# HYDROGEOLOGY OF CENTRAL NEWFOUNDLAND

**Submitted to:**

**Water Resources Management Division**
**Department of Environment and Conservation**
4th Floor, West Block
Confederation Building
P.O. Box 8700
St. John's, NL A1B 4J6

**Submitted by:**


**Environment & Infrastructure**
**A Division of AMEC Americas Limited**
133 Crosbie Road
P.O. Box 13216
St. John's, NL A1B 4A5



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## ABSTRACT

AMEC Environment & Infrastructure (formerly AMEC Earth & Environmental), a Division of AMEC Americas Limited (AMEC), was retained by the Government of Newfoundland & Labrador, 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 central 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 central Newfoundland region. Three accompanying maps outline the hydrogeological resources.

A total of 3,080 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 five bedrock hydrostratigraphic units. Groundwater yields vary from low (<1 L/min) to high (>650 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 50 meters. The sedimentary rock unit is the most widely used aquifer unit and offers potential to meet 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 most commercial groundwater needs. However, sand and gravel deposits are also susceptible to contaminants originating from surface water conditions due to high permeabilites.

Streamflow data were analyzed to determine the groundwater discharge as reflected in the baseflow component of total streamflow for given drainage divisions, which would include groundwater contributions and water released from storage in lakes, ponds and bogs. Based on the correlation between the groundwater stage and stream discharge, it is estimated that groundwater contribution to streamflow ranges from 10 to 56%. 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 deeper 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 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.

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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, 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 central zone of Newfoundland. This is the second 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 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 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 central 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 Central 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 western boundary extends from east of the White Bay apex along the south banks of Sandy and Grand Lakes and then south to Bay le Moine. The eastern boundary extends in a northeasterly direction from Fortune Bay in the south to Bonavista Bay in the north.

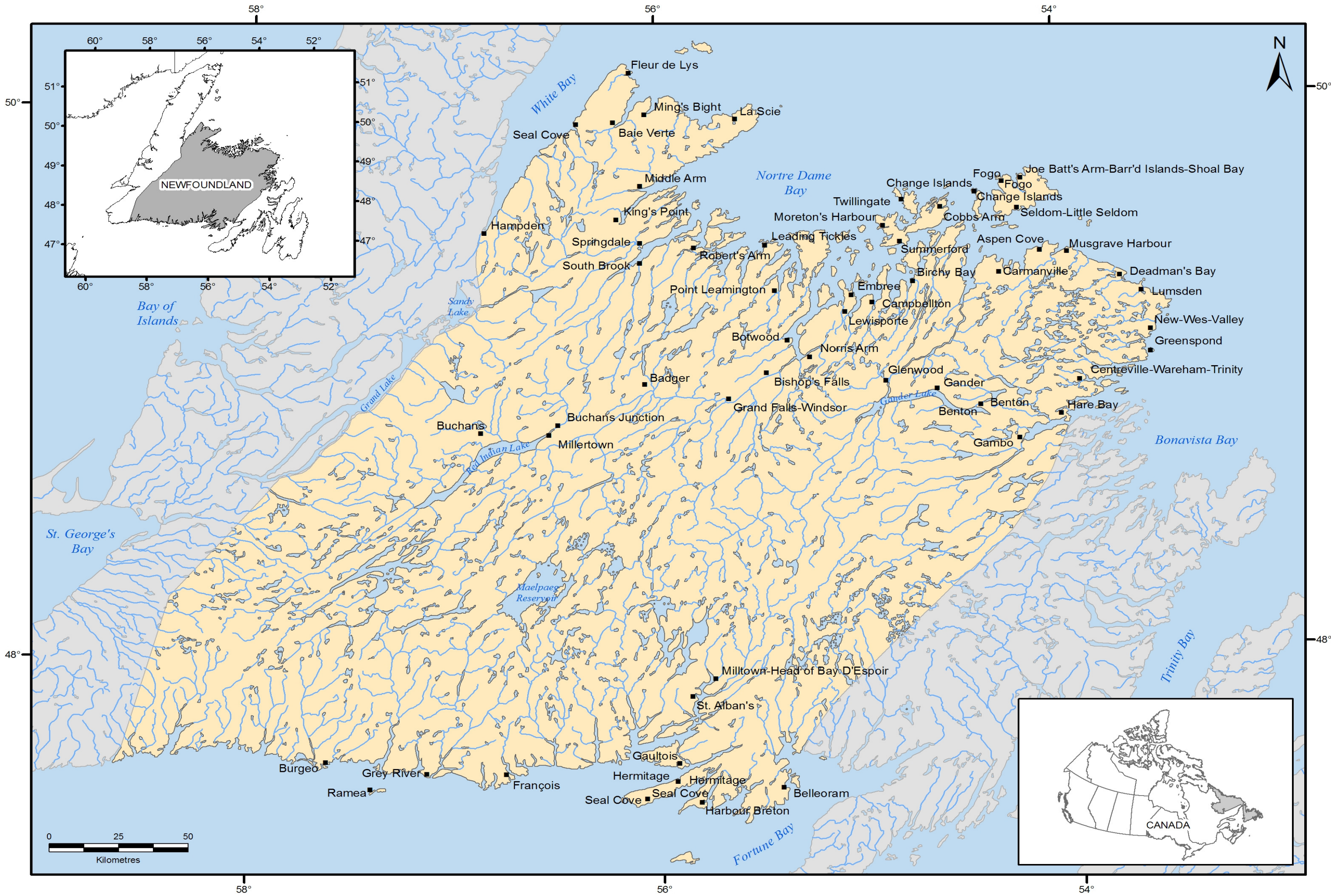



**Figure 1-1: Study Area and Places Mentioned in Text**

## 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 2008) 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 streamflow 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 climatic normals including temperature and precipitation were obtained from Environment Canada (Environment Canada, 2008). There are 13 climate station locations within the study area which are shown in Figure 1-2.

### 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 13 climate stations in the study area are provided in Table 1.1.

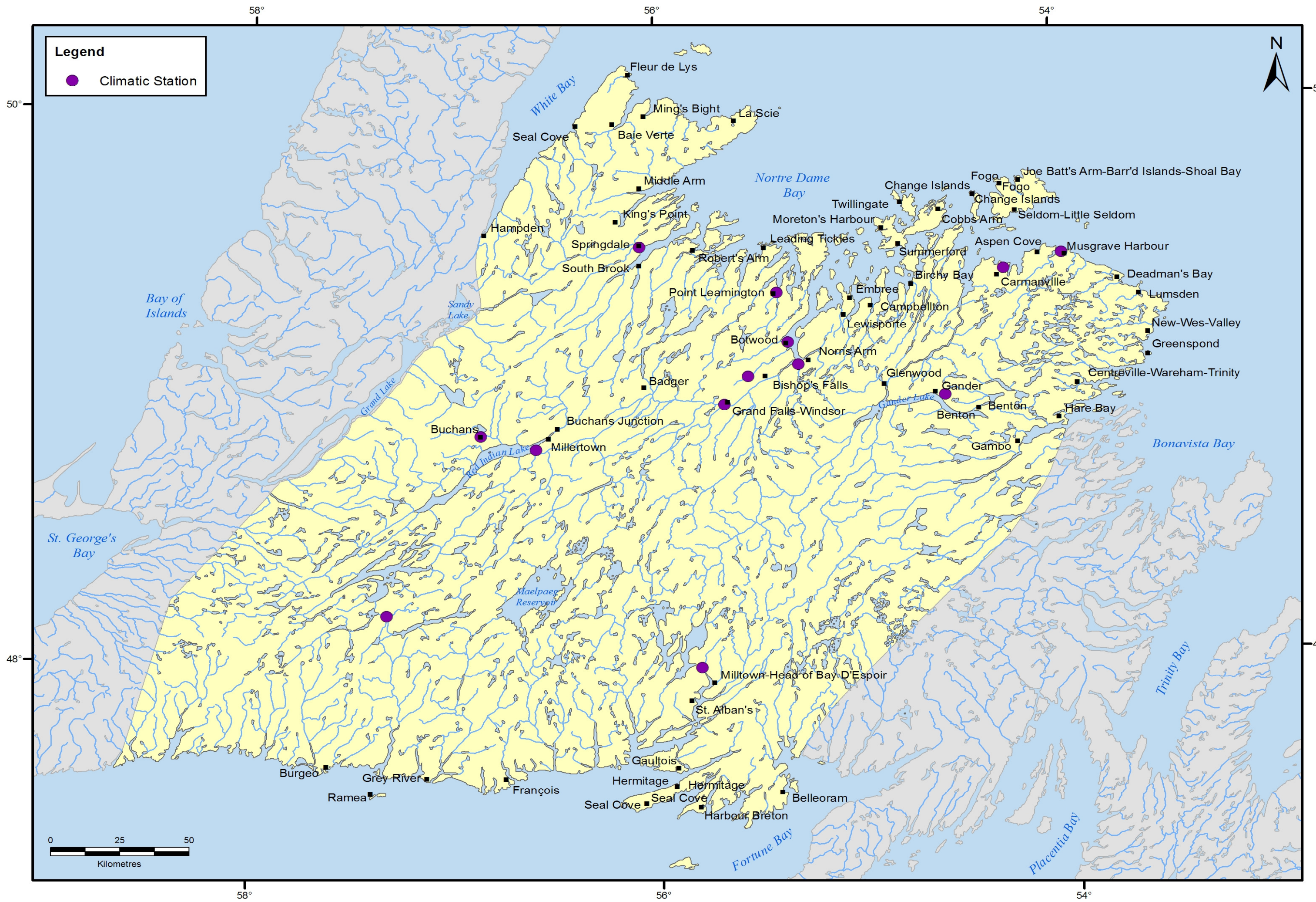



**Figure 1-2: Locations of Climatic Stations within the Study Area**

Winter temperatures in Central Newfoundland show the day-to-day variability that is characteristic of a maritime climate. However, there is a noticeable difference between inland and coastal temperatures throughout the study area. In the interior, winter temperatures average between -6℃ and -10℃, whereas on the southeast coast, where the moderating influence of the ocean is greatest, the winter average is between -2℃ and -4℃.

The Exploits Dam station reports the lowest mean annual temperature at 3.2℃ and Burnt Pond Station receiving the lowest monthly average temperature of -10.5℃ in February. The lowest Newfoundland temperature on record is -41.1℃, set at Woodale Bishop's Falls on February 4, 1975. The highest temperature ever recorded on the island is 36.7℃, occurring at Botwood, northeast of Grand Falls, on August 22, 1976.

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. St. Albans, in the sheltered Bay d'Espoir on the south coast, is the least windy location, with an average yearly speed of 11.5 km/h.

### 1.4.2 Precipitation

The monthly mean precipitation normals for the 13 climate stations in the study area are provided in Table 1.2. The area receives an annual precipitation ranging from approximately 770 mm at Musgrave Harbour to 1437 mm at Burnt Pond. Precipitation is generally greatest during the fall and early winter months and lowest in the spring or early summer months.

The frequency of precipitation is greatest over the south-central portion of the island, where measurable precipitation probably occurs on 200-250 days per year on average. Measurable precipitation is least frequent in the Baie Verte Peninsula-Green Bay area (100 – 130 days per year). Over the entire study area there is a marked increase in precipitation and strong wind frequencies during October and November. There is a significant reduction in both precipitation and the frequency of high winds during the period from May until July.

Snowfall dominates winter precipitation. It is heavy, with normal amounts exceeding 300 cm at most places in the study area. Along the south coast, however, snowfall totals are in the 200-300 cm range, less than elsewhere because much of the storm precipitation falls as rain.

Precipitation is discussed in further detail in Section 5.2.

### 1.4.3 Evapotranspiration

Evapostranspiration is broadly divided into two main categories: evaporation and transpiration. Evaporation, or lake evaporation, is the water that evaporates due to solar radiation, mild to hot temperatures, and wind. Evapotranspiration is the combination of evaporation and the transpiration that occurs from trees and plants. The proportion of precipitation that is available for direct runoff or recharge is dependant on the amount of evapotranspiration.

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

| Station | Code[1] | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bay D'espoir | A | -6.7 | -7 | -2.9 | 2.7 | 7.8 | 12.2 | 16 | 16.2 | 12.1 | 6.9 | 2.3 | -3.2 | 4.7 |
| Botwood | C | -7.5 | -8.1 | -3.6 | 2.1 | 7.5 | 12.4 | 17 | 16.5 | 12 | 6.6 | 1.5 | -4.3 | 4.3 |
| Buchans | A | -8.5 | -9.1 | -4.8 | 0.9 | 6.8 | 12.3 | 16.2 | 15.9 | 11.4 | 5.5 | 0.3 | -5.3 | 3.5 |
| Burnt Pond | A | -9.8 | -10.5 | -6.4 | -0.5 | 5.4 | 10.9 | 14.8 | 14.4 | 10.1 | 4.7 | -0.3 | -6.1 | |
| Carmanville | D | -6.5 | -7 | -3.2 | 2.1 | 7.2 | 11.5 | 16.1 | 16.4 | 12.2 | 6.9 | 2.1 | -3 | 4.6 |
| Exploits Dam | A | -8.6 | -9.8 | -5.2 | 1 | 6.5 | 11.5 | 15.7 | 15.1 | 10.8 | 5.4 | 0.7 | -4.9 | 3.2 |
| Gander Airport | A | -7.4 | -7.9 | -4 | 1.3 | 6.7 | 11.6 | 16 | 15.7 | 11.4 | 5.8 | 1 | -4.3 | 3.8 |
| Grand Falls | A | -7.7 | -8.2 | -3.7 | 2.3 | 7.9 | 13 | 17.3 | 16.6 | 12 | 6.3 | 1.5 | -4.3 | 4.4 |
| Musgrave Harbour | C | -6.1 | -7 | -3.2 | 1.5 | 6.4 | 10.7 | 15.4 | 15.7 | 11.8 | 6.6 | 2.1 | -2.9 | 4.3 |
| Point Leamington | D | -7.5 | -7.9 | -3.8 | 1.9 | 7.3 | 11.9 | 16.6 | 16.8 | 12.1 | 6.7 | 1.4 | -4 | 4.3 |
| Rattling Brook Norris Arm | A | -7.6 | -8 | -3.3 | 2.4 | 7.9 | 12.9 | 17.3 | 16.8 | 12.2 | 6.4 | 1.5 | -4.3 | 4.5 |
| Springdale | D | -9.2 | -9.3 | -4.5 | 1 | 6.4 | 11.8 | 16.5 | 15.7 | 11 | 5.7 | 0.7 | -5.8 | 3.3 |
| Woodale Bishops Falls | A | -7.7 | -8.3 | -3.6 | 2.2 | 7.8 | 12.6 | 17.1 | 16.5 | 11.9 | 6.1 | 1.3 | -4.6 | 4.3 |

**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, 2008).

**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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bay D'espoir | A | 97.7 | 76.1 | 93.7 | 97.6 | 98.2 | 111.6 | 120.5 | 108.7 | 130.5 | 154.2 | 136 | 108.7 | 1333.5 |
| Botwood | C | 83.8 | 74.8 | 74.1 | 64 | 73.2 | 88 | 76.8 | 96.8 | 91.9 | 106.1 | 78.6 | 78.4 | 986.4 |
| Buchans | A | 116.7 | 87.3 | 93.5 | 83.1 | 80.9 | 88.2 | 95.9 | 114 | 103 | 110.6 | 110.6 | 120.5 | 1204.2 |
| Burnt Pond | A | 156 | 117.4 | 121.4 | 102.9 | 93.6 | 97 | 103.1 | 106 | 107.4 | 134.7 | 139.3 | 158.5 | 1437.3 |
| Carmanville | D | 90.3 | 82.4 | 80.6 | 85.7 | 79.9 | 83.2 | 87.3 | 107.3 | 108.4 | 95.3 | 93.8 | 96.8 | 1090.9 |
| Exploits Dam | A | 97.7 | 78 | 85.4 | 74.7 | 77.7 | 84.8 | 95.6 | 98.3 | 90.4 | 105.1 | 98.6 | 96.7 | 1082.8 |
| Gander Airport | A | 111.5 | 98 | 110.4 | 95.4 | 86.3 | 85.2 | 83.9 | 96.4 | 101.9 | 112.4 | 106.7 | 113.8 | 1201.9 |
| Grand Falls | A | 32.7 | 25.7 | 38.3 | 49.8 | 70.9 | 83.4 | 83.9 | 102.7 | 90.2 | 96.7 | 71.4 | 40.1 | 785.9 |
| Musgrave Harbour | C | 25.6 | 18.8 | 29.7 | 50.7 | 70.2 | 76.7 | 79.7 | 97 | 107.7 | 96.1 | 78.4 | 40.1 | 770.4 |
| Point Leamington | D | 21 | 13.7 | 21.5 | 44.4 | 74.4 | 88.6 | 88.2 | 105.2 | 114.6 | 108 | 75.6 | 30.7 | 785.9 |
| Rattling Brook Norris Arm | A | 99.4 | 83.5 | 92.5 | 80.8 | 86.4 | 92.1 | 87.7 | 101.8 | 96.6 | 108.5 | 96.8 | 98.3 | 1124.2 |
| Springdale | D | 72.3 | 59 | 72.7 | 66.9 | 83.8 | 95.7 | 74 | 98.2 | 89.3 | 119.5 | 92.1 | 76.8 | 1000.3 |
| Woodale Bishops Falls | A | 98.7 | 81.4 | 83.8 | 75.6 | 76.5 | 84.2 | 84.1 | 98.2 | 98.6 | 103.3 | 91.6 | 91.3 | 1067.2 |

**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, 2008).

## 2.0 POPULATION

Census data for 2001 and 2006 (Statistics Canada, 2008) are included in Appendix A for those communities within the study area. The data indicate a population of approximately 75,649 located in 74 communities in 2006 compared to a population of 79,561 in 2001. The majority of the population is distributed in the centers of Grand Falls-Windsor (13,558), Gander (9,951), Bishops Falls (3,399), Botwood (3,052), Lewisporte (3,308), Springdale (2,764), Twillingate (2,448) and Gambo (2,072). The remainder of the population is distributed in smaller communities which range in population from 93 (Coachman's Cove) to 1,877 (Harbour Breton).

Most communities exhibited a decrease in population during the period of 2001 to 2006 which ranges from -0.1% (Lewisporte) to -26.2% (Coachman's Cove). However, the communities of Appleton, Beachside, Birch Bay, Gander, Grand Falls Windsor, Norris Arm and Northern Arm show a growth in population of 1%, 5.2%, 1%, 3.1%, 1.6%, 8.1%, and 2.7%, respectively.

## 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).

High points on ridges and plateaus coincide with resistant bedrock types such as granite plutons. Thus the Topsails Plateau in west central Newfoundland and Mount Peyton to the east are examples between granite batholith and high relief. Major lakes such as Grand Lake and Red Indian Lake occupy fault lines and valleys in the structural grain.

The island of Newfoundland can be divided into 12 physiographic regions (Twenhofel and MacClintock, 1940). Six of these regions are contained in the Central Newfoundland study area and are presented in Figure 3-1, along with the shaded relief.

### 3.1 LONG RANGE MOUNTAINS

The south western portion of the study area is made up of the Long Range Mountains physiographic region. The mountains rise from 450 m asl to 650 m asl and are harsh, uninhabited barrens consisting predominantly of exposed bedrock, bog and tundra vegetation. Inland, the area is comprised of the sparsely vegetated rolling plateau of the Topsails Plateau, which is the divide between the Exploits River drainage system to the east and the Humber River/Grand Lake drainage system to the west. The western slopes of the Long Range Mountains are steeply dissected by glacial valleys that form the headwaters of several rivers (Acres, 1994). Glacial erratics and frost-shattered rocks are scattered over the surface. Some talus slopes occur and there are numerous lakes and extensive shallow peat deposits.

## 3.2 GRAND LAKE-WHITE BAY BASIN

Along the western edge of the study area, a small portion of the study area is part of the Grand Lake-White Bay Basin physiographic region. This lowland area is characterized by extensive areas of fluvial deposits in glacial scoured basins. Thick till deposits, lacustrine and organic areas are also characteristic of this zone. The interior is a plateau like region with frequent undulations in the terrain representing the ridges and slopes of the watersheds carved out by the major stream system. The Humber River drains most of the area. The region supports extensive forest stands, particularly on the gentle slopes of the major watersheds, and thick overburden is found in many areas (Batterson, 2003).

## 3.3 BURLINGTON PENINSULA

The Burlington Peninsula is a plateau much of which is 300 m or more above sea level. The surface is flat to gently rolling with scattered monadnocks rising over the general level. The coastline is abrupt and deeply indented. The coastal area has for the most part a thin till veneer which is coarse textured and rapidly to well drained.

## 3.4 NORTHEAST TROUGH

This physiographic division includes the areas drained mainly by the Exploits, Gander, and Gambo rivers. The topography is primarily that of a flat to gentle rolling plain of low relief, sloping to the northeast. The coastline is characterized by numerous islands, drowned valleys and small rocky peninsulas.

West of the Bay of Exploits, the Northeast Trough is relatively rugged and ridged, with elevations attaining approximately 300 m. The region becomes lower and flatter in the east of the study area. The lower lying area is often covered by glacial till. Fluvioglacial sands, often overlain by till, have been identified but are generally sparse. For example, large glaciofluvial deposits are found near the extreme north border of the division at Halls Bay, Springdale and Gambo areas. Also in this central zone south of Grand Falls-Windsor and Gander Lake as well as the headwaters of the Gambo area, eskers are found.

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 deteriorates toward the coast and with increased wind exposure. There are numerous bogs, ponds and lakes that have drainage patterns reflecting glacial as well as strong structural and lithological controls.

## 3.5 CENTRAL PLATEAU

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).

### 3.6 SOUTH COAST HIGHLANDS

The South Coast Highlands is an area characterized by deep fiords, shallow tills and numerous rock outcrops. In the eastern portion of the region, some cliffs rise vertically over 300 m asl. The area is characterized by extensive man-made barrens, open peatlands and a fragmented forest landscape that has been decimated by fire.

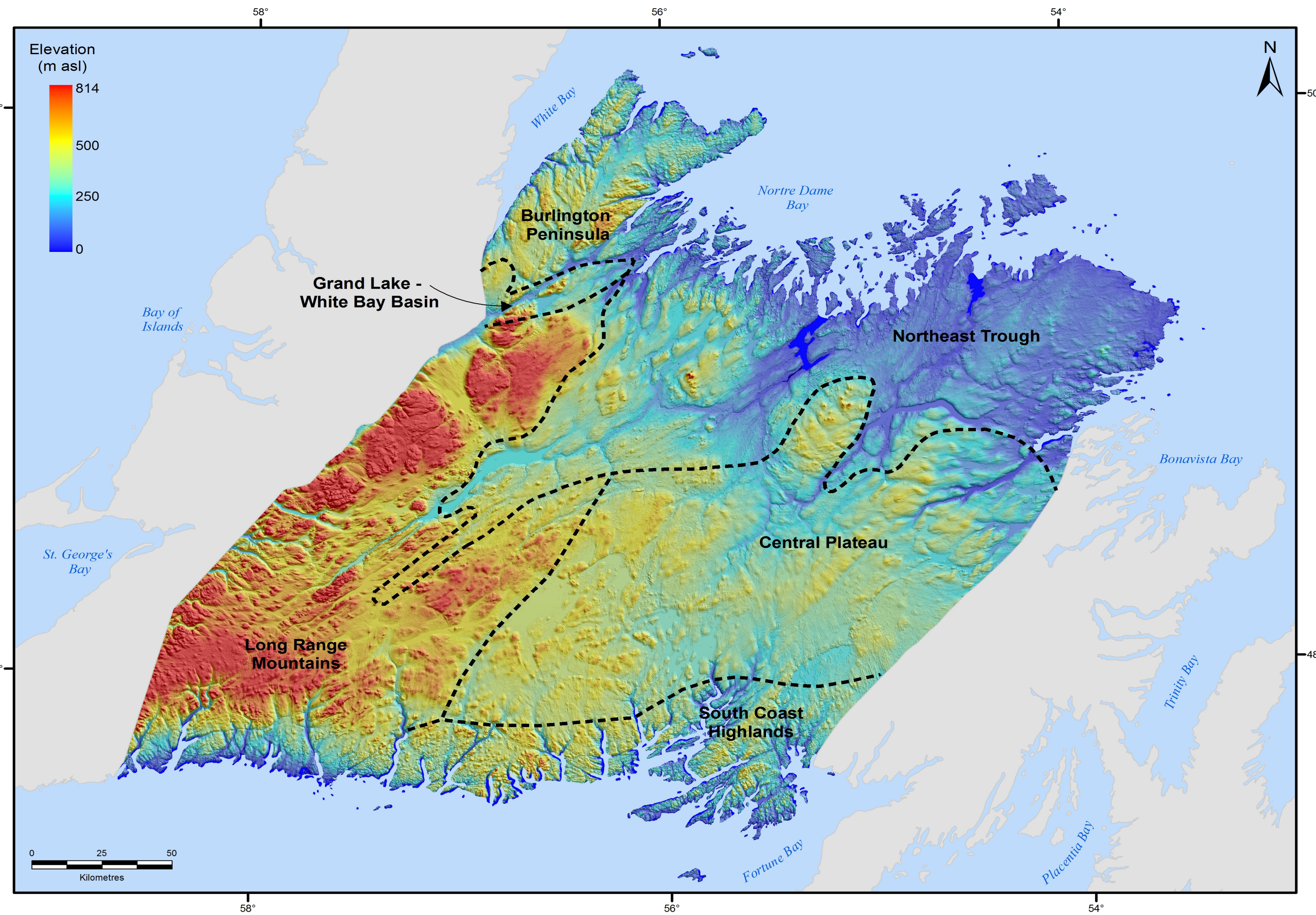



**Figure 3-1: Relief and Physiographic Divisions within the Study Area (based on Twenhofel and MacClintock, 1940)**

# 4.0 GEOLOGY

## 4.1 SURFICIAL GEOLOGY

The surficial geology of the central 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 (DOEL, 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;
- organic deposits.

### 4.1.1 Bedrock

This unit consists of bedrock, either exposed or concealed by soil development and vegetation. It is of limited extent in the study area, occurring generally on hilltops and along stream sections (Vanderveer et al., 1987). It is characterized by a glacially scoured surface with deranged drainage systems, numerous lakes and ponds, rugged hummocky to hilly topography with numerous cliffs and glacial erosional forms (Grant, 1994). Areas of exposed bedrock form extensive rock plains, knobs and ridges throughout much of the study area.

Much of the area of the coastal areas are 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

The most common depositional product of retreating glaciers was till, 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 (<1.5m) cover over bedrock, and as more extensive deposits commonly in the lowland areas (Batterson, 2003). The composition of the tills closely reflects the lithology of the underlying bedrock. For example, red, silty to sandy tills are common in areas underlain by the Botwood group, whereas tills covering the Mount Peyton Intrusive Suite are brown to grey and coarse grained (Batterson *et al.*, 1998)

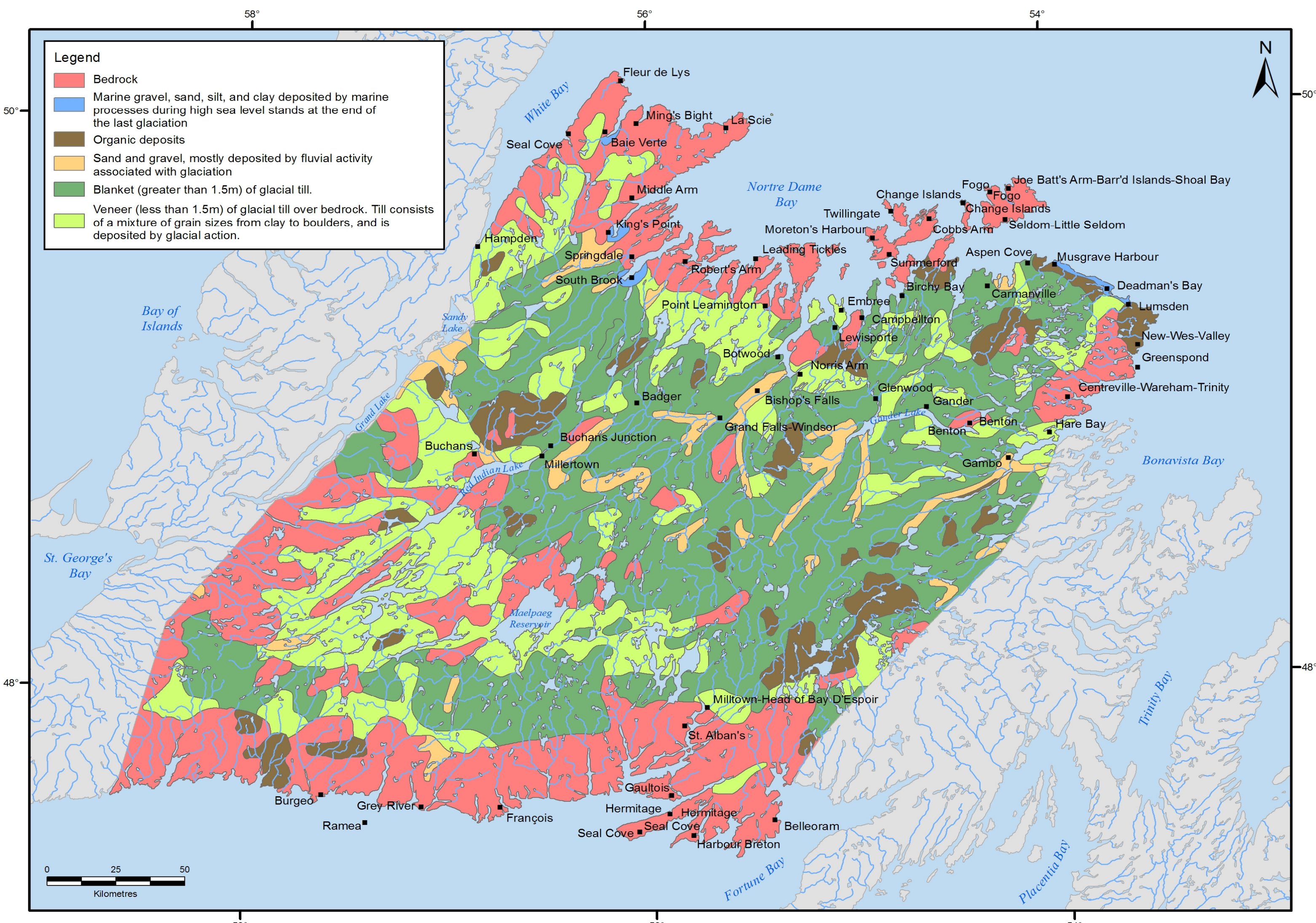



**Figure 4-1: Generalized Surficial Geology of the Study Area (based on Department of Environment and Lands, 1992)**

### 4.1.3 Sand and Gravel

Within the study area, glaciofluvial sediments comprising sand and gravel are of limited extent and are generally restricted to areas adjacent to major river valleys (Vanderveer *et al*., 1987). They are composed of varying proportions of sand and gravel (~30 to 70% gravel, Batterson, 2003), with less than 5% silt or clay. They consist of poorly to well-sorted gravel, containing subrounded to rounded clasts up to boulder size in a medium to coarse-sand matrix (Batterson, 2003).

The Exploits River valley is predominantly infilled with glaciofluvial sand and gravel deposits. Large glaciofluvial deposits, e.g. kame terraces, outwash plains and deltaic complexes are found near Halls Bay and Springdale and in the Gambo areas. Also, south of Grand Falls and Gander Lake as well as the headwaters of the Gambo area, eskers are found. The coarse textured glaciofluvial materials of all these deposits are rapidly to well drained.

### 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 only along the northeast coast from Deadman's Bay to Aspen and within the apex of some inlets within Notre Dame Bay.

### 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 is interspersed with most of the other units. It forms either by growth of wetland vegetation in place, or by progressive filling of lakes and ponds. On flat, coastal areas, such as the coastal lowlands, extensive plateau bogs occur and are commonly underlain by marine sediments (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 central Newfoundland was obtained from Colman-Sadd and Crisby-Whittle (2005) 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 study area consists mainly of the Dunnage and Gander zones, but also contains small portions of the Humber and Avalon zones. 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).

Rocks younger than about 430 Ma overlie those of the fundamental zones. They are sedimentary and volcanic rocks that show an upward change from marine to terrestrial rocks, with all rocks deformed together and cut by granite intrusions. These changes mark the final closing phases of Iapetus. The final stages of deformation are most significant in central Newfoundland.

### 4.2.2 Humber Zone

The rocks and structures of the Humber Zone fit the model of an evolving continental margin and spreading Iapetus Ocean. This began with rifting of existing continental crust dated at 600 to 550 Ma. The rifting is evidenced by liquid injections that filled cracks in the older crust and fed volcanic eruptions. It also led to deposition of coarse fragmental sedimentary rocks.

The Humber Zone in the study area is located on the Baie Verte Peninsula and is composed of the East Pond Complex and the Fleur de Lys Supergroup. These highly deformed schists and gneisses represent sediments which were metamorphosed in the sliding zone between oceanic crustal layers (Hibbard, 1983). The East Pond Complex is older and more deformed than the Fleur de Lys rocks, and has been metamorphosed at higher temperatures. The two units are in fault contact with each other (Hibbard, 1983).

### 4.2.3 Dunnage Zone

The boundary between the Dunnage Zone oceanic rocks to the east, and ancient continental margin gneisses and schists of the Humber Zone to the west is defined by the Baie Verte Line (Williams et al., 1988). The Dunnage Zone is characterized by its abundant volcanic rocks, oceanic crust and mantle rocks, and mixtures of discrete resistant blocks surrounded by shales. The rock units are of variable thickness and are commonly discontinuous. The Dunnage Zone is narrow or absent in southwest Newfoundland at the Cape Ray Fault

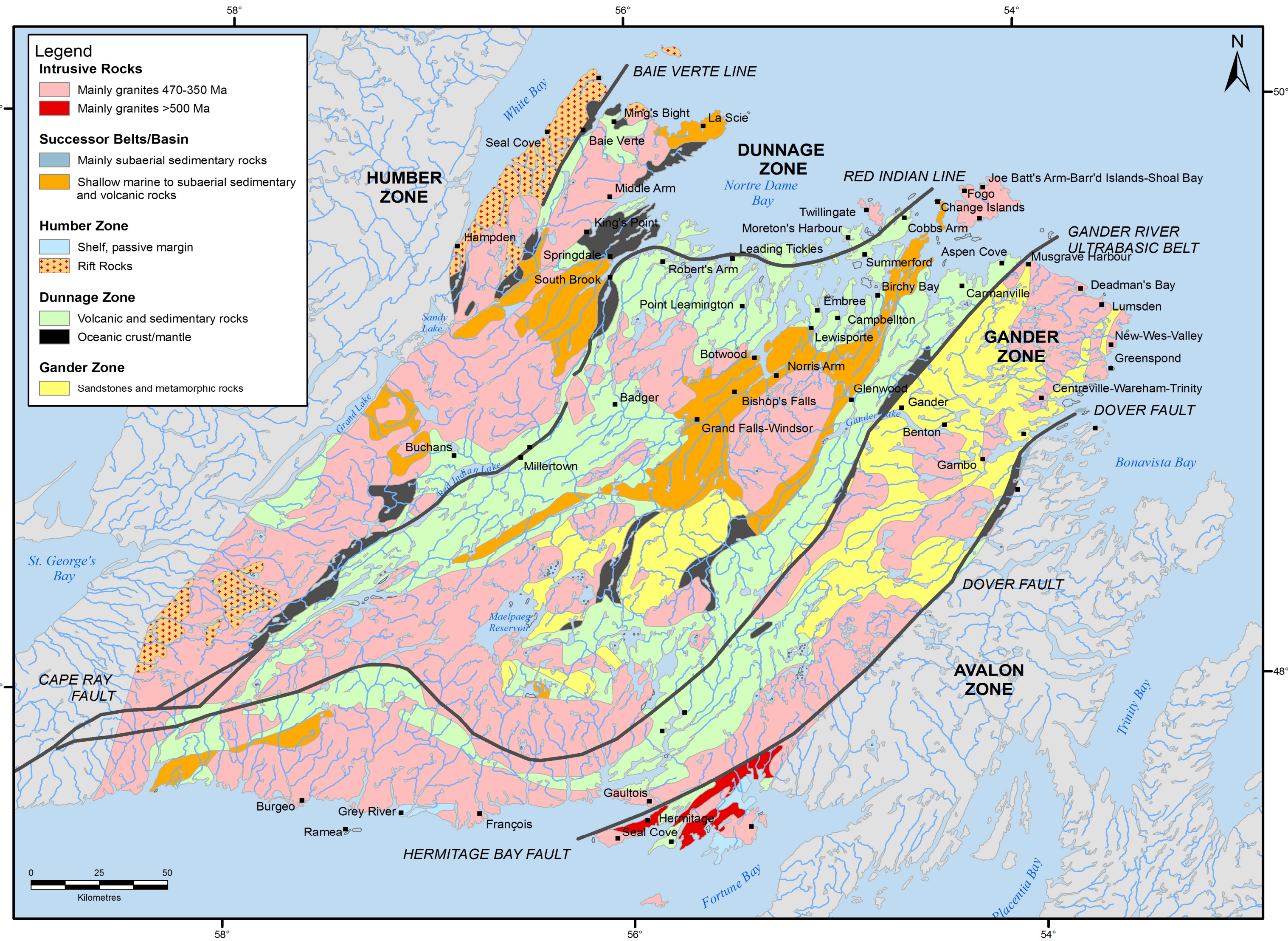



**Figure 4-2: Generalized Bedrock Geology within the Study Area (based on Hayes, 1987 and updated by Williams, 2004)**

The Dunnage Zone is separated into two sub-zones by the Red Indian Line. The sub-zones show contrasts in rock types and sequence of units. Northwest of Red Indian Lake the sedimentary and volcanic rocks of the Dunnage Zone consist mainly of lava and ash. Slate and sandstone occur to the northeast of Red Indian Lake and contain volcanic rocks, as well as thick sequences of conglomerate.

Ophiolitic rocks represent oceanic crust and mantle formed at ancient spreading or rifting centers, similar to the modern Mid-Atlantic Ridge (Hodych and King, 1989). The ultramafic rocks are interpreted as representing the upper part of the Earth's mantle in Ordovician time whereas the overlying pillow lava, dikes, and gabbro represent a remnant of Ordovician oceanic crust. An ophiolitic assemblage of ultramafic, mafic and felsic igneous rocks can be traced from the northeast coast of the island into central Newfoundland near Middle Ridge. Complete ophiolite suites are present at Betts Cove and north of Mings Bight. Pillow lavas representing the top of an ophiolite suite can be seen in the Springdale area and on Pilleys Island. Diabase Dikes which originally fed the ophiolitic pillow lavas can be seen on the north side of Pilley Island along Sunday Cove Island and at Indian Head in Halls Bay.

### 4.2.4 Gander Zone

The boundary of the Dunnage Zone and the Gander Zone is the Gander River Ultrabasic Belt (GRUB). Like the Baie Verte Line, it is marked by discontinuous occurrences of oceanic crust and mantle rocks. The Gander Zone has a thick, monotonous sequence of quartz sandstones, siltstones and shales that grade eastward into deformed and altered rocks. Almost one half of its rocks are granitic intrusions, and one half of the remainder are deformed and altered beyond recognition.

The interbedded sandstone and slate has been metamorphosed to quartzite, schist, and migmatite in many places. The intensity of deformation and metamorphism increases eastward toward the contact with the Avalon Zone. Metamorphism and deformation probably took place as the Avalon pushed the sediments ahead of it during the closing of Iapetus. These rocks were then intruded by granitoid plutons during the Silurian and Devonian time (435 to 325 Million years ago) (Blackwood, 1982).

In southwestern Newfoundland the Gander Zone makes contact with the Humber Zone, forming a 'cryptic suture' along the Cape Ray Fault. This junction between two continental plates is evidence of displaced oceanic crust. Numerous occurrences of gabbro and an ophiolite sequence are most likely oceanic remnants.

### 4.2.5 Avalon Zone

The Avalon Zone lies to the east of the Gander Zone and is separated from it by a major fault running from Dover to Hermitage Bay. The Avalon Zone is characterized by mildly deformed late Precambrian volcanic and sedimentary rocks. It contains a basement of subaerial and subaqueous volcanics, overlain by sedimentary rocks.

The development of the Avalon Zone in the late PreCambrian is quite separate from that of the Humber Zone. As the Avalon zone has no correlative to the west, it appears to be a far traveled terrain that collided with the Gander Zone about 400 million years ago (Williams, 1979). It probably predates the opening of the Iapetus, yet formed initially in an extensional tectonic environment.

### 4.2.6 Granitic and Gabbroic Intrusions

Most of the igneous intrusions in central Newfoundland are granite, but there are also large gabbro, diorite and anorthosite plutons. Most of the granitic batholiths that underlie a third of central Newfoundland are late Silurian or Devonian in age. They cut some Silurian and some Lower Devonian rocks that mostly had been folded prior to intrusion. This folding and the intrusion of granites with its associated metamorphism are part of the Silurian and Devonian mountain building event known as the Acadian orogeny.

## 5.0 HYDROGEOLOGY

Information of the Hydrogeology of the Central Newfoundland was primarily derived from available water well records. The available water well records for the Central Newfoundland study area are summarized in tabular form in Appendix II. A total of 3,080 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 145 overburden wells were reported, of which 119 provided well yield estimates, and 137 provided depths. Data on 2,900 bedrock wells were reported, of which 2,119 have well yield estimates, and 2,825 provided depths. There were 35 water well records that could not be placed into a bedrock or overburden well category due to incomplete data (e.g., missing lithology, well depth, etc.). There are also numerous drilled or dug wells in the study area for which no records exists.

## 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 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.

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.

## 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).

A total of 145 water wells within the study area were reported 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 on Map 1. The yield and depth characteristics of these units are summarized on Table 4.1. 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 tills 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 46 well records are available for Unit A. Well yields ranged from 2 L/min to 136 L/min with a median value of 18 L/min and averaged 29 L/min. Well depth ranged from 9 meters (m) to 50 m with a median value of 15 m and averaged 17 m. The available data indicate that, on average, wells drilled within Unit A have a moderate potential yield.

#### 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 hydrostratigraphic units in the study area. It consists of deposits of gravel, sand and silt representing primarily outwash plain deposits. These deposits occur extensively within the major river valleys. Thicknesses up to 27 m have been recorded in the Exploits River basin (Nolan Davis, 1991).

Due to their usually shallow position and their matrix chemistry 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 99 well records are available for Unit B. Wells drilled in Unit B are largely found near Springdale, Grand Falls, St. Alban's, Laurenceton, Badger and Browns Arm. Well yields ranged from 4 L/min to 683 L/min with a median value of 50 L/min and averaged 102 L/min. Well depth ranged from 9 m to 49 m with a median value of 22 m and averaged 23 m. The available data indicates that wells drilled within Unit B have a moderate to high potential yield.

**Table 5-1: Overburden Hydrostratigraphic Units, Central Newfoundland**

| **Hydrostratigraphic Unit** | **Number of Wells** | **Well Yield Characteristics[2] (L/min)** | | **Well Depth Characteristics (m)** | |
|---|---|---|---|---|---|
| | | Average | Median | Average | Median |
| **Unit A**<br>**Moderate Yield**<br>Till | 46 | 29 | 18 | 17 | 15 |
| **Unit B**<br>**Moderate to High Yield**<br>Sand and Gravel | 99 | 102 | 50 | 23 | 22 |

Notes:
1. The data presented are updated to December, 2005. 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 16 are reported for Unit A and 10 are reported for Unit B.

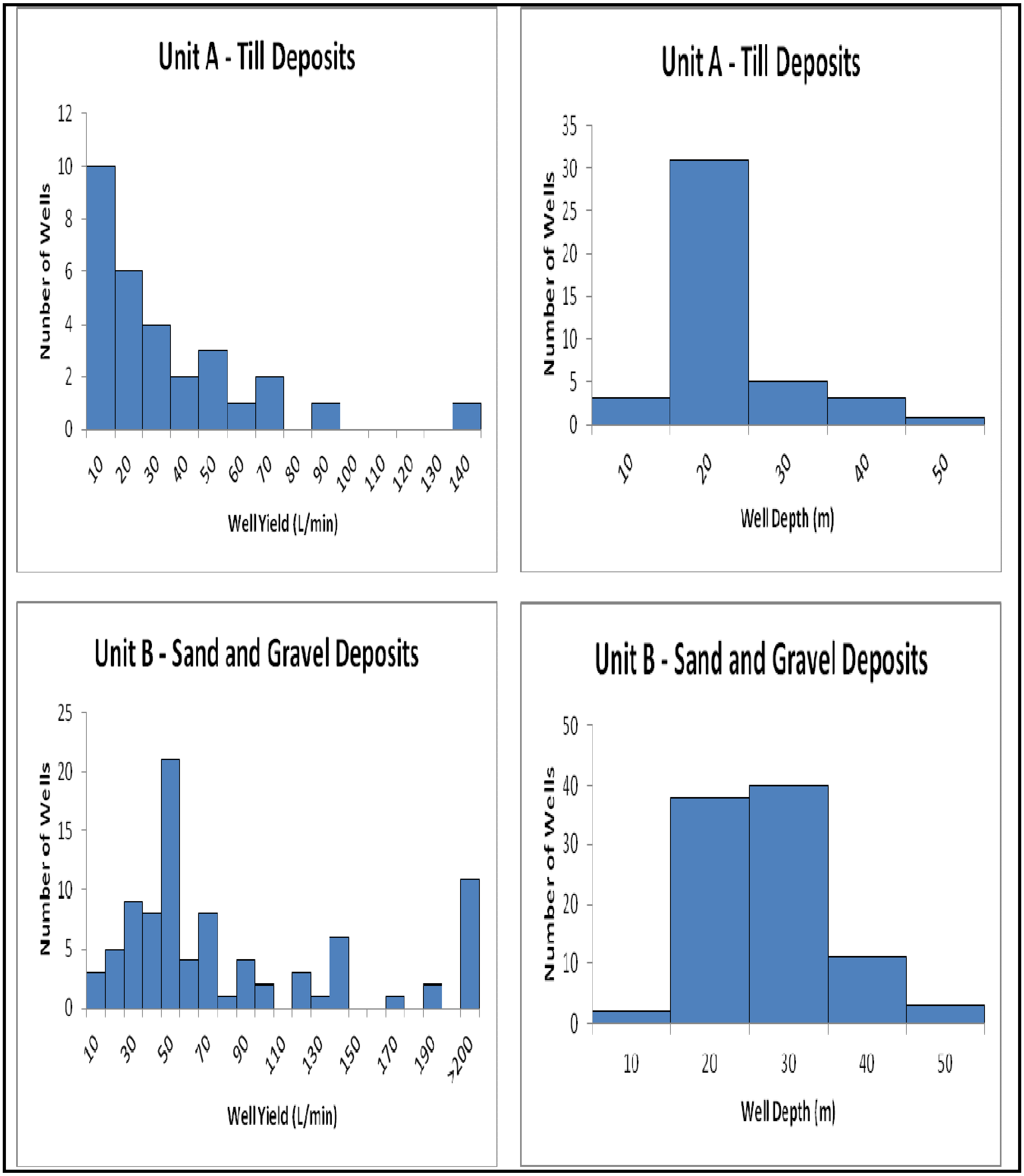



**Figure 5-1: Well Yield and Depth Relationships, Overburden Hydrostratigraphic Units A and B, Central Newfoundland (data from DOEC, 2005)**

### 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 five hydrostratigraphic units based on lithology, well depth and yield. These units are summarized in Table 4.2 and are shown on Map 3. Histograms of estimated yield and depth of wells completed in bedrock hydrostratigraphic units 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 the wells 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.

#### 5.2.2.1 Unit 1 – Metamorphic Strata

Highly metamorphosed rocks, comprising schist, gneiss, quartzite, and slate, with minor volcanic flows of Precambrian and Ordovician age occur in the Notre Dame Bay and Bonavista Bay areas. Metamorphic rocks are formed under extreme pressure and temperature. When other rocks, such as sandstones or granites, are subjected to great pressures and temperatures, the rocks get 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 gets 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 73 well records are available for Unit 1. Well yields ranged from 0.5 L/min to 270 L/min with a median value of 6 L/min and averaged 20 L/min. Well depth ranged from 15 m to 120 m with a median value of 48 m and averaged 51 m. The available data indicate that wells drilled within Unit 1 generally have a low to moderate potential yield. Four wells drilled in Unit 1 were reported to have been abandoned due to insufficient water supply.

#### 5.2.2.2 Unit 2 – Sedimentary Strata

The sedimentary rock unit includes several moderately metamorphosed sedimentary formations, mainly of Ordovician to Silurian age, which comprise sandstone, siltstone, conglomerate, argillite, greywacke, with minor volcanic flows and tuff. Carbonate rocks are essentially absent in these formations.

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 1,403 well records are available for Unit 2. Well yields ranged from 0.1 L/min to 491 L/min with a median value of 7 L/min and averaged 20 L/min. Well depth ranged from 6.6 m to 219 m with a median value of 46 m and averaged 51 m. The available data indicate that wells drilled within Unit 2 generally have a low to moderate potential yield. Seventy wells drilled in Unit 2 were abandoned due to insufficient supply.

#### 5.2.2.3 Unit 3 – Volcanic Strata

This unit comprises the relatively unmetamorphosed volcanic rocks; essentially consisting of basic pillow lava, flows, breccia and tuff, with major intercalated, volcanic -derived sedimentary units in places, mainly ranging in age from Ordovician to Silurian. 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. Some of the pillow basalts belong to ophiolite complexes, e.g. Baie Verte and Springdale Peninsulas. 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 723 well records are available for Unit 3. Large areas of the study area are underlain by Unit 3. Well yields ranged from 0.1 L/min to 455 L/min with a median value of 9 L/min and averaged 22 L/min. Well depth ranged from 5 m to 159 m with a median value of 46 m and averaged 50 m. The available data indicate that wells drilled within Unit 3 have a low to moderate potential yield. Fifty one wells drilled in Unit 3 were abandoned due to insufficient supply.

#### 5.2.2.4 Unit 4 – Ophiolite Complexes

This unit consists of mafic and ultramafic intrusions of ophiolite complexes. They are composed of hard rocks—basalt, dolerite, diabase gabbro and peridotite, which are formed at the mid-oceanic ridges, with specific ridge-related tectonic fracturing and intense hydrothermal alteration. Their geological and thus their hydrogeological properties differ from those of both granite or “classical” gabbro and “classical” basaltic. In ophiolite rocks, groundwater circulation takes place mostly in the near-surface fissures and, to a lesser degree, in the tectonic fractures.

A total of 13 well records are available for Unit 4. Well yields ranged from 1 L/min to 35 L/min with a median value of 7 L/min and averaged 9 L/min. Well depth ranged from 32 m to 93 m with a median value of 61 m and averaged 58 m. The available data indicate that wells drilled within Unit 4 have a low potential yield. One well drilled in Unit 4 was 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 Ordovician 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, because these rocks extend over large areas, large volumes of ground water are withdrawn from them, 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 688 well records are available for Unit 5. Well yields ranged from 0.1 L/min to 550 L/min with a median value of 9 L/min and averaged 22 L/min. Well depth ranged from 9 m to 207 m with a median value of 37 m and and averaged 44 m. The available data indicate that wells drilled within Unit 5 have a low to moderate potential yield. Fifty six wells in Unit 5 were abandoned due to insufficient supply.

**Table 5-2: Bedrock Hydrostratigraphic Units, Central Newfoundland**

| **Hydrostratigraphic Unit** | **Lithology** | **Number of Wells** | **Well Yield Characteristics[2] (L/min)** | | **Well Depth Characteristics (m)** | |
|---|---|---|---|---|---|---|
| | | | Average | Median | Average | Median |
| <u>**Unit 1**</u><br>**Low to Moderate Yield**<br>Metamorphic Strata | schist, gneiss, quartzite, slate | 73 | 20 | 6 | 51 | 48 |
| <u>**Unit 2**</u><br>**Low to Moderate Yield**<br>Sedimentary Strata | siltstone, conglomerate, argillite, greywacke, with minor volcanic flows and tuff. | 1403 | 20 | 7 | 51 | 46 |
| <u>**Unit 3**</u><br>**Low to Moderate Yield**<br>Volcanic Strata | basic pillow lava, flows, breccia and tuff | 723 | 22 | 9 | 50 | 46 |
| <u>**Unit 4**</u><br>**Low Yield**<br>Ophiolite Complexes | mafic and ultramafic intrusions of ophiolite complexes | 13 | 9 | 7 | 58 | 61 |
| <u>**Unit 5**</u><br>**Low to Moderate Yield**<br>Plutonic Strata | granite, granodiorite, diabase, and diorite intrusions | 688 | 22 | 9 | 44 | 37 |

Notes:

1. The data presented are updated to December, 2005. 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 5 (7%) are reported for Unit 1, 373 (27%) are reported for Unit 2, 187 (26%) are reported for Unit 3, 4 (31%) are reported for Unit 4, and 241 (35%) are reported for Unit 5.

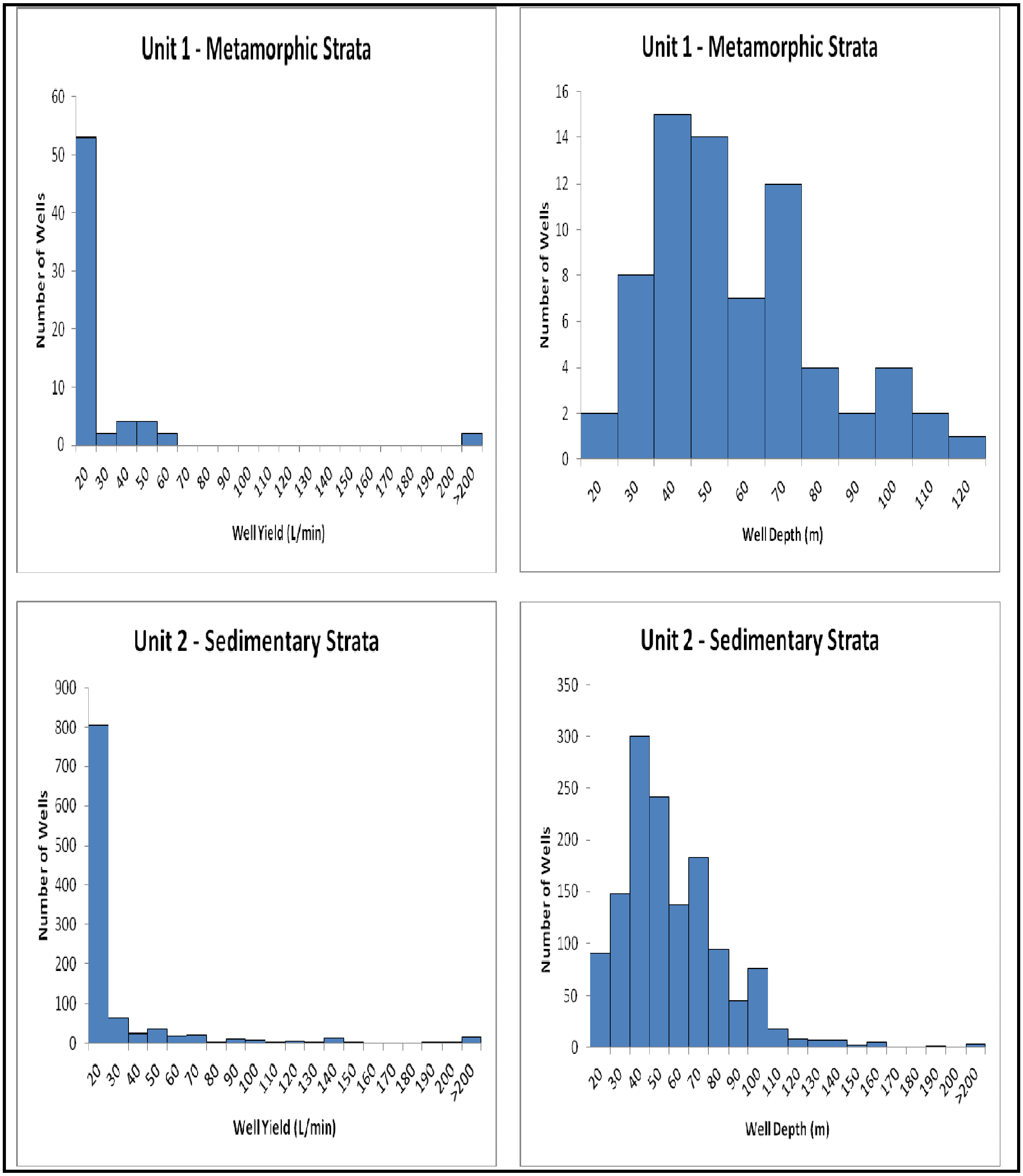



**Figure 5-2: Well Yield and Depth Relationships, Bedrock Hydrostratigraphic Units 1 and 2, Central Newfoundland (data from DOEC, 2005).** Not including 0 values.

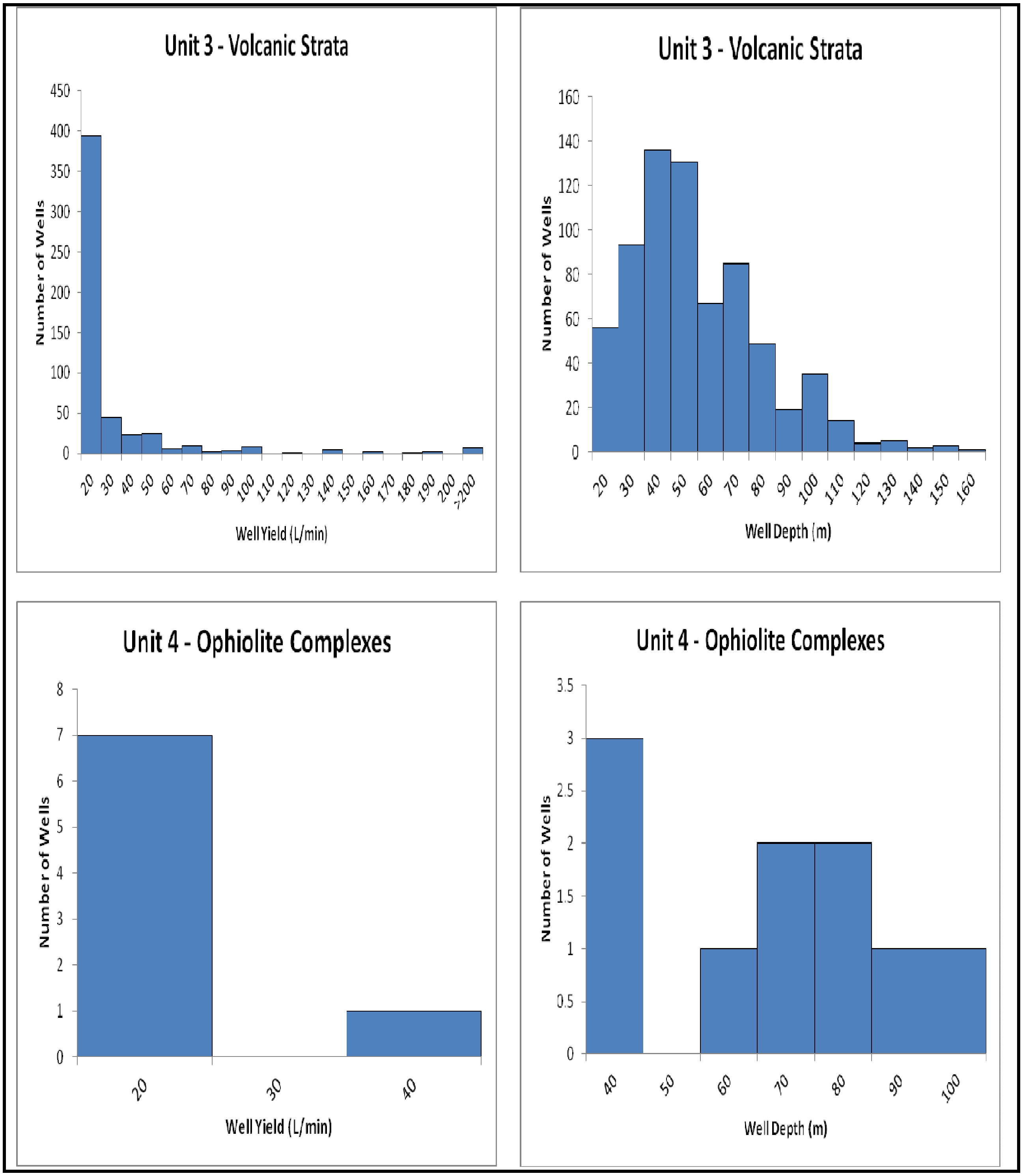



**Figure 5-3: Well Yield and Depth Relationships, Bedrock Hydrostratigraphic Units 3 and 4 Central Newfoundland (data from DOEC, 2005).** Not including 0 values.

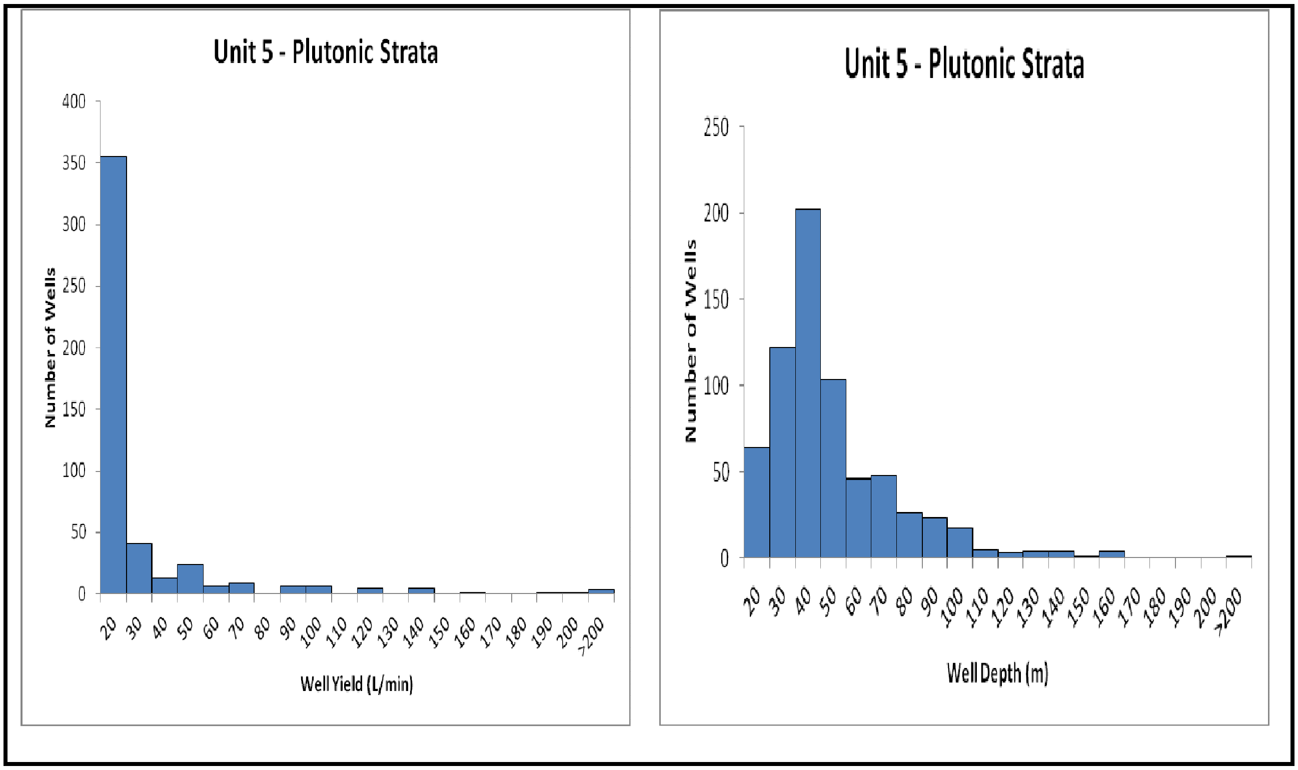



**Figure 5-4: Well Yield and Depth Relationships, Bedrock Hydrostratigraphic Unit 5, Central Newfoundland (data from DOEC, 2005).** Not including 0 values.

## 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 246 aquifer tests are reported to have been conducted in the study area, and ranged in length from 30 to 720 minutes. Appendix III lists the available aquifer tests completed in the study area according to community and hydrostratigraphic unit. Aquifer test data was not available from Unit 4.

Table 4.3 presents a comparison of well supply aquifer tests with the results of the yield tests for mainly single domestic well yields as determined by water well drillers. Generally the results are similar for the two datasets, except where there is very limited aquifer test data to provide a statistically meaningful average or median value. Where there is very limited aquifer test data, such as for Units A, 1, and 5, the two datasets cannot be reliably compared.

Problems associated with the aquifer test database for Central 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 (Kruseman *et al*, 1970). 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 3 days is required.

In addition, reliable aquifer tests performed in a confined aquifer give an estimate of storage parameters such as specific yield and storativity. However, none of the aquifer tests conducted in Central Newfoundland provided storage parameters

As shown in Appendix III there were 246 pump tests that took place and none of these 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 Central 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 Safe Yield Estimates**

| Hydrostratigraphic Unit | Aquifer Test Data | | | Water Well Record Data | | |
|---|---|---|---|---|---|---|
| | No. of tests | Average (L/min) | Range (L/min) | No. of tests | Average (L/min) | Range (L/min) |
| **Unit A**<br>**Moderate Yield**<br>Till | 2 | 0 | 0 | 46 | 29 | 2 - 136 |
| **Unit B**<br>**Moderate to High Yield**<br>Sand and Gravel | 11 | 77 | 9 - 500 | 99 | 102 | 4 - 683 |
| **Unit 1**<br>**Low to Moderate Yield**<br>Metamorphic Strata | 1 | 3 | 3 | 73 | 20 | 0.5 - 270 |
| **Unit 2**<br>**Low to Moderate Yield**<br>Sedimentary Strata | 110 | 23 | 0.5 - 273 | 1403 | 20 | 0.1 - 491 |
| **Unit 3**<br>**Low to Moderate Yield**<br>Volcanic Strata | 72 | 17 | 1 - 114 | 723 | 22 | 0.1 - 455 |
| **Unit 4**[2]<br>**Low Yield**<br>Ophiolite Complexes | 0 | NA | NA | 13 | 9 | 1 - 35 |
| **Unit 5**<br>**Low to Moderate Yield**<br>Plutonic Strata | 52 | 24 | 1 - 113 | 688 | 22 | 0.1 - 550 |

Notes:

1. The data presented are updated to December, 2005. 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. Test data was not available for Unit 4.

## 5.4 GROUNDWATER 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 3,080 water well records within the study area only 2270 records provided water usage. Of these, 2,008 are for domestic use, 37 are for commercial use, 66 are for public supply, 47 are for industrial, 111 are for municipal and 1 is for stock.

The larger towns that use groundwater as their primary source for drinking water within the study are Badger and St. Albans. Groundwater also provides vital water supplies for agriculture and mining activities within the study area. In addition, groundwater is used as a heating and cooling source using heat pumps.

# 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 baseflow. Baseflow 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 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 shows the sub-sub drainage divisions identified by Environment Canada covering the study area. There are a total of 11 sub-sub divisions (divided by the dash line).

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 and the topographic features, the study area is divided into five sub-regions for the purpose of this study, as follows:

- Sub-region 1: which encompasses drainage sub-sub divisions of 2YM and 2YP;
- Sub-region 2: which encompasses drainage sub-sub divisions of 2YN and 2YO;
- Sub-region 3: which encompasses drainage sub-sub division of 2YQ, 2YR, and 2YS;
- Sub-region 4: which encompasses drainage sub-sub divisions of 2ZC and 2ZD; and
- Sub-region 5: which encompasses drainage sub-sub drainage divisions of 2ZE and 2ZF.

## 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 on line (http://climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html). Among the meteorological stations listed for Newfoundland at the website, 13 are 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 and 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.

Table 6.2 indicates that the annual precipitation amounts for the two sub-regions along the southern coast range from 1437 mm to 1584 mm and are generally comparable. The precipitation amounts for the three sub-regions along the northern coast range from 1036 mm to 1105 mm and are generally comparable. It is also apparent that the sub-regions along the southern coast generally have significantly higher annual precipitation than those along the northern coast.

The average monthly precipitation for the five sub-regions is shown in Figure 6-2. Average precipitation for the three northern sub-regions are somewhat higher in the fall, but are otherwise relatively evenly distributed through the year. For the two southern sub-regions, the precipitation is significantly higher in the fall and winter months than for the remainder of the year.

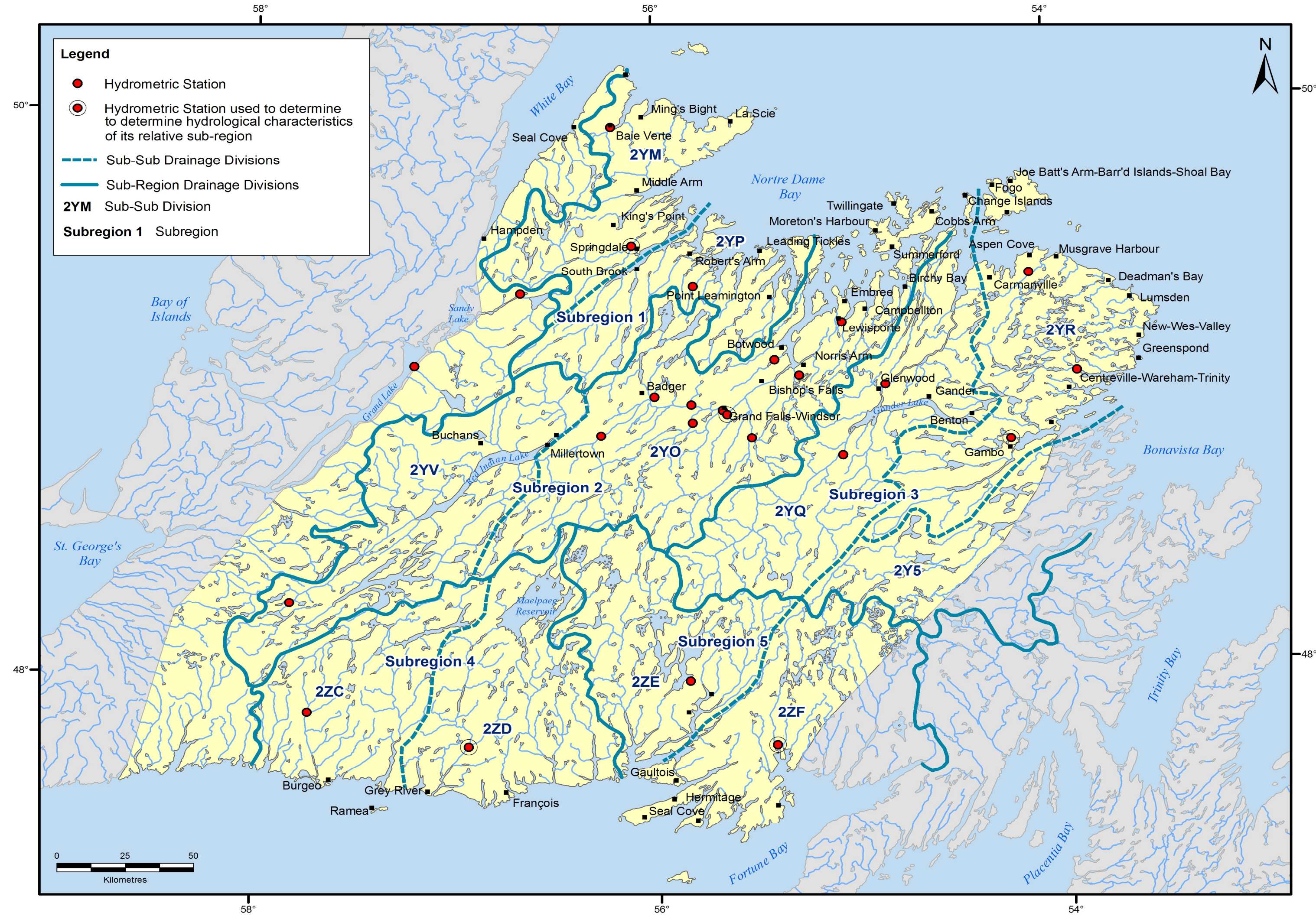



**Figure 6-1: Drainage Divisions within the Study Area (based on Environment Canada, 1987)**

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 relatively frequently and a proportion of the precipitation in the winter is in the form of rainfall.

**Table 6-1: Climatic Stations within the Study Area Grouped into Subregions**

| Station Name | Latitude | Longitude | Elevation | Drainage Sub-sub Division |
|---|---|---|---|---|
| **Sub-region 1** | | | | |
| Springdale | 49° 30.000' N | 56° 4.800' W | 23.00 m | 2YM |
| Point Leamington | 49° 19.800' N | 55° 24.000' W | 07.60 m | 2YP |
| **Sub-region 2** | | | | |
| Woodale Bishops Falls | 49° 1.800' N | 55° 33.000' W | 45.70 m | 2YO |
| Rattling Brook Norris Arm | 49° 4.200' N | 55° 18.000' W | 08.80 m | 2YO |
| Grand Falls | 48° 55.800' N | 55° 40.200' W | 60.00 m | 2YO |
| Exploits Dam | 48° 46.200' N | 56° 36.000' W | 153.60 m | 2YO |
| Botwood | 49° 9.000' N | 55° 21.000' W | 15.20 m | 2YO |
| **Sub-region 3** | | | | |
| Musgrave Harbour | 49° 27.000' N | 53° 58.800' W | 03.00 m | 2YR |
| Gander Airport | 48° 57.000' N | 54° 34.800' W | 151.20 m | 2YQ |
| Carmanville | 49° 24.000' N | 54° 16.200' W | 04.00 m | 2YR |
| **Sub-region 4** | | | | |
| Burnt Pond | 48° 10.200' N | 57° 19.800' W | 298.70 m | 2ZC |
| **Sub-region 5** | | | | |
| Buchans | 48° 49.200' N | 56° 52.200' W | 269.70 m | 2ZD |

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

**Table 6-2: Hydrologic Budget for Central Newfoundland**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Subregion 1** | | | | | | | | | | | | | |
| Temperature | -8.35 | -8.6 | -4.2 | 1.45 | 6.85 | 11.9 | 16.6 | 16.2 | 11.6 | 6.2 | 1.0 | -4.9 | 3.8 |
| Precipitation (mm) | 17 | 10 | 25 | 45 | 77 | 92 | 81 | 102 | 102 | 112 | 73 | 31 | 766 |
| Rainfall (mm) | 62 | 58 | 47 | 22 | 4 | 0 | 0 | 0 | 0 | 3 | 21 | 53 | 269 |
| Snowfall (mm) | 79 | 68 | 72 | 67 | 81 | 92 | 81 | 102 | 102 | 115 | 93 | 84 | 1036 |
| Runoff Depth (mm) | 27 | 20 | 33 | 97 | 164 | 60 | 26 | 24 | 21 | 42 | 51 | 38 | 601 |
| Surface Runoff (mm) | | | | | | | | | | | | | 422 |
| Baseflow (mm) | | | | | | | | | | | | | 178 |
| Evaporation and Transpiration (mm) | | | | | | | | | | | | | 435 |
| **Subregion 2** | | | | | | | | | | | | | |
| Temperature | -7.9 | -8.6 | -4.0 | 1.8 | 7.4 | 12.5 | 16.8 | 16.2 | 11.7 | 6.1 | 1.1 | -4.6 | 4.0 |
| Precipitation (mm) | 33 | 24 | 38 | 52 | 74 | 86 | 87 | 102 | 95 | 101 | 73 | 41 | 807 |
| Rainfall (mm) | 66 | 58 | 49 | 25 | 4 | 1 | 0 | 0 | 0 | 5 | 22 | 55 | 283 |
| Snowfall (mm) | 99 | 81 | 87 | 77 | 78 | 87 | 87 | 102 | 95 | 106 | 95 | 97 | 1091 |
| Runoff Depth (mm) | 60 | 55 | 61 | 94 | 113 | 72 | 60 | 60 | 55 | 63 | 64 | 63 | 825 |
| Surface Runoff (mm) | | | | | | | | | | | | | 612 |
| Baseflow (mm) | | | | | | | | | | | | | 214 |
| Evaporation and Transpiration (mm) | | | | | | | | | | | | | 265 |
| **Subregion 3** | | | | | | | | | | | | | |
| Temperature | -6.7 | -7.3 | -3.5 | 1.6 | 6.8 | 11.3 | 15.8 | 15.9 | 11.8 | 6.4 | 1.7 | -3.4 | 4.2 |
| Precipitation (mm) | 26 | 22 | 32 | 51 | 72 | 80 | 84 | 100 | 106 | 95 | 72 | 37 | 777 |
| Rainfall (mm) | 71 | 65 | 56 | 33 | 8 | 2 | 0 | 0 | 0 | 6 | 24 | 62 | 328 |
| Snowfall (mm) | 97 | 88 | 88 | 84 | 80 | 82 | 84 | 100 | 106 | 102 | 96 | 100 | 1106 |
| Runoff Depth (mm) | 55 | 47 | 68 | 133 | 130 | 58 | 33 | 24 | 26 | 51 | 68 | 65 | 758 |

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surface Runoff (mm) | | | | | | | | | | | | | 334 |
| Baseflow (mm) | | | | | | | | | | | | | 424 |
| Evaporation and Transpiration (mm) | | | | | | | | | | | | | 347 |
| **Subregion 4** | | | | | | | | | | | | | |
| Temperature | -9.8 | -10 | -6.4 | -0.5 | 5.4 | 10.9 | 14.8 | 14.4 | 10.1 | 4.7 | -0.3 | -6.1 | 2.225 |
| Precipitation (mm) | 69 | 45 | 59 | 72 | 90 | 97 | 103 | 106 | 107 | 131 | 114 | 83 | 1075 |
| Rainfall (mm) | 88 | 72 | 62 | 31 | 4 | 0 | 0 | 0 | 0 | 4 | 26 | 75 | 362 |
| Snowfall (mm) | 156 | 117 | 121 | 103 | 94 | 97 | 103 | 106 | 107 | 135 | 139 | 159 | 1437 |
| Runoff Depth (mm) | 103 | 82 | 107 | 238 | 191 | 72 | 64 | 63 | 83 | 113 | 137 | 107 | 1354 |
| Surface Runoff (mm) | | | | | | | | | | | | | 1219 |
| Baseflow (mm) | | | | | | | | | | | | | 135 |
| Evaporation and Transpiration (mm) | | | | | | | | | | | | | ND [2] |
| **Subregion 5** | | | | | | | | | | | | | |
| Temperature | -6.7 | -7 | -2.9 | 2.7 | 7.8 | 12.2 | 16 | 16.2 | 12.1 | 6.9 | 2.3 | -3.2 | 4.7 |
| Precipitation (mm) | 98 | 76 | 94 | 98 | 98 | 112 | 121 | 109 | 131 | 154 | 136 | 109 | 1334 |
| Rainfall (mm) | 67 | 55 | 48 | 16 | 2 | 0 | 0 | 0 | 0 | 1 | 14 | 48 | 251 |
| Snowfall (mm) | 164 | 131 | 142 | 113 | 100 | 112 | 121 | 109 | 131 | 155 | 150 | 157 | 1584 |
| Runoff Depth (mm) | 104 | 87 | 106 | 171 | 144 | 63 | 49 | 42 | 48 | 87 | 102 | 103 | 1103 |
| Surface Runoff (mm) | | | | | | | | | | | | | 621 |
| Baseflow (mm) | | | | | | | | | | | | | 391 |
| Evaporation and Transpiration (mm) | | | | | | | | | | | | | 482 |

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, 2008).
2. ND = Not Determined

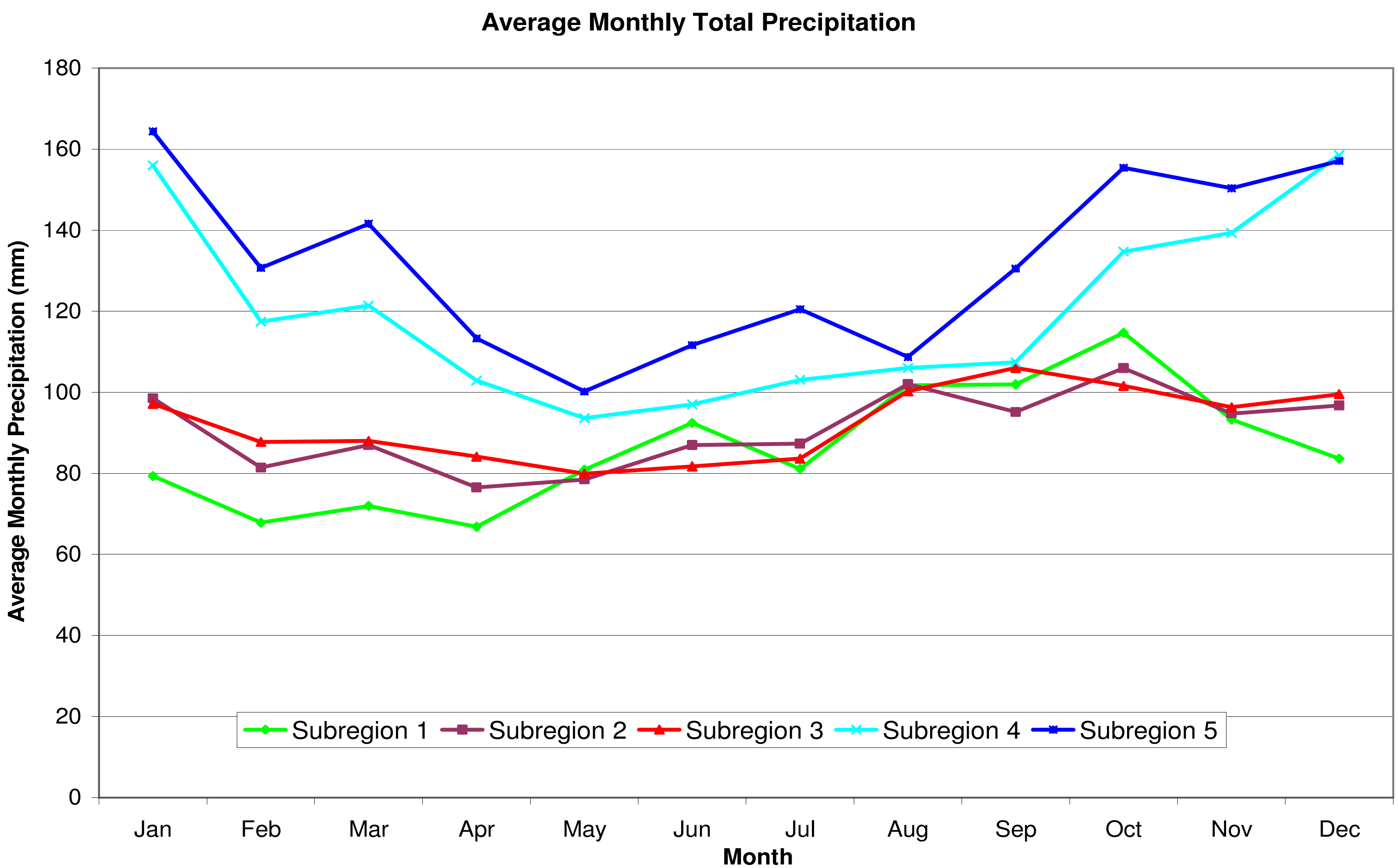



**Figure 6-2: Average Monthly Precipitation for the Five Subregions**

## 6.4 TOTAL RUNOFF

There are numerous hydrometric stations in the study region. A summary of the hydrometric stations with relatively long flow record periods and their locations in the identified subregions is provided in Table 6-3. To evaluate the hydrological characteristics of the identified subregions, it is necessary to select a limited number of hydrometric stations whose hydrological characteristics will be considered representative of that Subregion. 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 sub-regions as follows, whose hydrological conditions will be considered representative for that sub-region:

- Subregion 1: Indian Brook at Indian Falls (02YM001)
- Subregion 2: Exploits River at Grand Falls (02YO001)
- Subregion 3: Middle Brook near Gambo (02YR001)
- Subregion 4: Grey River near Grey River (02ZD002)
- Subregion 5: Bay Du Nord River at Big Falls (02ZF001)

The flow in Exploits River at Grand Falls is subject to regulation by power dams upstream. There are a number of hydrometric stations in Subregion 2 with record periods spanning from 1971 to 2000. However, the flows for all these hydrometric stations are regulated. These regulations are expected to alter the daily flow distribution, but will have diminished effect on monthly distribution.

The monthly and total annual runoff estimated from 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. It is seen that 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 increases again in the fall when precipitation increases and evaporation and transpiration decreases.

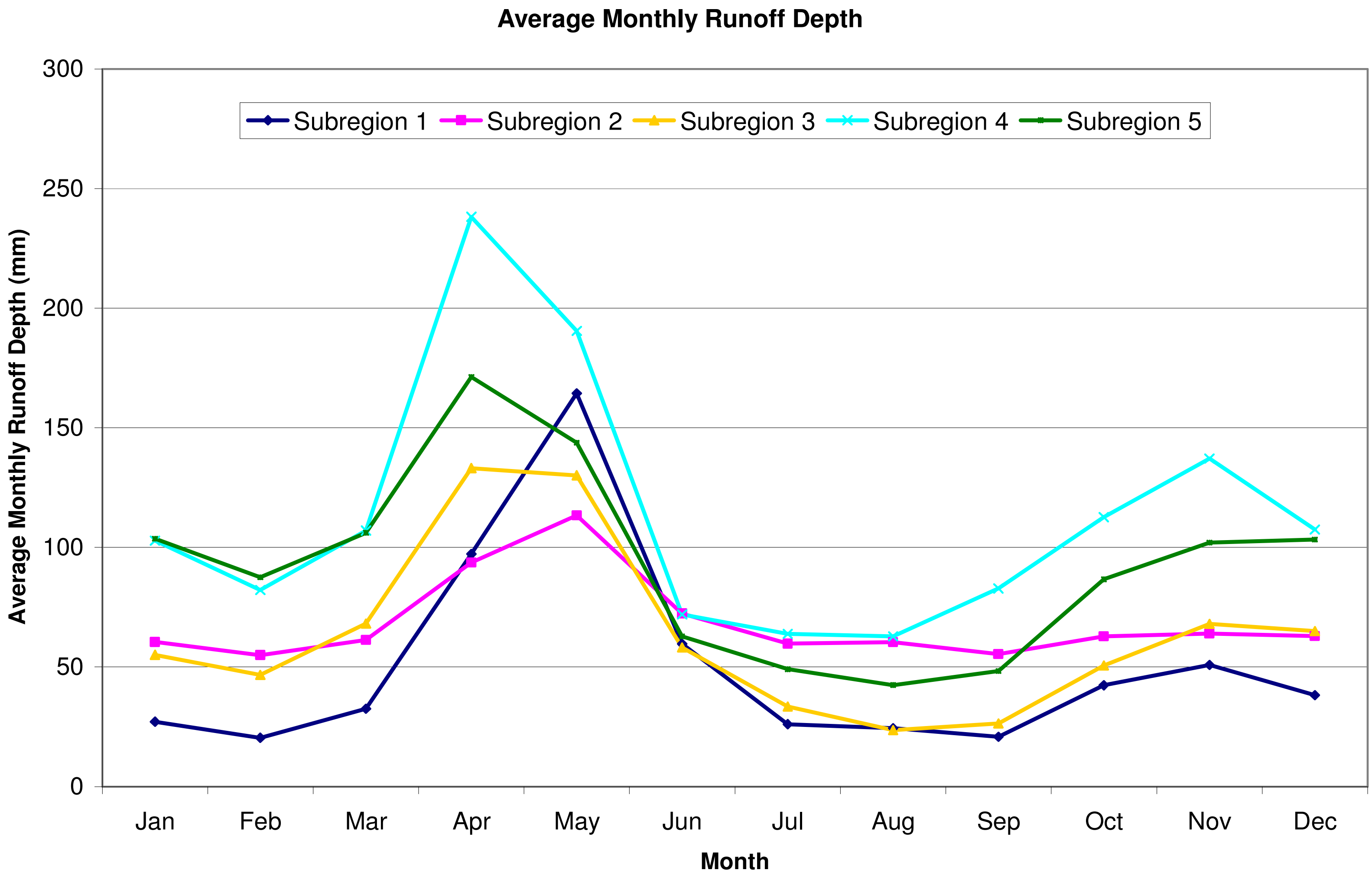



**Figure 6-3: Average Monthly Runoff Depth for the Five Sub-Regions within the Study Area**

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

| Station Name | Drainage Sub-sub Division | Regulation Type | Drainage Area (km$^2$) | Period of Record | Latitude | Longitude |
|---|---|---|---|---|---|---|
| **Subregion 1** | | | | | | |
| Indian Brook at Indian Falls | 02YM001 | Natural | 974 | 1954-1996 | 49º30'43" | 56º6'45" |
| South West Brook near Baie Verte | 02YM003 | Natural | 93.2 | 1980-2006 | 49º53'36" | 56º13'19" |
| Shoal Arm Brook near Badger Bay | 02YP001 | Natural | 63.8 | 1982-1997 | 49º22'18" | 55º48'44" |
| **Subregion 2** | | | | | | |
| Lloyds River below King George IV Lake | 02YN002 | Natural | 469 | 1981-2006 | 48º14'23" | 57º49'41" |
| Exploits River at Grand Falls | 02YO001 | Regulated | 8390 | 1944-2006 | 48º55'50" | 55º40'7" |
| Rattling Brook at Rattling Brook Powerhouse | 02YO003 | Regulated | 378 | 1962-2006 | 49º3'12" | 55º17'12" |
| Sandy Brook at Sandy Brook Powerhouse | 02YO004 | Regulated | 508 | 1964-2006 | 48º53'18" | 55º49'14" |
| Exploits River below Stony Brook | 02YO005 | Regulated | 8640 | 1968-1996 | 48°55'27" | 55°39'29" |
| Peters River near Botwood | 02YO006 | Natural | 177 | 1981-2006 | 49º6'13" | 55º23'48" |
| **Subregion 3** | | | | | | |
| Gander River at Big Chute | 02YQ001 | Natural | 4450 | 1949-2006 | 49º0'58" | 54º51'2" |
| Salmon River near Glenwood | 02YQ005 | Natural | 80.8 | 1987-2006 | 49º0'40" | 54º55'0" |
| Middle Brook near Gambo | 02YR001 | Natural | 275 | 1959-2006 | 48º48'28" | 54º13'28" |
| Ragged Harbour River near Musgrave Harbour | 02YR002 | Natural | 399 | 1977-1997 | 49º23'35" | 54º6'25" |
| Indian Bay Brook near Northwest Arm | 02YR003 | Natural | 554 | 1981-2006 | 49º2'24" | 53º53'0" |
| Southwest Brook at Terra Nova National Park | 02YS003 | Natural | 36.7 | 1967-2006 | 48º36'25" | 53º58'50" |
| Terra Nova River at Glovertown | 02YS005 | Natural | 2000 | 1985-2006 | 48º39'43" | 54º1'5" |
| **Subregion 4** | | | | | | |
| Grandy Brook below Top Pond Brook | 02ZC002 | Natural | 230 | 1982-2006 | 47º51'21" | 57º43'59 |

| Station Name | Drainage Sub-sub Division | Regulation Type | Drainage Area (km$^2$) | Period of Record | Latitude | Longitude |
|---|---|---|---|---|---|---|
| Grey River near Grey River | 02ZD002 | Natural | 1340 | 1969-2006 | 47º44'35" | 56º56'2" |
| **Subregion 5** | | | | | | |
| Salmon River at Round Pond | 02ZE003 | Regulated | 5910 | 1967-2006 | 47º59'0" | 55º51'12" |
| Conne River at Outlet of Conne River Pond | 02ZE004 | Natural | 99.5 | 1989-2006 | 48º10'7" | 55º28'58" |
| Bay du Nord Rive at Big Falls | 02ZF001 | Natural | 1170 | 1950-2006 | 47º44'48" | 55º26'24" |

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

## 6.5 BASEFLOW

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 presented 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. It is seen that for 1992, the flows for the five representative hydrometric stations are close to average conditions, and the daily flow records for 1992 are used to represent an average year condition.

The baseflow contributions to total stream flow for the representative hydrometric stations are presented in Figures 6-5 through 6-9. The baseflow would include groundwater discharge along with water released from storage in lakes, ponds, bogs, and water migrating through the shallow subsurface. For Subregion 2, it was found that the flow records for the hydrometric station 02YO001 are not suitable for the purpose of separating baseflow due to flow regulations by the hydroelectric dams upstream. For this subregion, the flow records for 1992 for the hydrometric station 02YO006, where the flow is not regulated, is used for the purpose of baseflow separation.

The total annual baseflow contributions to stream flow expressed as a depth over the watershed area are also summarized in Table 6-2. For the three northern subregions, the total annual baseflow contribution for Subregion 1 and Subregion 2 are estimated to be 30% (178 mm) and 26% (214 mm) respectively, and are generally comparable. The total annual baseflow contribution for Subregion 3 is estimated to be in the order of 56% (424 mm) of total annual runoff and is significantly higher than that for the other two northern subregions. This is assessed to be the result of the comparatively low topography and relief for this subregion.

For the two southern subregions, the total annual baseflow contribution for Subregion 4 estimated using flow records for Hydrometric Station 02ZD002 is approximately 10% (135 mm). The total annual baseflow contribution for Subregion 5 estimated using flow records for Hydrometric Stations 02ZF001 is 35% (391 mm) and is significantly higher than that for Subregion 4. This is assessed to be the result of the comparatively lower topography and relief of Subregion 5 than that for Subregion 4.

Under similar topographic conditions, the southern regions generally have lower baseflow contribution than that for the northern regions. It is suspected that the southern regions receive higher precipitation, and the ground moisture content on average is much higher than in the northern regions. This results in a higher proportion of precipitation generating surface runoff.

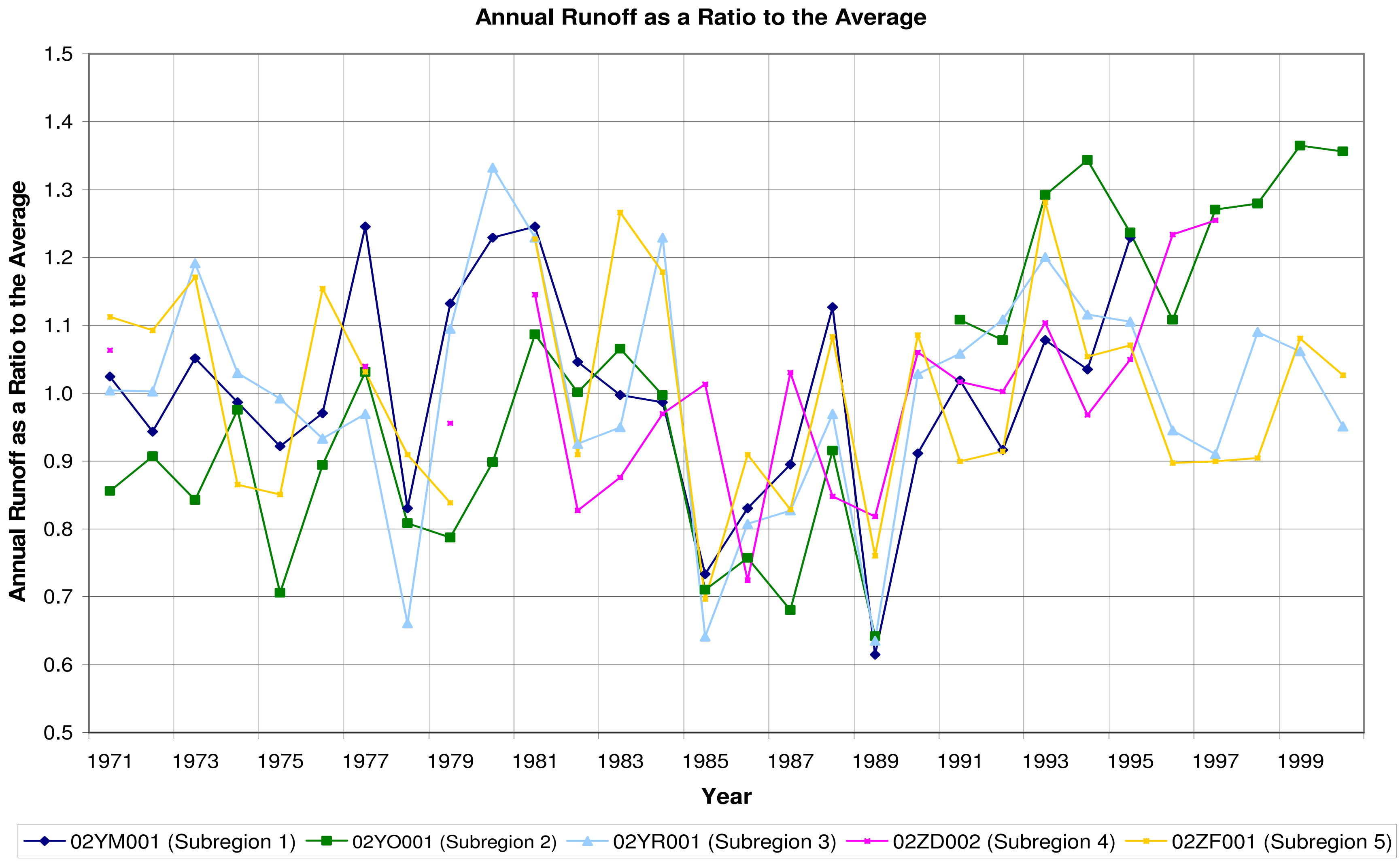



**Figure 6-4: Average Runoff as a Ratio to the Average in the Five Subregions**

## 6.6 HYDROLOGICAL BUDGET

Table 6.2 summarizes the major hydrological components for the five subregions identified for the study area. It is seen that on an annual basis, the total runoff represents generally between 58 to 76 percent of total annual precipitation. However, for Subregion 4, the annual runoff represents over 94 percent of the total annual precipitation as calculated using the available hydrological and meteorological records. This annual runoff ratio is very high and is considered very unlikely. The hydrological Atlas of Canada prepared by Environment Canada explained that this 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 gages 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”.

Subregion 4 is relatively mountainous and the precipitation varies more significantly over the subregion than over the other subregions. It is probable that the precipitation records available for this subregion is not representative and underestimate the average precipitation in this subregion.

Annual evaportranspiration is estimated as the difference between the total precipitation and annual runoff. The annual evaportranspiration is not estimated for Subregion 4 due to the suspected poor representation of the precipitation records in this subregion.

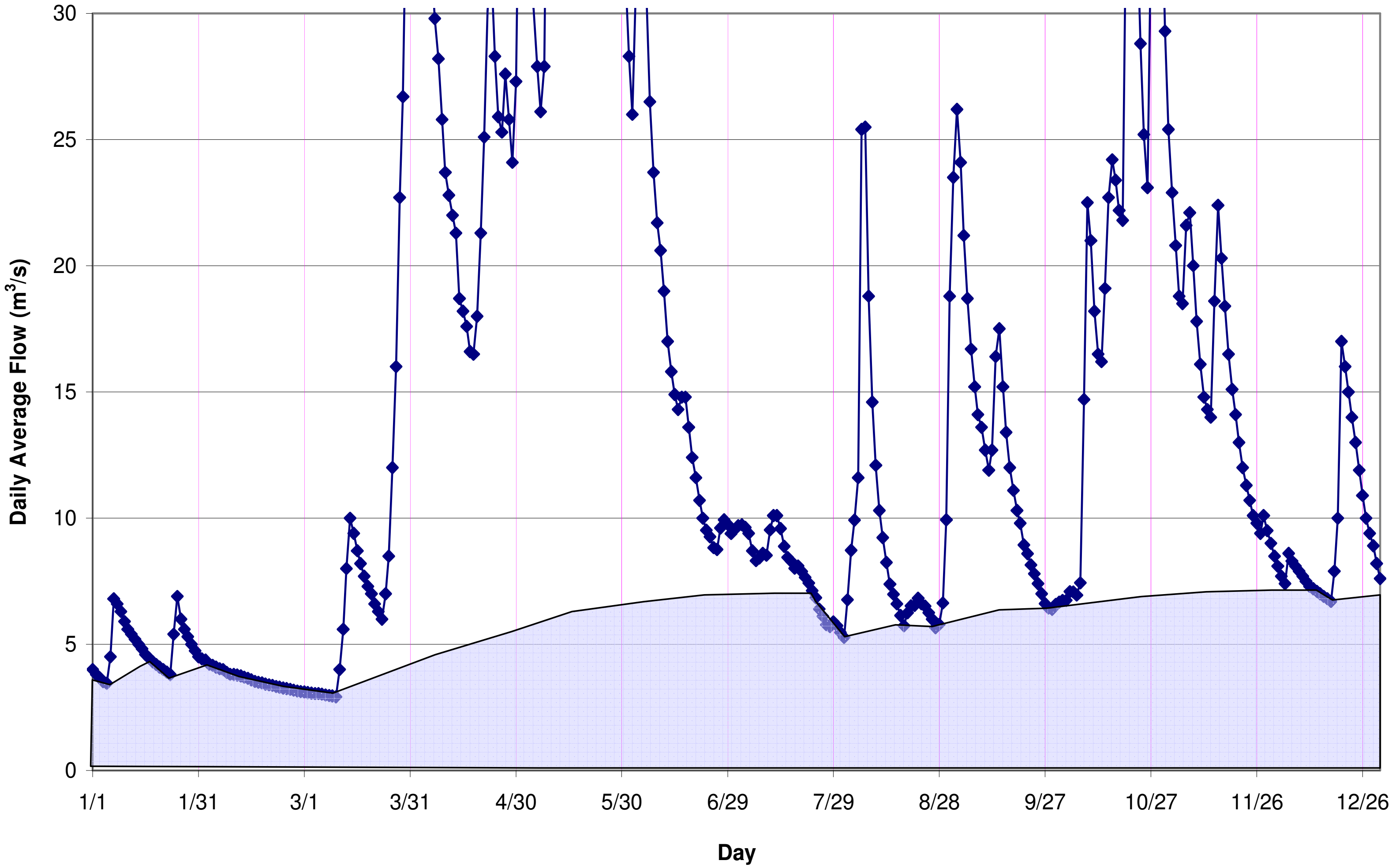



**Figure 6-5: Baseflow Separation for the Hydrometric Station 02YM001 (Subregion 1)**

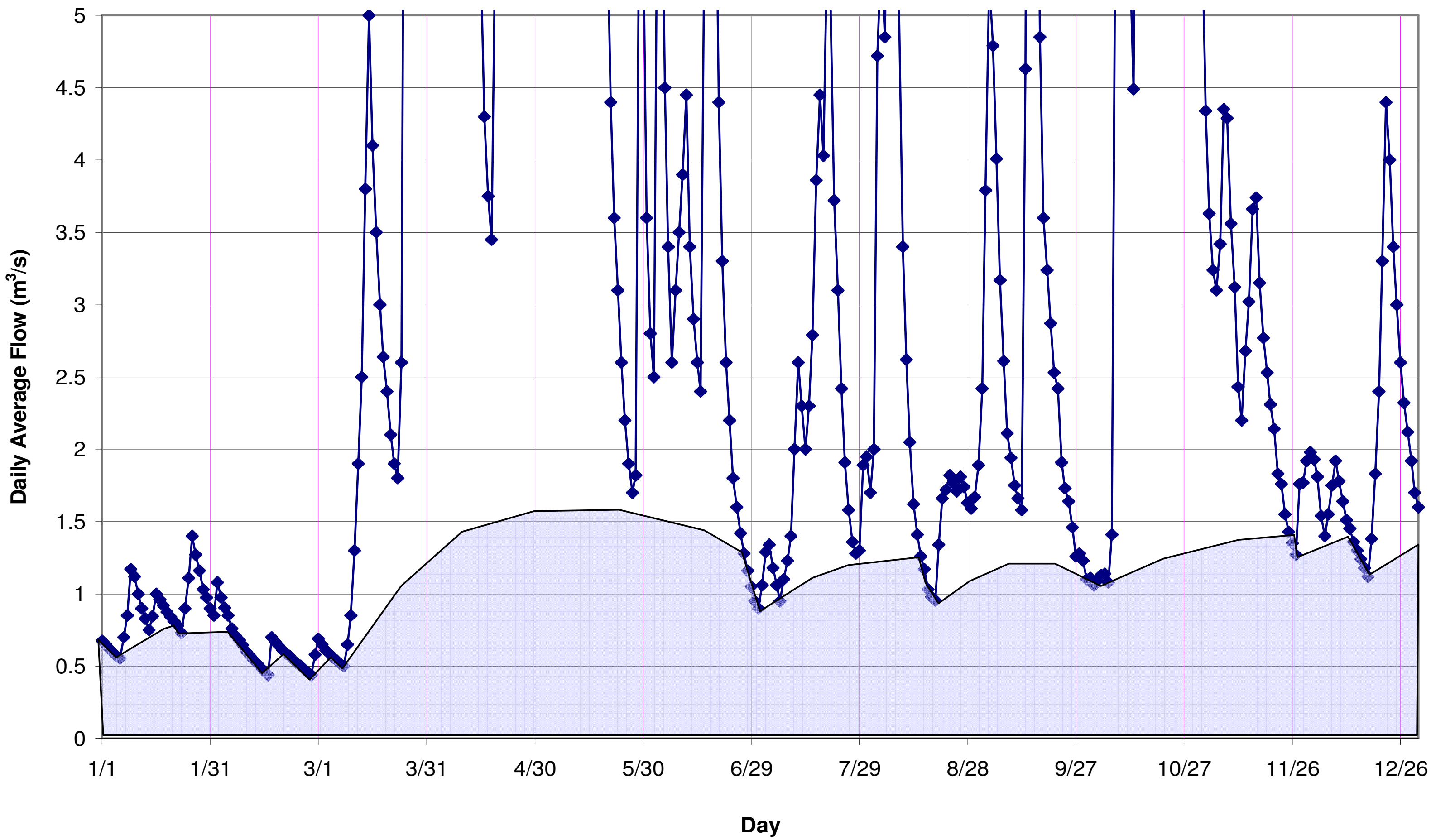



**Figure 6-6: Baseflow Separation for the Hydrometric Station 02YO006 (Subregion 2)**

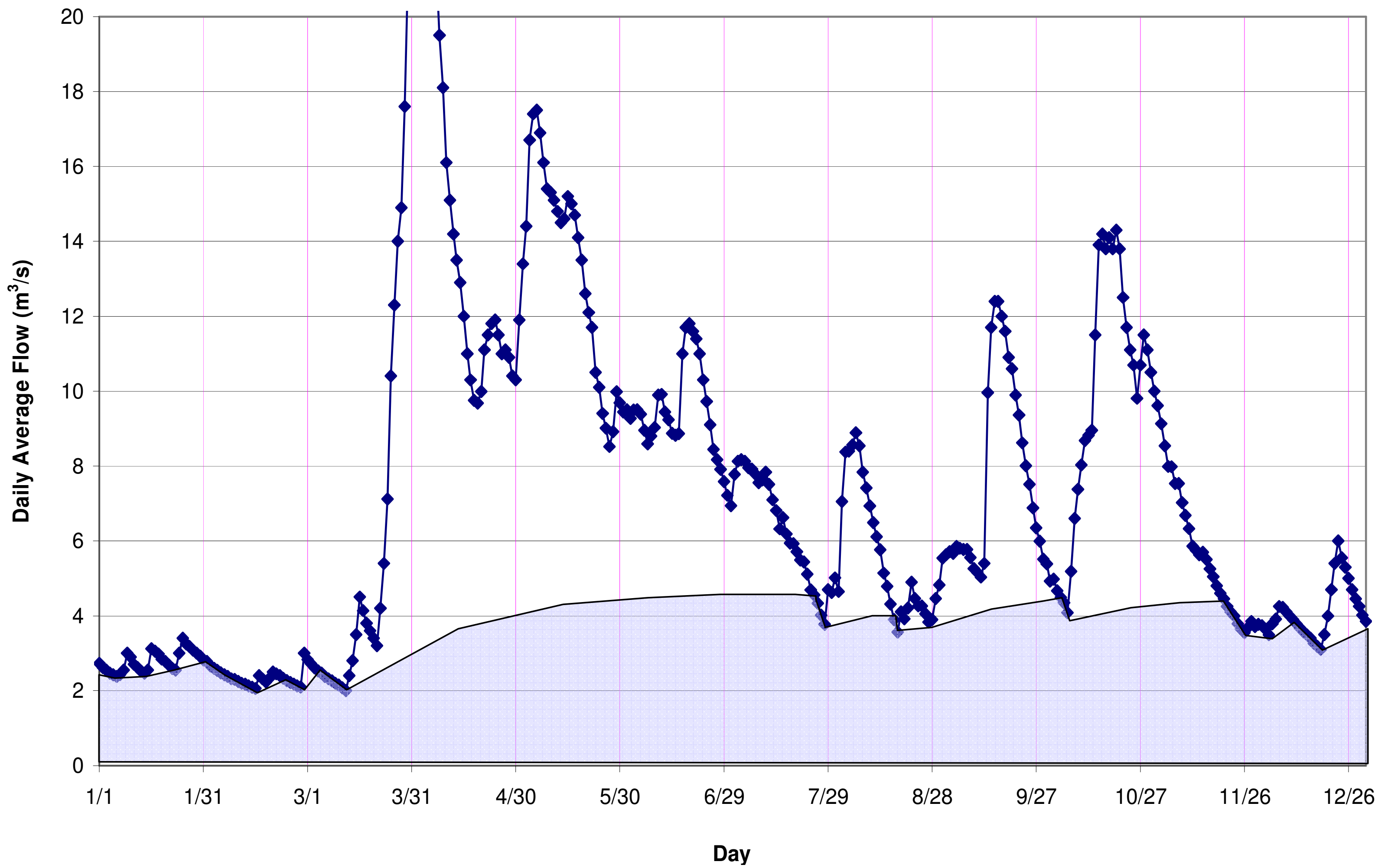



**Figure 6-7: Baseflow Separation for Hydrometric Station 02YR001 (Subregion 3)**

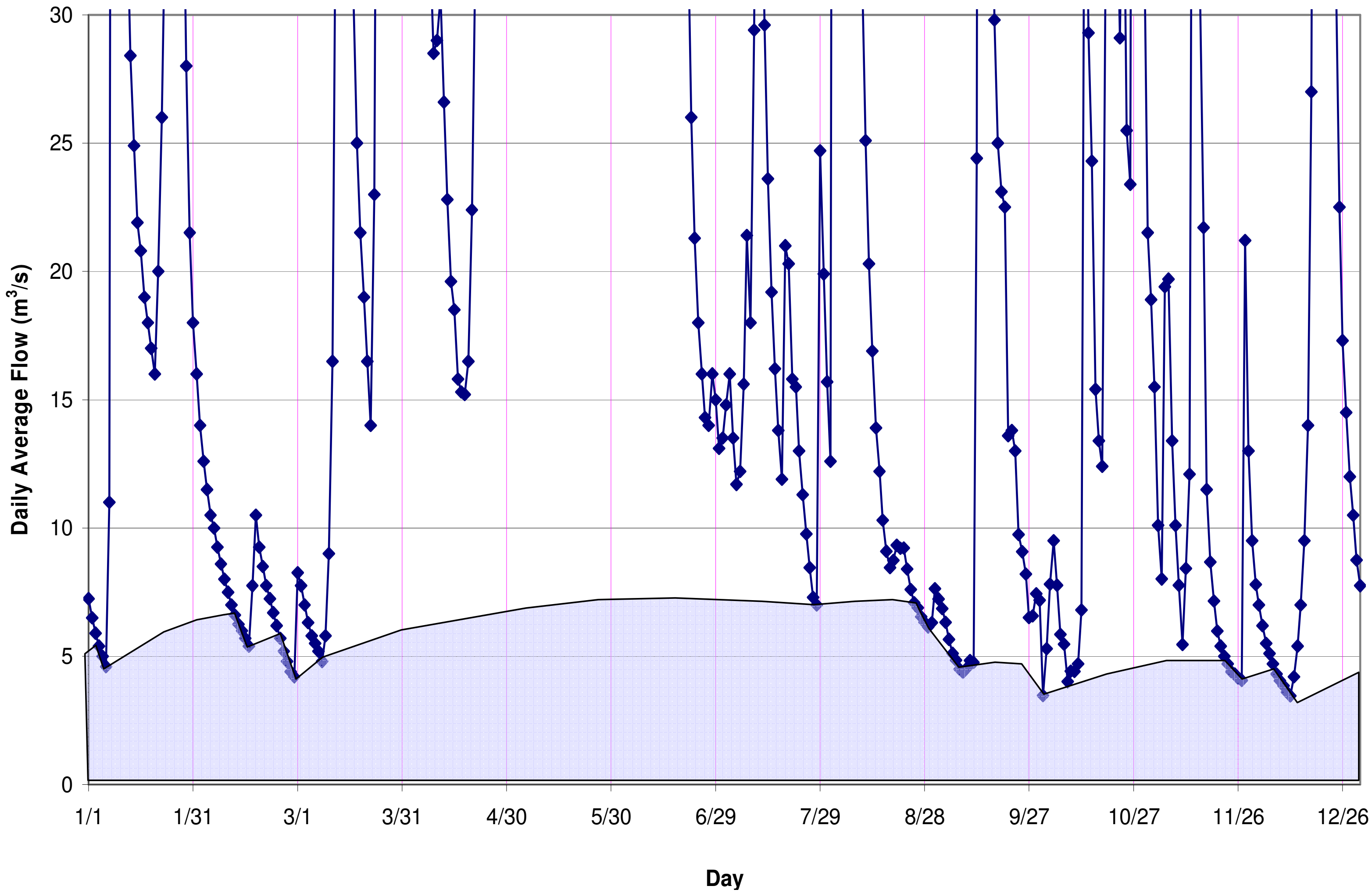



**Figure 6-8: Baseflow Separation for Hydrometric Station 02ZD002 (Subregion 4)**

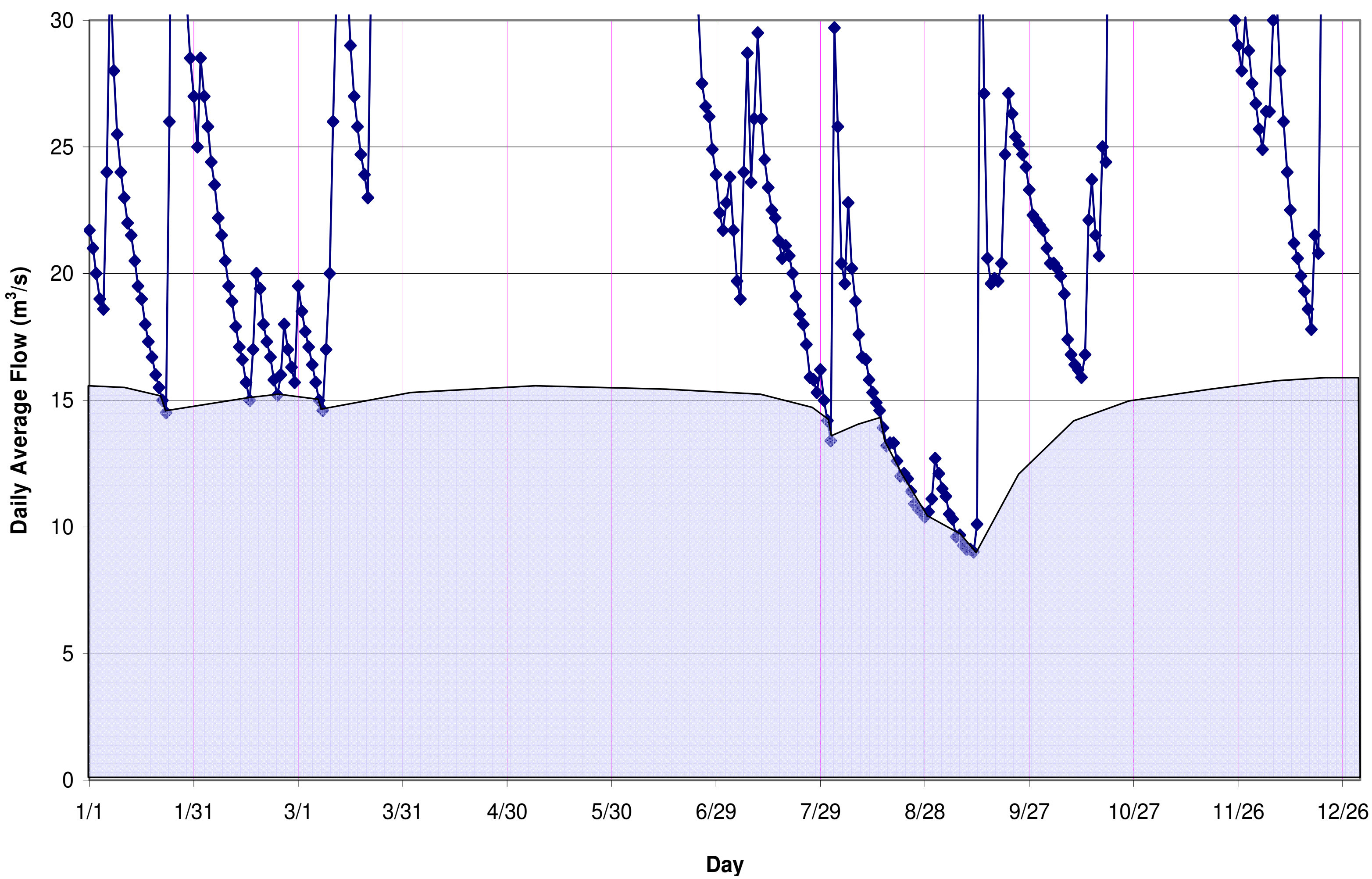



**Figure 6-9: Baseflow Separation for Hydrometric Station 02ZF001 (Subregion 5)**

## 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 Central 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.

In addition, groundwater tends to be harder and more saline than surface water. It is also generally the case that groundwater becomes more saline with increasing depth.

### 7.1 SURFACE WATER QUALITY

There are 1,518 surface water quality records from 91 source waters within the study area. Parameters that exceed the GCDWQ include colour, pH, turbidity, iron, manganese lead, copper, arsenic. The WQI ratings vary from fair to excellent. The public water supply's located in Brent's Cove, Buchans, Cape Freels North, Gaultois, La Poile, New-Wes-Valley and Seldom 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 1,518 surface water samples, 1,395 exceeded the GCDWQ of 15 true colour units (TCU) (Health Canada, 2006). The average colour value recorded for all surface water samples is 55 TCU, with minimum and maximum values of 1 TCU and 355 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.

Approximately 15% of samples exceeded the GCDWQ of 1 NTU (Health Canada, 2006). The average turbidity recorded for all surface water samples is 0 nephelometric turbidity units (NTU) with minimum and maximum values of 0 NTU and 47.4 NTU, respectively. 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.

Approximately 50% of surface water samples had average values below the guideline for drinking water of 6.5–8.5 pH units (Health Canada, 2006). The average pH value recorded for all water supplies is 6.3 pH units, with minimum and maximum values of 4.1 and 8.2 respectively. 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 and gneissic rocks.

Approximately 15% of samples exceeded the 0.3 mg/L drinking water guideline for iron, whereas about 6% of samples exceeded 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 subject to the chemical properties of bedrock and overlying unconsolidated sediments. 173 groundwater quality records were reviewed from 26 source waters 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. Only 4 of the 7 units within Central Newfoundland have groundwater chemistry information available (Overburden Unit B and Bedrock Units 2, 3 and 5). Where it existed, the groundwater chemistry was discussed in relation 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 meteorological conditions within the region. Parameters that exceed the GCDWQ within the study area include colour, pH, turbidity, TDS, iron, lead and manganese, arsenic, sodium and chloride. The WQI ratings vary from good 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 $SO_4$ (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 shows 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 7-11 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.

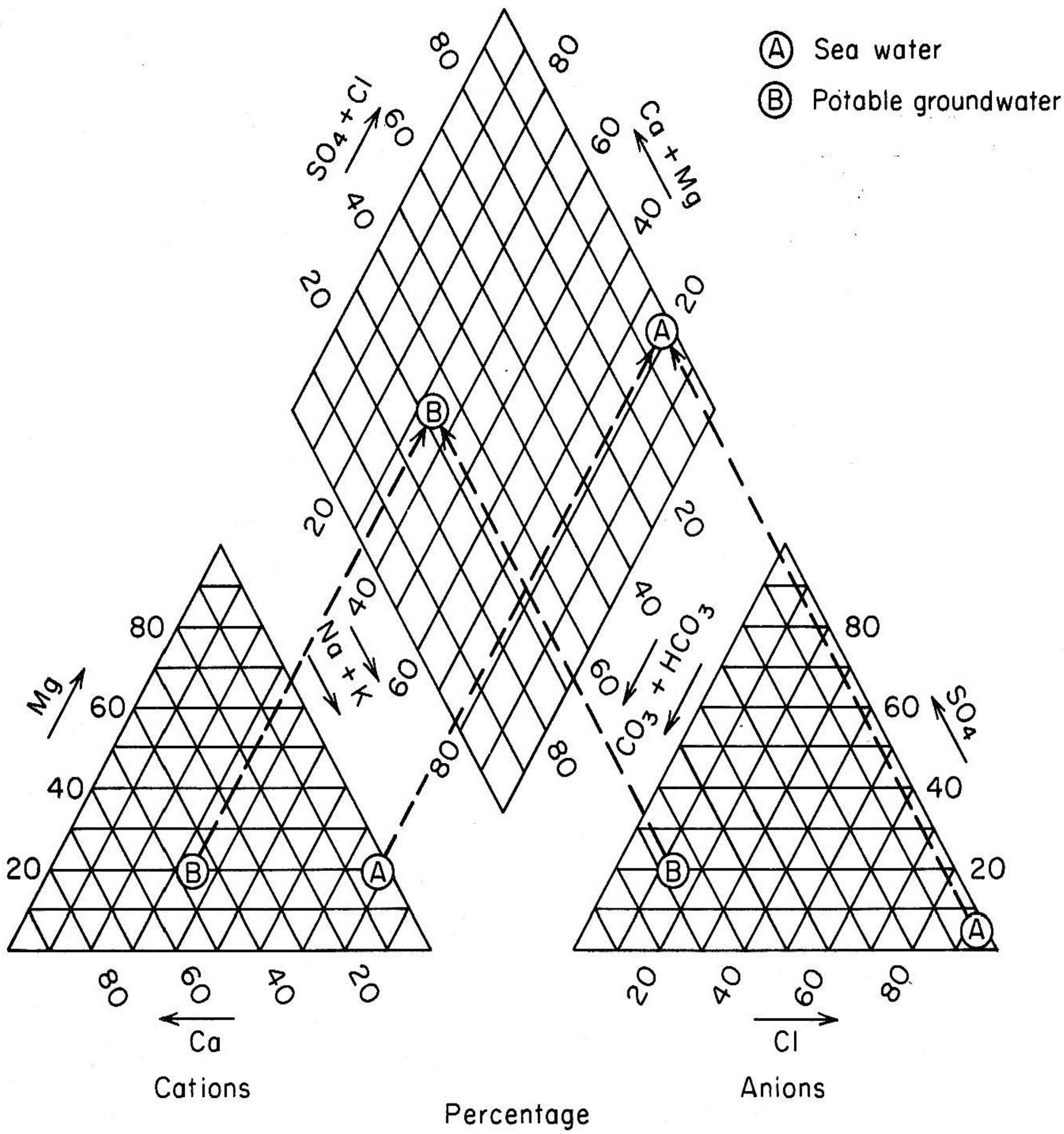



**Figure 7-1: Trilinear diagram of the type used to display the results of water-chemistry studies (Piper, 1944). Diagram taken from Freeze and Cherry (1979).**

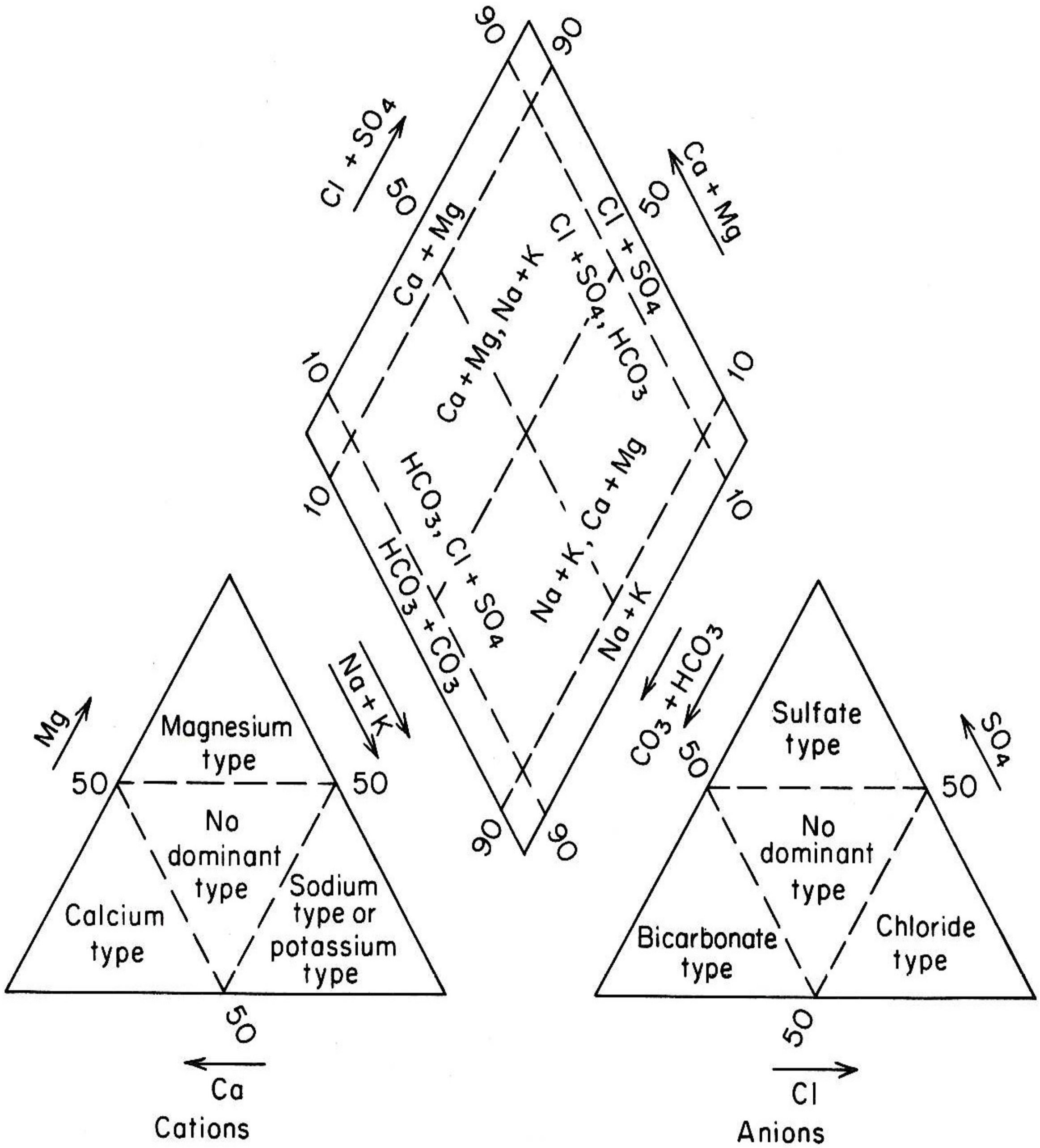



**Figure 7-2: Hydrogeochemical classification system for natural waters using the trilinear diagram (Back, 1966). Diagram taken from Fetter (1994).**

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 7-6. Due to the limitations of the data, the comments that can be made are restricted.

**Unit B – Sand and Gravel**

51 samples from 3 source waters were identified for overburden Unit B. Communities with source waters in Unit B include Badger and St Alban's. Based on the trilinear diagram represented in Figure 7-3, the groundwater from Unit B can generally be described as calcium-bicarbonate, sodium-bicarbonate, and sodium-chloride type. The cation base triangle demonstrates a trend from calcium to sodium-potassium dominated water. The anion base triangle demonstrates domination of bicarbonate (HCO3) anions relative to chloride (Cl).

Where classified by the WQI, the waters within Unit B are classified as very good to excellent. Parameters that exceeded the GCDWQ include turbidity, pH, colour, copper, iron and manganese.

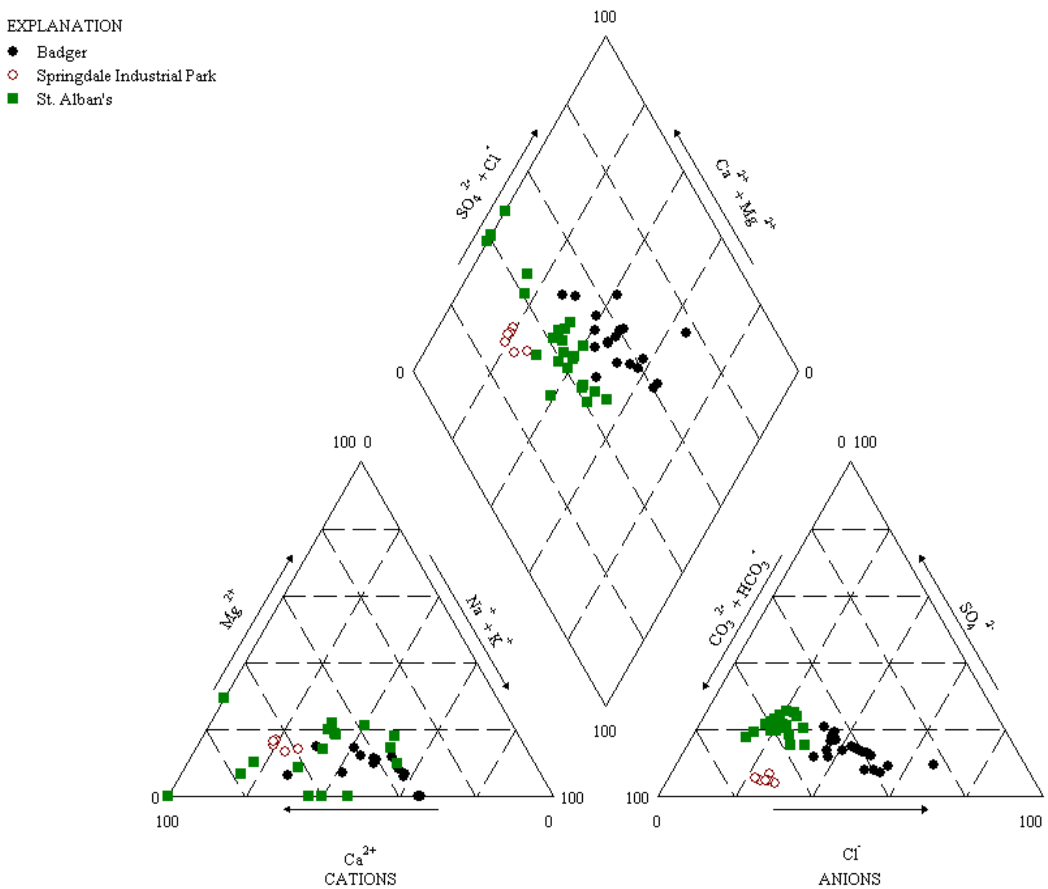



**Figure 7-3: Major Ion Chemistry Represented by a Trilinear Diagram for Samples within Hydrostratigraphic Unit B**

## Unit 2 – Sedimentary Strata

Sandstones and shales are composed mainly of low soluble minerals and contain soft groundwater. 47 samples from 9 sources were identified for Unit 2. Communities with source waters in Unit 2 include Stanhope, Glenwood, Harry's Harbour, and Cambellton. Based on the trilinear diagram presented in Figure 7-4, these waters are classified as having no dominant type.

Where classified by the WQI, the water quality is classified as being very good to excellent. Parameters that exceeded the GCDWQ include turbidity, TDS, colour, sodium, arsenic, cadmium, iron, lead and manganese.

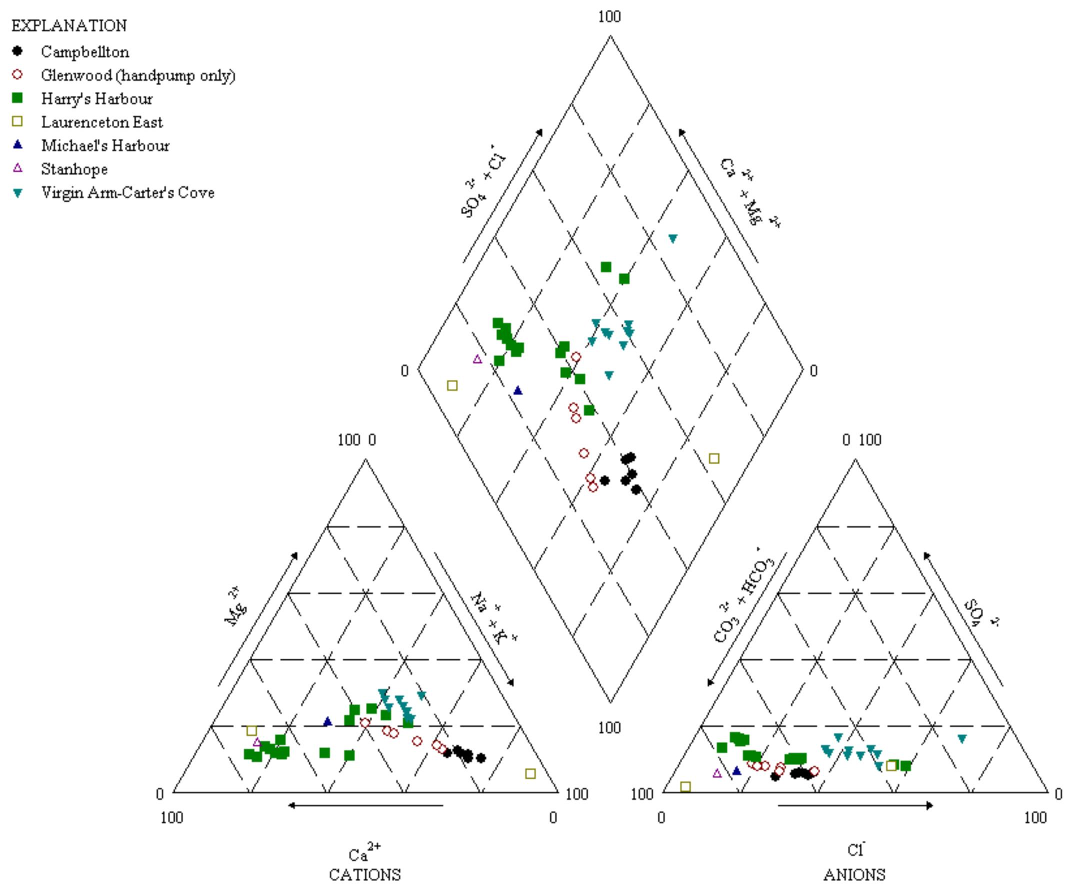



**Figure 7-4: Major Ion Chemistry Represented by a Trilinear Diagram for Samples within Hydrostratigraphic Unit 2**

## Unit 3 – Volcanic Strata

There were 66 water samples from 13 source waters identified for Unit 3. Communities with source waters in Unit 3 include Jackson's Cove, Langdon's Cove, St. Patricks, Millertown and

Change Islands. Based on the trilinear diagram presented in Figure 7-4, these waters are classified as having no dominant type. Rocks in this category are commonly composed of minerals with low solubility, therefore containing soft groundwater which has a low buffering capacity.

Where classified by the WQI, the water quality is classified as being very good to excellent. Parameters that have exceeded the GCDWQ include colour, pH, TDS, turbidity, chloride, arsenic, iron, lead and manganese.

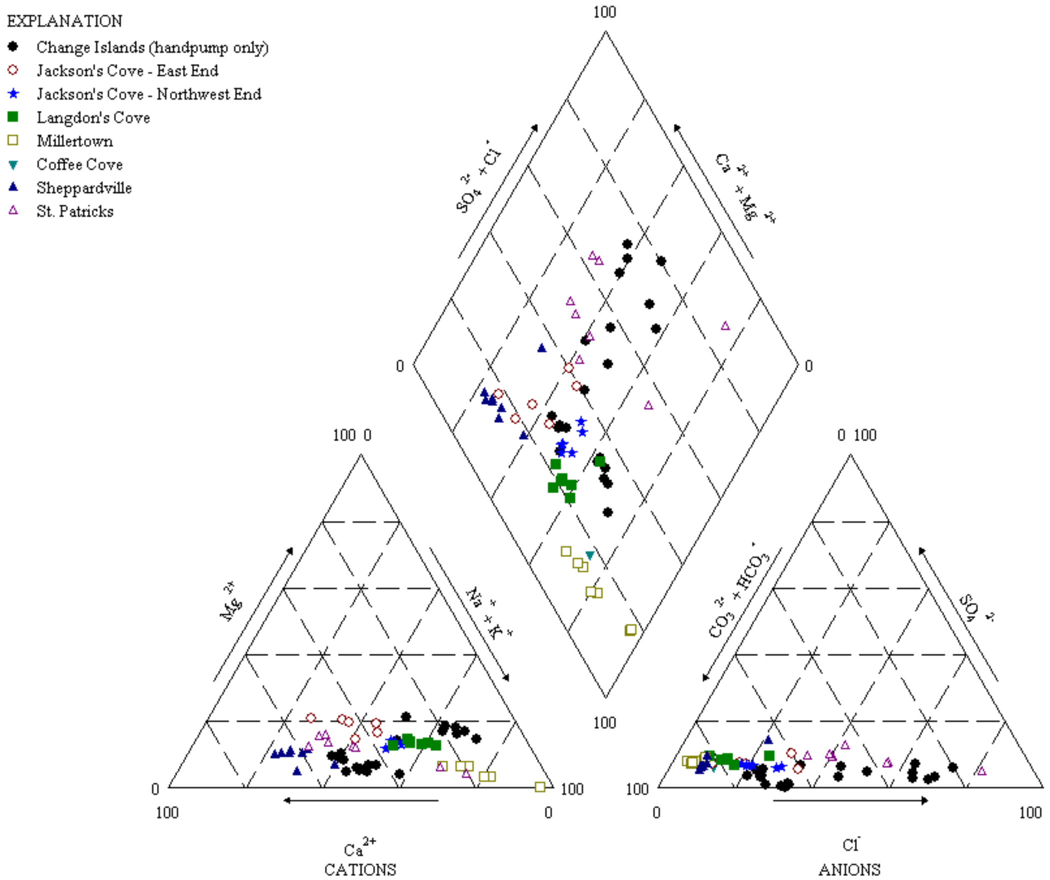



**Figure 7-5: Major Ion Chemistry Represented by a Trilinear Diagram for Samples within Hydrostratigraphic Unit 3**

## Unit 5 – Plutonic Strata

This unit contains only 9 of the available analyses, and all of these analyses belong to the same source water in McCallum. Based on the Piper Diagram of these analyses presented in Figure 7-6, these waters are classified as being sodium-bicarbonate type.

Turbidity, colour, pH, iron, lead, manganese, and uranium are parameters that have exceeded the GCDWQ. The water is classified by the Water Quality Index (WQI) as fair to good.

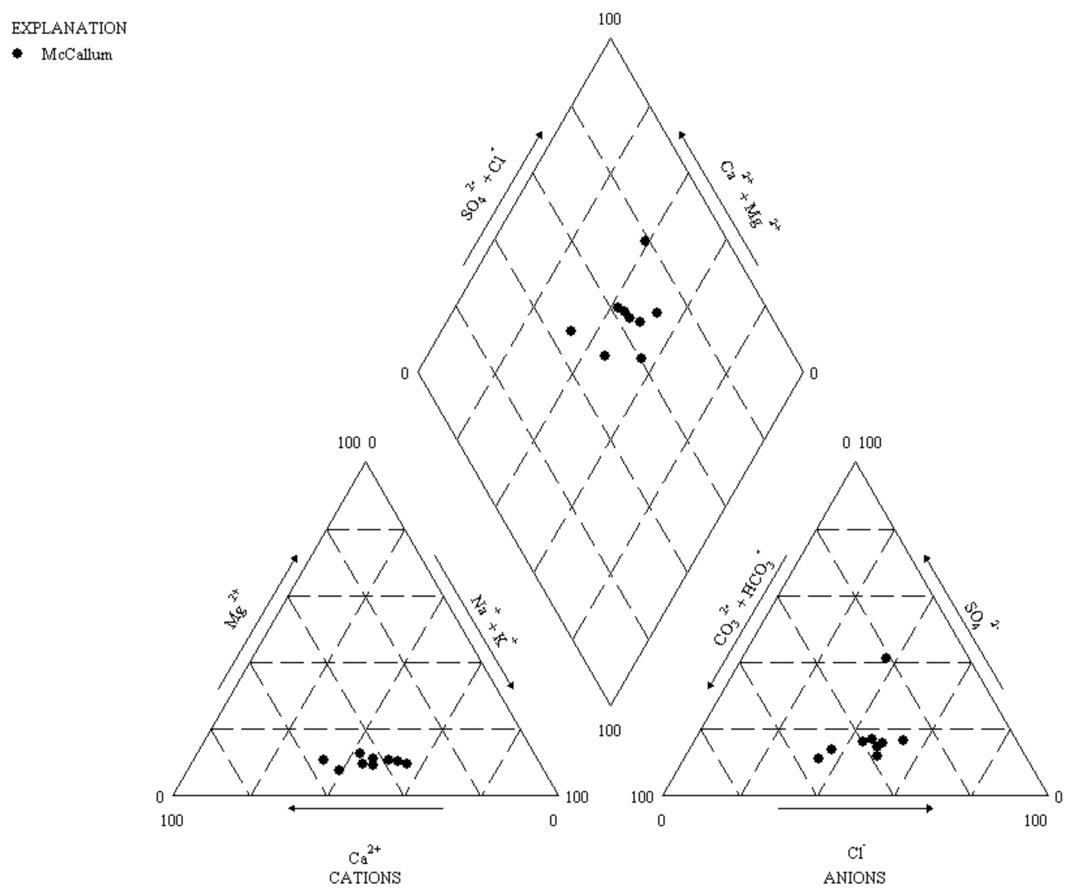



**Figure 7-6: Major Ion Chemistry Represented by a Trilinear Diagram for Samples within Hydrostratigraphic Unit 5**

## 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 permeabilites. 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 GCDWQ is a common problem in domestic wells throughout Newfoundland and is linked to high concentrations of arsenic in the igneous and metamorphic rock found throughout the province. According to Guzzwell and Liverman, 2002, the DOEC conducted random sampling of 25 private wells on Fogo Island, identified as an area of high arsenic in lake sediments and numerous private wells drilled into bedrock. Out of the 25 wells, 10 showed arsenic exceedances in excess of the GCDWQ of 25 ug/L with a maximum of 239 ug/L.

The Town of Seldom–Little Seldom, Fogo Island undertook a sampling program in September 2002 of wells within their jurisdiction (Guzzwell and Liverman, 2002). Thirty-nine wells were sampled, and 25 (or 64% of the wells sampled) had arsenic exceedances. One private well reported an arsenic concentration of 790 ug/L or 32 times the GCDWQ interim arsenic maximum concentration of 25 ug/L.

In addition, routine testing of public wells and a pilot project of chemically testing all school wells in the province has revealed arsenic concentrations of 25 ug/L or more in Little Seldom on Fogo Island (59 ug/L) and Wings Point in Gander Bay (48 ug/L).

The results of public water-supply sampling to date 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. For example, the St. Alban's area is underlain by bedrock containing high arsenic, but is supplied by wells drilled into gravels and sands rather than the 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 by 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 wells that draw from water from aquifers 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 include; Barr'd Islands, Bay d'Espoir, Belleoram, Boot Harbour, Brent Cove, Change Islands, Clarkes Head, Deep Bay, Fogo, Lumsden, Noggin Cove, Northern Arm, Pikes Arm, Port Anson, Seldom, Springdale, Stanhope, St. Alban's, Tilting and West Bottom.

#### 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 affect 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 seven Agricultural Development Areas (ADAs) are currently defined within the study area. These include Springdale ADA, Botwood ADA, Comfort Cove ADA, Woodale ADA, Lewisporte ADA, Gander ADA and Bay D'Espoir ADA.

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 Pulp and Paper Industry

A pulp and paper mill operated in the town of Grand Falls-Windsor from 1909 until 2009. Pulp and paper mills produce bark waste which can present a groundwater quality problem. Wastes of this type are capable of generating a leachate containing tannic acids and dissolved organic constituents with high biological oxygen demand. Care should be taken when placing a well near such a facility.

#### 7.3.3.8 Mining Industry

There are over 45 active and abandoned metal mines within the study area. 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 (Golder, 1985).

## 8.0 CONCLUSIONS

The overburden and bedrock strata within Central 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 3,080 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 five bedrock hydrostratigraphic units. Groundwater yields vary from low (<1 L/min) to high (>600 L/min).

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 Central 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 have the greatest groundwater potential of any of the hydrostratigraphic units in the study area. The average yield is 102 L/min from an average depth of 23 m. However, the results of 11 aquifer tests indicate an average yield of 77 L/min. Based on the aquifer test data, Unit B offers 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 permeabilities.

The well records indicate that the bedrock strata underlying the study area are capable of producing a broad range of well yields. In general, the ophiolite complexes are considered to provide low well yields averaging 9 L/min. The other bedrock units on average produce low to moderate yields of similar magnitude. Volcanic and Plutonic strata of Units 3 and 5 offer the highest yields in the bedrock strata within the study area, both averaging 22 L/min.

Hydrostratigraphic Unit 2 is the most widely utilized bedrock aquifer unit. This sedimentary rock unit includes several moderately metamorphosed sedimentary formations, mainly of Ordovician to Silurian age, which comprise sandstone, siltstone, conglomerate, argillite, greywacke, with minor volcanic flows and tuff. The average yield is 20 L/min from an average depth of 51 m. The results of the 110 aquifer tests completed in Unit 2 suggest that the average yield is 23 L/min. Unit 2 offers potential to meet domestic groundwater needs.

Streamflow data were analyzed to determine the groundwater discharge as reflected in the baseflow component of total streamflow for given drainage divisions. Based on the correlation between the groundwater stage and stream discharge, it was estimated that baseflow contribution to streamflow ranged from 10 to 56%. This would include water released from storage in lakes, ponds, bogs in addition to groundwater.

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

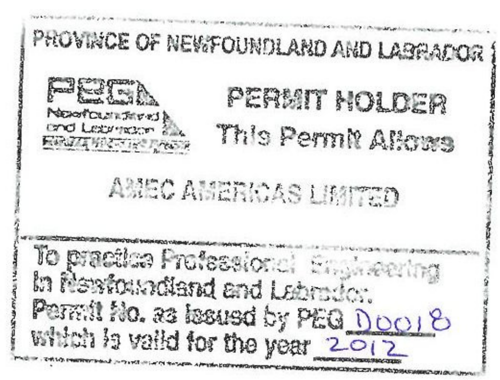
This hydrogeological report is a desktop study only and has been prepared based on reports which were produced by others. As a result, the findings and conclusions presented in this report are based exclusively on the information that was available at the time of preparation of this report. This report 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,

**AMEC Environment & Infrastructure,**
**A Division of AMEC Americas Limited**

| Prepared by | Reviewed by: |
|---|---|
| Simon Gautrey, M.Sc., P.Geo. | Calvin Miles, P.Geo |
| Associate Hydrogeologist | Senior Associate Geologist |

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**Appendices Provided on Accompanying CD**