the area. The majority of the rivers have their source in the uplands of the eastern part of the area, whereas others flow from the central part of the area. Many small streams drain the highlands in the southwestern and northeastern areas. The larger streams include the Salmonier River, Crossing Place, Northeast River, Southeast River and Manuels River.

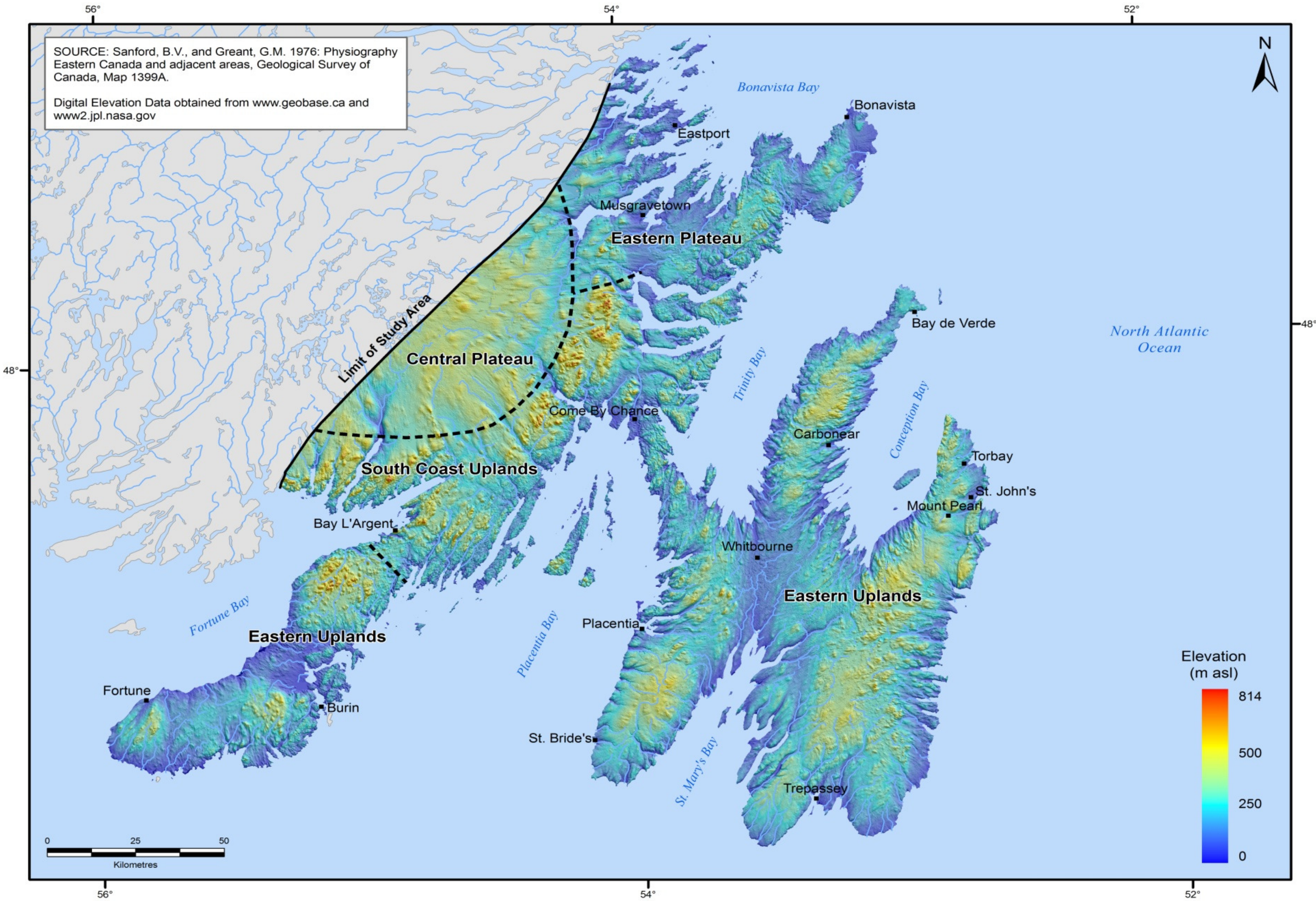

Figure 3-1: Relief and Physiographic Divisions within the Study Area (based on Twenhofel and MacClintock, 1940)

4.0 GEOLOGY

4.1 SURFICIAL GEOLOGY

The surficial geology of the eastern region of Newfoundland was obtained from Liverman and Taylor (1990b) and has been compiled at a scale of 1:250,000 on Map 1 accompanying this report. Figure 4-1 presents the generalized surficial geology of the study area at a scale of 1:1,000,000 (Department of Environment & Labour, 1992). The surficial geology is dominated by the effects of the last glaciation, the late Wisconsnian, which occurred between 25,000 and 10,000 years ago. For the purposes of this study, the surficial geology units represented have been simplified into five subdivisions. These subdivisions include;

- bedrock,
- till,
- sand and gravel,
- marine diamicton, gravel, sand and silt, and;
- bog deposits.

Much of the study area is characterized by barren, irregular and rough topography with numerous rock outcrops. The soil cover is generally thin, and the proximity of bedrock has led to the formation of many bogs and ponds.

4.1.1 Bedrock

This is the most common surficial unit across the study area. It consists of bedrock, either exposed or concealed by soil development and vegetation including scrub and peat bog. The bedrock is typically characterized by a rugged surface indicative of exposed bedrock and is commonly streamlined (Batterson et al. 2006).

Exposed bedrock is often capped with a thin veneer of broken clasts derived from frost weathering. Much of the study area is comprised largely of exposed bedrock or concealed bedrock. In these places, poor infiltration of rainwater into the ground results in significant surface runoff and flows in rivers draining these areas tend to rise and fall rapidly with precipitation events.

4.1.2 Till

Much of the study area is covered by a thin discontinuous Quaternary deposit of ground moraine (till) of variable textures. Till is the most common depositional product of retreating glaciers. It is a poorly sorted, generally well compacted sediment containing a mixture of grain sizes ranging from clays to boulders. Till deposits are found throughout the study area as, both a thin surficial veneer (<1.5 m) cover over bedrock, and as more extensive deposits.

Usually, the composition of the till closely reflects the lithology of the underlying bedrock. For example, till on the Bay de Verde Peninsula are commonly poorly consolidated, very poorly sorted to unsorted, with a silty sand matrix (Batterson et al., 2003). In contrast, some till is composed of farther traveled sediment as a result of ice flow movement. For example, till on the east side of Conception Bay have a sandy matrix and are dominated by granite clasts from the Holyrood horst located to the south (Batterson *et al.*, 2004).

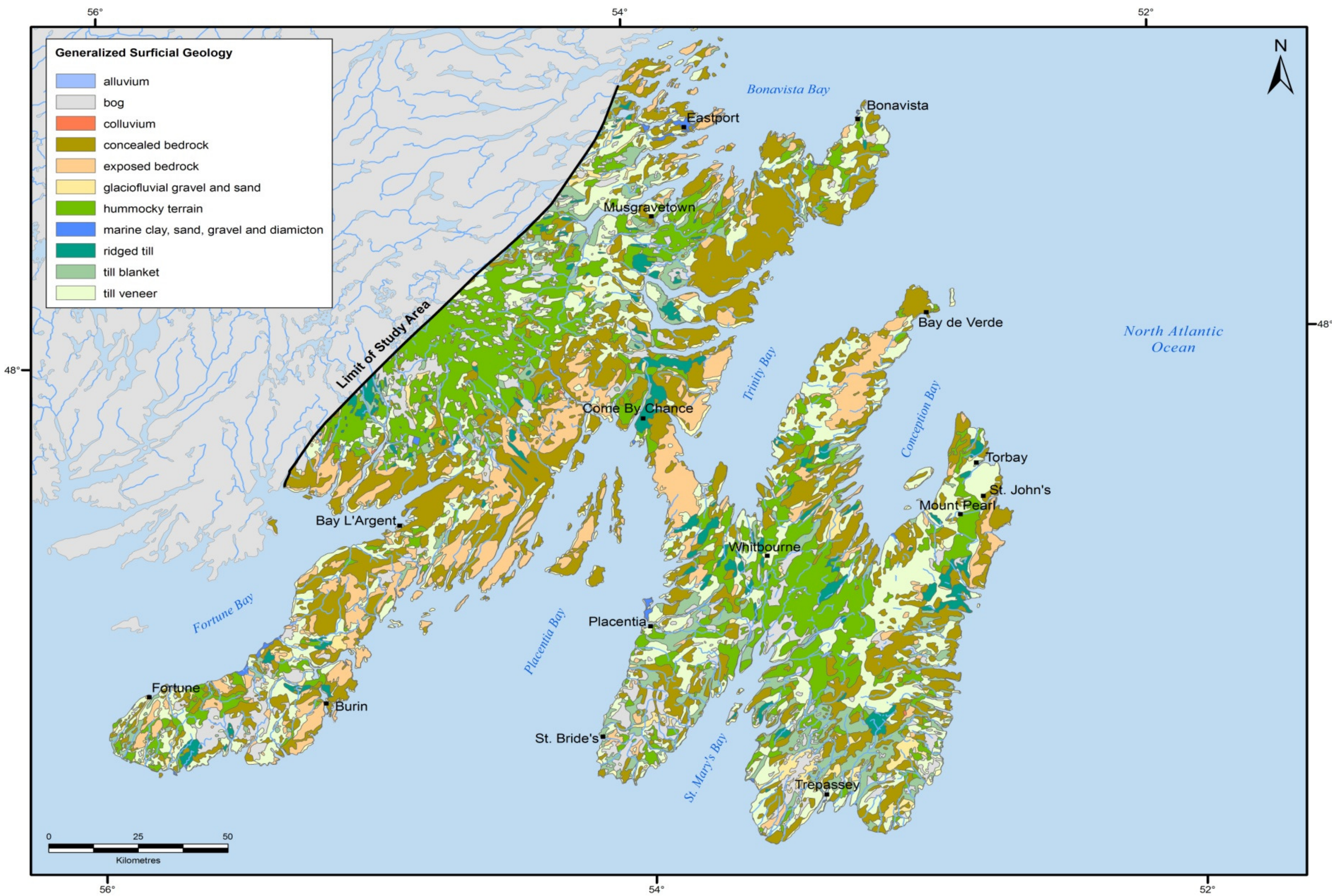

Figure 4-1: Generalized Surficial Geology of the Study Area (based on Department of Environment and Lands, 1992)

4.1.3 Sand and Gravel

Within the study area, glaciofluvial sediments comprising sand and gravel are of limited extent and are generally confined to stream and river valleys. They are composed of varying proportions of sand and gravel, with less than 5% silt or clay. They typically consist of poorly to well-sorted gravel, containing subrounded to rounded clasts up to boulder size in a medium to coarse-sand matrix.

Although not extensive, these deposits are fairly widespread and in many instances occur in the vicinity of established communities. Major areas of sand and gravel deposits located on the Bonavista Peninsula include the valleys draining into Clode Sound, Smith Sound and Northwest Arm (Batterson et al., 2001). On the Burin Peninsula, the main sand and gravel deposits are located in the Swift Current Valley (Batterson et al., 2007). On the Bay de Verde Peninsula, small glaciofulvial deposits are located within the South Brook and Shearstown Brook Valleys. Similarly, glaciofluvial deposts are common in valley areas along the coastline of the Southern Avalon Peninsula such as the Holyrood Bay and O'Briens Pond areas (Ricketts, 2008).

4.1.4 Marine Diamicton, Gravel, Sand and Silt

Marine diamicton, gravel, sand and silt varies in composition, and is recognized by its topographic position relative to the modern sea level (Liverman *et al.,* 1990). The distribution of this unit is controlled by the amount of isostatic rebound (postglacial uplift of land depressed by the weight of overlying ice). This unit is found adjacent to the present coastline at elevations up to 75 m asl (Liverman *et al.,* 1990). The most common surficial sediment within this unit is moderate to well sorted gravel and sand found in marine terraces.

The unit is of limited extent within the study area and is recognized mainly along the shores of Bonavista and Placentia Bays and in small coastal areas of the Bay de Verde and Burin Peninsulas.

4.1.5 Organic Deposits

This unit consists of aggraded and degraded organic matter. It is 1-10 m thick, and preserved by a reducing and acid environment in low-lying, water-saturated, poorly drained areas (Liverman *et al.*, 1990b). Bog overlies most of the other units. It forms either by growth of wetland vegetation in place, or by progressive filling of lakes and ponds. Much of the open terrain of eastern Newfoundland is characterized by numerous smaller peat deposits of slope and basin bog (South, 1983). This unit is well dispersed throughout the study area and is found both inland and on the coast.

4.2 BEDROCK GEOLOGY

For the purposes of this study, the geology is discussed mainly in terms of the lithology and distribution of the various rock strata. The bedrock geology of eastern Newfoundland was obtained from a variety of maps and has been compiled at a scale of 1:250,000, as illustrated on Map 2 accompanying this report. Figure 4-2 presents the generalized bedrock geology at a scale of 1:1,000,000.

4.2.1 Introduction

The island of Newfoundland is the northeast extremity of a chain of deformed and elevated rocks called the Appalachian Orogen. The Appalachian Orogen evolved through a cycle of ocean opening, beginning 600 million years ago (Ma), then ocean closing ending with continental collision at 300 Ma. The geologic divisions of Newfoundland record the development of the margins and oceanic tract of this ocean, called Iapetus. From west to east, these divisions are called the Humber Zone, Dunnage Zone, Gander Zone, and Avalon Zone (Williams, 1979).

The Humber Zone represents the ancient continental margin of eastern North America or the western margin of Iapetus. The Dunnage Zone represents remnants of Iapetus, the Gander Zone represents the eastern margin of Iapetus, and the Avalon Zone originated somewhere east of Iapetus and is of African affinity (Williams, 1979).

The study area consists primarily of the Avalon Zone which is an area of mainly thick, relatively unmetamorphosed sequences of Precambrian aged (~ 750-570 Ma) volcanic and sedimentary rocks, locally overlain by Paleozoic aged fossiliferous sedimentary rocks (King, 1990). Bimodal volcanic rocks, which formed mainly in a subaerial environment, are diagnostic of the Avalon Zone and are exposed in separate, mainly northeast trending belts. A small portion of the western boundary of the study area is part of the Gander Zone.

4.2.2 Avalon Zone Stratigraphy

Sedimentary and volcanic rocks of the Avalon Zone range in age from Late Precambrian to Upper Cambrian. They are weakly metamorphosed and are relatively undeformed compared to rocks to the west, that were been folded by open to locally tight northeast trending anticlines and synclines. At the base of the sequence, the Love Cove Group consists of predominantly metamorphosed subaerial volcanic rocks and is overlain by an upper assemblage of Precambrian sedimentary and minor volcanic rocks in which sandstone predominates (Connecting Point and Musgravetown Groups). An intermediate assemblage of marine siliceous slates and greywackes (Conception Group) is widely present in the Avalon Zone. A Cambrian sequence (Random Formation, Adeyton Group and Harcourt Group) overlies these Precambrian rocks and represents a time when the Zone was a stable platform or marine shelf.

The Avalon Zone was first deformed in the late Precambrian Avalonian Orogeny and subsequently regionally deformed and metamorphosed during the mid-Paleozoic Acadian Orogeny. Evidence of Precambrian deformation is found mostly on the Avalon Peninsula; elsewhere in eastern Newfoundland the metamorphism is attributed to Acadian orogenesis.

The effects of Acadian deformation and metamorphism are variable, but are most pronounced west of the Isthmus of Avalon. Metamorphism within the Avalon Zone occurred under prehnite-pumpellyite to mid-greenschist facies conditions. The intensity of the Acadian tectonothermal event is greatest adjacent to the Dover-Hermitage Bay Fault (Blackwood and Kennedy, 1975). In contrast, both the Avalon and Bonavista Peninsulas have undergone only prehnite-pumpellyite facies metamorphism (Papezik, 1974).

4.2.2.1 Avalon Peninsula Area

On the Avalon Peninsula, the Precambrian succession of rocks include in ascending order, volcanic, turbiditic, basinal-deltaic and mosasse-like rocks of the Harbour Main Group, Conception Group, St. John's Group and Signal Hill Group respectively (King, 1990). The oldest rocks on the Avalon Peninsula comprise a bimodal volcanic assemblage, the Harbour Main Group. Volcanic and volcaniclastic rocks of the Harbour Main Group are presumed to be conformably overlain by the Conception Group. The Conception Group is characterized by units of fine-grained siliceous sandstone and siltstone having continuous, well-developed parallel lamination, accentuated by laminae and thin laminar beds of grey, green and black mudstone and siltstone (O'Brien and King, 2004). The Conception Group is overlain by the St. John's Group, a thick and aerally extensive sedimentary succession characterized by variably cleaved, dark grey to black shales having interbedded sandstones. The dark grey shales of the upper St. John's Group pass conformably and gradationally upward into massive grey sandstones with granule and pebble beds correlated with the Gibbett Hill Formation of the Signal Hill Group..

The western Avalon Peninsula and the area immediately west and north of the Isthmus of the Avalon Peninsula are also underlain by Late Precambrian rocks. The Love Cove sedimentary and volcanic rocks which extend from Bonavista Bay to the head of Placentia Bay are very similar to the Harbour Main volcanic rocks. The Connecting Point Group slates and argillites resemble those of the Conception Group in eastern Avalon Peninsula. The shales, red sandstones and conglomerates of the Hodgewater Group underlie a large area east and west of Trinity Bay and east of Placentia Bay.

4.2.2.2 Bonavista Peninsula Area

The Bonavista Peninsula is underlain by Neoproterozoic rocks of the Love Cove, Connecting Point and Musgravetown Groups (O'Brien and King, 2004). The Love Cove Group has the oldest rocks in the area; these are mostly sericite and chloritic schist, associated acidic and intermediate, volcanic lava and pyroclastic rocks that are common south of Clode Sound. The Love Cove Group is unconformably underlain by the Connecting Point Group, a north-south-trending sequence of greywacke and slate containing minor quartzite, conglomerate and volcanic rocks. Most of the Bonavista Peninsula is underlain by the Neoproterozoic Musgravetown Group rocks that consist of red and green conglomerate, sandstone, siltstone and some lava and tuff. Some small areas of Early and Middle Cambrian shale, slate, quartzite and limestone (Adeytown Group) and Middle to Late Cambrian shale and siltstone (Harcourt Group) underlie the remainder of the peninsula (O'Brien and King, 2004). Tectonic and regional metamorphic activities have gently folded these rocks into a broad shallow syncline and an anticline trending northeast.

4.2.2.3 Burin Peninsula Area

The Burin Peninsula area is largely underlain by rocks of Late Precambrian age, as well as rocks of Neoproterozoic and Devonian age. These include volcanic and sedimentary strata of the Burin, Love Cove, Marystown, and Long Harbour Groups.

Volcanic strata predominate on the Burin Peninsula. These rocks are mainly composed of subaerial, felsic porphyritic flows and pyroclastics. The felsic volcanics form massive highly indurated outcrops characteristic of the upland terrain within the area. Mafic volcanic and sericitic and chlororitic schistose rocks occur but are less prevalent. However, the Burin Group located along the southeast shore of the Burin Peninsula is predominantly tholeiitic basalt. Volcanioclastic sediments also occur to a minor degree interbedded within the volcanic strata.

The upper half of the Neoproterozoic sequence comprises sedimentary rocks that both conformably, and locally disconformably, overlie the volcanic rocks although they are much less extensive than the volcanics. The sediments are characteristically, volcanically derived, grey, green or purple sandstones, siltstones, argillites and conglomerates. The sediments form a belt within the Love Cove Group that extends from the Point Enragee area northeastward past Terrenceville and these strata also occur to a more limited extent within the Marystown Group. Similar strata occur within the Long Harbour Group east of the Long Harbour inlet.

Devonian sedimentary strata occur locally near Terrenceville. The strata are predominately thickly bedded conglomerate and sandstone. They overlie Neoproterozoic and Precambrian strata in angular unconformity and have not been subjected to significant regional metamorphism.

4.2.3 Granitic and Gabbroic Intrusions

Granitic plutons of Devonian age underlie a portion of the study area. The granites are massive textured, fine to coarse grained bodies with intrusive contacts and associated metamorphism of the Devonian sedimentary rocks and the other older strata within the area. Most of the intrusive rocks in the study area are granite, but there are also gabbro, diorite and anorthosite plutons. The following section describes some of the more major intrusions within the study area.

The Holyrood Intrusive Suite intrudes the Harbour Main Group on the Avalon Peninsula and is a 620 Ma intrusion mostly composed of medium-grained, massive, pink and grey granite, and lesser amounts of quartz monzonite (King, 1988).

The study area west of the Avalon Peninsula is intruded by the aerially extensive Ackley Granite. This is a commonly pink, coarse-grained, massive, biotite granite. Several other granite plutons have been mapped in the area, including the Red Island Granite, Bar Haven Granite and Ragged Islands Intrusive Suite, all of which outcrop around Placentia Bay. The Clarenville Granite, a pink to red, medium-grained, biotite granite is found along the western shore of Northwest Arm, and by the Powder Horn Intrusive Suite. The Powder Horn Intrusive Suite is composed mostly of fine to medium grained diorite, but also contains gabbro and minor granite (King, 1988).

Neoproterozoic age granite and granodiorite plutons intrude and locally metamorphosed the volcanic and sedimentary strata of the Love Cove Group in the northern half of the Burin Peninsula. The plutons are northeast-southwest elongated features with foliated margins and massive interiors. The plutons are resistant features that form upland areas. A large gabbro sill approximately 25 km in length occurs within the Burin Group along the southeast shore of the Burin Peninsula.

The Whalesback Gabbro is a uniform, medium to coarse grained massive pyroxene-plagioclase rock. Spread Eagle Peak is a plug of gabbro intruded into Cambrian sediments and may have been a feeder to the Middle Cambrian pillow basalts exposed, together with associated fossilliferous black shales, along the shore of Chapel Arm. The Bull Arm Formation is intruded by the Hadrynian pink to grey, medium-grained Swift Current Granite.

The St. Lawrence Granite comprises a north south trending pluton on the southern end of the Burin Peninsula that extends from St. Lawerence to Winterland. It is extensively fractured and open vugs and fissures are common. The Grand Beach Complex, located on the southwestern shore of the Burin Peninsula is composed of massive poryohyritic rhyolite that includes lesser amounts of sedimentary strata, felsic pyroclastic and mafic volcanics.

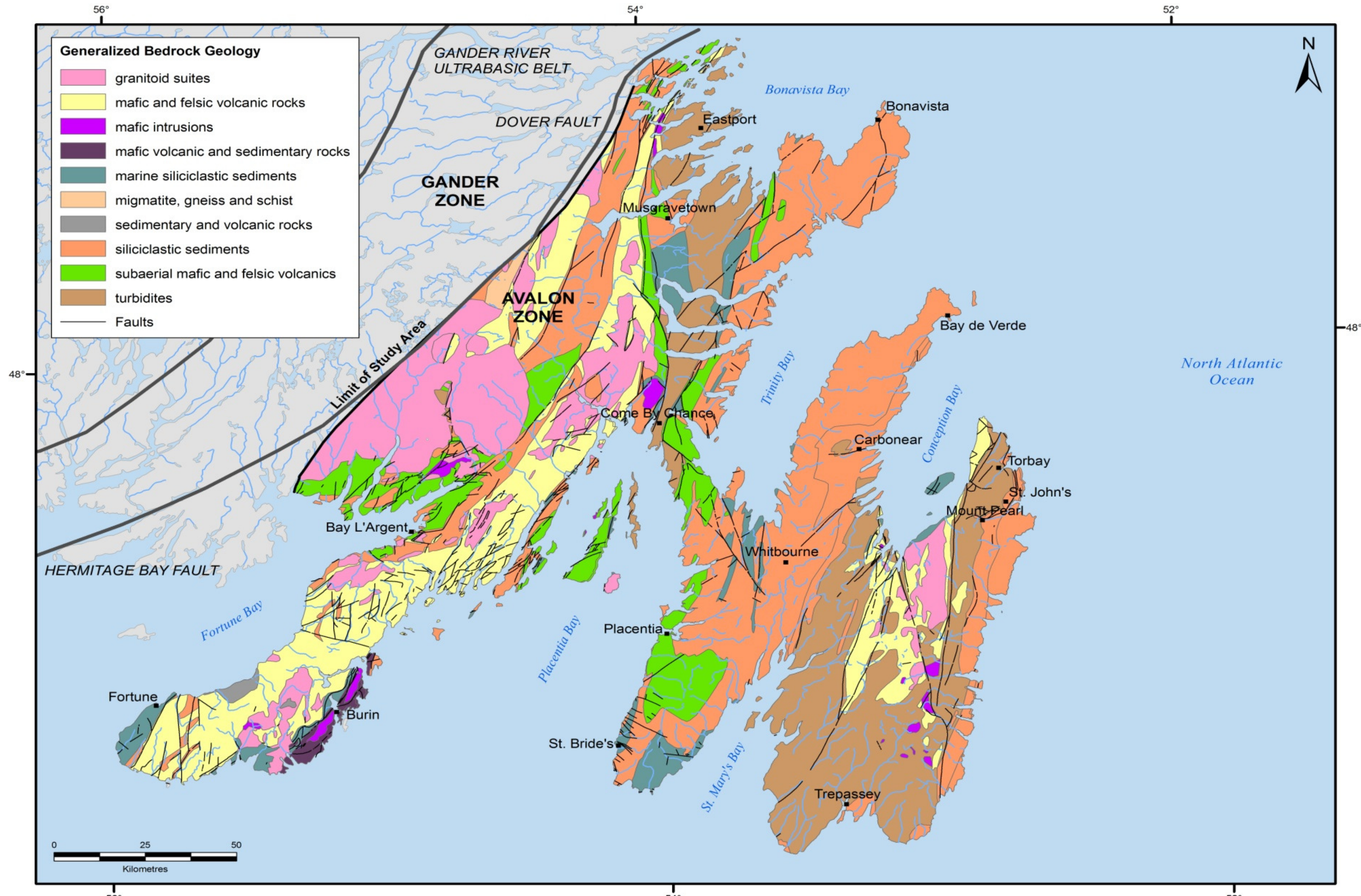

Figure 4-2: Generalized Bedrock Geology within the Study Area (based on Hayes, 1987 and updated by Williams, 2004)

5.0 HYDROGEOLOGY

Information of the Hydrogeology of Eastern Newfoundland was primarily derived from available water well records. The available water well records for the Eastern Newfoundland study area are summarized in tabular form in Appendix II. A total of 11,966 individual records of drilled wells were obtained for the study area from published (Department of Environment, 1950-2001) and unpublished DOEC water well records. Yield and depth data recorded by the drilling companies were not always consistent, resulting in information gaps (e.g., missing well depth, well yield, and/or lithology). Data on 301 overburden wells were reported, of which 252 provided well yield estimates, and 301 provided depths. Data on 11,665 bedrock wells were reported, of which 8,768 have well yield estimates, and 11,454 provided depths. There are also numerous drilled or dug wells in the study area for which no records exists.

It is noted that the available water well records are not distributed evenly across the study area, and are clustered in coastal areas and river valleys, where overburden is generally thicker.

5.1 GROUNDWATER FLOW SYSTEMS AND STORAGE

Groundwater sources can be classified into three categories;

- Overburden sources: groundwater stored in unconsolidated surficial deposits, above bedrock and typically exploited in shallow wells;
- Bedrock with primary permeability: typically sedimentary rock formations where the rock mass is generally permeable via pores between grains;
- Bedrock with secondary permeability: rocks in which significant water movement occurs mainly through fracture systems associated with folding or faulting, or in solution channels along fractures and bedding planes.

Most bedrock formations within the study area, because of their age, genesis and composition, contain little if any primary permeability, thus rock formations with secondary permeability predominate. In this kind of terrain it is the structural features such as faults and shear zones that are of prime interest when searching for groundwater.

In crystalline rock, the primary porosity may be as low as 0.05%, but a typical sand aquifer usually has a porosity of 30% or greater (Novakowski, 2000). Thus, the volume of water stored in fractured bedrock aquifers is often orders of magnitude less than that stored in more porous media. Consequently, sustained pumping for municipal supply or even for domestic usage from fractured bedrock will draw groundwater from greater distances. This response has two implications. First, bedrock aquifers without a source of recharge have limited supply for sustained removal of groundwater and are often more susceptible to well interference and over consumption than porous aquifers of equivalent scale. Second, the zone in which the recharging water must be protected from contamination may be significantly larger than for porous aquifers because of the shorter travel times typical of fractured rock aquifers.

The shallow groundwater system will be largely controlled by surface runoff and local recharge, while at moderate depths the flow system may be influenced by lateral inflow of groundwater from up-gradient areas. Shallow groundwater flow tends to mimic variations in local topography, although under more subdued hydraulic gradients. A topography driven flow system is one in which groundwater flows from higher-elevation recharge areas, where hydraulic head is higher, to lower-elevation discharge areas, where hydraulic head is lower such as wetlands, ponds, rivers and lakes.

Groundwater flow systems in the study area are closely tied to surface water systems. Wells are dug or drilled in both overburden and bedrock. Both till and bedrock flow systems are closely connected with surface water. Lakes and ponds serve as both local and regional discharge points. The implication of the close surface water/groundwater connection is that groundwater levels are very sensitive to dry periods, unless substantial storage is available.

5.2 HYDROSTRATIGRAPHIC UNITS

The starting point for any regional hydrogeological characterization study is to establish the hydrostratigraphy by identifying hydrostratigraphic units. The term hydrostratigraphic unit was first proposed by Maxey (1964) for "bodies of rock with considerable lateral extent that compose a geologic framework for a reasonably distinct hydrologic system". Maxey (1964) identified the need to define the groundwater units that are based not solely on specific lithological characteristics but also included parameters "that apply especially to water movement, occurrence and storage."

An assessment of the potential groundwater yield of the geological strata within the study area was made by subdividing the overburden deposits and bedrock into hydrostratigraphic units. Each hydrostratigraphic unit was defined by considering strata with similar water bearing capabilities, which may include one formation or a group of formations. The water bearing potential was then quantified by assessing the reported well yields and depths from the records of wells completed within each unit. The yield and depth characteristics of overburden and bedrock hydrostratigraphic units from the water well records are summarized in Tables 5.1 and 5.2, respectively. A zero (0) or blank represents no information available in the database; therefore these values were not included in the calculation of mean and median values.

Well yields are generally classified as low, moderate or high for well potential classification. A low yield well will provide between 5 L/min to 25 L/min for usage. This is suitable for a single dwelling home. A moderate yield will provide between 25 L/min and 125 L/min for usage. This is suitable for all domestic uses and some commercial uses. A high yield well will provide greater than 125 L/min for usage (Acres, 1994) and can be used for domestic, industrial, commercial, or municipal needs.

The well yield characteristics were generally determined by either bailing or air lifting for a period of time considered sufficient by the driller for the required well use (usually less than 2 hours and usually for a small producing domestic well). The typically low pumping rates and short time frame of the tests means that individual bail down or air lift tests from the water well records are more affected by the geologic units immediately adjacent to the well than well yields derived from longer term aquifer tests with monitoring wells, which may be more representative of larger segments of the aquifer. As such the reported yields for the various units within the study area do not represent precise pump test well yield characteristics.

5.2.1 Overburden Hydrostratigraphic Units

Materials ranging in texture from fine sand to coarse gravel are capable of being developed into a water-supply well (Fetter, 1994). Material that is well sorted and free from silt and clay is best. The permeabilities of some deposits of unconsolidated sands and gravels are among the highest of any earth materials. Generally, till will have a low permeability (Fetter, 1994). Many domestic water supplies inside the study area are derived from dug wells constructed within overburden units.

Wells were classified as overburden wells when the casing length equaled the well depth or when the overburden thickness equaled the well depth. A total of 301 water wells within the study area were drilled in overburden aquifers. The surficial deposits previously described in Section 3.1 were subdivided into two broad hydrostratigraphic units: Unit A consisting of till, and Unit B consisting of glacial outwash sands and gravels together with marine terraces. Identification of data for each unit was done by locating the community name and where the well is located on Map 1. The yield and depth characteristics of these units are summarized on Table 5-1. Histograms of yield and depth of wells completed in overburden hydrostratigraphic units are illustrated in Figure 5-1.

5.2.1.1 Unit A – Till Deposits

The till deposits form a thin veneer over much of the study area within stream valleys and on the flanks of bedrock hills. The composition of the till varies from silty sand to clayey silt, generally representing materials of moderate to low permeability. However, the till deposits may be interbedded with sand and gravel, which produce greater groundwater yields.

A total of 153 well records are available for Unit A. Well yields ranged from 1.5 L/min to 227 L/min with a median value of 45 L/min and averaged 59 L/min. Well depth ranged from 1.5 meters (m) to 45.1 m and averaged 17 m. The available data indicate that, on average, wells drilled within Unit A have a moderate to high potential yield. However, in many cases the logs for these wells indicate that they are completed in sand or gravel layers within the till unit, and the yield values are positively biased by wells not completed in till. Where wells are not completed in sand or gravel layers within the till, the well yields are expected to be considerably lower.

5.2.1.2 Unit B – Sand and Gravel Deposits

This hydrostratigraphic unit is believed to have the greatest groundwater potential of any of the other units in the study area. It consists of deposits of gravel, sand and silt representing primarily outwash plain deposits and to a lesser extent kames. These deposits occur mainly in valleys leading from inland areas to the ocean and have been described as well stratified sands, to pebbly sands to stratified sands and gravel.

Due to their usually shallow position and their permeability, the sand and gravel deposits are susceptible to contamination. Road salt and household sewage from septic tanks can pose dangers to these highly permeable overburden aquifers. Where shallow aquifers have been heavily pumped near the coasts, saltwater intrusion can locally contaminate the ground water.

A total of 148 well records are available for Unit B. Wells drilled in Unit B are largely found along a large continuous body of stratified drift that extends from Seal Cove to Topsail Head, along the southern shore of Conception Bay. Other smaller glaciofluvial deposits are scattered throughout the study area. Well yields ranged from 2 L/min to 270 L/min with a median value of 36 L/min and averaged 54 L/min. Well depths ranged from 4.6 m to 40 m and averaged 19 m. The available data indicates that most wells drilled within Unit B have a high potential yield.

Table 5-1: Yield and Depth Characteristics of Overburden Hydrostratigraphic Units, Eastern Newfoundland from Water Well Record information

Hydrostratigraphic Unit	Number of Wells	Well Yield Characteristics[2] (L/min)		Well Depth Characteristics (m)	
		Average	Median	Average	Median
Unit A **Moderate to High Yield** Till	153	59	45	17	15
Unit B **Moderate to High Yield** Sand and Gravel	148	54	36	19	17

Notes:
1. The data presented are updated to December, 2009. The information was supplied by the DOEC and was recorded by water well drillers as required under the "Well Drilling Regulations", 1982, and amendments.
2. Not including 0 values, of which 24 are reported for Unit A and 18 are reported for Unit B.

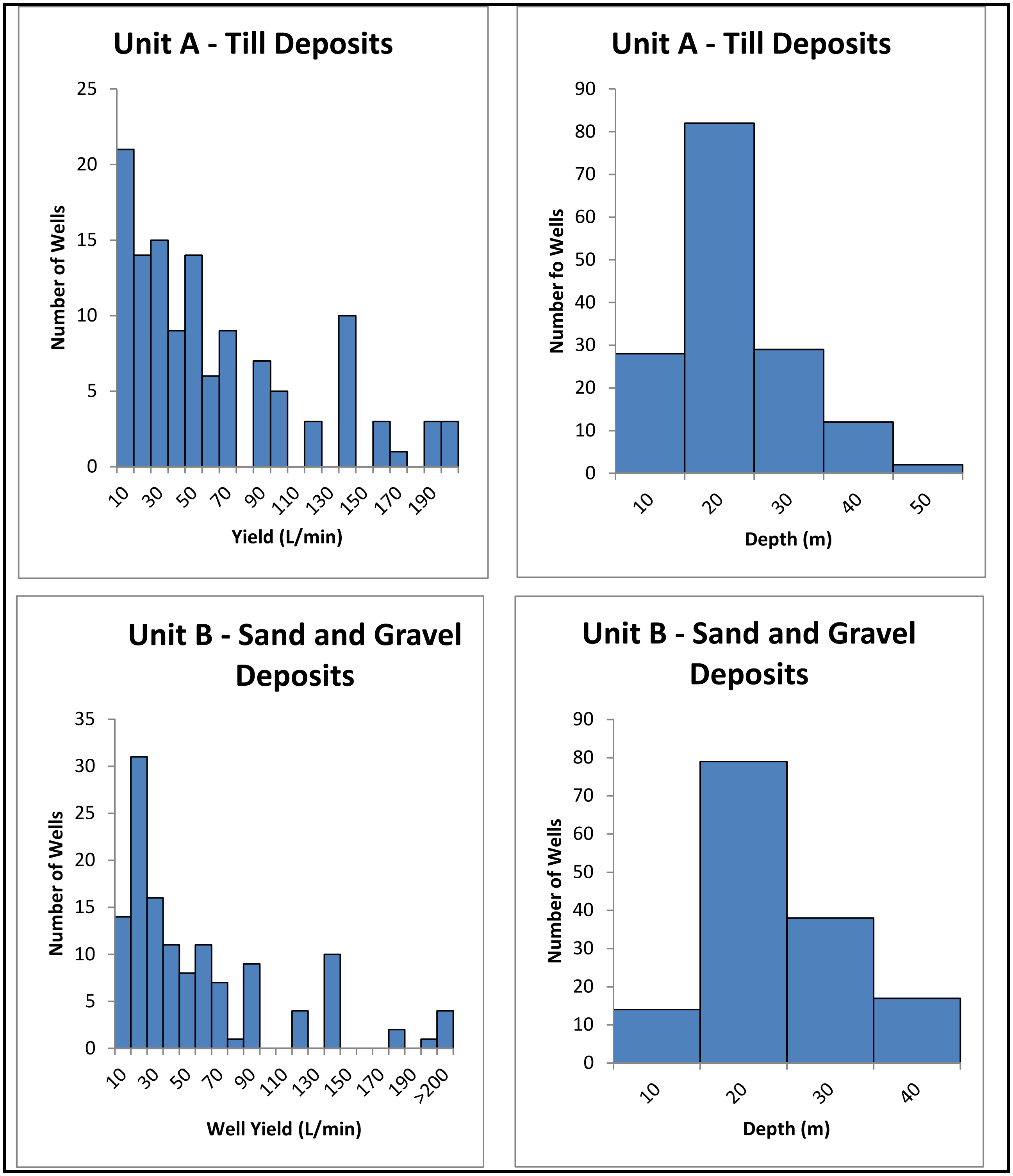

Figure 5-1: Well Yield[1] and Depth Relationships, Over burden Hydrostratigraphic Units A and B, Eastern Newfoundland (data from DOEC, 2009). [1] Not including 0 values.

5.2.2 Bedrock Hydrostratigraphic Units

Most of the wells drilled in the study area have been drilled into bedrock. The bedrock underlying the study area was subdivided into six hydrostratigraphic units based primarily on lithology. These units are summarized in Table 5-2 and are shown on Map 3. Histograms of estimated yield and depth of wells completed in bedrock hydrostratigraphic units from water well records within the study area are illustrated in Figures 5-2, 5-3 and 5-4.

Wells were assigned to the various hydrostratigraphic units by first locating them by community then assigning those wells to the appropriate hydrostratigraphic unit that underlies that community. The well driller's descriptions of rock types were also considered for this purpose but they were sometimes vague and of limited value in this regard.

The approach in producing these hydrostratigraphic units was to relate well yields to bedrock formations. This approach, though necessary in a preliminary investigation of groundwater, is very approximate and should be used cautiously especially in areas where groundwater resources depend on secondary permeability.

In this study, data on the location of individual wells did not provide sufficient information to determine the nature or degree of bedrock fracturing at the well locations. Therefore, the water well data have been examined in order to determine the hydrogeologic characteristics of the "rock-masses" or fractured bedrock units as a whole and not those of the individual structural features.

5.2.2.1 Unit 1 –Siltstone and Shale Strata

Primarily, this hydrostratigraphic unit comprises shale and siltstone and, to a lesser extent, sandstone and conglomerate. In general, the permeability of shale and siltstone is less than that of sandstone and conglomerate.

Most sedimentary rock types are formed from small particles packed closely together with voids in between. Groundwater moves along the irregular pathways through these void spaces, as intergranular flow. There are many factors that control the primary porosity of sedimentary rocks. Some of these include the roundness of the grain, sorting, and degree of cementation and metamorphism.

A total of 5100 well records are available for Unit 1. Well yields ranged from 0.1 L/min to 546 L/min with a median value of 9 L/min and averaged 20 L/min. Well depth ranged from 7 m to 220 m and averaged 64 m. The available data indicate that wells drilled within Unit 1 generally have a low to moderate potential yield. 52 wells drilled in Unit 1 were reported abandoned due to insufficient supply.

5.2.2.2 Unit 2 –Sandstone and Conglomerate

Primarily, this hydrostratigraphic unit is composed of sandstone and conglomerate and, to a lesser extent, shale and siltstone. In general, the permeability of sandstone and conglomerate is only slightly larger than that of shale and siltstone.

A total of 2789 well records are available for Unit 2. Well yields ranged from 0.3 L/min to 454 L/min with a median value of 9 L/min and averaged 22 L/min. Well depth ranged from 12 m to 287 m and averaged 64 m. The available data indicate that wells drilled within Unit 2 generally have a low to moderate potential yield. 4 wells drilled in Unit 2 were reported abandoned due to insufficient supply.

5.2.2.3 Unit 3 –Cambro-Ordovician Sedimentary Strata

The permeability of sedimentary strata generally decreases with increasing age of the sediments. Therefore, this hydrostratigraphic unit is composed of the younger sedimentary strata within the study area ranging from Cambrian to Early Ordovician age.

A total of 1694 well records are available for Unit 3. Well yields ranged from 0.5 L/min to 591 L/min with a median value of 14 L/min and averaged 29 L/min. Well depth ranged from 7 m to 235 m and averaged 54 m. The available data indicate that wells drilled within Unit 3 generally have a moderate potential yield. 11 wells drilled in Unit 3 were reported abandoned due to insufficient supply.

5.2.2.4 Unit 4 – Volcanic Strata

This unit comprises the relatively unmetamorphosed volcanic rocks; essentially consisting of basic pillow lava, flows, breccia and tuff, with minor sedimentary rocks, ranging in age from Neoproterozoic to Devonian.

Volcanic rocks have a wide range of chemical, mineralogical, structural, and hydraulic properties, due mostly to variations in rock type and the way the rock was ejected and deposited. Unaltered pyroclastic rocks, for example, might have porosity and permeability similar to poorly sorted sediments. Hot pyroclastic material, however, might become welded as it settles, and, thus, be almost impermeable. Silicic lavas tend to be extruded as thick, dense flows, and they have low permeability except where they are fractured. Basaltic lavas can be full of hot gases when they form and may have abundant pores due to the gas bubbles present as the lava cools and the rock forms. Basaltic rocks are the most productive aquifers in volcanic rocks.

A total of 1819 well records are available for Unit 4. Well yields ranged from 0.3 L/min to 455 L/min with a median value of 9 L/min and averaged 25 L/min. Well depth ranged from 8 m to 228 m and averaged 67 m. The available data indicate that wells drilled within Unit 4 generally have a low to moderate potential yield. 18 wells drilled in Unit 4 were reported abandoned due to insufficient supply.

5.2.2.5 Unit 5 – Plutonic Strata

This unit comprises all of the plutonic rocks, ranging in age from Neoproterozoic to Devonian, and includes major granite, granodiorite, diabase, and diorite intrusions. Spaces between the individual mineral crystals of plutonic rocks are microscopically small, few, and generally unconnected; therefore, porosity is insignificant. These plutonic rocks are permeable only where they are fractured, and they generally yield only small amounts of water to wells. However, these rocks extend over large areas, and, in many places, they are the only reliable source of water supply. Large areas of the study area are underlain by plutonic rocks.

A total of 95 well records are available for Unit 5. Well yields ranged from 0.5 L/min to 182 L/min with a median value of 14 L/min and averaged 31 L/min. Well depth ranged from 9 m to 207 m and averaged 69 m. The available data indicate that wells drilled within Unit 5 generally have a moderate potential yield. One well drilled in Unit 5 was reported abandoned due to insufficient supply.

5.2.2.6 Unit 6 – Metamorphic Strata

Meta-volcanic and minor meta-sedimentary rocks of the Love Cove Group are composed of sericite and chlorite schist derived from mafic and felsic volcanic rocks, conglomerate, sandstone and shale. Minor migmatite and gneiss in the extreme west belong to the Square Pond and Hare Bay gneiss. These rocks are of Late Neoproterozoic to Early Cambrian age and occur north and south of Clode Sound and north of the Burin Peninsula.

Metamorphic rocks are formed under extreme pressure and temperature deep within the earth's crust. When sedimentary and igneous rocks are subjected to great pressures and temperatures, the rocks become altered and form metamorphic rocks. Because metamorphic rocks have been under such pressures and temperatures, any pore spaces that might have been present in the rock is reduced or erased. Only when these rocks are brought back to the surface, as overlying rocks are removed by erosion, is there a chance of secondary porosity developing.

A total of 168 well records are available for Unit 6. Well yields ranged from 0.5 L/min to 296 L/min with a median value of 4 L/min and averaged 18 L/min. Well depth ranged from 12 m to 134 m and averaged 61 m. The available data indicate that wells drilled within Unit 6 generally can have a low to moderate potential yield, but were the least productive of all the hydrostratigraphic units. Five wells drilled in Unit 6 were reported abandoned due to insufficient supply.

Table 5-2: Yield and Depth Characteristics of Bedrock Hydrostratigraphic Units, Eastern Newfoundland from Water Well Record information

Hydrostratigraphic Unit	**Lithology**	**Number of Wells**	**Well Yield Characteristics[2] (L/min)**		**Well Depth Characteristics (m)**	
			Average	Median	Average	Median
Unit 1 **Low to Moderate Yield** Siltstone and Shale Strata	Siltstone, shale, with minor volcanic flows and tuffs	5100	20	9	64	61
Unit 2 **Low to Moderate Yield** Sandstone and Conglomerate	Sandstone, conglomerate, breccia, greywacke, with minor volcanic flows and tuff.	2789	22	9	64	56
Unit 3 **Moderate Yield** Cambro-Ordovician Sedimentary Strata	Shale, siltstone, sandstone, with minor slate and limestone beds	1694	29	14	54	44
Unit 4 **Low to Moderate Yield** Volcanic Strata	basic pillow lava, flows, breccia and tuff, with minor sedimentary rocks	1819	25	9	67	61
Unit 5 **Moderate Yield** Plutonic Strata	granite, granodiorite, diorite and gabbro	95	31	14	69	64
Unit 6 **Low to Moderate Yield** Meta Volcanic Strata	Sericite & chlorite schist derived from felsic and mafic volcanic and sedimentary rocks; minor gneiss and migmatite	168	18	4	61	52

Notes:

1. The data presented are updated to December, 2009. The information was supplied by the DOEC and was recorded by water well drillers as required under the “Well Drilling Regulations”, 1982, and amendments.
2. Not including 0 values, of which 649 (13%) are reported for Unit 1, 391 (14%) are reported for Unit 2, 281 (17%) are reported for Unit 3, 209 (11%) are reported for Unit 4, 20 (4%) are reported for Unit 5 and 17 (10%) are reported for Unit 6.

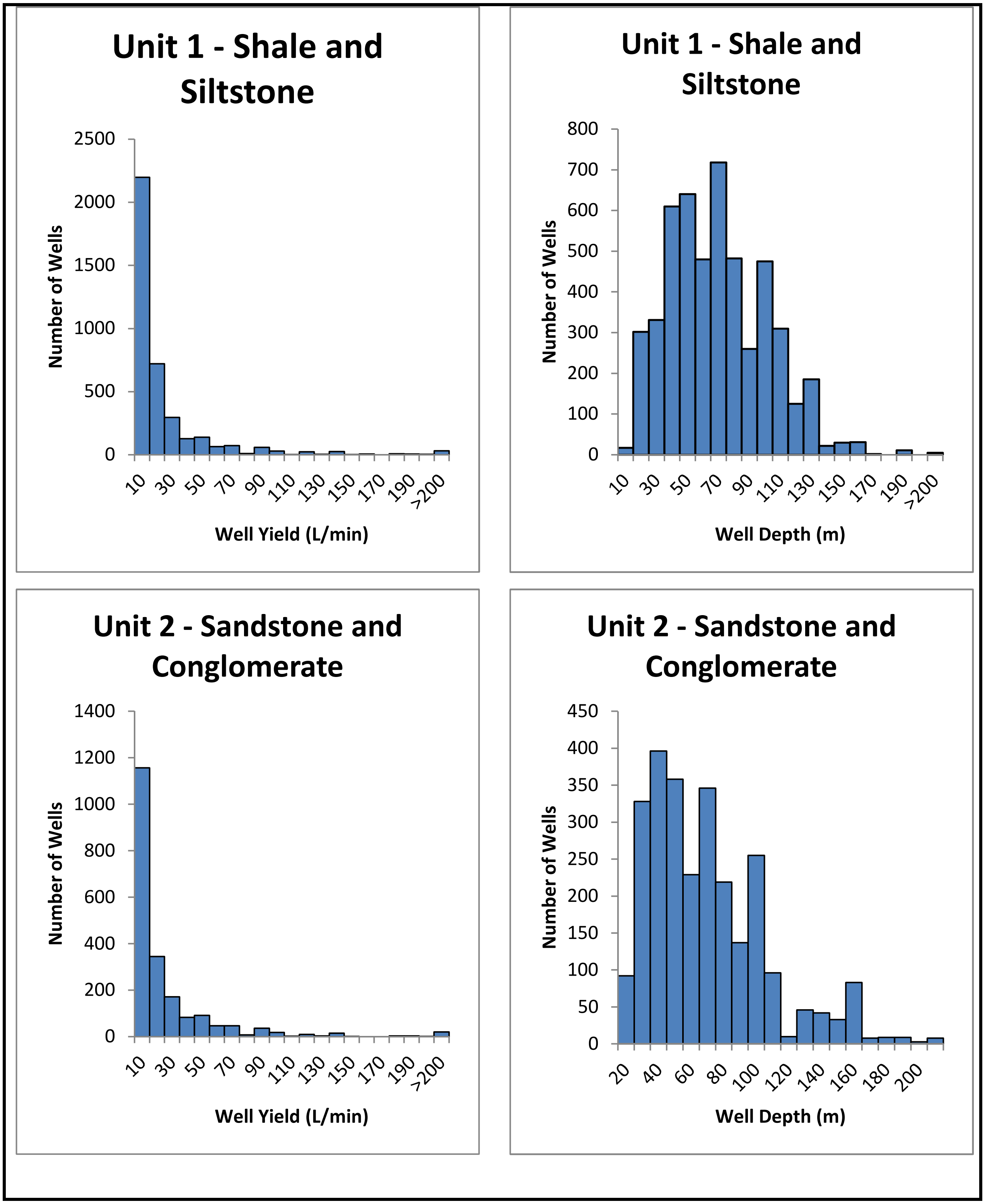

Figure 5-2: Well Yield[1] and Depth Relationships, Bedrock Hydrostratigraphic Units 1 and 2, Eastern Newfoundland (data from DOEC, 2009). [1] Not including 0 values.

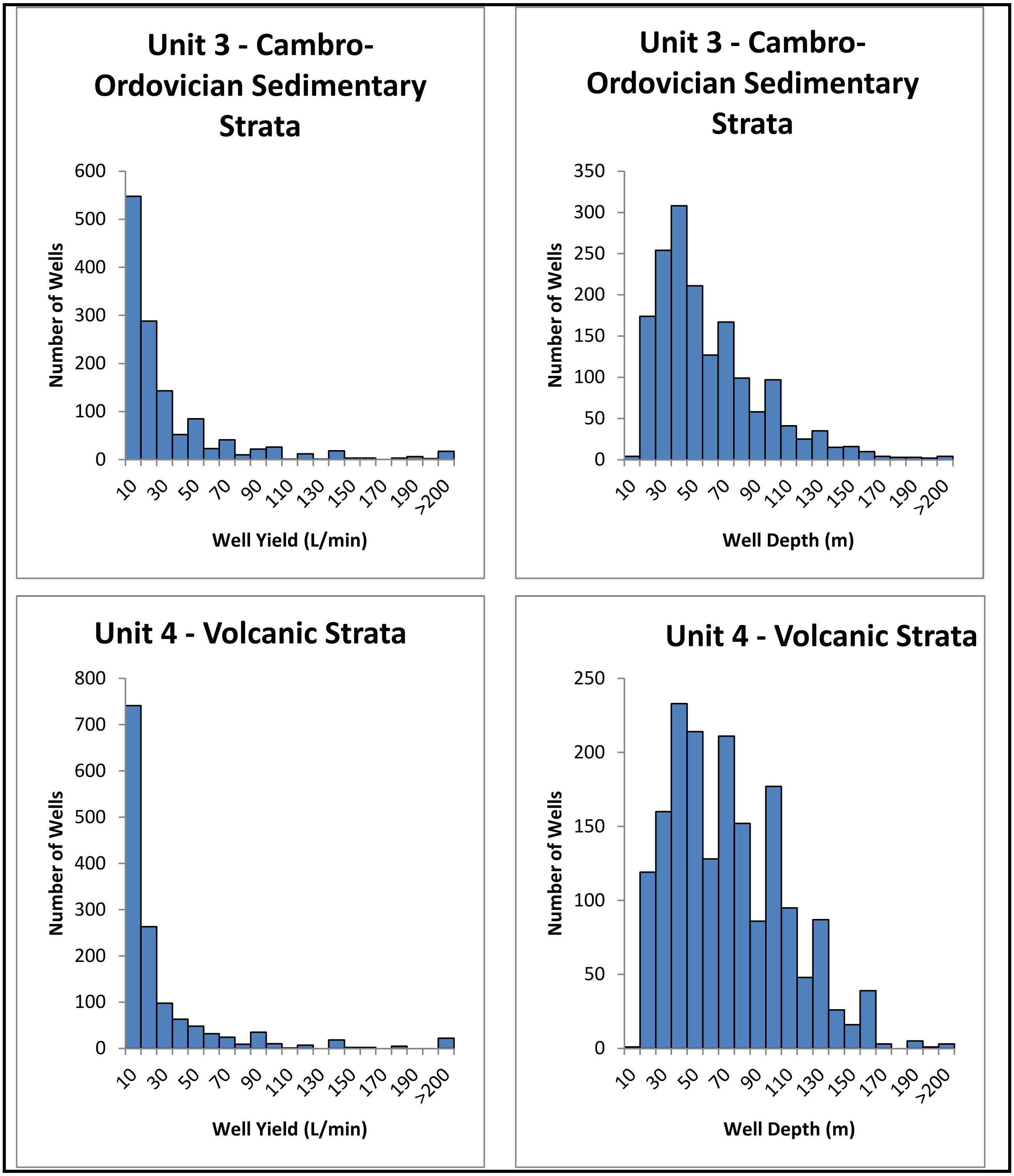

Figure 5-3: Well Yield[1] and Depth Relationships, Bedrock Hydrostratigraphic Units 3 and 4 Eastern Newfoundland (data from DOEC, 2009). [1] Not including 0 values.

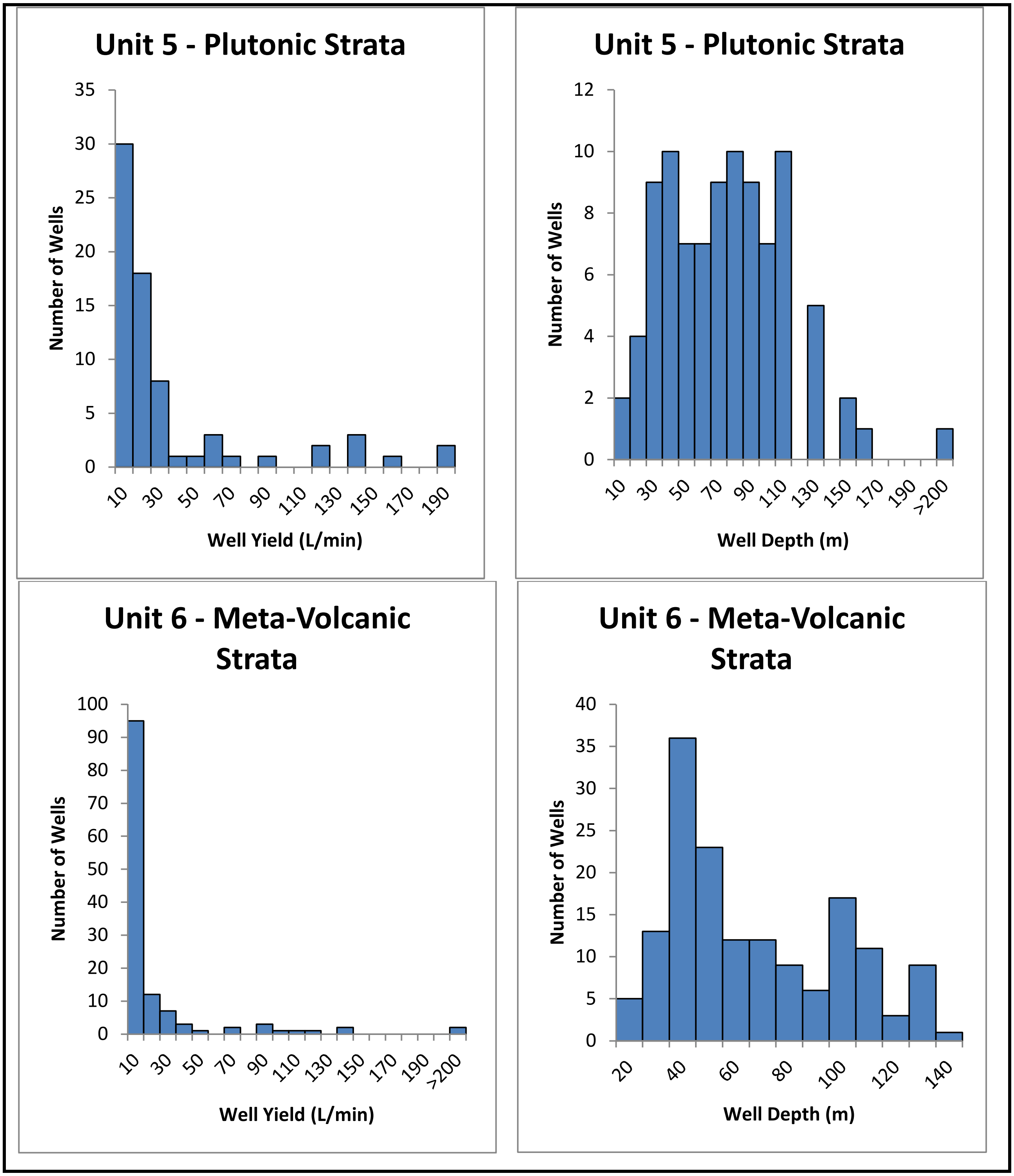

Figure 5-4: Well Yield[1] and Depth Relationships, Bedrock Hydrostratigraphic Unit 5 and 6, Eastern Newfoundland (data from DOEC, 2009). [1] Not including 0 values.

5.3 AQUIFER TESTS

An additional source of data for both overburden and bedrock hydrogeological characteristics is provided by aquifer tests that have been completed as part of an evaluation of community water supplies or as part of a specific engineering activity. A total of 4,458 aquifer tests are reported to have been conducted in the study area, and ranged in length from 1 to 4320 minutes. Appendix III lists the available aquifer tests completed in the study area according to community and hydrostratigraphic unit. Table 5-3 presents a comparison of water well supply aquifer tests with the results of the yield tests for mainly single domestic well yields as determined by water well drillers. In general the results from the two data sets are similar.

Problems associated with the aquifer test database for Eastern Newfoundland include the absence of step-drawdown tests and their short duration. Better and more reliable data are obtained if pumping continues until steady flow has been obtained. In some tests steady flow conditions occur a few hours after the start of pumping; in others, they occur within a few days or weeks; in yet others, they never occur. Kruseman *et al.* (1970) suggest that in a confined aquifer it is good practice to pump for 24 hours; in an unconfined aquifer, because the cone of depression expands slowly, a longer period of at least 72 hours is required.

As presented in Appendix III there were 4,458 pumping tests that took place within the study area and only 4 of these pumping tests were 24 hours or more. In most cases the data reported is incomplete. In addition, step-drawdown tests were either not reported or not conducted as part of the procedure for any of the tests. Aquifer tests are also more likely to be conducted in areas of development where communal water supply systems or engineering works are required, and may be weighted to particular areas within a hydrostratigraphic unit where the dataset is small. Therefore, the aquifer tests conducted in Eastern Newfoundland may not represent a significantly more reliable source of average well yield data than records taken from individual water wells.

Table 5-3: Comparison of Aquifer Test and Water Well Record Yield Estimates

Hydrostratigraphic Unit	Aquifer Test Safe Yield Estimate Data[2] (from Appendix III)			Water Well Record Yield Estimate Data[2] (from Appendix II)		
	No. of tests	Average (L/min)	Range (L/min)	No. of tests	Average (L/min)	Range (L/min)
Unit A **Moderate to High Yield** Till	39	63	5-225	123	59	1.5-227
Unit B **High Yield** Sand and Gravel	56	55	4.5-200	129	54	2-270
Unit 1 **Low to Moderate Yield** Siltstone and Shale Strata	1585	22	0.57-500	3826	20	0.1-546
Unit 2 **Low to Moderate Yield** Sandstone and Conglomerate	760	19	0.6-454	2057	22	0.3-454
Unit 3 **Moderate Yield** Cambro-Ordovician Sedimentary Strata	439	32	0.9-454	1304	29	0.5-591
Unit 4 **Low to Moderate Yield** Volcanic Strata	650	24	1-450	1380	25	0.3-455
Unit 5 **Moderate Yield** Plutonic Strata	23	29	1-182	71	31	0.5-182
Unit 6 **Low to Moderate Yield** Meta Volcanic Strata	40	15	0.6-135	130	18	0.5-296

Notes:
1. The data presented are updated to December, 2009. The information was supplied by the DOEC and was recorded by water well drillers as required under the "Well Drilling Regulations", 1982, and amendments.
2. Not including 0 values.

5.4 GROUNDWATER USAGE

5.4.1 Drinking Water Usage

Approximately 83% of people in Newfoundland and Labrador receive water from public sources and 17% from private sources. The majority of people in the province use surface water to supply their water needs. Approximately 88% of the total serviced population (i.e. on public water supplies) uses surface water from 314 sources and 12% of people rely on groundwater from 293 sources (Source to Tap, 2001).

Of the 11,966 water well records within the study area only 9,600 records provided water usage. Of these, 8,903 are for domestic use, 234 are for municipal use, 150 are for industrial use, 140 are for public supply use, 108 are for commercial use, 63 are for heat pump use, and 2 are for stock use.

Presently, the groundwater resource is primarily utilized by individuals to meet domestic needs. Some communities such as Admiral's Beach, Baine Harbour, Harbour Main, Fermeuse, Holyrood, Makinsons, Eastport, Riverhead, Shoal Harbour and Wabana utilize groundwater as a source of supply, although most communities within the study area exploit surface water. Groundwater also provides vital water supplies for agriculture, a heating and cooling source using heat pumps, golf course irrigation, and fish plants.

6.0 HYDROLOGY

6.1 HYDROLOGICAL CYCLE

The hydrologic cycle for a region typically starts with precipitation in the form of rainfall or snowfall. A portion of the rainfall is returned back into the atmosphere in the forms of evaporation or transpiration by the vegetation cover on the ground surface. Depending on the ground moisture conditions at the time of the precipitation event, a portion of the remaining rainfall may generate surface runoff, which feeds into the streams and causes relatively rapid rise in stream flow. The remainder of the rainfall will percolate down to the groundwater table; from there it will migrate slowly toward and feed into the receiving stream in the form of base flow. Base flow input into a stream may continue long after the surface runoff ceases. The hydrological cycle for snowfall is similar to that for rainfall. However, snowfall generally becomes accumulated through the winter and generates runoff in the spring when the temperature rises above freezing. A much lower proportion of the snowfall will be lost to evaporation and transpiration than rainfall due to lower temperature and significantly reduced consumption by the ground vegetation cover.

Many factors govern the hydrological cycle, and proportioning of the total precipitation into the various hydrological components. The most significant factors include temperature, topography, vegetation cover, soil conditions, and significant drainage features of the watershed (e.g., large lakes). Many of these factors vary seasonally and from watershed to watershed.

This section provides a generalized hydrological condition for the study region. It is understood that the presented hydrological condition may not be representative of a local area due to its hydrologic characteristics that are significantly different from the average conditions of the study region.

6.2 DIVISION OF HYDROLOGICAL REGIONS

Environment Canada divides all the watersheds across Canada into main divisions, sub-divisions, and sub-sub divisions for the purpose of planning a hydrometric station network. The hydrologic condition in the same drainage sub-sub division is considered more comparable than with other sub-sub divisions. Figure 6-1 illustrates the drainage divisions identified by Environment Canada covering the study area. There are a total of seven sub-sub divisions (divided by the dash line) belonging to the same sub-divisions (divided by the solid line) within the study area.

All the drainage sub-sub divisions in the study area have stream flow gauging stations historically and/or at the present time. However, the periods of data available for these hydrometric stations vary significantly, which can make it difficult to compare the stream flow for one sub-sub division with another. Considering the drainage divisions developed by Environment Canada, the topographic features, and annual precipitation distribution, the study area is divided into three sub-regions for the purpose of this study, as follows:

- Sub-region 1: encompasses drainage sub-sub divisions of 2ZG, 2ZH;
- Sub-region 2: encompasses drainage sub-sub divisions of 2ZK, 2ZM and 2ZN; and
- Sub-region 3: encompasses drainage sub-sub division of 2ZL, 2ZJ.

6.3 CLIMATIC CONDITIONS

Environment Canada prepares climate norms for the available meteorological stations based on 30 year records. The latest climate norms were prepared based on meteorological records for the period from 1971 to 2000. These data are available online (http://climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html). Among the meteorological stations listed for Newfoundland at the website, 12 are identified to be located in the study region. These meteorological stations are provided in Table 6-1, and are grouped according to the hydrological sub-regions discussed above. The monthly temperature, rainfall, and precipitation for each meteorological station and the average conditions for the sub-region are calculated (see Table 6-2). A summary of the monthly average temperature and precipitation conditions for each of the hydrological sub-regions identified is also provided in Table 6-2. The snowfall amount presented in Table 6-2 is calculated as the difference between total precipitation and total rainfall.

In the preparation of Table 6-2, the average conditions for the sub-region are calculated as the arithmetic mean of the corresponding values for all the meteorological stations located in that sub-region. It is recognized that, since the meteorological stations are typically located along the coast at low elevations, the values presented in Table 6-2 are more representative of these areas. It is possible that the watershed areas with high topography and large distance from the coast may exhibit somewhat different climatic characteristics from the summary presented in Table 6-2. The availability of data does not permit a thorough evaluation of the climatic conditions as they vary with topography and distance from the coast.

Table 6-2 indicates that the annual precipitation amounts for the two sub-regions along the southern and southeastern coast range from 1473.2 mm for Sub-region 2 to 1528.9 mm for Sub-region 1, and are generally comparable. The precipitation amount for Subregion 3 along the northern coast is 1242.8 and is somewhat lower than for the two other sub-regions.

The average monthly precipitation for the three sub-regions is shown in Figure 6-2. Average precipitation for the three sub-regions are somewhat higher in the fall, but are otherwise relatively evenly distributed through the year.

The summer in the study area is mild. Although the average temperature in the winter months is below freezing, temperatures throughout the study area do rise above freezing often and a high proportion of the precipitation in the winter is in the form of rainfall.

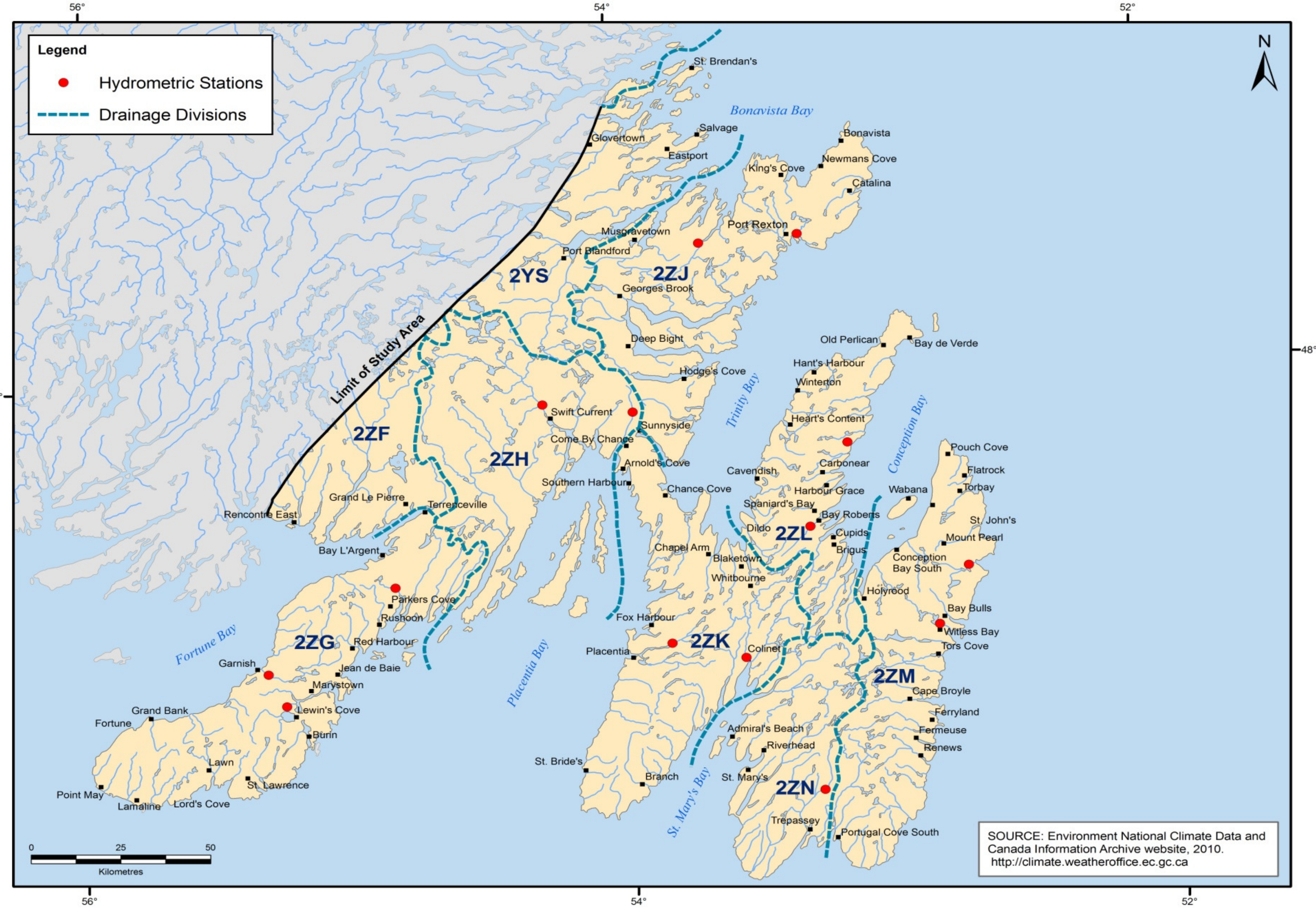

Figure 6-1: Drainage Divisions within the Study Area

Table 6-1: Climate Stations within the Study Area Grouped into Sub-regions

Station Name	Latitude	Longitude	Elevation	Drainage Sub-sub Division
Sub-region 1				
St. Lawrence	49° 55′ N	56° 23′ W	49 m	2ZG
Boat Harbour	49° 25′ N	56° 50′ W	15 m	2ZG
Swift Current	49° 53′ N	56° 12′ W	18 m	2ZH
Sub-region 2				
Long Harbour	47° 25′ N	53° 49′ W	8 m	2ZK
Colinet	47° 13′ N	53° 33′ W	27 m	2ZK
St. Mary's	46° 55′ N	53° 34′ W	16 m	2ZN
Cappahayden	46° 52′ N	52° 57′ W	15 m	2ZM
St. John's Airport	47° 37′ N	52° 44′ W	141 m	2ZM
Sub-region 3				
Hearts Content	47° 25′N	53° 23′ W	9 m	2ZL
New Chelsea	48° 02′N	53° 13′ W	9 m	2ZL
Lockston	48° 24′N	53° 23′ W	18 m	2ZJ
Port Union	48° 30′N	53° 05′ W	6 m	2ZJ

Notes:
1. Data obtained from National Water Data Archive provided by Environment Canada, Water Survey Branch.

Table 6-2: Hydrologic Budget for Eastern Newfoundland

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Sub-region 1 (2ZG, 2ZH)													
Temperature	-4.9	-5.3	-2.4	2.3	6.4	10.2	14.3	15.6	12.2	7.3	2.8	-1.9	4.7
Rainfall(mm)	80.2	73.5	88.6	107/9	104.4	121.9	109.0	103.7	145.6	152.7	129.8	94.5	1311.3
Snowfall (mm)	59.8	54.0	35.3	10.5	1.8	0.1	0.0	0.0	0.0	1.3	13.6	41.4	217.7
Precipitation (mm)	139.9	127.4	123.9	118.4	106.2	122.0	109.0	145.6	145.6	154.0	143.3	135.8	1528.9
Runoff Depth (mm)	134.4	108.4	148.2	193.6	133.1	83.3	64.0	88.2	88.2	132.0	137.3	138.7	1415.1
Sub-region 2 (2ZK, 2ZM, 2ZN)													
Temperature	-3.9	-4.3	-1.6	2.5	6.4	10.4	14.7	15.5	12.3	7.6	3.4	-1.2	5.2
Rainfall(mm)	88.2	74.5	93.5	96.5	99.1	113.3	103.1	110.1	128.9	145.8	128.3	99.0	1280.4
Snowfall (mm)	51.1	44.5	32.6	13.6	2.8	0.3	0.0	0.0	0.0	1.0	11.2	35.9	192.8
Precipitation (mm)	139.3	119.0	126.1	110.1	102.0	113.7	103.1	110.1	128.9	146.7	139.5	134.9	1473.2
Runoff Depth (mm)	130.4	103.2	141.0	142.7	94.7	64.1	53.0	46.3	69.0	111.9	119.0	118.6	1194.4
Sub-region 3 (2ZL, 2ZJ)													
Temperature	-4.3	-4.8	-1.6	2.4	6.4	11.0	15.5	16.2	12.5	7.5	3.3	-1.5	5.2
Rainfall(mm)	59.2	47.6	63.5	79.8	80.6	86.8	84.6	89.4	115.8	141.5	109.4	71.6	1029.8
Snowfall (mm)	52.4	52.3	35.8	15.7	2.0	0.2	0.0	0.0	0.0	1.3	12.1	41.3	213.0
Precipitation (mm)	111.6	100.0	99.3	95.5	82.6	87.0	84.6	89.4	115.8	142.8	121.5	112.9	1242.8
Runoff Depth (mm)	86.8	65.9	116.0	194.7	132.6	49.6	35.2	21.9	42.2	87.4	90.8	84.2	1013.4

Notes:
1. Climate data obtained from National Water Data Archive provided by Environment Canada, Water Survey Branch and the National Climate Data and Information Archive website operated and maintained by Environment Canada (Environment Canada, 2010).

Table 6-3: A Summary of the Hydrometric Stations and their Locations in the Identified Sub-regions

Station Name	Drainage Sub-sub Division	Regulation Type	Drainage Area (km^2)	Period of Record	Latitude	Longitude
Sub-region 1						
Garnish River near Garnish	02ZG001	Natural	205	1958-2008	47°12'59" N	55°19'48" W
Tides Brook below Freshwater Pond	02ZG002	Natural	166	1977-1997	47°7'38" N	55°15'54" W
Rattle Brook near Boat Harbour	02ZG004	Natural	42.7	1981-2008	47°27'0" N	54°51'10" W
Pipers Hole River at Mothers Brook	02HG001	Natural	764	1952-2008	47°56'48" N	54°17'3" W
Come by Chance River near Goobies	02ZH002	Natural	43.3	1961-2008	47°55'7" N	53°56'55" W
Sub-region 2						
Rocky River near Colinet	02ZK001	Natural	301	1948-2008	47°13'37" N	53°34'7" W
Northeast River near Placentia	02ZK002	Natural	89.6	1979-2008	47°16'26" N	53°50'19" W
Northwest Brook at Northwest Pond	02ZN001	Natural	53.3	1966-1996	46°51'8" N	53°18'11" W
Petty Harbour River at Second Pond	02ZM001	Regulated	134	1962-2008	47°27'27" N	52°43'47" W
Pierres Brook at Gull Pond	02ZM002	Regulated	117	1962-2008	47°17'50" N	52°51'0" W
Sub-region 3						
Spout Cove Brook near Spout Cove	02ZL003	Natural	10.8	1979-1997	47°48'43" N	53°9'15" W
Shearstown Brook at Shearstown	02ZL004	Natural	28.9	1983-2008	47°34'59" N	53°18'29" W
Southern Bay River near Southern Bay	02ZL001	Natural	67.4	1976-2008	48°22'50" N	53°40'26" W
Salmon Cove River near Chapneys	02ZL002	Natural	73.6	1983-2008	48°23'45" N	53°18'5" W

Data obtained from National Water Data Archive provided by Environment Canada, Water Survey Branch.

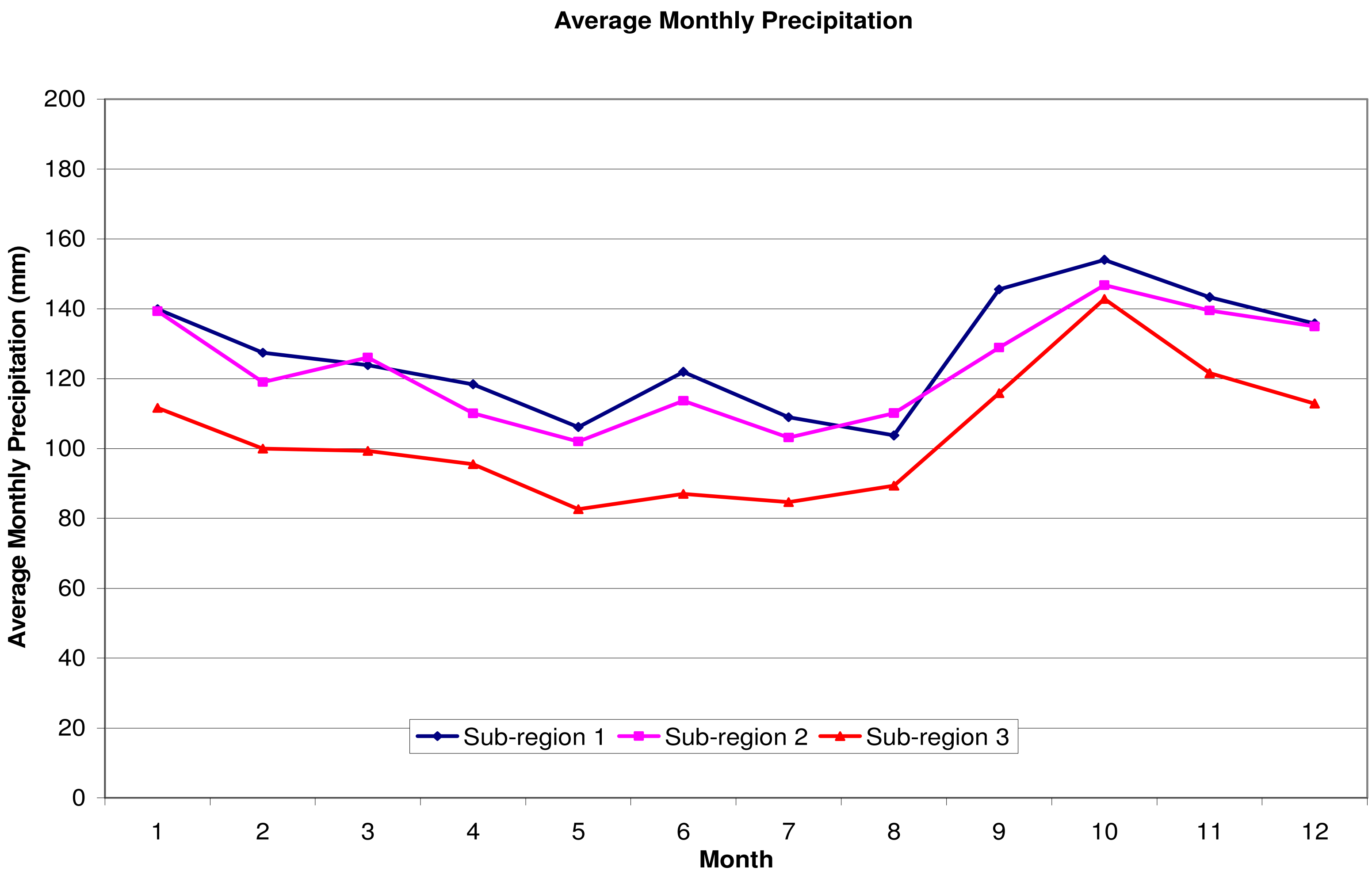

Figure 6-2: Average Monthly Precipitation for the Three Sub-regions

6.4 RUNOFF AND BASEFLOW

Following a precipitation or snowmelt event, surface runoff will be generated which feeds into the streams and causes relatively rapid rise in stream flow. A portion of the rainfall and snowmelt will also percolate down to the groundwater table; from there it will migrate slowly toward and feed into the receiving stream where it will form a component of the baseflow, along with water released from storage in lakes, ponds, bogs, and water migrating through the shallow subsurface. Base flow input into a stream may continue long after the surface runoff ceases.

Water Survey Canada operates a network of hydrometric stations that measure stream flow. The measured stream flow represents the combination of surface runoff and baseflow, which is termed total runoff for the purposes of this report. Hydrological procedures are available to separate the total runoff into surface runoff and baseflow. The following sections discuss the selection of hydrometric stations to obtain representative total runoff for the sub-regions, and estimate baseflow and surface runoff using the representative total runoff data.

6.4.1 Selection of Representative Hydrometric Stations

There are numerous hydrometric stations in the study region. A summary of the hydrometric stations with relatively long flow record periods and the location of the stations in the identified sub-regions is provided in Table 6-3. To evaluate the hydrological characteristics of the identified sub-regions, it is necessary to select a limited number of hydrometric stations whose hydrological characteristics will be considered representative of that sub-region. The following considerations have been identified in the selection of the representative hydrometric stations:

- The selected hydrometric stations should preferably have flow records for the period from 1971 to 2000 so that the calculated runoff, expressed in mm/year, can be compared with precipitation norms determined by Environment Canada;
- The flow for the selected hydrometric stations should preferably be unregulated by man-made hydraulic structures; and
- Watersheds with significantly higher than average storage features (e.g. large lakes) should be avoided as these features can significantly affect the stream flow characteristics.

Based on the above considerations, a hydrometric station was selected from each of the identified three sub-regions as follows, whose hydrological conditions will be considered representative for that sub-region:

- Sub-region 1: Garnish River near Garnish (02ZG001)
- Sub-region 2: Rocky River near Colinet (02ZK001)
- Sub-region 3: Southern Bay River near Southern Bay (02ZJ001)

6.4.2 Total Runoff

The monthly and total annual runoff estimated for the identified representative hydrometric stations using flow records for the period from 1971 to 2000 is provided in Table 6-2. The monthly runoff distributions for the study area are shown in Figure 6-3. Runoff in the study area exhibits significantly higher seasonal variation than precipitation. The highest runoff generally occurs in the spring, when snow accumulation through the winter months melts. The lowest runoff generally occurs in the summer when evaporation and transpiration by the ground vegetation cover is the highest. The runoff depth increases again in the fall when precipitation increases and evaporation and transpiration decreases.

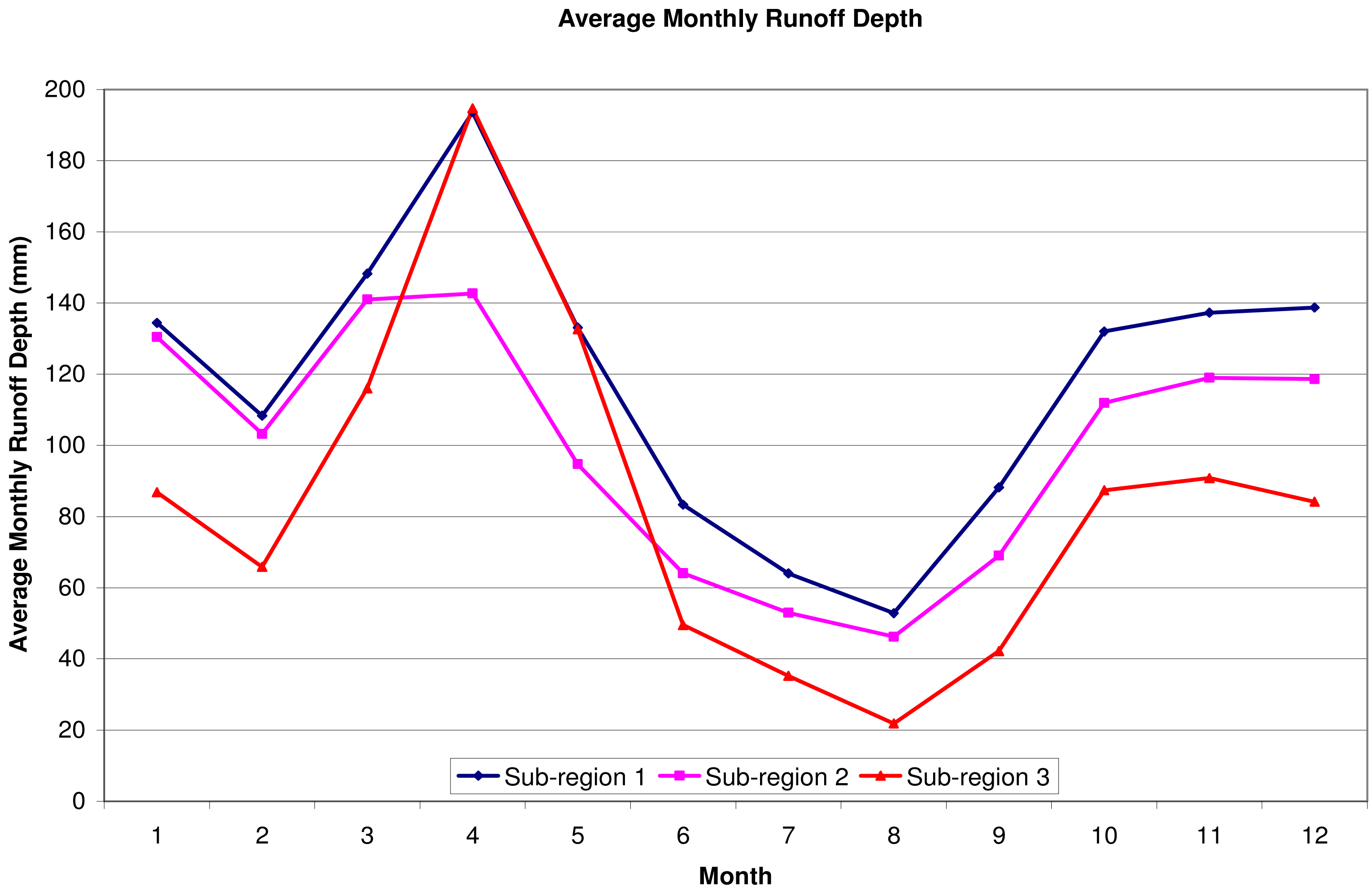

Figure 6-3: Average Monthly Runoff Depth for the Three Sub-Regions

6.4.3 Baseflow and Surface Runoff

To determine the baseflow portion of the total runoff, it is necessary to analyze the daily runoff records for an average year. The annual flows as a ratio of the average for the period from 1971 to 2000 for the identified representative hydrometric stations are shown in Figure 6-4. For any given year, if the ratio is above one, it is a relatively wet year. If the ratio is below one, it is a relatively dry year. When the ratio is close to one, the flow condition for that year is near average. As shown in Figure 6-4, in 1986 the flows for the three representative hydrometric stations are all close to average conditions, therefore the daily flow records for 1986 are used to represent an average year condition.

The baseflow contributions to total stream flow for the representative hydrometric stations are shown in Figure 6-5 to 6-7 for 1986. The total annual baseflow contributions to stream flow expressed as a depth over the watershed area, as estimated using Figure 6-5 to 6-7, are also summarized in Table 6-4. On an annual basis, the base flow contribution to total runoff for the three sub-regions is calculated to be 50% for Sub-region 1, 37% for Sub-region 2, and 42% for Sub-region 3.

Baseflow contribution to total annual runoff includes groundwater and water released from lakes, ponds, and bogs. For Newfoundland, which has a high proportion of boggy terrain, the baseflow contribution will include a significant amount of water stored in bogs, particularly during wet periods. The baseflow contributions for the three sub-regions as determined above are somewhat comparable, and the cause for the differences are not immediately apparent. Many factors affect this parameter, including precipitation, soil and geological conditions, topography, the presence of large lakes and bog cover. For example, in regions with high precipitation, the watershed becomes relatively more saturated, and a higher proportion of precipitation becomes surface runoff than for regions with low precipitation. Under these conditions, the proportion of baseflow contribution to total runoff is reduced. In watersheds with high slope, the precipitation will have less opportunity to infiltrate to groundwater table to generate baseflow, and baseflow contribution to total annual runoff is reduced. A combination of these factors could have contributed to the difference of this parameter between the regions.

Table 6-4: Summary of Annual Hydrologic Budget for Eastern Newfoundland

Description	Annual Depth (mm)
Sub-region 1 (2ZG, 2ZH)	
Precipitation	1528.9
Runoff Depth	1415.1
Surface Runoff	709.4
Baseflow	705.7
Evaporation and transpiration estimated by subtracting total runoff from precipitation	113.8
Evaporation and transpiration estimated based on Environment Canada study	510.0
Sub-region 2 (2ZK, 2ZM, 2ZN)	
Precipitation	1473.2
Runoff Depth	1194.4
Surface Runoff	748.2
Baseflow	446.2
Evaporation and transpiration estimated by subtracting total runoff from precipitation	278.8
Evaporation and transpiration estimated based on Environment Canada study	512.0
Sub-region 3 (2ZL, 2ZJ)	
Precipitation	1242.8
Runoff Depth	1013.4
Surface Runoff	588.0
Baseflow	425.3
Evaporation and transpiration estimated by subtracting total runoff from precipitation	229.5
Evaporation and transpiration estimated based on Environment Canada study	480.0

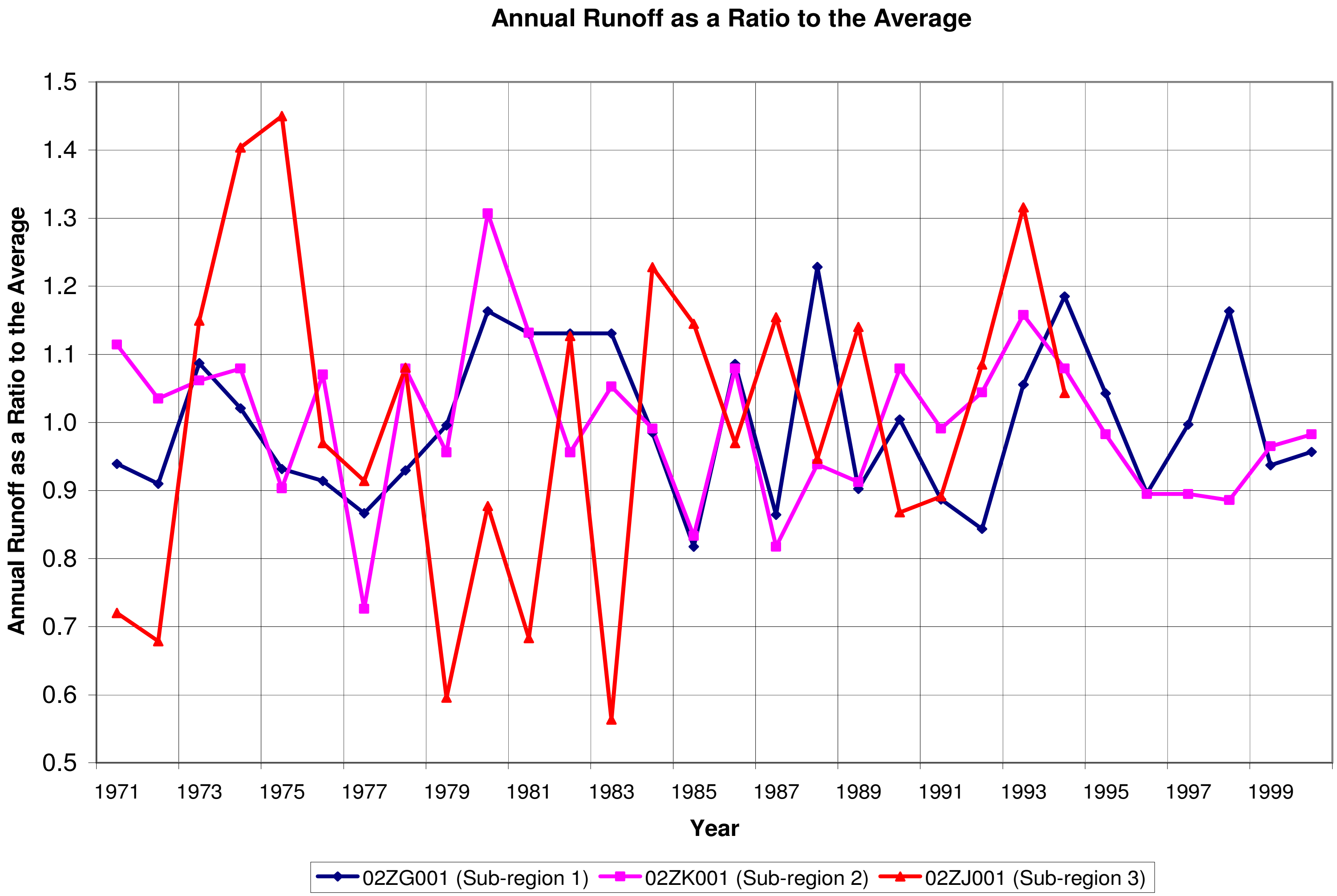

Figure 6-4: Average Runoff as a Ratio to the Average in the Three Sub-regions

6.5 HYDROLOGICAL BUDGET

Table 6-4 summarizes the major hydrological components for the three sub-regions identified for the study area. On an annual basis, the total runoff represents generally between 81 to 93 percent of total annual precipitation. These annual runoff ratios seem high. The hydrological Atlas of Canada prepared by Environment Canada explained that the high and unlikely runoff ratio "seems to be inadequate areal estimates of precipitation, for which three specific causes can be isolated. First, the precipitation network provides inadequate representative measurements. This is especially true in mountainous regions where precipitation stations are usually located in the valleys, although higher values of precipitation occur at higher altitudes. This results in an underestimation. Secondly, precipitation gauges tend to catch less than the true precipitation. This undercatch is related in a complicated manner to the gauge dimensions, wind speed, and type of precipitation. Solid precipitation is affected to a much greater extent than liquid precipitation, and in general, the higher the wind speed, the greater the undercatch. The undercatch problem is accentuated when stations are located in open sites where the wind speeds are higher. The third cause relates specifically to snowfall measurement". "The measured depth of snow is converted to water equivalent, using a density factor of 0.1. This ratio is known to vary significantly from place to place".

Annual evapotranspiration is estimated as the difference between the total precipitation and annual runoff, and ranges from 113.8 mm for Sub-region 1 to 278.8 mm for Sub-region 2 (see Table 6-4). Due to possible underestimate of the total annual precipitation, it is possible that the actual evapotranspiration for the three regions is higher than those calculated using this method.

Table 1-3 presents potential and actual evapotranspiration calculated by Environment Canada. Using these data, the evapotranspiration for the three sub-regions can be estimated, as presented in Table 6-4. The evapotranspiration calculated by Environment Canada for the three sub-regions ranges from 480 mm to 520 mm annually, and is consistent over the three sub-regions. These values are much higher than the evapotranspiration calculated using available precipitation and stream flow data. Assuming the evapotranspiration calculated by Environment Canada is representative, it can be calculated that the precipitation network underestimate the actual annual precipitation over the watershed by 233.2 mm and 396.2 mm.

As indicated in Table 6-4, the annual runoff depth for the three sub-regions ranges from 1013.4 mm for sub-region 3 to 1415.1 mm for sub-region 1. On an annual basis, the baseflow component of runoff is estimated to range from 425.3 mm for Sub-region 3 to 705.7 mm for Sub-region 1 for 1986, which is assumed to exhibit typical or average conditions. Over the long term, the groundwater discharge is equal to groundwater recharge, and the baseflow estimate provides an indication of maximum annual groundwater recharge. During the summer, flow decreases significantly as precipitation decreases and evapotranspiration increases causing the bogs to release less water to the creeks.

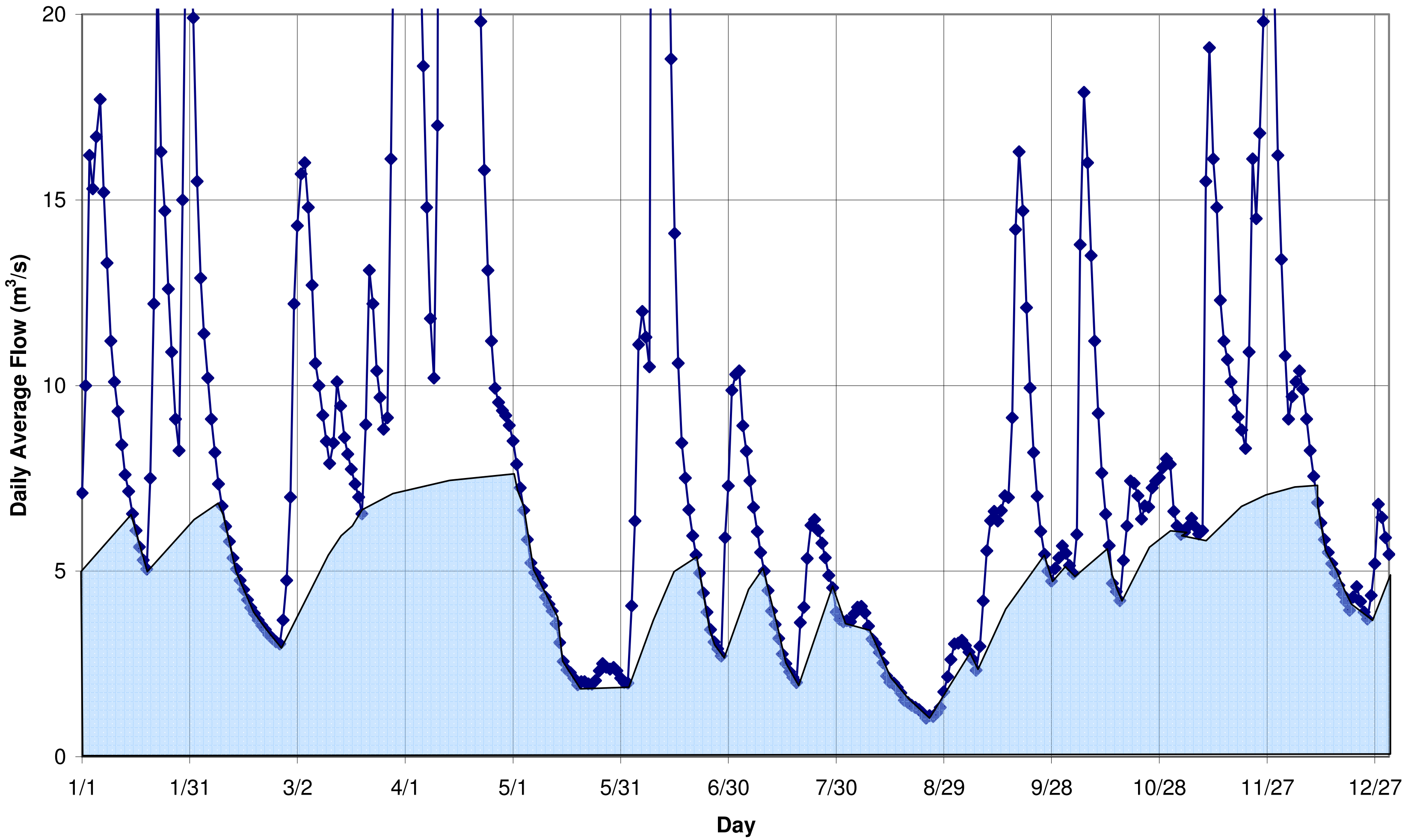

Figure 6-5: Baseflow Separation for the Hydrometric Station 02ZG001 (Sub-region 1) for 1986

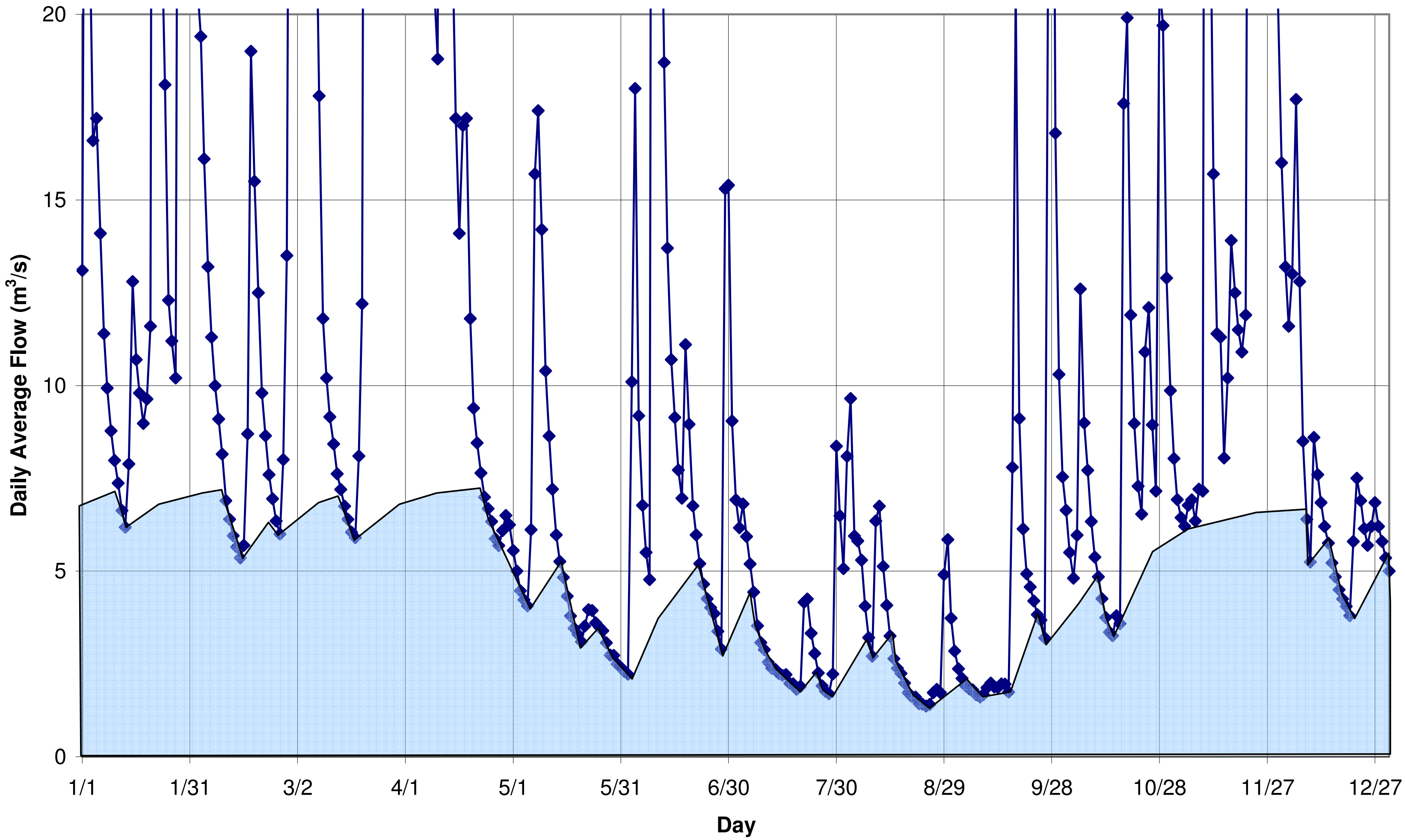

Figure 6-6: Baseflow Separation for the Hydrometric Station 02ZK001 (Sub-region 2) for 1986

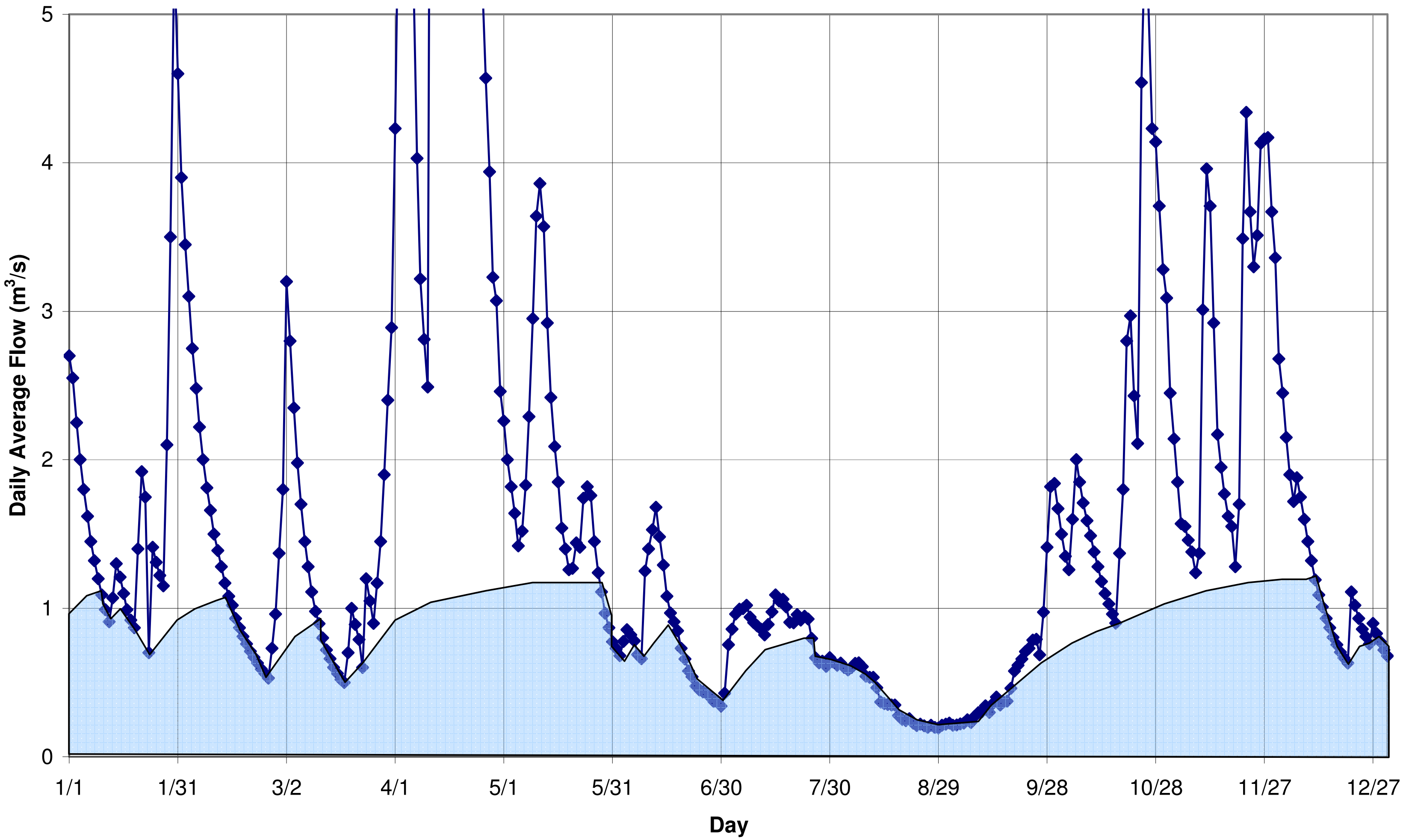

Figure 6-7: Baseflow Separation for Hydrometric Station 02YR001 (Sub-region 3) for 1986

7.0 WATER QUALITY

Existing surface water and groundwater quality data were obtained from the Drinking Water Quality Database from the DOEC, Water Resources Management Division. These data are collected as part of a public water supply testing program and include water quality results from source waters from sampled communities located in Eastern Newfoundland. Tabulated analytical results are presented in Appendix IV.

The Water Quality Index (WQI) was developed by the Canadian Council of the Ministers of the Environment in 2001 (CCME, 2001) with the intent of providing a tool for simplifying the reporting of water quality data. It is used by the DOEC and is 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 Guidelines for Canadian Drinking Water Quality (Health Canada, 2006). An explanation of how the calculation is computed and what the rankings mean is provided in Appendix V.

The quality of surface and groundwater resources is assessed with the objectives of identifying existing or potential water quality problems. However, the water of even the healthiest sources is not absolutely pure. All water (even if it is distilled) contains many naturally occurring substances – mainly bicarbonates, sulphates, sodium, chlorides, calcium, magnesium, and potassium. They reach the surface and groundwater from:

- soil, geologic formations and terrain in the catchment area (river basin);
- surrounding vegetation and wildlife;
- precipitation and runoff from adjacent land;
- biological, physical and chemical processes in the water; and
- human activities in the region.

Water hardness is primarily the amount of calcium and magnesium, and to a lesser extent, iron in the water. The optimum range of hardness in drinking water is from 80 to 100 mg/L. Groundwater tends to be harder than surface water and can range to greater than 1000 mg/L. Water hardness in most groundwater is naturally occurring from weathering of limestone, sedimentary rock and calcium bearing minerals. Hardness can also occur locally in groundwater from chemical and mining industry effluent or excessive application of lime to the soil in agricultural areas. It is also generally the case that groundwater becomes more saline with increasing depth.

7.1 SURFACE WATER QUALITY

There are 1953 surface water quality records from 104 source waters within the study area. Parameters that exceed the GCDWQ include colour, pH, turbidity, iron, lead and manganese. The WQI ratings vary from fair to excellent. The public water supply's located in Bellevue Beach, Come By Chance, Harbour Mille, Little Harbour East, Point Lance and St. Bride's had the lowest rating (fair) in the study area.

The physical quality of the water is generally acceptable throughout the study area with the exception of colour. Of the 1953 surface water samples, 1395 exceeded the GCDWQ of 15 true colour units (TCU) (Health Canada, 2008). The average colour value recorded for all surface water samples is 38 TCU, with minimum and maximum values of 0 TCU and 292 TCU, respectively. High colour values are typical of surface waters near wetlands in Newfoundland and Labrador. Wetland drainage contributes high levels of colour to surface runoff; whereas less organic soils or exposed bedrock in a basin contribute little to no colour.

Turbidity is a measure of how cloudy water appears and results from suspended solids and materials, such as clay and silt or microorganisms in the water. It may also be caused by naturally occurring silt and sediment runoff from watersheds. Disturbed areas, such as those with road construction, tend to have higher levels of turbidity than undisturbed areas because of increased sediment input. The average turbidity recorded for all surface water samples is 0.6 nephelometric turbidity units (NTU) with minimum and maximum values of 0 NTU and 12.8 NTU, respectively. Approximately 10% of samples exceeded the GCDWQ of 1 NTU (Health Canada, 2008).

The average pH value recorded for all water supplies is 6.2, with minimum and maximum values of 4.2 and 7.7 respectively. Approximately 70% of surface water samples had average values below the guideline for drinking water of 6.5–8.5 pH units (Health Canada, 2008). Low pH values are typical of surface waters in Newfoundland and Labrador, due to large amounts of organic materials produced by bogs, swamps and boreal forest. In addition, water tends to be slightly more acidic throughout the study area where the underlying geology is primarily granitic rocks and there is little limestone to buffer the acidity.

Approximately 15% of samples exceeded the 0.3 mg/L drinking water guideline for iron and the 0.05 mg/L drinking water guideline for manganese. Iron and manganese concentrations are primarily an aesthetic objective and do not present a health concern unless in excessive concentrations. The ions enter the water system through geochemical weathering and from native soils and bedrock.

7.2 GROUNDWATER QUALITY

Groundwater quality is dependent on the chemical properties of bedrock and overlying unconsolidated sediments. 1006 groundwater quality records were reviewed from 115 source waters within 60 communities located in the study area. These source waters are from municipal wells that are collected as part of a public water supply testing program. For the most part, the chemical composition of the groundwater reflects the geochemistry of the adjacent bedrock or unconsolidated sediments and is similar to the surface water chemistry. However, because the groundwater is less dilute, the concentrations of dissolved constituents tend to be higher than the corresponding surface water.

No information regarding well type, well depth or lithology was provided by DOEC. Assignment of the water chemistry data to various hydrostratigraphic units is based entirely upon the geologic units underlying the various communities. Due to the limited information available, all water chemistry data is assigned to the bedrock hydrostratigraphic units. Where it existed, the groundwater chemistry was compared to the hydrostratigraphic unit based on major ion chemistry represented by trilinear diagrams (explained in Section 7.2.1) and the WQI.

The presence of a specific element or compound and its concentration in groundwater are directly linked to both the geological material through which the groundwater flows, and the physical, hydrological, and meterological conditions within the region. Parameters that exceed the GCDWQ within the study area include colour, pH, turbidity, TDS, chloride, arsenic, barium, cadmium, iron, lead, manganese, mercury and selenium. The WQI ratings vary from fair to excellent.

7.2.1 Trilinear Diagrams

The major ionic species in most natural waters are Na^+, K^+, Ca^+, Mg^+, Cl^-, CO_3^{2-}, HCO_3^-, and SO_4^{2-} (Fetter, 1994). A trilinear diagram can show the percentage composition of three ions. By grouping Na^+ and K^+ together, the major cations can be displayed on one trilinear diagram. Likewise, if CO_3^{2-} and HCO_3^- are grouped, there are also three groups of the major anions. Figure 7-1 demonstrates the form of a trilinear diagram that is commonly used in water-chemistry studies (Piper, 1944). Analyses are plotted on the basis of the percent of each cation (or anion). The diamond-shaped field between the two triangles is used to represent the composition of water with respect to both cations and anions.

The diagram presented in Figure 7-1 is useful for visually describing differences in major-ion chemistry in groundwater flow systems. However, there is also a need to be able to refer to water compositions by identifiable groups or categories. For this purpose, the concept of hydrochemical facies was developed by Back (1966). The term hydrochemical facies is used to describe the bodies of groundwater, in an aquifer, that differ in their chemical composition. The facies are a function of the lithology, solution kinetics, and flow patterns of the aquifer (Back, 1966). As shown in Figure 7-2, hydrochemical facies can be classified on the basis of the dominant ions by means of a trilinear diagram.

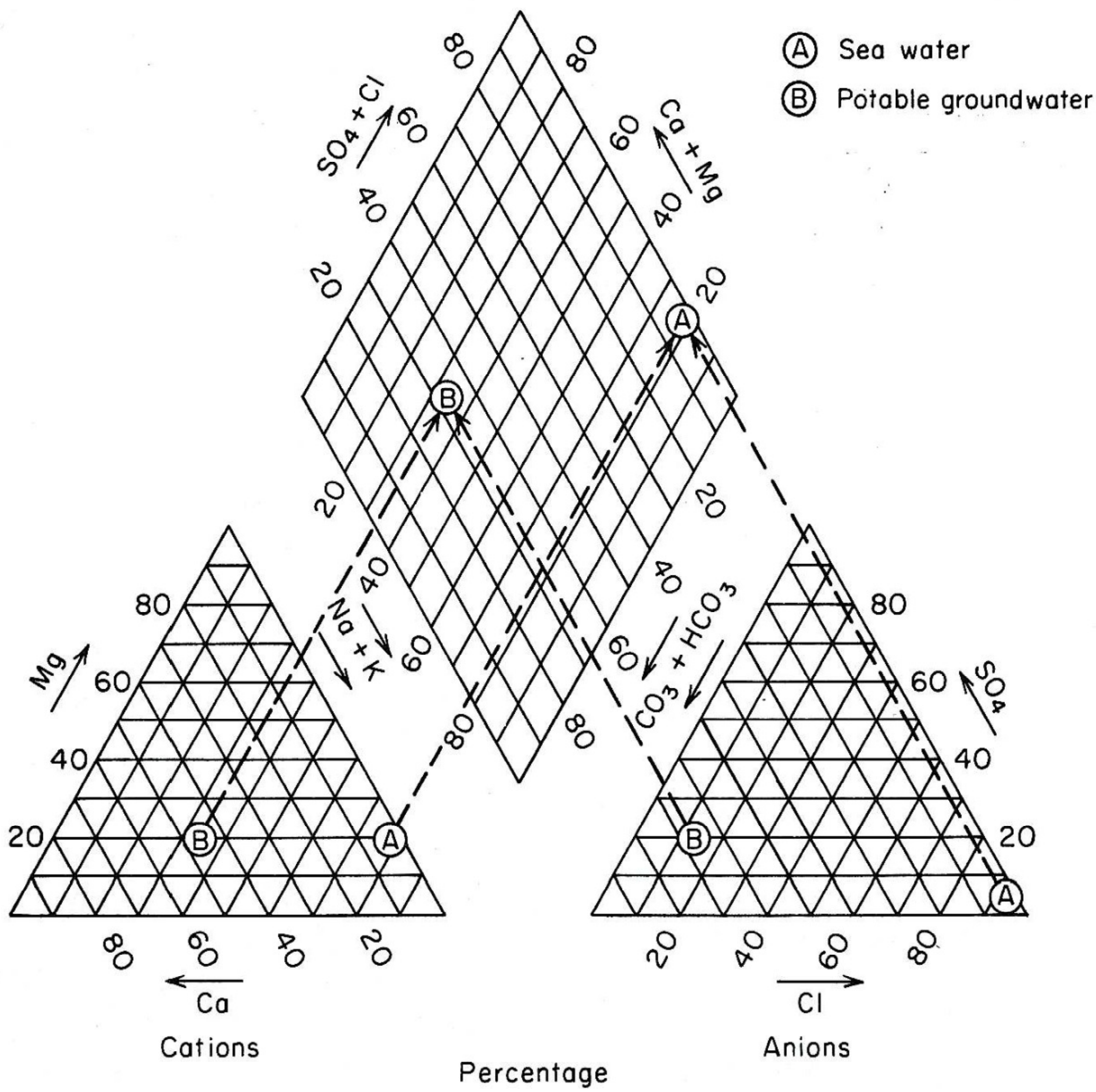

Figure 7-1: Trilinear Diagram of the Type Used to Display the Results of Water-Chemistry Studies (Piper, 1944). Diagram taken from Freeze and Cherry (1979).

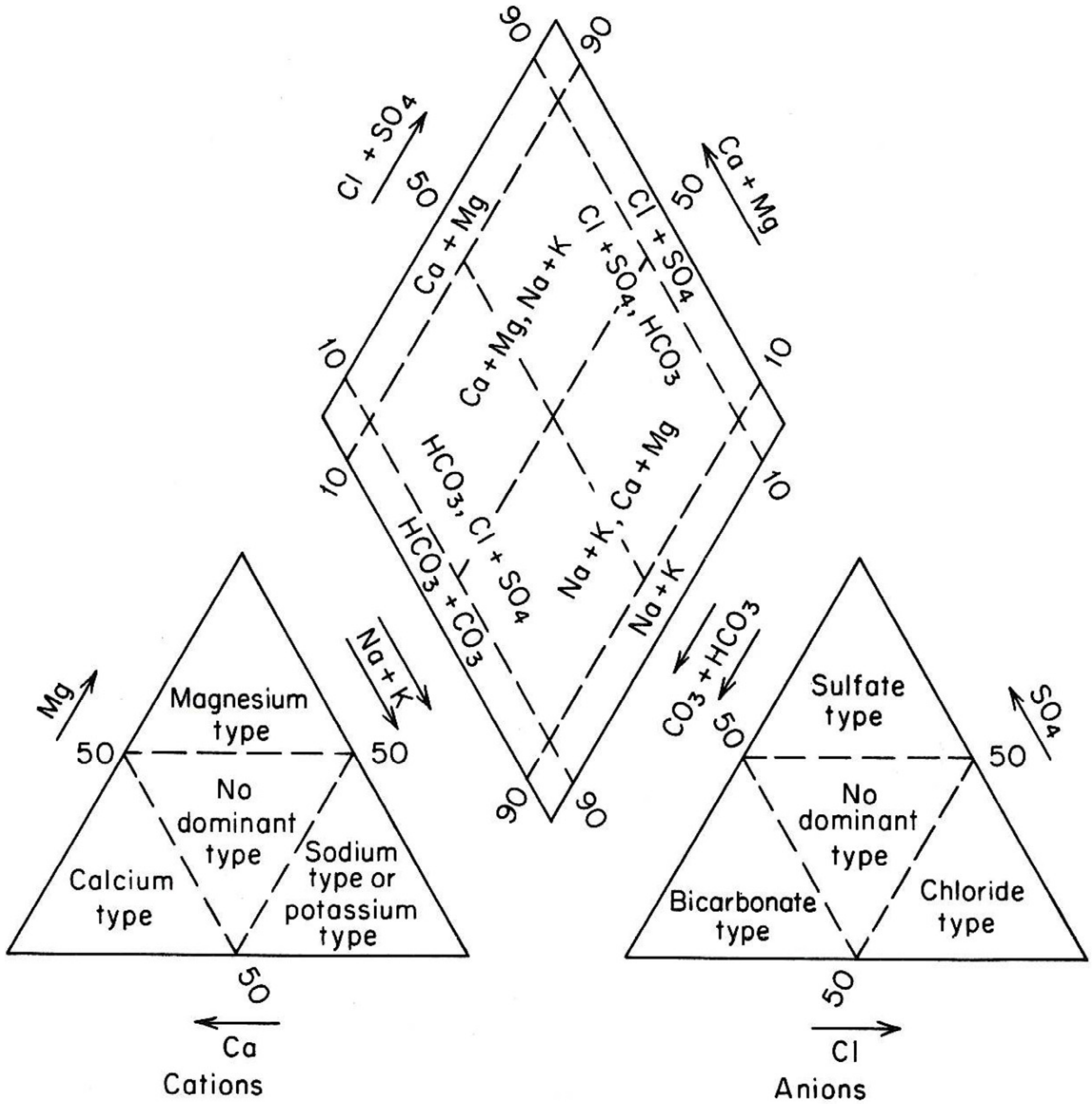

Figure 7-2: Hydrogeochemical Classification System for Natural Waters Using the Trilinear Diagram (Back, 1966). Diagram taken from Fetter (1994).

Trilinear diagrams developed by Piper (1944) in addition to the hydrochemical facies subdivisions developed by Back (1966) were used to visually represent and categorize the major ion data for each hydrostratigraphic unit with water quality data within the study area. The major ion chemistry for each hydrostratigraphic unit commonly involves some combination of calcium, sodium, and bicarbonate. The results are presented in Figures 7-3 to 7-7. Due to the limitations of the data, the comments that can be made are restricted.

Unit 1 –Siltstone and Shale

431 samples from 43 source waters located within 26 communities were identified for Unit 1. Based on the trilinear diagram represented in Figure 7-3, the groundwater from Unit 1 is classified as being calcium bicarbonate type, sodium bicarbonate type, and sodium chloride type. The resulting water types generally indicate low solubility of the parent rock materials. Major ion chemistry usually involves some combination of calcium, chloride, sodium and bicarbonate.

Groundwater often has appreciable hardness and alkalinity (>50 mg/L as $CaCO_3$) and is slightly basic to slightly acidic. Classification of groundwater according to total dissolved solids and specific conductance indicates fresh conditions.

Where ranked, all waters within Unit 1 are classified by the WQI as fair to excellent. Parameters that exceeded the GCDWQ include colour, pH, turbidity, arsenic, copper, iron, lead, manganese, mercury and selenium. The GCDWQ guidelines for colour, pH, copper, iron, and manganese are aesthetic objectives only and levels of these parameters detected in the wells do not pose any health concerns. However, problems may be experienced such as foul taste, deposition or staining, and corrosion.

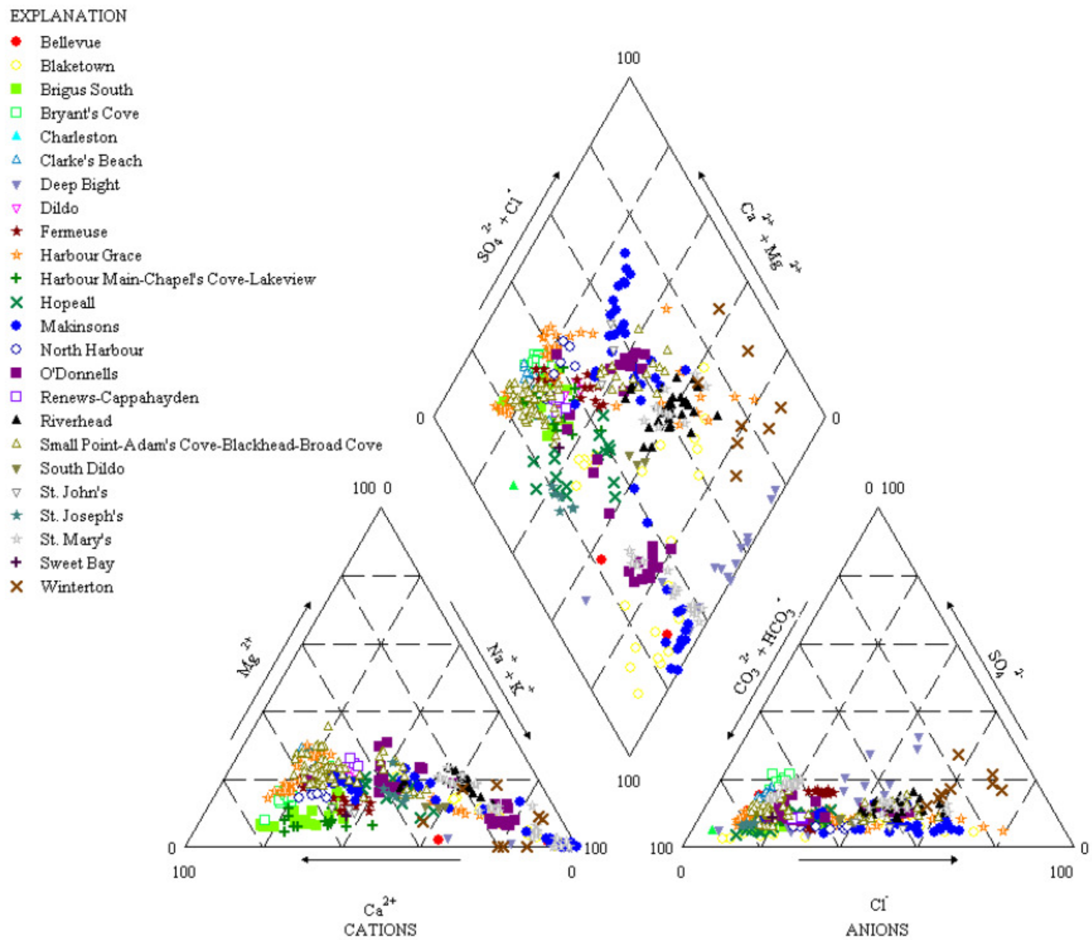

Figure 7-3: Major Ion Chemistry Represented by a Trilinear Diagram for Samples within Bedrock Hydrostratigraphic Unit 1

Unit 2 –Sandstone and Conglomerate

130 samples from 28 sources within 16 communities were identified for Unit 2. Communities with source waters in Unit 2 include Grates Cove, Makinsons and Lower Island Cove. Based on the trilinear diagram presented in Figure 7-4, these waters are classified as either being calcium bicarbonate type or having no dominant type. Major ion chemistry usually involves some combination of calcium and bicarbonate.

The concentration of hardness (due to calcium) and alkalinity (due to bicarbonate) are directly proportional to the availability of carbonate minerals in the bedrock of the flow system. The groundwater in Unit 2 often has appreciable hardness and alkalinity (>50 mg/L as $CaCO_3$) and is slightly basic to slightly acidic. Classification of groundwater according to total dissolved solids and specific conductance indicates fresh conditions.

Where ranked, the water quality is classified as being fair to excellent. Parameters that exceeded the GCDWQ include turbidity, colour, pH, iron, lead and manganese. The GCDWQ guidelines for colour, pH, iron, and manganese are aesthetic objectives.

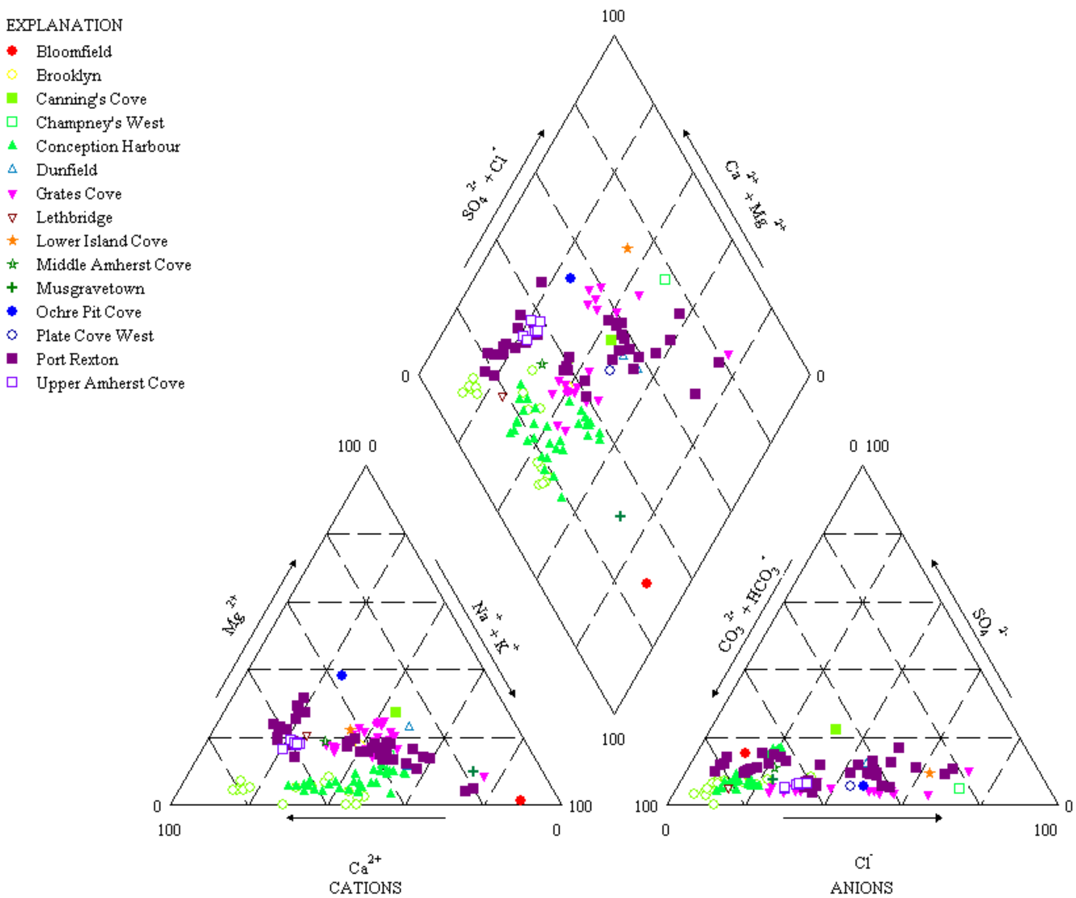

Figure 7-4: Major Ion Chemistry Represented by a Trilinear Diagram for Samples within Bedrock Hydrostratigraphic Unit 2

Unit 3 – Cambro-Ordovician Sedimentary Strata

Sedimentary strata are composed mainly of low soluble minerals and contain soft groundwater. 159 samples from 17 sources within 5 communities were identified for Unit 3. Communities with source waters in Unit 3 include Cavendish, Harcourt-Monroe-Waterville, Lance Cove, Petley and Wabana. Based on the trilinear diagram presented in Figure 7-5, these waters are classified as calcium bicarbonate to sodium bicarbonate type.

Groundwater ranges from very soft to hard, basic to slightly basic and of moderate to high alkalinity. Classification of groundwater according to total dissolved solids and specific conductance indicates fresh conditions.

Where ranked, the water quality is classified as being good to excellent. Parameters that exceeded the GCDWQ include turbidity, colour, pH, iron, and manganese. The GCDWQ guidelines for colour, pH, iron, and manganese are aesthetic objectives.

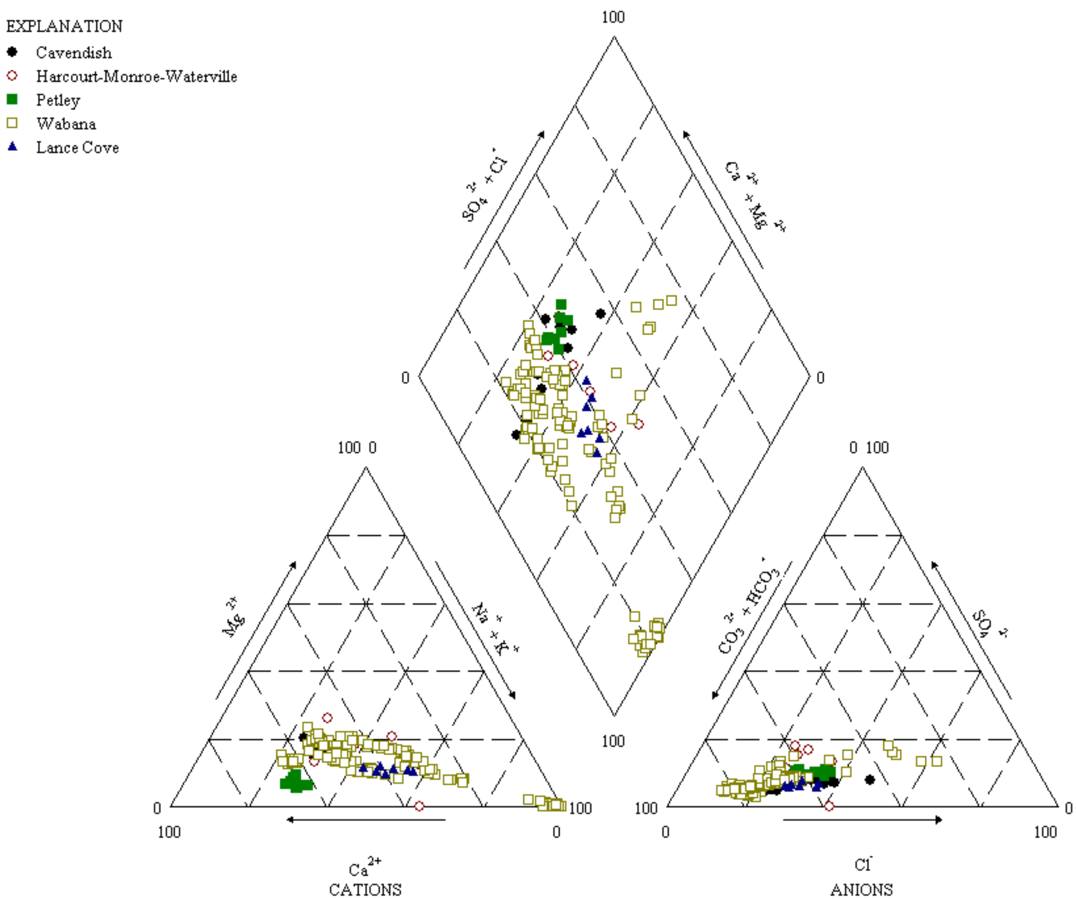

Figure 7-5: Major Ion Chemistry Represented by a Trilinear Diagram for Samples within Bedrock Hydrostratigraphic Unit 3

Unit 4 – Volcanic Strata

There were 230 water samples from 20 source waters within 9 communities identified for Unit 4. Communities with source waters in Unit 4 include Cavendish, Lance Cove and Wabana. Based on the trilinear diagram presented in Figure 7-6, these waters are classified as calcium bicarbonate, sodium chloride or sodium bicarbonate type.

Where ranked, the waters within Unit 4 are classified by the WQI as fair to excellent. Parameters that exceeded the GCDWQ include turbidity, colour, pH, TDS, arsenic, barium, copper, iron, lead, and manganese. The GCDWQ guidelines for colour, pH, iron, copper, and manganese are aesthetic objectives.

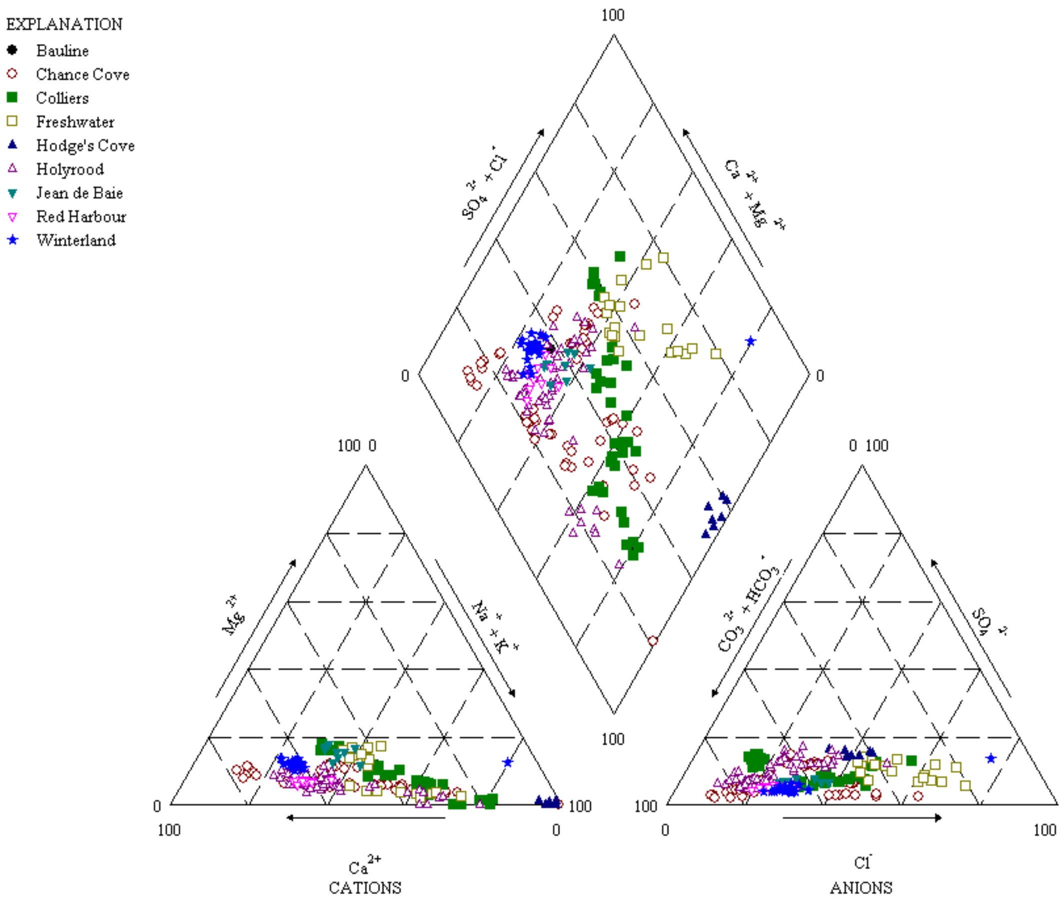

Figure 7-6: Major Ion Chemistry Represented by a Trilinear Diagram for Samples within Bedrock Hydrostratigraphic Unit 4

Unit 5 – Plutonic Strata

14 samples from 2 source waters within 2 communities were identified for bedrock Unit 5. Communities with source waters in Unit 5 include Baine Harbour, and Swift Current. Based on the trilinear diagram represented in Figure 7-7, the groundwater from Unit 5 can generally be described as no dominant type, and sodium-chloride type. The cation base triangle demonstrates a trend from calcium to sodium-potassium dominated water, however with only two sources, within this unit, the conclusions are particularly subject to bias.

Where ranked, the waters within Unit 5 are classified by the WQI as good to very good. Parameters that exceeded the GCDWQ include turbidity, colour, pH, iron and manganese. The GCDWQ guidelines for colour, pH, iron, and manganese are aesthetic objectives.

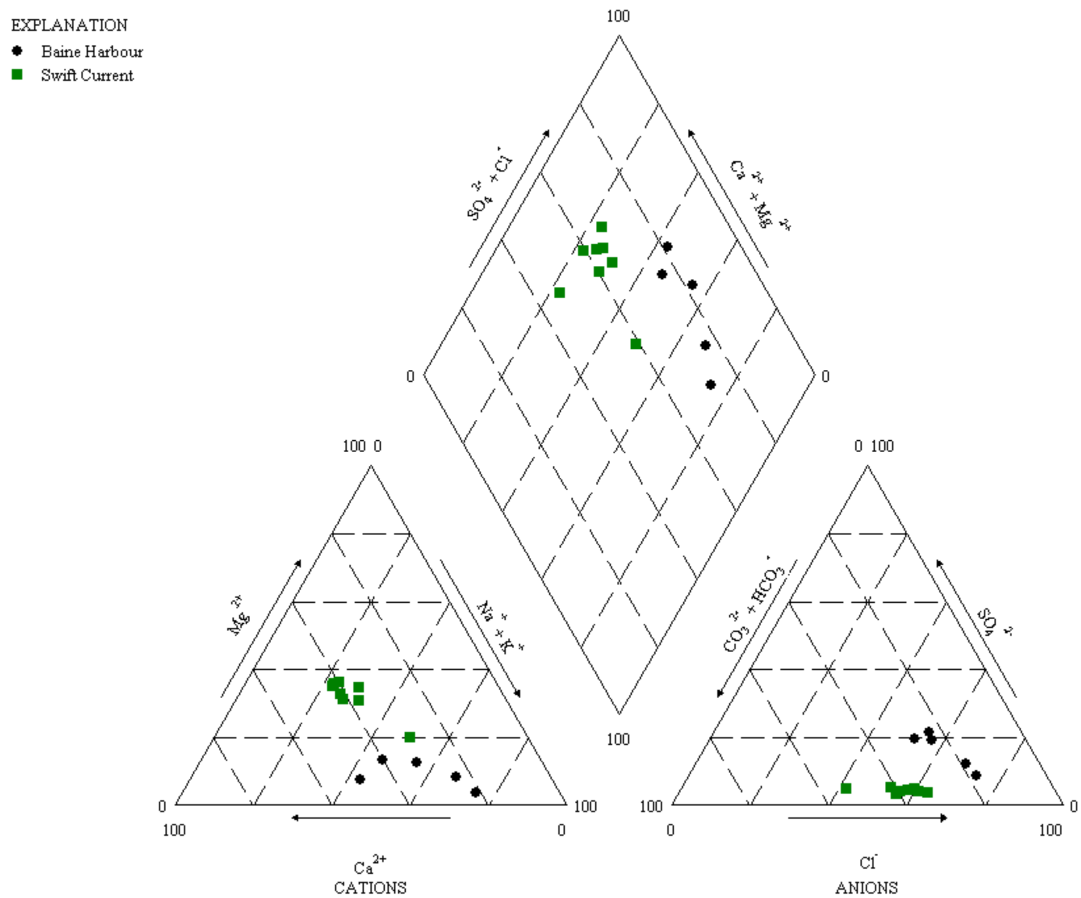

Figure 7-7: Major Ion Chemistry Represented by a Trilinear Diagram for Samples within Bedrock Hydrostratigraphic Unit 5

Unit 6 – Metamorphic Strata

42 samples from 5 source waters within 2 communities were identified for bedrock Unit 6. Communities with source waters in Unit 5 include Bunyan's Cover and North West Brook-Ivany's Cove. Based on the Piper Diagram of these analyses presented in Figure 7-8, these waters are classified as being sodium-bicarbonate type however with only two communities within this unit, the conclusions are subject to bias.

Where ranked, the waters within Unit 6 are classified by the WQI as good to excellent. Parameters that did not to meet the GCDWQ include colour, pH, Turbidity, chloride, arsenic, iron and manganese. The GCDWQ guidelines for colour, pH, chloride, iron, and manganese are aesthetic objectives.

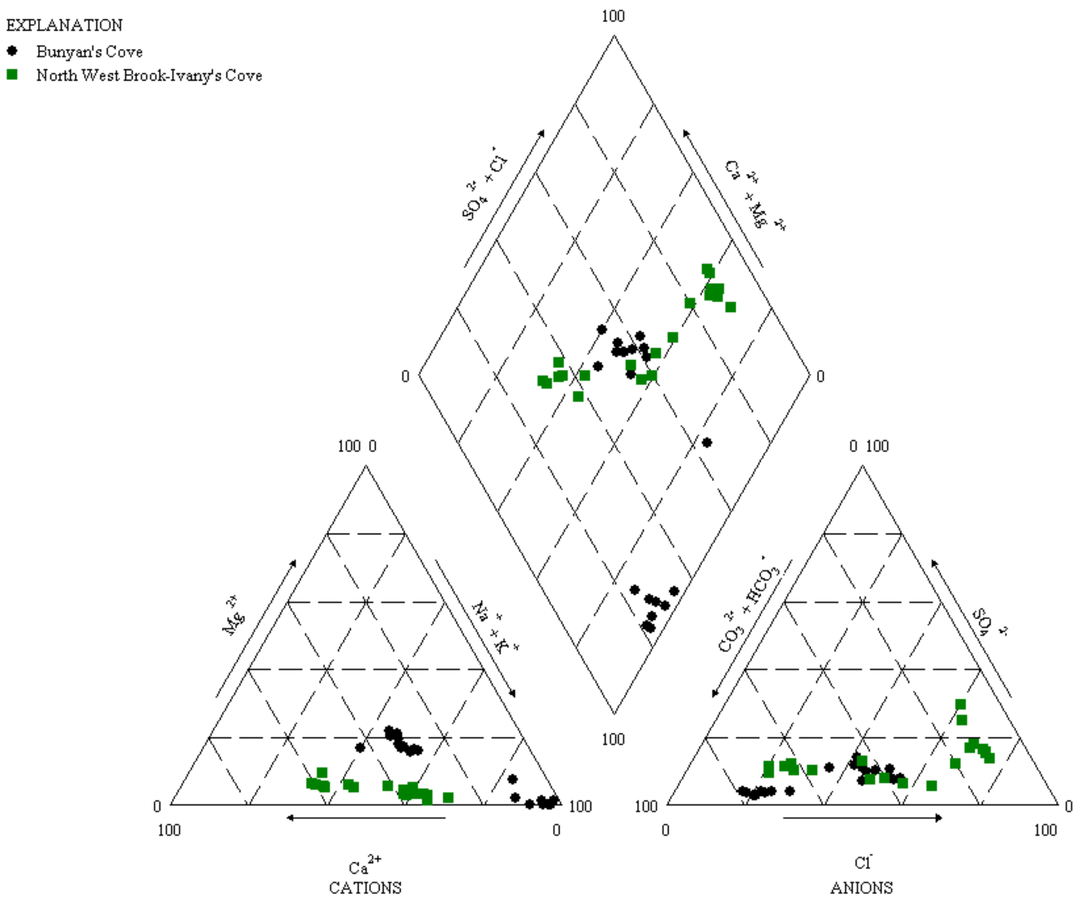

Figure 7-8: Major Ion Chemistry Represented by a Trilinear Diagram for Samples within Bedrock Hydrostratigraphic Unit 6

7.3 POTENTIAL AND EXISTING GROUNDWATER QUALITY CONCERNS

7.3.1 Contaminant Movement

Shallow aquifers or aquifers located in highly permeable units (e.g., sand and gravel) are most susceptible to contaminants originating from surface water conditions due to high permeabilities. Many fractured rock aquifers (both sedimentary and crystalline rock) have little overburden to protect them from contaminants in surface water or runoff. Therefore, these aquifers are also vulnerable to surface sources of anthropogenic contamination.

The structure of porous media, within its interconnected pores can give rise to widespread dispersion of contaminants, and the extent of groundwater contamination will increase with increasing distance from the contaminant source.

In fractured rock, contaminant movement is restricted to an individual fracture or a few fractures. Although there may be little lateral spreading in fractured rock aquifers with respect to porous media aquifers, the distance traveled by a contaminant may be considerably greater in the fractured rock aquifers. Fracture networks provide the groundwater pathways in most bedrock aquifers and are often complex and unpredictable. Horizontal fractures may quickly spread a contaminant, and vertical fractures provide conduits that rapidly move a contaminant from the surface to depth.

7.3.2 Naturally Occurring Sources of Poor Groundwater Quality

There are many naturally occurring substances in groundwater, and in many instances concentrations of these substances may be present above water quality guidelines. Some may present a risk when at elevated concentrations including:

- Metals: arsenic, mercury, lead, selenium;
- Non-metals: fluoride, nitrate, sulfide;
- Radioactive elements: uranium, thorium;
- Gases: radon

Other naturally occurring substances that are often above water quality guidelines only present aesthetic problems, and are no risk to human health at concentrations typically encountered in groundwater. Although aesthetic problems related to taste, colour, and odour do not present a health risk, there is public perception that if the water does not look or smell good it is unsafe to drink. Examples include:

- Iron and manganese: staining on plumbing fixtures
- High dissolved solids (especially chloride): taste problems
- Calcium and magnesium: hardness in the water
- Hydrogen sulfide gas: odour problems

7.3.2.1 Arsenic

Arsenic at concentrations above the GCDWQ is a common problem in domestic wells throughout Newfoundland and is linked to high concentrations of arsenic in the rock found throughout the province. According to Guzzwell and Liverman, 2002, the DOEC discovered arsenic in the water supply for Chapels Cove, Conception Bay in late 2001. The Chapels Cove area contains bedrock that likely could provide a natural source for the arsenic found in these wells. Based on this discovery, the DOEC evaluated the potential for finding arsenic concentrations in drinking water across the province. The interim maximum acceptable concentration for arsenic in Health Canada's GCDWQ is 10 µg/L. Routine testing of public wells and a pilot project of chemically testing school wells revealed arsenic concentrations of 10 µg/L or more at the following localities within the study area:

Table 7-1: Water Supply Well Locations with Arsenic Concentrations of 10 µg/L or more

Location	Arsenic Concentration (µg/L)
Avondale	30-47
Bellevue	10-25
Blaketown	10-25
Chapels Cove, Conception Bay	up to 350
Chance Cove	22-36
Dunfield, Trinity Bay	19-28
Freshwater (Carbonear)	13-42
Harbour Grace	10-25
Holyrood	53
Norman's Cove	22-31
Small Point-Adam's Cove-Blackhead-Broad Cove	29-63

The results of public water-supply sampling have shown that wells drilled into overburden sediments generally do not have dissolved arsenic in their well water. This indicates that groundwater feeding these wells is from a shallow aquifer and not from any groundwater that may have spent significant time in contact with underlying bedrock.

In addition, water samples showing elevated arsenic appear to be mostly from wells drilled into bedrock rather than dug wells. A tentative explanation for the elevated arsenic levels is that groundwater is entering affected wells through deep groundwater flow systems where it can be affected the release of arsenic during reactions between iron oxide and organic carbon or between iron oxide and groundwater under alkaline conditions in felsic volcanic rock. Such water has a comparatively long residence time in the groundwater system, thus greatly increasing the opportunity for the fairly insoluble arsenic to dissolve in the groundwater.

7.3.2.2 Groundwater Under Direct Influence of Surface Water (GUDI)

Groundwater under direct influence of surface water (GUDI) refers to groundwater sources (e.g., wells, springs, infiltration galleries, etc.) which are susceptible to microbial pathogens that are able to travel from nearby surface water to the groundwater source. GUDI in drinking water wells can be obtained from a well that is not a drilled well or from a well that does not have a water tight casing, or from wells in which pumping can induce recharge from nearby surface water features.

This problem can usually be eliminated by ensuring that there is no hydraulic connection between the well and the surface water/precipitation, usually by ensuring that the casing is grouted, completely isolating the well from surface water, and by confirming that there are no pathways through the subsurface that allow for the rapid capture of surface water by the well.

7.3.3 Anthropogenic Sources

In addition to naturally occurring mineralized sources, anthropogenic sources often lead to groundwater quality degradation. The potential groundwater quality degradation within the study area may occur due to sewage effluent, salt water intrusion, spills, solid waste disposal leachate, road salt, agriculture, pulp and paper, and mine wastes.

7.3.3.1 Sewage Effluent

Contamination problems related to sewage effluent from septic systems can potentially affect shallow, dug wells and poorly cased drilled wells. Contamination by sewage is a major area of concern with respect to groundwater quality within the study area. Dug wells and poorly constructed drilled wells are common in many small, rural communities, and are particularly vulnerable to impacts from septic systems.

Bacterial generation from human waste in septic systems and outhouses, as well as animal waste, can be introduced into a shallow well either through surface runoff or direct infiltration. Infiltration of bacteria into a well is commonly encountered where the shallow well is located in close proximity to the contaminant source. Groundwater contamination problems that arise are commonly related to the presence of nitrogen, ammonia, phosphate, chloride and bacteria.

Problems encountered with surface runoff tend to be related to poor well construction which allows direct introduction of surface water into the well system. This problem can usually be eliminated by ensuring the casing is grouted, completely isolating the well from surface water.

7.3.3.2 Salt Water Intrusion

In coastal areas, a natural state of dynamic equilibrium is maintained as the discharge of fresh groundwater to the sea prevents the encroachment of seawater into the aquifer. Extensive pumping of groundwater in these coastal areas can reduce the discharge of groundwater and disturb the balance between fresh water and seawater, thus leading to advancement of seawater inland and contamination of wells.

The likelihood of a well encountering this problem is usually dependent upon the well's proximity to the coast, the depth of the well, the dip of the geological formation, the orientation/permeability of fracture zones within the well and/or the pumping rate. Salt water intrusion can often be controlled in a limited fashion by reducing the pumping of the well. Each case, however, must be assessed on an individual basis due to variations of the geological and hydraulic characteristics of the flow system.

Within the study area, communities that have reported salt water intrusion include: Little Bay East, Spread Eagle, Bauline, Bareneed, St. Chad's, Topsail, Charlottetown, Brigus and Lawn.

7.3.3.3 Spills

Chemical leaks or spills frequently involve organic substances that do not readily dissolve in water (know as Non-Aqueous-Phase-Liquids or NAPLS). NAPLs are associated with gasoline (benzene, toluene, xylene), electrical transformers (PCBs), wood preservatives (creosote), industrial degreasing agents and dry cleaning fluids. Most contaminated sites due to spills are small, such as gasoline stations or dry cleaning stores. Other sites are larger, such as waste disposal facilities and industrial sites. The most common sources are from above ground storage tanks (ASTs) and underground storage tanks (USTs). Ruptures or leaks in the tanks can release chemicals, which then seep into the ground. Trace concentrations of petroleum chemicals can contaminate water in both shallow and deep wells for long periods of time.

7.3.3.4 Solid Waste Disposal Leachate

All solid waste disposal facilities produce a fluid by-product referred to as leachate. This fluid is produced by precipitation that migrates downward, through the overburden materials, dissolving soluble organic and inorganic components of the waste material and the evolution of dissolved gases. This leachate eventually enters the water table.

Proper site selection, design, and maintenance of such facilities will minimize the effect on groundwater supplies. Waste disposal sites should be located in areas where there are no down-gradient wells and where there are sufficient quantities of overburden material for adequate burial which will allow for downward infiltration to avoid the formation of surface leachate springs. For this reason, areas of thick till are desirable. Sand and gravel deposits should be avoided due to their potential as aquifers. New sites should consider designs with impermeable liners to prevent leaching into groundwater.

7.3.3.5 Road Salt

The use of road salt for winter de-icing purposes can result in chloride and/or sodium groundwater contamination. This is a problem that more commonly may affects shallow, dug wells that are in close proximity to roads. The salt is carried from the roadway as runoff and may wash into surface streams or seep into the groundwater. Depending on the nature of the flow system, down-gradient contamination of wells may not occur for months after road salt applications have stopped, as contaminants are flushed through the system. Road salt is a potential groundwater contaminant throughout the entire study area with a road network.

7.3.3.6 Agricultural Industry

A total of eight Agricultural Development Areas (ADAs) are currently defined within the study area. These include Avalon South ADA, Lamaline ADA, Markland ADA, Musgravetown ADA, St. John’s ADA, Terra Nova ADA, Winterbrook ADA and Winterland ADA (Jacques Whitford, 2008).

Groundwater quality in agricultural areas is affected by agricultural activities such as application of pesticides, fertilizer and manure on fields, storage and disposal of animal wastes, improper disposal and spills of chemical and irrigation. In general, analyses of groundwater from wells near agricultural areas commonly exhibit nitrate, bacteria and/or pesticide contamination (Coote et al, 2000). Manure or pesticide spreading on the land surface is particularly a problem if undertaken close to an improperly constructed or inappropriately located municipal well or well field.

7.3.3.7 Mining Industry

There are approximately 16 active and abandoned metal mines within the study area (Martin, 1983). The waste rock and tailings at these sites can be introduce high concentrations of acid, sulfate and metals several orders of magnitude above GCDWQ into groundwater. The waste sites can be a source of groundwater contamination for 10s to 1000s of years.

Waste rock has a large grain size, and hence a high hydraulic conductivity. This permits the rapid transport of water (as infiltrating precipitation) and oxygen through the waste rock. In the study area both mine tailings and mine waste rock are stored at the surface. The leaching action of rainwater on mine waste contributes to acidic groundwater and metal leaching conditions. To date, mining operations within the study area have been in remote areas and do not pose any immediate threats to groundwater quality used for drinking water. However, consideration must be given at the development stages of mining operations to prevent problems related to acid generation and drainage which are generally associated with water containing high concentrations of dissolved heavy metals.

8.0 CONCLUSIONS

The overburden and bedrock strata within Eastern Newfoundland are capable of producing low to high potential well yields. Accordingly, groundwater has been utilized in populated areas for domestic, municipal, commercial and industrial supplies.

A total of 11,966 individual provincial water well records of drilled wells were obtained for the study area. Water well records and geologic maps were used to subdivide the overburden deposits into two overburden hydrostratigraphic units and to identify six bedrock hydrostratigraphic units. Groundwater yields vary from low (<1 L/min) to high (>550 L/min). The reliance of the conclusions drawn for each of these units varied with the amount of data available for each unit, which varied significantly with population, and the quality of the water wells records.

Aquifer test data was also used to help determine hydrostratigraphic unit characteristics. However, aquifer tests are more likely to be conducted in areas of development where communal water supply systems or engineering works are required, and may be weighted to particular areas within a hydrostratigraphic unit where the dataset is small. Therefore, the aquifer tests conducted in Eastern Newfoundland may not represent a significantly more reliable source of average well yield data than records taken from individual water wells.

The sand and gravel deposits of overburden hydrostratigraphic Unit B and wells completed in gravel layers within the till hydrostratigraphic Unit A have the greatest groundwater potential of any of the hydrostratigraphic units in the study area. For Unit B, the median yield is 36 L/min from an average depth of 19 m. For Unit A, the median yield is 45 L/min from an average depth of 17 m. Based on the aquifer test data, wells completed in Unit B or gravel layers within Unit A offer the potential to meet any domestic and most commercial needs. However, sand and gravel deposits are also susceptible to contaminants originating from surface water conditions due to high permeabilites.

The well records indicate that the bedrock strata underlying the study area are capable of producing a broad range of well yields. In general, volcanic, siltstone and shale, and sandstone and conglomerate rocks are considered to provide low to moderate well yields with median yields of 9 L/min. In general, the least productive wells are reported in the metamorphic rock unit for which wells reported a median yield of 4 L/min. Cambo-Ordovician sedimentary, and plutonic rocks of Units 3 and 5 offer the highest yields in the bedrock strata within the study area with median values of 14 L/min.

Hydrostratigraphic Unit 1 is the most widely utilized bedrock aquifer unit due it having the largest populations reliant on groundwater. This sedimentary rock unit includes several sedimentary formations, which comprise shale and siltstone with minor volcanic flows and tuff. The average yield is 20 L/min from an average depth of 64 m. The results of the 1585 aquifer tests completed in Unit 1 suggest that the average yield is 22 L/min. Unit 1 offers potential to meet domestic groundwater needs.

Streamflow data were analyzed to estimate the average annual groundwater discharge as reflected in the baseflow component of total streamflow for given drainage divisions. Considering the drainage divisions developed by Environment Canada, the topographic features, and annual precipitation distribution, the study area is divided into three sub-regions for the purpose of this study. The annual runoff depth for the three sub-regions ranges from 1013.4 mm for Sub-region 3 to 1415.1 mm for Sub-region 1. The baseflow component of annual streamflow is estimated to range from 425.3 mm for Sub-region 3 to 705.7 mm for Sub-region 1. This would include water released from storage in lakes, ponds, bogs in addition to groundwater. Streamflows decrease in the summer when contributions from bogs are decreased by evapotranspiration. During these periods, groundwater would make up a larger component of streamflow, but would be expected to be significantly less than the annual average baseflow.

Groundwater quality data within the study area are limited to public water supply testing carried out by the DOEC. This chemical data are not entirely representative of the groundwater quality within the study area. However, based on the public water supply data, the quality of the groundwater is generally quite acceptable, and in most cases falls within the criteria established for drinking water purposes. For the most part, the chemical composition of the groundwater reflects the geochemistry of the adjacent bedrock or unconsolidated sediments and is similar to the surface water chemistry. However, because the groundwater is less dilute, the concentrations of dissolved constituents tend to be higher than the corresponding surface water. Three groundwater quality types were identified from the groundwater chemistry data. These include calcium bicarbonate, sodium bicarbonate, and sodium chloride types.

9.0 CLOSURE/LIMITATIONS OF REPORT

This hydrogeological report is a desktop study only and has been prepared based on reports which were produced by others. As a result, the findings and conclusions presented in this report are based exclusively on the information that was available at the time of preparation of this report. This report gives a professional opinion and, by consequence, no guarantee is attached to the conclusions or expert advice depicted in this report.

We trust this meets your current needs. If you have any questions, do not hesitate to contact the undersigned to discuss.

Regards,

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Appendices Provided on

Accompanying CD