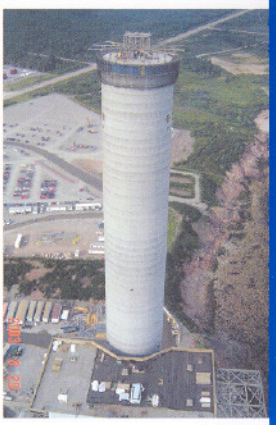

Unama'ki Institute Of Natural Resources
Bras d'Or Lakes
State of the Environment Report
Fresh Water Resources

ADI Limited
Report: **(24) 5810-001.1**
Date: **March 2006**

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1.0 INTRODUCTION TO THE WATERSCAPE

This State of the Environment (SOE) report focuses on the physical and chemical aspects of the waterscape that defines the 2512 km^2 Watershed flowing into the Bras d'Or Lakes. It defines the **State** of that environment. Human induced **Impacts**, **Driving Forces**, **Pressures** and **Responses** are being dealt with separately by others.

The *waterscape* is where the *weatherscape* joins the *landscape*. It is that uniquely habitable zone of the Watershed where humans can comfortably dwell.

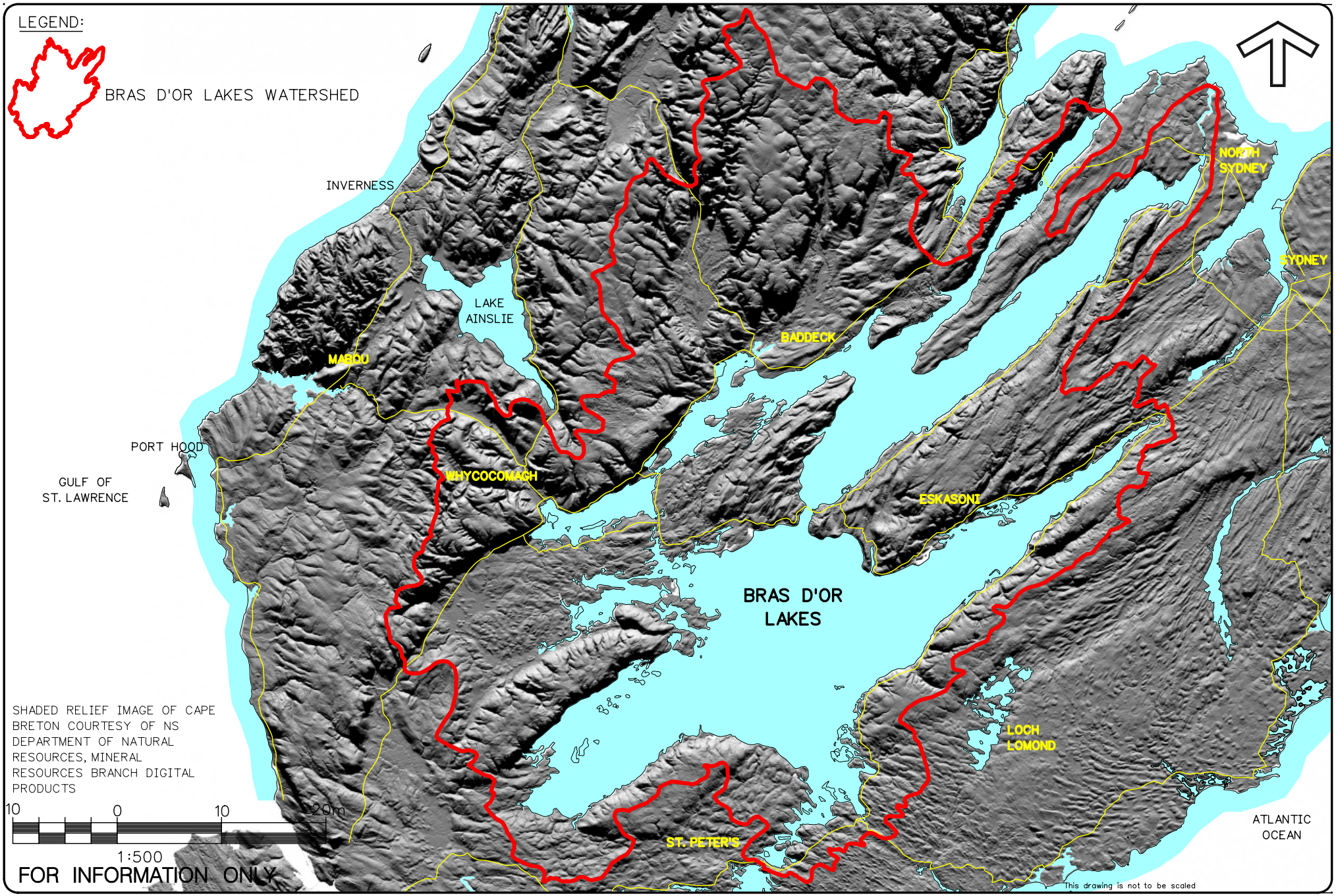
The waterscape of the Bras d'Or Lakes is unique to say the least. It was conceived on both sides of an ancient ocean, forged in the tropics within a supercontinent; all the while being weathered by the aggressive alliance of fire, ice and water for some 600 million years. This sculptured a rugged waterscape combining lakes, canyons, river valleys, foothills and plains (Figure 1-1) that now form a series of four islands surrounding an inland sea, in turn surrounded by the North Atlantic and Gulf of St. Lawrence.

This SOE offers a chance to stand back and look at the "forest for the trees". It offers a time to break away from the day-to-day rapid pace of events and reflect on what has been learned so far about the Watershed of the Bras d'Or Lakes. It is designed as a practical "snapshot" of our knowledge as of the end of 2005, using a Western Science approach. The Traditional Ecological Knowledge gathered from Elders is presented elsewhere.

The impetus to undertake this work was driven by the need for the Collaborative Environmental Planning Initiative (CEPI) to take a more active role in managing the fresh water resources, especially surrounding key issues such as:

Integrated Ecosystem Planning and Management

As a Canadian society, we are gradually becoming more cognizant about the importance of water through high profile issues such as global impacts (climate change), contamination of water supplies (Walkerton), terrorism (911) and industrial legacies (Sydney Tar Ponds). Yet the Bras d'Or Lakes Watershed in large measure mirrors the rest of the country in the minimal emphasis placed to date on understanding the bigger issues. How much fresh water do we have? Where is it? How much is replenished each year? How much is required to sustain natural ecosystems? The bottom line is: *You can't manage what you don't understand!* A preliminary attempt was made to address these issues within the



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Proj.
STATE OF ENVIRONMENT
BRAS D'OR LAKES WATERSHED
FRESH WATER RESOURCES

Dwg.
SHADED RELIEF IMAGE
BRAS D'OR LAKES
WATERSHED

Drawn By: NEB	Proj. No. 5810-001.1	
Dwg Standards Chk. By:	Dwg. No. FIGURE 1-1	
Designed By: FEB	Dwg Design Ckd By: FEB	Rev. 0

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Bras d'Or Lakes Watershed by Nova Scotia Environment in the mid 1980's (MacMahon et al, 1986), but was cancelled prior to completion.

The Need and Ability to Plan for Change

The Bras d'Or Lakes Watershed is fortunate in that it has relatively plentiful water, a low population and only localized contamination. The timing for this work is opportune to provide the technical basis upon which to manage the resource for the long-term; to prepare adequately for the decisions that await future generations.

Taking Water for Granted

Except for floods, droughts and use of springs for healing (Glengarry) and salt (Whycocomagh) (Cross et al, 2000), we tend to ignore water. It is imperative for residents and managers to no longer take water for granted as a plentiful resource that will always be available when we need it, for however much we want.

For the purpose of this report the following definition of Hydrology has been adopted:

> *Hydrology is the science that treats the waters of the earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living things. The domain of hydrology embraces the full life history of water on the Earth.* Van Buren and Watt (1998)

Hydrogeology (groundwater), surface water hydrology (streams) and limnology (lakes) are considered specialized branches of hydrology.

2.0 PALAEOHYDROLOGY – LESSONS FROM THE PAST

2.1 Concept

Palaeohydrology is the science the of earth's waters, their composition, distribution and movement within ancient landscapes, from first rainfall to the beginning of continuous hydrological record (Schumm, 1965).

By studying the palaeohydrology of the Bras d'Or Lakes Watershed, the intention is to:

1. Set the scene for the modern waterscape: to define the origin of the building blocks that control the present day waterscape.

2. Aid in visualizing long-term changes: our environment is in a continuous state of geologic flux, but by operating on a longer time frame than a human lifetime, it appears static.

3. Aid in predicting future environmental change: just as models attempting to predict the future need to embody the best that scientists can say about the real world, it is also necessary to explore the real experience of that world for the best that it can say to us (Arnell, 1996). This approach is embedded within the International Geosphere-Biosphere Program (IGBP) - Past Global Changes (PAGES) project (Pilcher, 1996). Palaeohydrology provides a means for such analysis by employing the "past as an analogue for the future".

The following discussion summarized from Baechler et al (in preparation) divides the Watershed's complex 600 million year (Ma) geological history into five time lines, or more fittingly, "temporal streams", summarized as:

• Mountain Building	(1000 to 365 Ma)
• Mountain Erosion and Basin Infilling	(365 to 65 Ma)
• Uplift/Tilting/Erosion	(65 to 1 Ma)
• Ice Age	(1 Ma to 10,000 years ago)
• Interglacial	(10,000 to present)

2.2 Temporal Stream 1 - Mountain Building (From 1000 to 365 Million Years Ago)

Remnants of two ancient mountain building episodes have left their mark on the Watershed, resulting from multiple opening and closings of the Atlantic Ocean, driven by plate tectonics. Barr et al (1989) divided the rocks created by these collisions (Figure 2-1A) into terranes, three of which are found within the Watershed including the Aspy, Bras d'Or and Mira Terranes (the latter two form the Avalon Terrane, dark green in Figure 2-1B, C and D).

With the opening of the Iapetus Ocean, the eastern side of the Ocean became the zone for mountain building creating the Avalon Terrane (Figure 2-1B). The Mira Terrane

GEOLOGICAL TERRANES

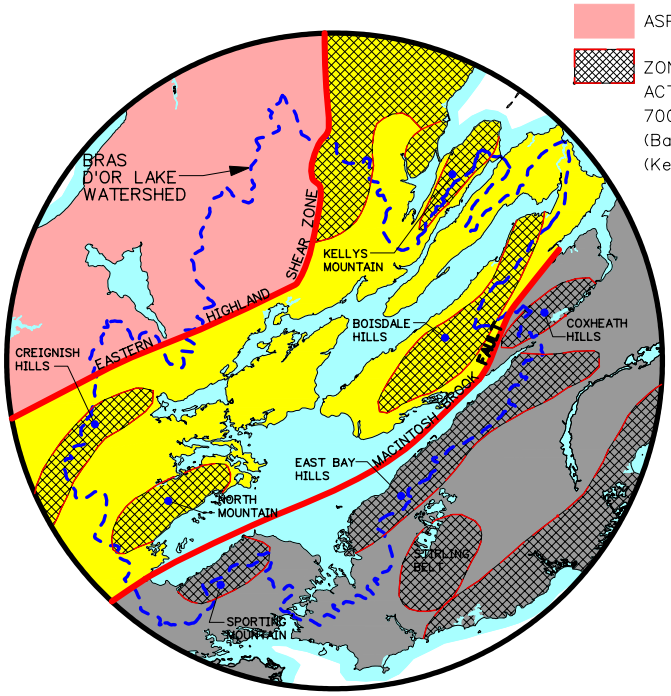
ASPY TERRANE

ZONES OF VOLCANIC ACTIVITY BETWEEN 700 TO 550 Ma (Barr, 1996) (Keppie et al,1998)

BRAS D'OR TERRANE

MIRA TERRANE

AVALON ZONE



Modified after Barr et al, 1989

FIGURE 2-1A

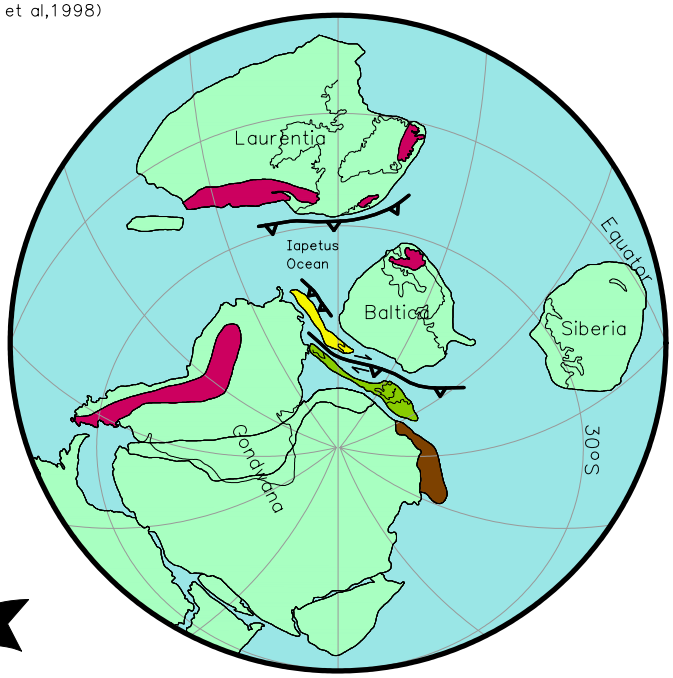


FIGURE 2-1B - 515MA
(Cambrian)

IAPETUS OCEAN OPENS, MIRA AND BRAS D'OR TERRANES FORMED ON OTHER SIDE OF OCEAN

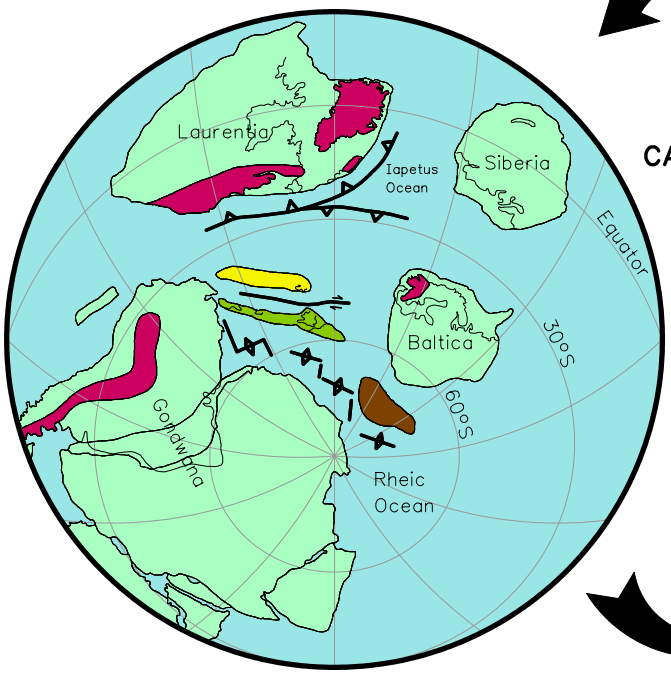


FIGURE 2-1C - 475MA
(Early Ordovician)

IAPETUS OCEAN CLOSING

CAPE BRETON ISLAND

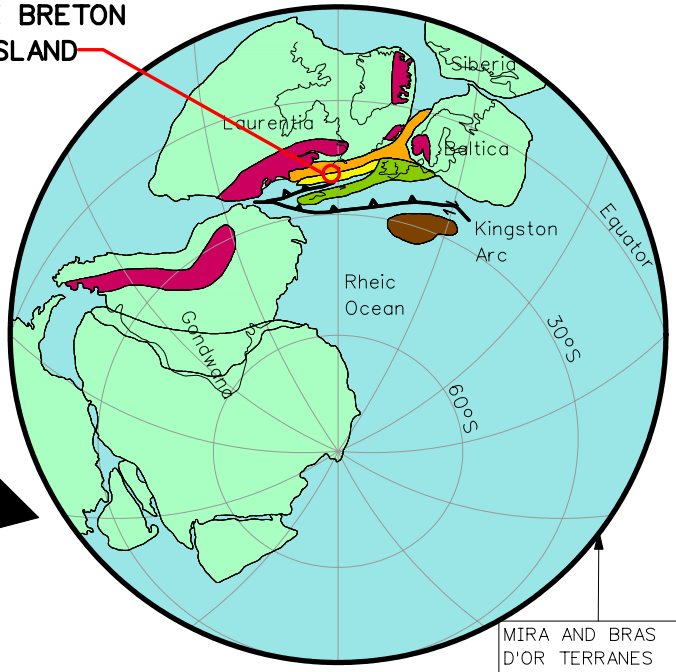


FIGURE 2-1D - 435MA
(Early Silurian)

SECOND MOUNTAIN BUILDING EPISODE

MIRA AND BRAS D'OR TERRANES "DOCK" ONTO ASPY TERRANE AND BLAIR RIVER COMPLEX - MEGUMA TERRANE STILL MOVING

Legend:

- Grenville Oregon
- Avalon (Mira) Terrane
- Miramichi-Bras d'Or Terrane
- Northern Acadian Orogen
- Meguma Terrane
- Volcanic arc terranes (arrow indicates direction of subduction)
- Transform fault (arrows indicate relative movement along fault)
- Spreading Ocean ridge

(Modified after Atlantic Geoscience Soc, 2001)

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Proj. STATE OF ENVIRONMENT BRAS D'OR LAKES WATERSHED FRESH WATER RESOURCES

Dwg. TEMPORAL STREAM 1: GLOBAL PALAEOGRAPHIC RECONSTRUCTION

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Dwg. Standards Chk. By:	Dwg. No. FIGURE 2-1
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underlying the southern rim of the Watershed was formed during this time as part of a volcanic island arc complex, similar to present day Japan (Barr et al, 1996) (Figure 2-1B).

Around 475 million years ago the Iapetus Ocean began to close and the east coast of North America became the active continental margin (Figure 2-1C). This second period of mountain building formed the Canadian Appalachians, as the Avalon and Bras d'Or Terranes collided with the North American Continent (Figure 2-1D).

During this collision they sandwiched an offshore volcanic island arc system between the two, called the Aspy Terrane (Barr et al, 1989). The Bras d'Or Terrane was thrust on top of the Aspy. The latter melted and magma rose into the overlying crust some 400 to 365 million years ago and eventually hardened into plutons of granite, which now forms the "basement" rocks or core of the Watershed. These occur in seven fault controlled belts, referred to as the East Bay Hills, Sporting Mountain, Creignish Hills, North Mountain, Boisdale Hills, Kellys Mountain and part of the Highlands (Figure 2-1A).

By 250 million years ago, the landmasses had come together to create the supercontinent of Pangea (Figure 2-2A). The Appalachian Mountains, within which the Watershed found itself, reached their fullest extent, resembling today's Andes.

2.3 Temporal Stream 2 - Mountain Erosion and Basin Infilling (From 365 to 65 Million Years Ago)

The collision events created a complex of inter-mountain basins (Figure 2-3A), collectively referred to as the Maritimes Basin (MB) (Calder, 1998), three of which were located within the Watershed (Figure 2-3B).

The first sediments deposited were sandstones and conglomerates of the Horton Group. This was followed by flooding of the basin by the "Windsor Sea", during which time marine rocks including extensive evaporite beds were deposited within the Windsor and Mabou Groups. This was similar to the restricted hypersaline tropical gulf conditions of the present day Caspian Sea (Calder, 1998).

The final closing of the Iapetus Ocean occurred as the continental crust of Africa collided with North America. This resulted in the sandstones of the Cumberland Group being deposited under Boularderie Island. In response to erosion of the new uplifted mountains, extensive rainforest swamps and bogs now flourished across tropical lowlands as the climate became more humid.

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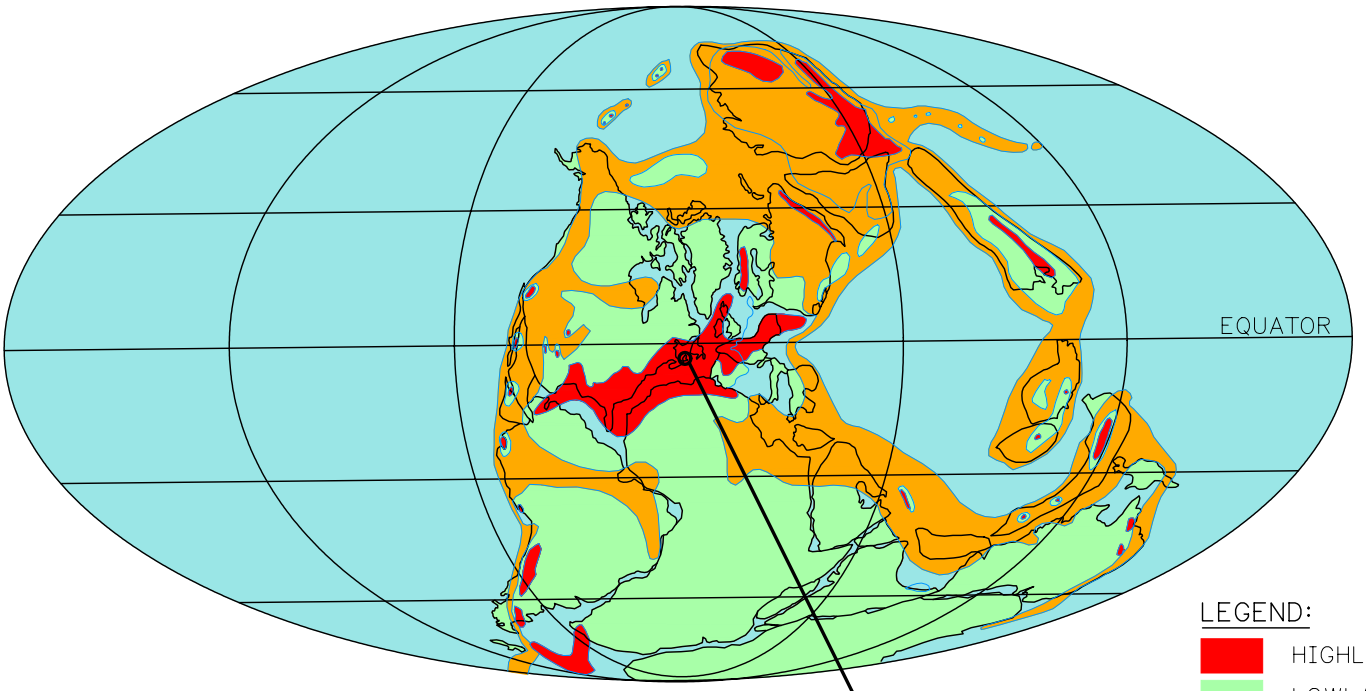
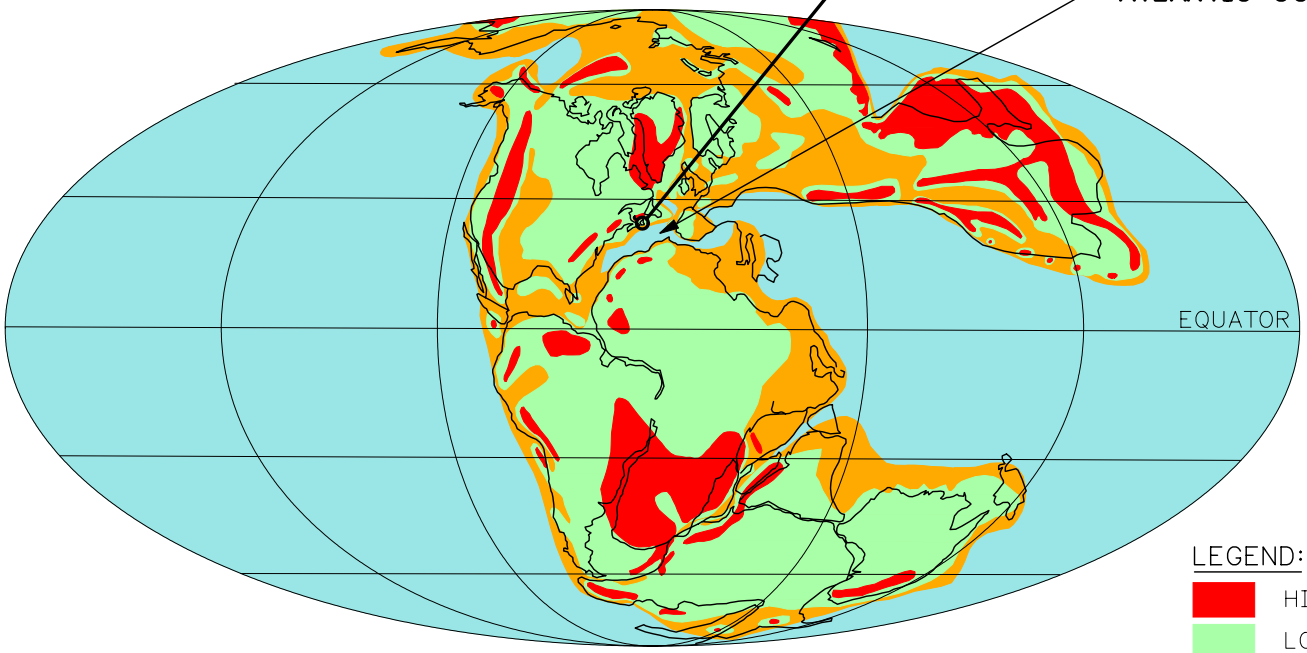


2-2A 305 Ma (LATE CARBONIFEROUS)

LEGEND:
- HIGHLAND
- LOWLAND
- SHELF
- DEEP WATER

CAPE BRETON ISLAND

OPENING OF ATLANTIC OCEAN



2-2B 165 Ma (PALEOGEOGRAPHY OF THE MIDDLE JURASSIC)

LEGEND:
- HIGHLAND
- LOWLAND
- SHELF
- DEEP WATER

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BRAS D'OR LAKES WATERSHED
FRESH WATER RESOURCES

Dwg. GLOBAL PALAEOGEOGRAPHY
TEMPORAL STREAMS 2 & 3
(After Atlantic GeoScience Soc. 2001)

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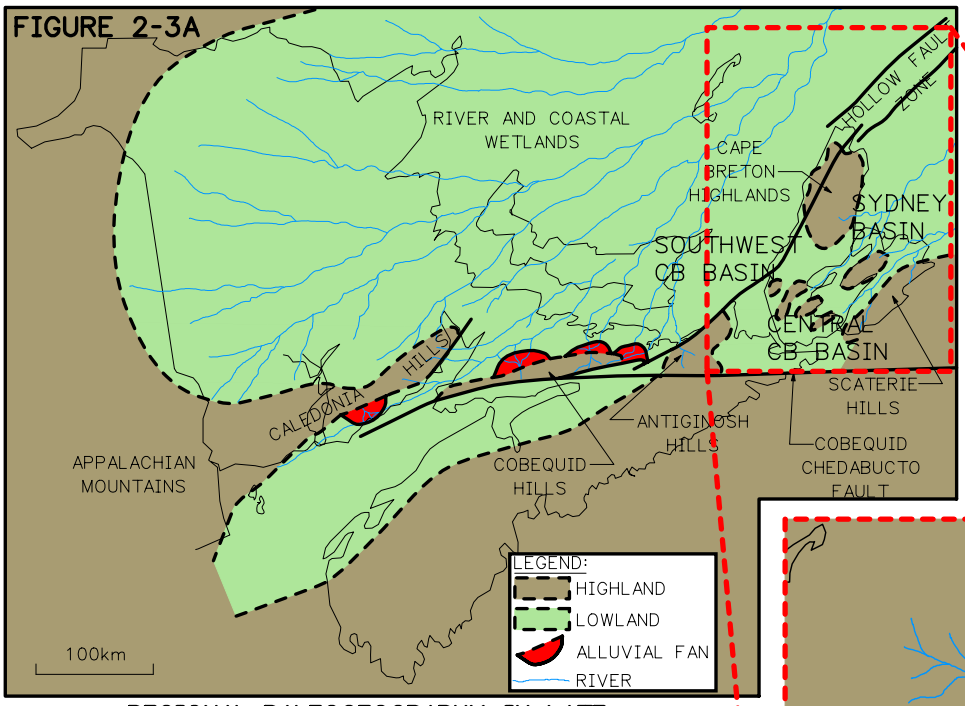
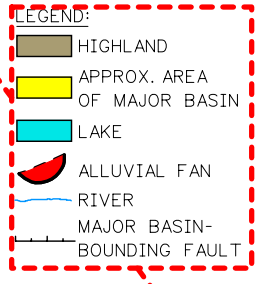
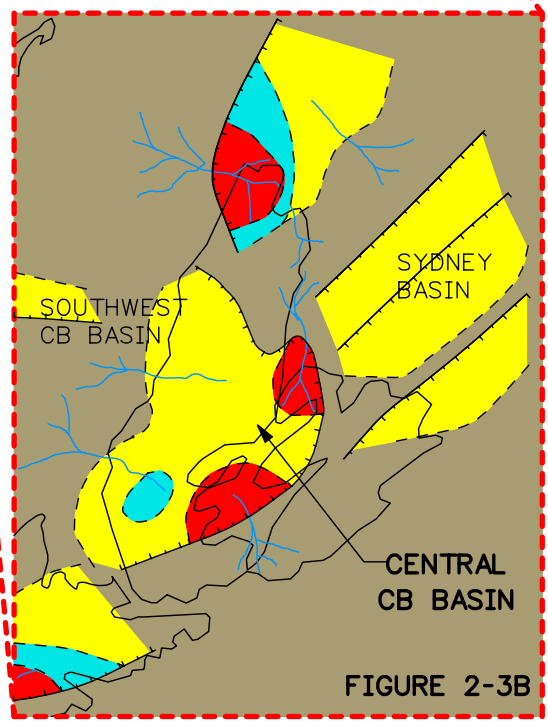
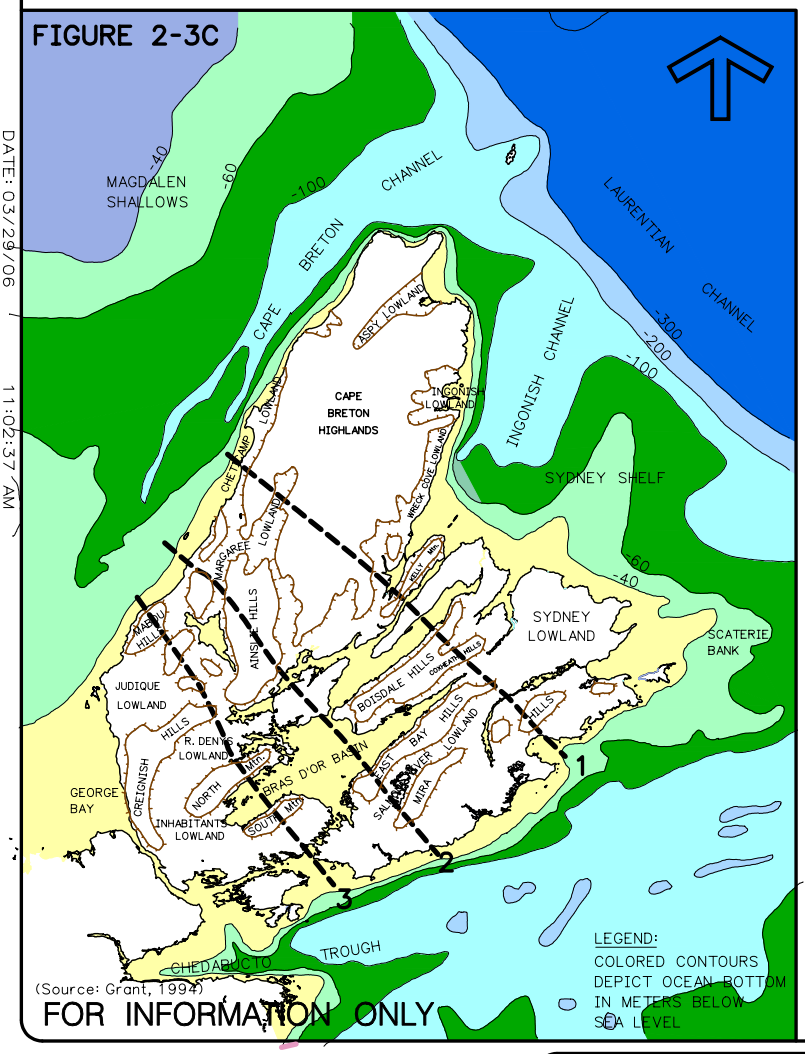


REGIONAL PALEOGEOGRAPHY IN LATE CARBONIFEROUS, 310 TO 355 MILLION YEARS AGO

(Source: Atlantic Geoscience Soc., 2001)







(Source: Grant, 1994)

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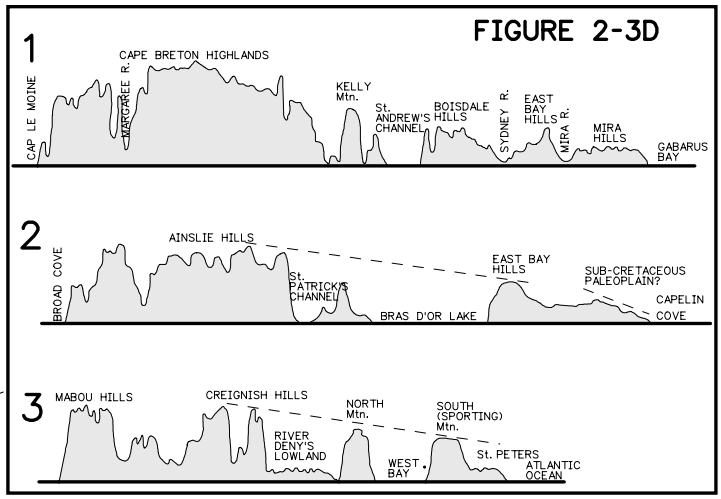

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Proj. STATE OF ENVIRONMENT BRAS D'OR LAKES WATERSHED FRESH WATER RESOURCES

Dwg. **TEMPORAL STREAM 2 & 3 INFILLING OF CARBONIFEROUS BASINS**

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Dwg. Standards Chk. By:	Dwg. No. FIGURE 2-3
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The rocks of the Watershed remained in the interior of Pangaea for over 100 million years, until near the end of the Triassic (180 Ma) when crustal movement started to fragment the continent and a new ocean formed, the present day Atlantic Ocean (Figure 2-2D). During separation, those rocks of the Watershed within the Avalon zone, which were at one time situated on the other side of the ocean, were left attached to North America.

This geological activity had profound implications for the present day waterscape. It was throughout this period that water, acting as a geological agent, created many of today's important groundwater aquifers. Complex and variable economic mineralization was introduced to the Watershed throughout this time line, including hydrocarbon generation (Malagawatch), as well as the formation of gypsum (Melford, Little Narrows).

2.4 Temporal Stream 3 - Uplift/Tilting/Erosion (From 65 to 1 Million Years Ago)

The opening of the Atlantic Ocean left this region along a passive continental margin and moved it northward into a temperate climate zone. By 60 million years ago, erosional forces had been so effective on wearing down the mountains that the Maritimes was positioned over a broad, relatively uniform, lowland plain almost at sea level. This peneplain gradually uplifted and tilted toward the east as the weight of overlying rock was eroded and deposited off shore.

Drainage systems developed on the tilted plain and downcut deeply into the terrain. Igneous and metamorphic rocks of Temporal Stream 1 were not worn down appreciably, and became more prominent on the waterscape. The surrounding softer sedimentary rocks, formed during Temporal Stream 2, were more susceptible to erosion and formed the lowlands. The geomorphic character of the Watershed was established with its distinctive strong landscape contrasts, including isolated hills and highlands, standing in sharp relief above extensive complex lowlands. Representative topographic profiles across the Island (Figure 2-3 C, D) reveal the summit level of each highland appears to conform to a single, gently undulating surface sloping to the southeast (Grant, 1994).

The main drainage patterns on the Island were created as differential erosion dissected the landscape, creating, for example, the deep-water trough of the St. Andrews and Great Bras d'Or Channels.

2.5 Temporal Stream 4 - Ice Age (From 1 Million Years to 10,000 Years Ago)

The Watershed records evidence of the last two major glaciations, the Illinoian and Wisconsin. The last glaciation started approximately 75,000 years ago, peaked at around 21,000 and finally ended between 12,000 to 10,000 years ago (Nova Scotia Museum, 1996). It covered the Watershed with ice in four phases (Figure 2-4).

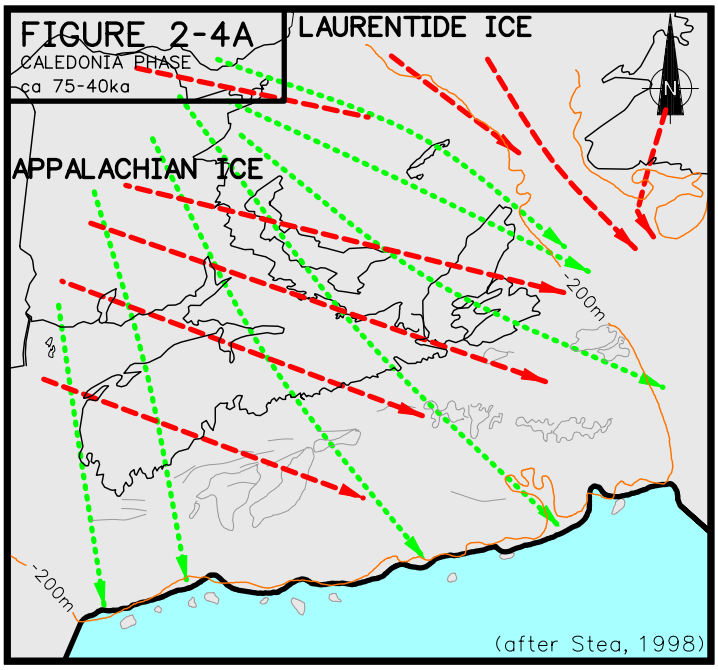
The earliest and most extensive ice flow was east-southeast (Figure 2-4A), covering the Island (Stea et al, 1998). The second major ice flow was to the south-southwest from an ice centre in the Prince Edward Island area (Figure 2-4B). An ice divide in southern Nova Scotia created a northward ice flow across the Watershed (Figure 2-4C). Finally, during Phase 4 ice retreated to centres developed over the Canso Strait, Bras d'Or Lakes and Cape Breton Highlands, around 11,000 years ago. Ice impinged on the Island's west coast blocking west draining valleys, and together with Cape Breton ice created a series of pro-glacial lakes within the Watershed (Figure 2-4D).

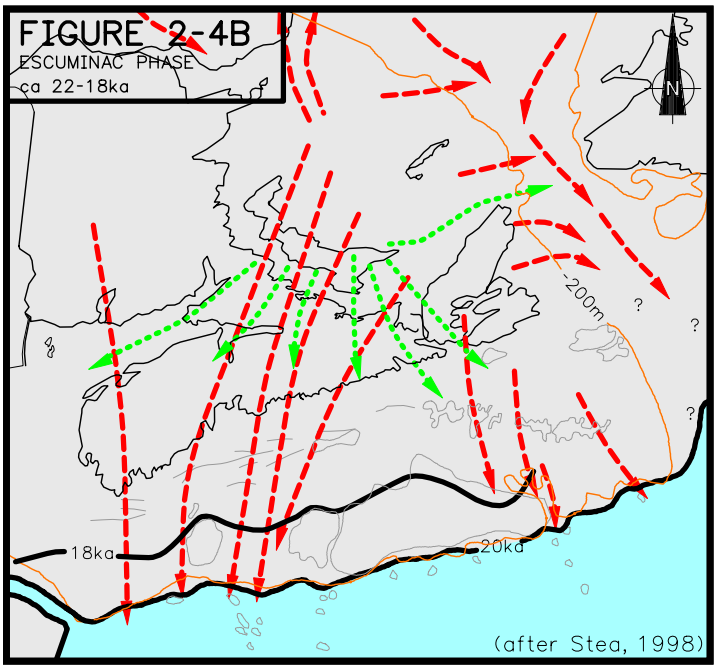
Associated with ice movement were large fluctuations in sea level (Figure 2-5A). During the period of maximum glaciation, around 18,000 years ago, sea level was 121 ±5 metres (Figure 2-5B) below the present level. The first rise came between 17,000 and 12,500 years ago, during which time sea level increased by 20 metres, followed by an exceedingly rapid rise of 24 metres in less than 1,000 years (Fairbanks, 1989).

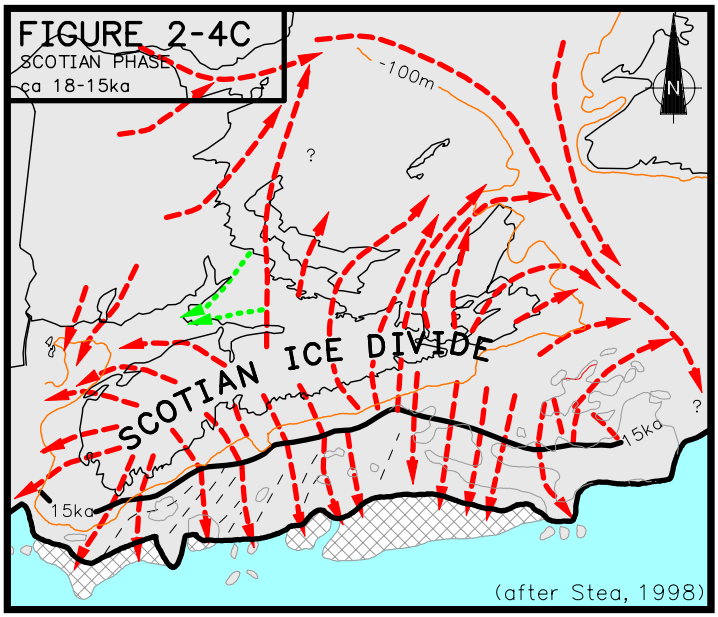
Modification of the Watershed's topography by glaciation was relatively minor, but with major hydrological implications. It included fluvial incision, glacial scouring of upland areas and voluminous till deposition in lowland areas. The 200+ metre deep Bras d'Or Basin was scoured out of weak Windsor Group rocks, exhibiting selective and localized erosion on a scale unmatched in the region (Grant, 1994). Extensive sand/gravel "outwash" deposits were formed in the Middle, Skye, Baddeck and Denys Rivers. Several major river valleys were carved into bedrock at a time of low sea level, and then later filled with glacio-fluvial deposits and till. They have been found at Melford (ADI Limited, 2001) and Orangedale (Stea, 2003a) and are inferred at the Skye River Valley and Middle River near Lake O'Law. The lacustrine deposits in glacial lakes were limited to localized areas, notably in the River Denys Lowlands.

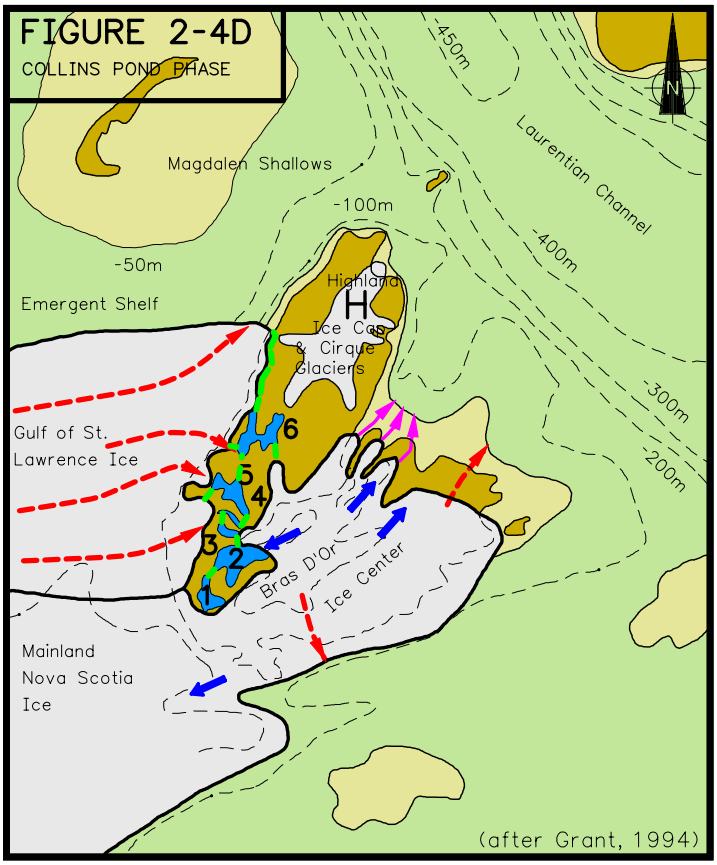
2.6 Temporal Stream 5 - Present Interglacial (From 10,000 to 300 Years Ago)

The time of warming and glacial retreat commenced around 12,000 years ago (Figure 2-6A, B). The Watershed's rivers responded to large and rapid changes to their regime.









Legend:

1 Glacial Lake Dawson
2 Glacial Lake Bell
3 Bridgend Lake Basin
4 Skye Glen Lake Basin
5 Glacial Lake Fletcher
6 Glacial Lake Margaree

Glacier Ice
Glacier Dammed Lake
Emerged Shelf Area
Submarine Area
Present Land

Ice Flow Trend
Readvance
Meltwater Spillway
Outwash Valley

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Proj. STATE OF ENVIRONMENT BRAS D'OR LAKES WATERSHED FRESH WATER RESOURCES

Dwg. TEMPORAL STREAM 4 GLACIATIONS

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Dwg. Standards Chk. By:	Dwg. No. FIGURE 2-4
Designed By: FEB	Dwg. Design Chk. By: FEB / Rev. 0

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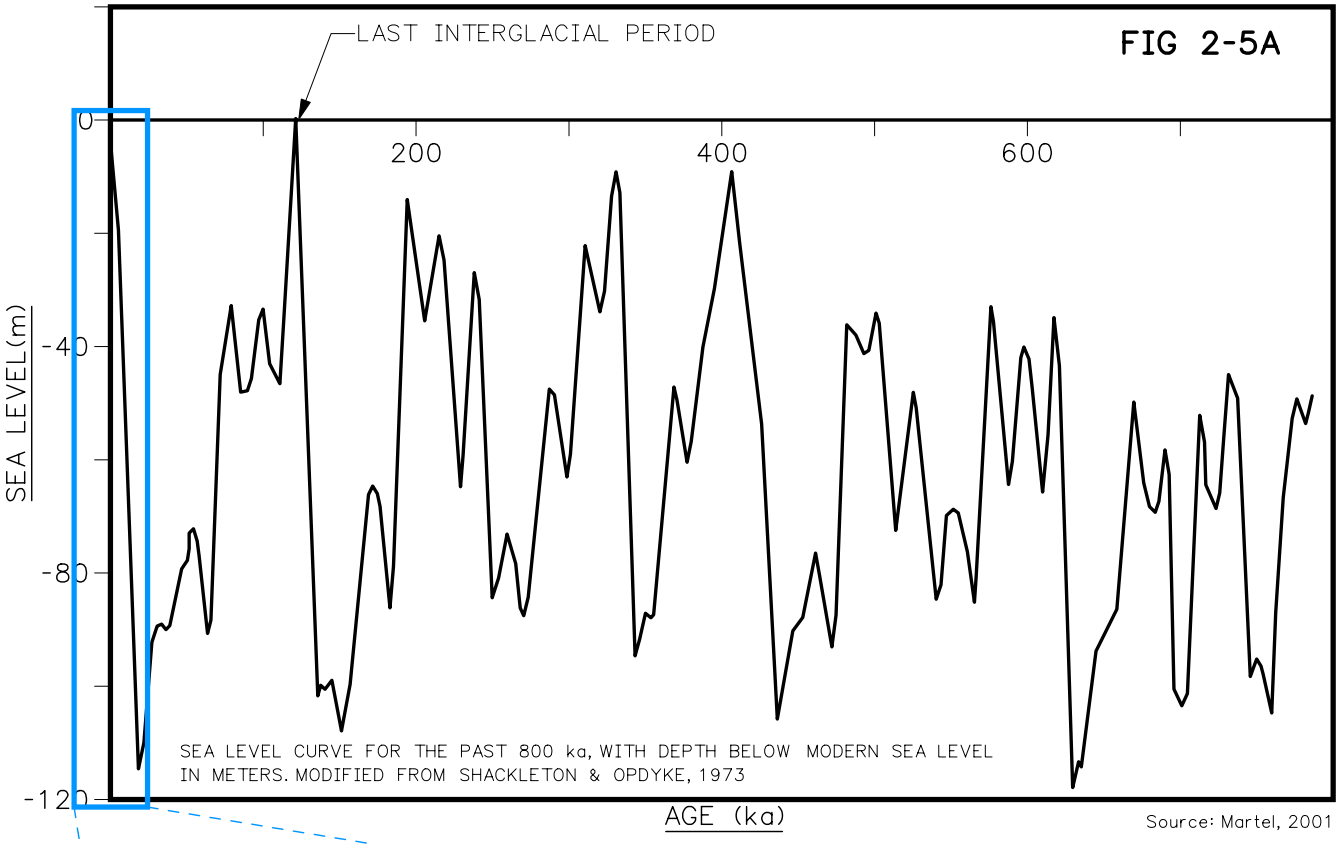
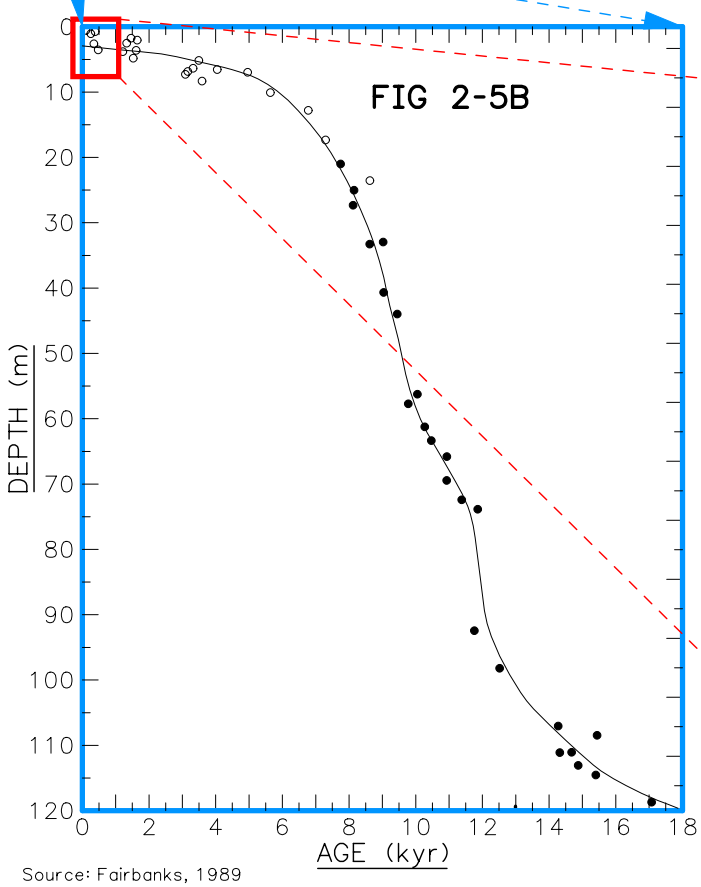
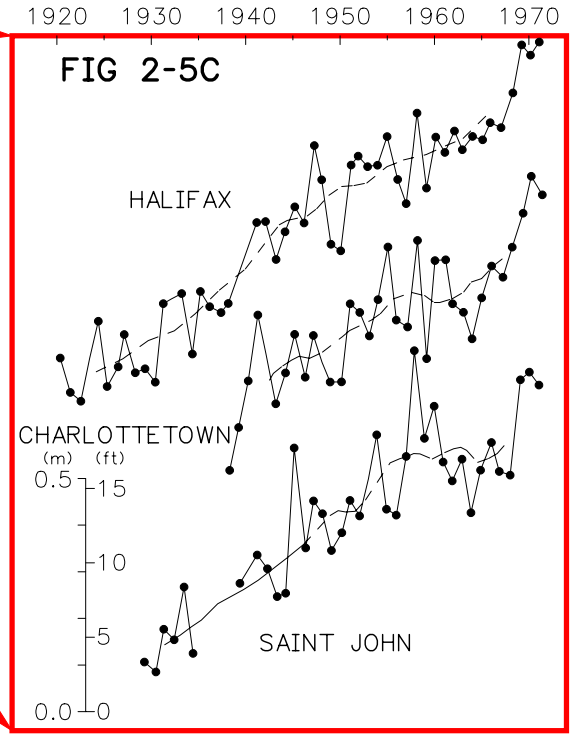
SEA LEVEL CURVE (782 ka)



Source: Martel, 2001



Source: Fairbanks, 1989



TREND OF RISING SEA LEVEL SHOWN BY TIDAL RECORDS
(POINTS ARE YEARLY MEANS; DASHED LINE IN 10yr MOVING MEAN)

Source: Grant, 1994

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Proj. STATE OF ENVIRONMENT
BRAS D'OR LAKES WATERSHED
FRESH WATER RESOURCES

Dwg. TEMPORAL STREAMS 4,5,6:
SEA LEVEL FLUCTUATIONS

Drawn By: NEB	Proj. No. 5810-001.1
Dwg. Standards Chk. By:	Dwg. No. FIGURE 2-5
Designed By: FEB	Dwg. Design Chk. By: FEB / Rev. 0

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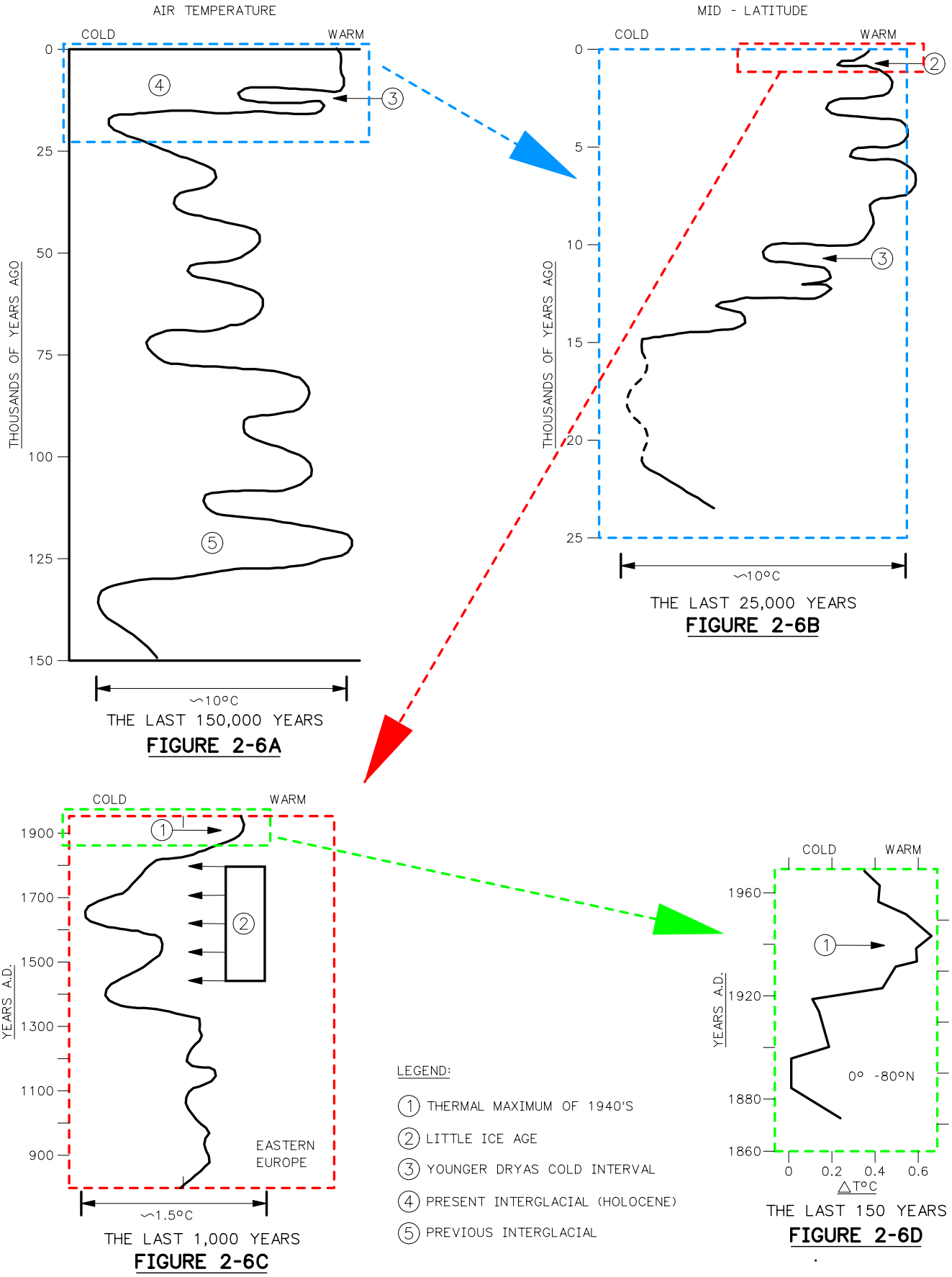

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SOURCE: Webb III et al, 1993

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Proj. STATE OF ENVIRONMENT
BRAS D'OR LAKES WATERSHED
FRESH WATER RESOURCES

Dwg. TEMPERATURE STREAM 5 & 6
MAIN TRENDS IN GLOBAL CLIMATE
OVER THE PAST 150,000 YEARS

Drawn By: NEB	Proj. No. 5810-001.1
Dwg. Standards Chk. By:	Dwg. No. FIGURE 2-6
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Initially, there was a period of massive discharge, associated with glacial melting and low sea level. With time, this evolved into reduced flows and recharge.

The climatic optimum between 6,000 and 3,000 years ago spanned the warmest postglacial time (Figure 2-6A and B). Temperatures rose to as much as 2°C above present temperatures. This was followed by a time of cooling over the last 4,000 years (Figure 2-6B), during which time there was a significant cooling of world climate.

With global warming, the sea level rose submerging the landscape resulting from a rapid sea level rise approximately 11,600 years ago (Figure 2-5B). The Bras d'Or Lakes were created at approximately 5,000 to 4,000 years ago, when sea level overtopped a bedrock sill at about 8 metres below sea level (Grant, 1994), changing the lakes from fresh to salt. Streams within the Watershed are now just the upper headwater portions of much larger drainage basins, which use to extend well off shore. In areas where evaporites and limestones were not covered with a thick till blanket, they became hydraulically active forming sinkholes, such as those at Melford and over the Iona Peninsula.

2.7 Summary

This palaeohydrological view of the Island has revealed how the modern waterscape within the Bras d'Or Lakes and Watershed was conceived on both sides of an ancient Atlantic Ocean, and then forged in the tropics within the middle of a supercontinent, all the time being weathered by 600 million years of geological history. This history has engraved into the Island's rock and soil the memories of mountains ranges, volcanoes, earthquakes, massive faults (which tore her apart and along which she was welded together), tropical climates, flooding by warm seas, erosion by rivers, dense tropical forests, opening and closing of oceans, blanketing chiselling, gouging by glaciers and the rise and fall of sea level, as it drifted northward to our present temperate climate.

It is the creation and stacking of these rocks and soils that now controls the occurrence, storage, movement and quality of fresh water throughout the Watershed. This then is the legacy that must be understood to effectively manage her fresh water resources.

3.0 CLIMATE - THE WATER PUMP

3.1 Introduction

This section deals with the "Water Pump", which showers water, snow and ice onto the waterscape; then, along with vegetation, pumps it back into the atmosphere through evapotranspiration to begin the cycle anew. The information presented is abstracted from Baechler et al (in preparation).

3.2 Classification

The Bras d'Or Lakes Watershed exhibits a humid continental climate. The Nova Scotia Museum (1997) identified two climatic regions within the Watershed (Figure 3-1A). The *Highlands* Region receives the highest total precipitation in the province, exhibiting cool temperatures and severe winters. Most of the Watershed is positioned within the *Eastern Nova Scotia* Region; a diverse geographic area with high rainfall and cool temperatures.

3.3 Governing Forces

The climatic variability is caused by the shifting positions of three air masses. *Continental Arctic Air* from the northwest is very dry and cold in winter. *Maritime Polar Air* from the north or northeast, has been somewhat warmed by its passage over the ocean and is cool and moist. *Maritime Tropical Air* from the south or southwest is warm and moist.

The Icelandic Low and Bermuda-Azores High influence the circulation of these air masses through the North Atlantic Oscillation (NAO). This is the dominant mode of atmospheric variability in the North Atlantic Basin throughout the year; but is most pronounced during the winter season affecting river runoff, lake levels and ice cover (Hurrell et al, 2003).

A prominent feature of these low-pressure systems includes hurricanes and Nor'easters. Although June 1st marks the official beginning of the hurricane season in the North Atlantic Basin, they generally do not become a major issue for the Watershed until August or September. Although mostly weakened versions of once much stronger storms, some do remain as hurricanes. Two notable hurricanes have made landfill in Cape Breton within the last 15 years. Gustav and Hortense came ashore in September 2002 and September 1996, respectively, as Category 1 hurricanes, resulting in 52.6 and 102.4 mm of precipitation, respectively, at Sydney. Nor'easters occur throughout the

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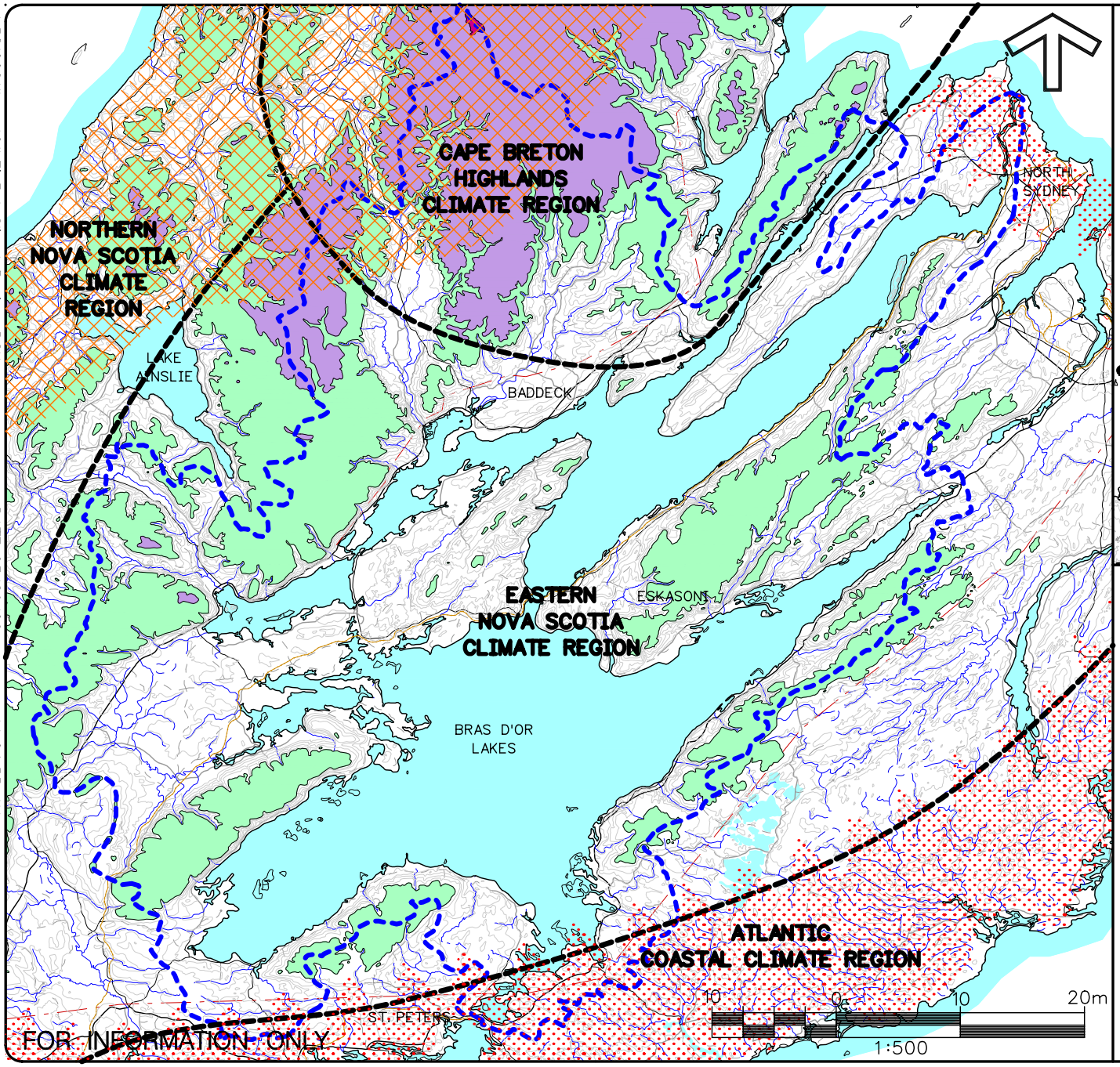
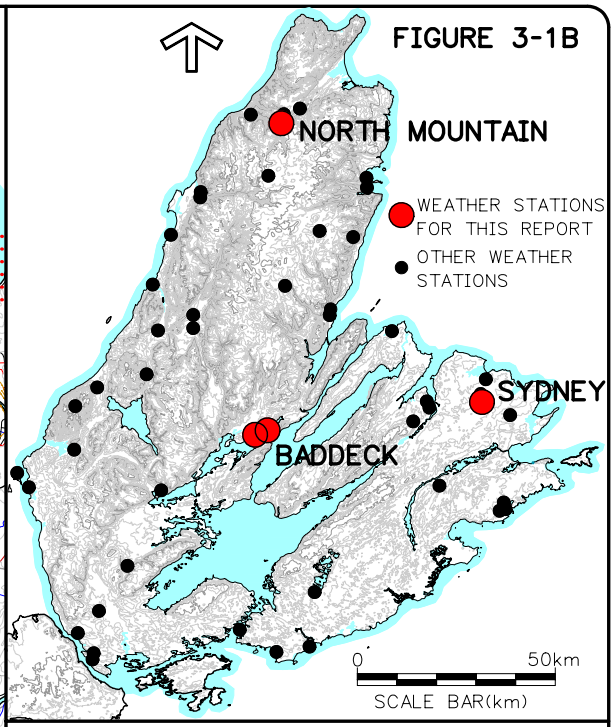


FIGURE 3-1B



DIGITAL ELEVATION MODEL

ELEVATION RANGES - ft(m)

- LESS THAN 0ft (0m) - WATER
- 0-500ft (0-152m)
- 500-1000ft (152-305m)
- 1000-1500ft (305-457m)
- 1500-2000ft (457-610m)
- CLIMATE REGIONS (from Nova Scotia Museum, 1997A - boundaries are approximate)

COASTAL INFLUENCES

- PREDOMINANCE OF SEA FOG
- SNOW BELT
- BRAS D'OR LAKES WATERSHED BOUNDARY

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BRAS D'OR LAKES WATERSHED
FRESH WATER RESOURCES

Dwg.

CLIMATE REGIONS
(after NS Museum, 1997)

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Dwg Standards Chk. By:	Dwg. No. FIGURE 3-1	
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winter season from October to April, peaking in February (Davis et al, 1993). They overlap in late fall with the hurricane season. Examples of these storms include the Great Ash Wednesday Storm (March 1962) and the All Hallow's Eve Storm (October 1991).

Local and seasonal climatic effects within the Watershed are strongly influenced by the temperature of the sea that completely surrounds it, creating two notable features:

> *Seasonal Influences*: The Watershed is caught between two opposing temperature phenomena. In summer, the west coast of the Island is relatively warm and dry because of the 18 to 20°C Gaspe Current within the Gulf of St. Lawrence. The east and south coasts are chilled by a branch of the cold (10 to 15°C) Labrador Current. In winter, however, the west is colder than the east because pack ice covers the Gulf, whereas the Atlantic Ocean is ice-free. Cold winds from coastal waters, therefore, delay the arrival of spring. Similarly, fall is extended and the onset of winter delayed.
>
> *Snowbelt:* In winter, cold winds blow inland from the west off open water picking up moisture. This modified air mass rises upon encountering the rugged high western coastline of Cape Breton. The moisture precipitates out orographically as heavy snow (Figure 3-2B and D). This ceases once the Gulf of St. Lawrence freezes over.

3.4 Climate Stations

Since the commencement of weather monitoring in the late 1800's, a total of 36 Environment Canada stations with more than two years of continuous records have operated over the Island (Figure 3-1B). At present, there is only one active station within the Watershed, located at Baddeck.

Given the intermittent data collection at Baddeck, the Sydney station is utilized to represent the Eastern Nova Scotia climate region, which encompasses most of the Watershed. It exhibits the longest record with the most parameters, which have been reviewed and homogenized by Environment Canada for inclusion in their "Historically Adjusted Data Base for Canada" (Mekis et al, 1999 and Vincent et al, 1999). The most recent 30 year Normals (1971-2000) will be utilized to define "average" conditions.

Only one Environment Canada station is present in the snowbelt, identified as North Mountain (Figure 3-1B), which will be used to best represent conditions within the

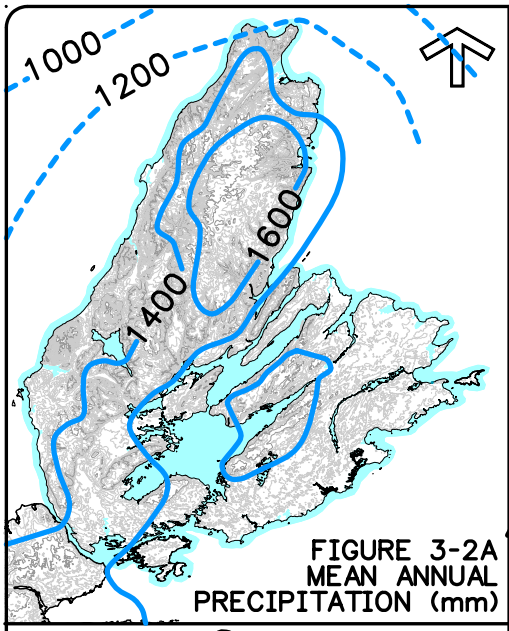

FIGURE 3-2A
MEAN ANNUAL
PRECIPITATION (mm)

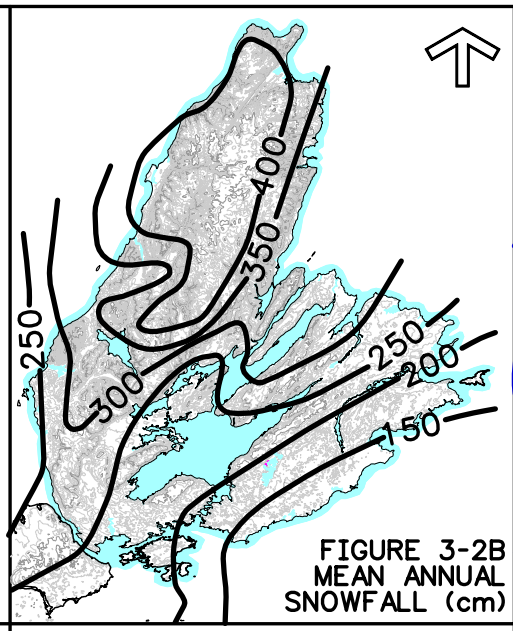

FIGURE 3-2B
MEAN ANNUAL
SNOWFALL (cm)

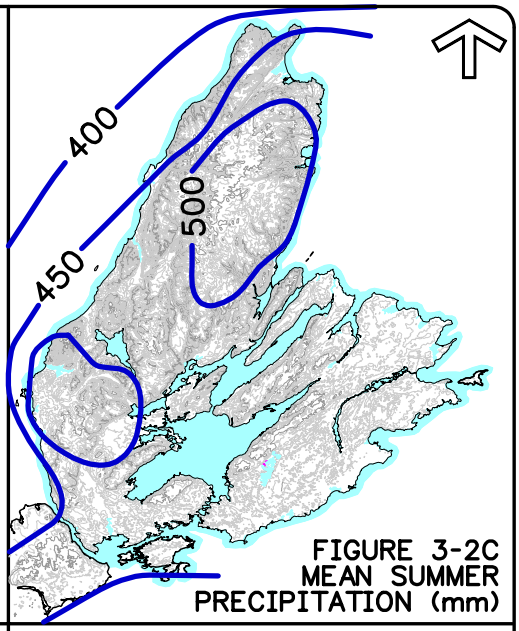

FIGURE 3-2C
MEAN SUMMER
PRECIPITATION (mm)

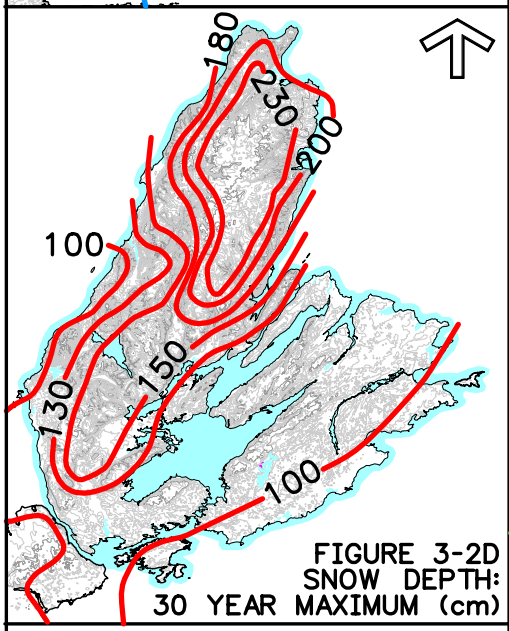

FIGURE 3-2D
SNOW DEPTH:
30 YEAR MAXIMUM (cm)

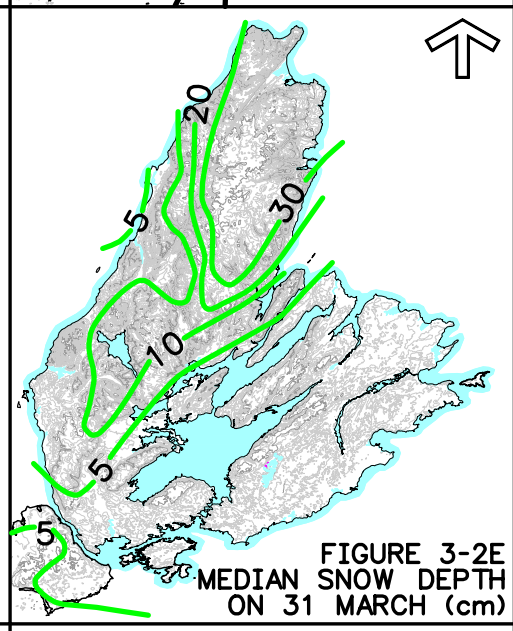

FIGURE 3-2E
MEDIAN SNOW DEPTH
ON 31 MARCH (cm)

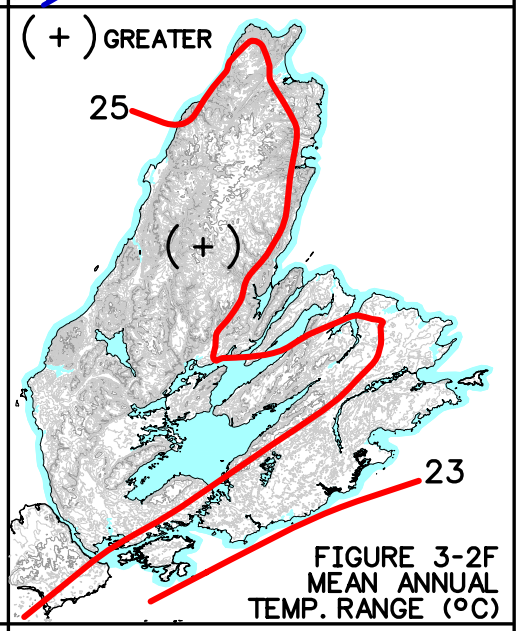

FIGURE 3-2F
MEAN ANNUAL
TEMP. RANGE (°C)

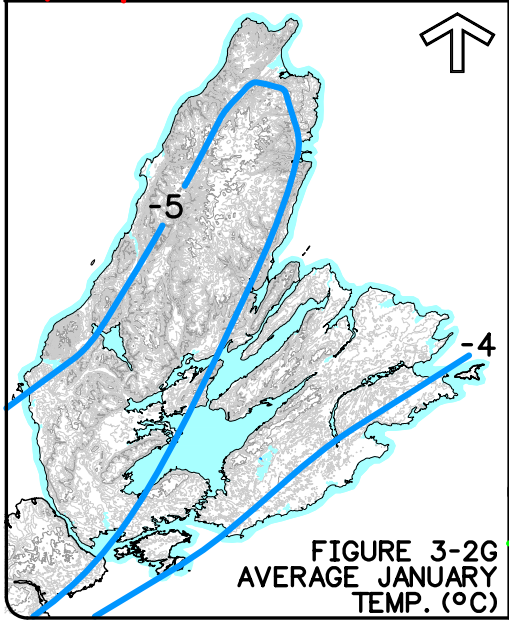

FIGURE 3-2G
AVERAGE JANUARY
TEMP. (°C)

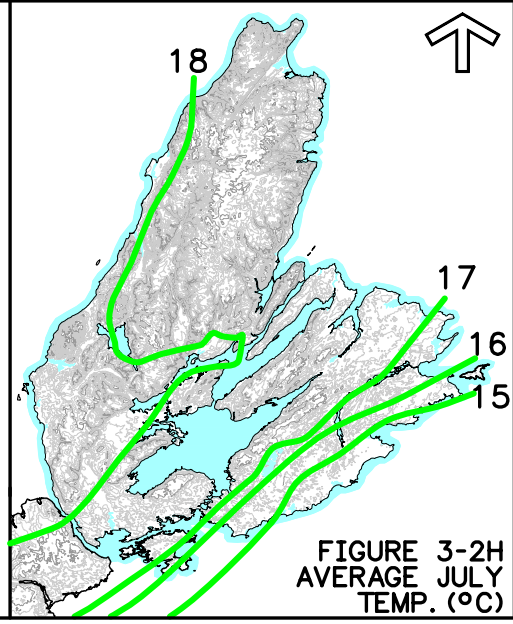

FIGURE 3-2H
AVERAGE JULY
TEMP. (°C)

FIGS A to E, FROM GATES (1975)
FIG F, AFTER GRANT (1994)
FIGS G & H, AFTER NS MUSEUM (1996)

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Proj. STATE OF ENVIRONMENT
BRAS D'OR LAKES WATERSHED
FRESH WATER RESOURCES

Dwg. DISTRIBUTION AND TIMING
OF SELECTED CLIMATE
PARAMETERS

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Highlands Region. Unfortunately, it has only been recording since 1998 with intermittent records, due to severe winter conditions.

3.5 Precipitation

The 1971-2000 Normal total annual precipitation (rain and snow) at Sydney is 1501.3 mm. It is generally well distributed on a seasonal basis, with minimums in June, July and August. High intensity, infrequent thunderstorm activity peaks in July and August (Gates, 1975). Maximum precipitation occurs during the fall rains caused by the overlap of the Hurricane and Nor'easter seasons.

Isohyets, identifying zones of similar precipitation (Gates, 1975), trend north-south (Figure 3-2A), revealing a decline from an average of 1600 mm in the snowbelt along the west coast, to 1000 to 1200 mm along the east. The eastward decline is mostly attributable to snowfalls (Figure 3-2B); during the summer months rainfall is similar throughout (Figure 3-2C). As the most significant portion of the precipitation received results from the passage of major low-pressure systems, precipitation events are generally long duration, low intensity events, which optimize groundwater recharge.

North Mountain has three years with sufficient information to determine a total annual precipitation, which ranges from 1411 mm (2005), 1609.7 mm (2000) and 1555.4 mm (1999). Interestingly, these values were similar to those recorded at Sydney of 1433.5, 1543.9 and 1608.2 mm, respectively.

3.6 Air Temperature

The Normal mean annual air temperature is 5.6^{o}C. The 23 to 25°C fluctuation in temperature over a year (Figure 3-2F) is relatively small, being more representative of coastline stations where oceanic moderation depresses the cycle.

The minimum mean monthly temperature (Figure 3-2G) occurs in February (-6.5^{o}C). Mean monthly values, below freezing, occur during December through March inclusive. Maximum mean monthly temperatures peak in July and August (Figure 3-2H). The advent of warmer temperatures is delayed in the spring, due to the cold Labrador Current and pack ice surrounding the Island.

North Mountain recorded mean annual temperatures of 5.3^{o}C (2005), 4.9^{o}C (2000) and 6.7^{o}C (1999). At Sydney, the same years recorded notably higher temperatures of 6.6^{o}C, 6.3^{o}C and 7.7^{o}C, respectively.

3.7 Snow

Snowfall has a Normal value of 297.2 cm, ranging from 467.8 to 167.4 cm. Approximately 25% of precipitation originates as snow in the Sydney area, falling over four and a half months between early December and mid April. The percent snow fraction is lowest near the ocean (<15%) and highest at greater elevations (>30%) and at places remote from the ocean (Gates, 1975). The reliability of snow cover is relatively low over the Lowlands, resulting from the moderating effect of the Atlantic. Due to the delay in the onset of spring at higher elevations, the snowpack melt within the snowbelt is delayed in the highlands by at least one month (Figure 3-2E).

Two representative winter thermographs (Figure 3-3) combine mean daily air temperature and depth of snow cover during the period from first to last snowfall. Figure 3-3A uses the winter of 1998-1999 to represent the milder winters of the 1980's and 1990's at Sydney, with Figure 3-3B for the North Mountain station. These illustrate the influence of more frequent above freezing melt events and rainfall on minimizing snow cover in the Lowlands. In the highlands, the heavy snowfall and minimal melt events results in snowpack that is retained into May.

3.8 Evapotranspiration

The loss of precipitation available for runoff and infiltration is controlled through transpiration by the forest cover and evaporation from lakes and streams. The Island generally belongs to the Acadian Forest Region, which exhibits coniferous elements of the boreal forest, and deciduous species of the Great Lakes-St. Lawrence Forest (Loucks, 1962). There is a relatively short frost-free period of 145 days and a growing season of 186 days at Sydney, resulting in reduced evapotranspiration (ET) loss.

The Normal annual actual evapotranspiration (ET) at Sydney, assuming a 100 mm soil holding capacity, is approximately 515 mm (34% of total precipitation) as calculated by Environment Canada using the Thornthwaite method (1948). During the 1999-2000 water year, the only time when data is available at both North Mountain and Sydney, the actual ET was higher at the former (494 mm) than the latter (393 mm), as expected.

3.9 Water Balance

The integration of the above climate components creates the water balance for a climate region. This determines the character of the water surplus, when and how much water is available for runoff in streams and recharge to groundwater. The water balances for the

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FIGURE 3-3A
LOWLAND REGION SYDNEY AIRPORT: 1998-1999

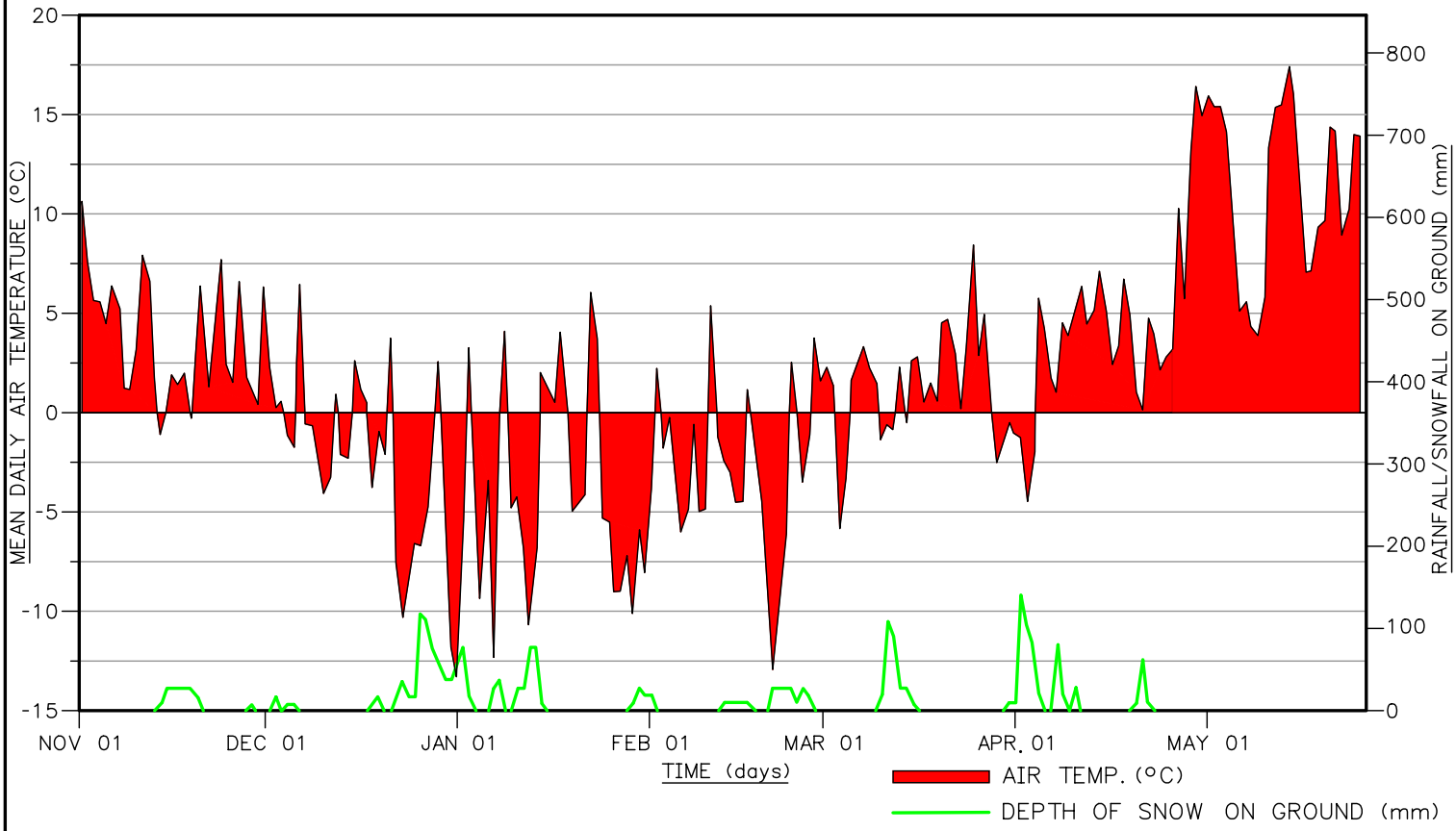
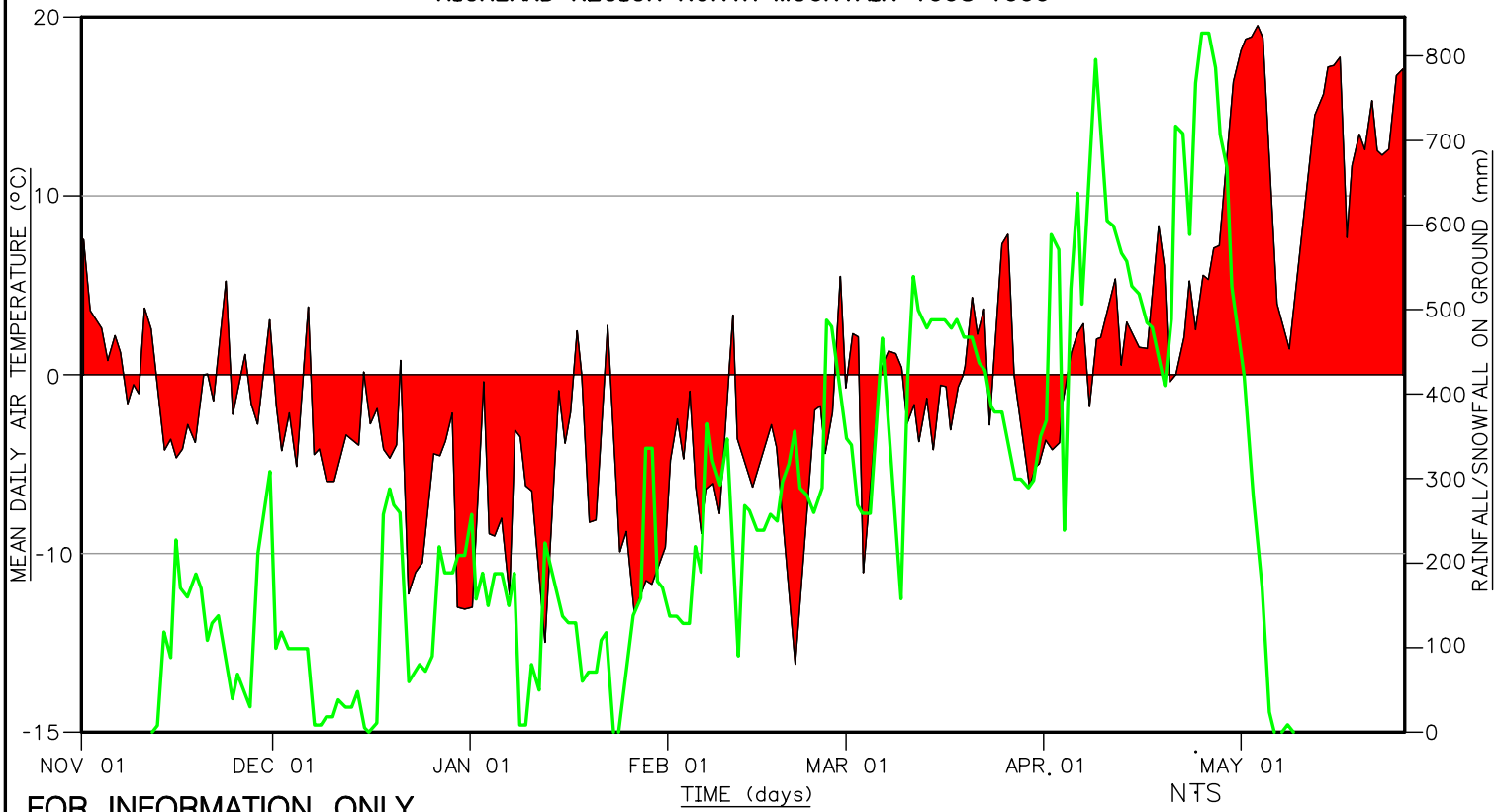


FIGURE 3-3B
HIGHLAND REGION NORTH MOUNTAIN: 1998-1999



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BRAS D'OR LAKES WATERSHED
FRESH WATER RESOURCES

Dwg. WINTER THERMOGRAPHS FOR LOWLAND & HIGHLAND REGIONS

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Dwg. Standards Chk. By:	Dwg. No. FIGURE 3-3
Designed By: FEB	Dwg. Design Chk. By: FEB
Rev. 0	

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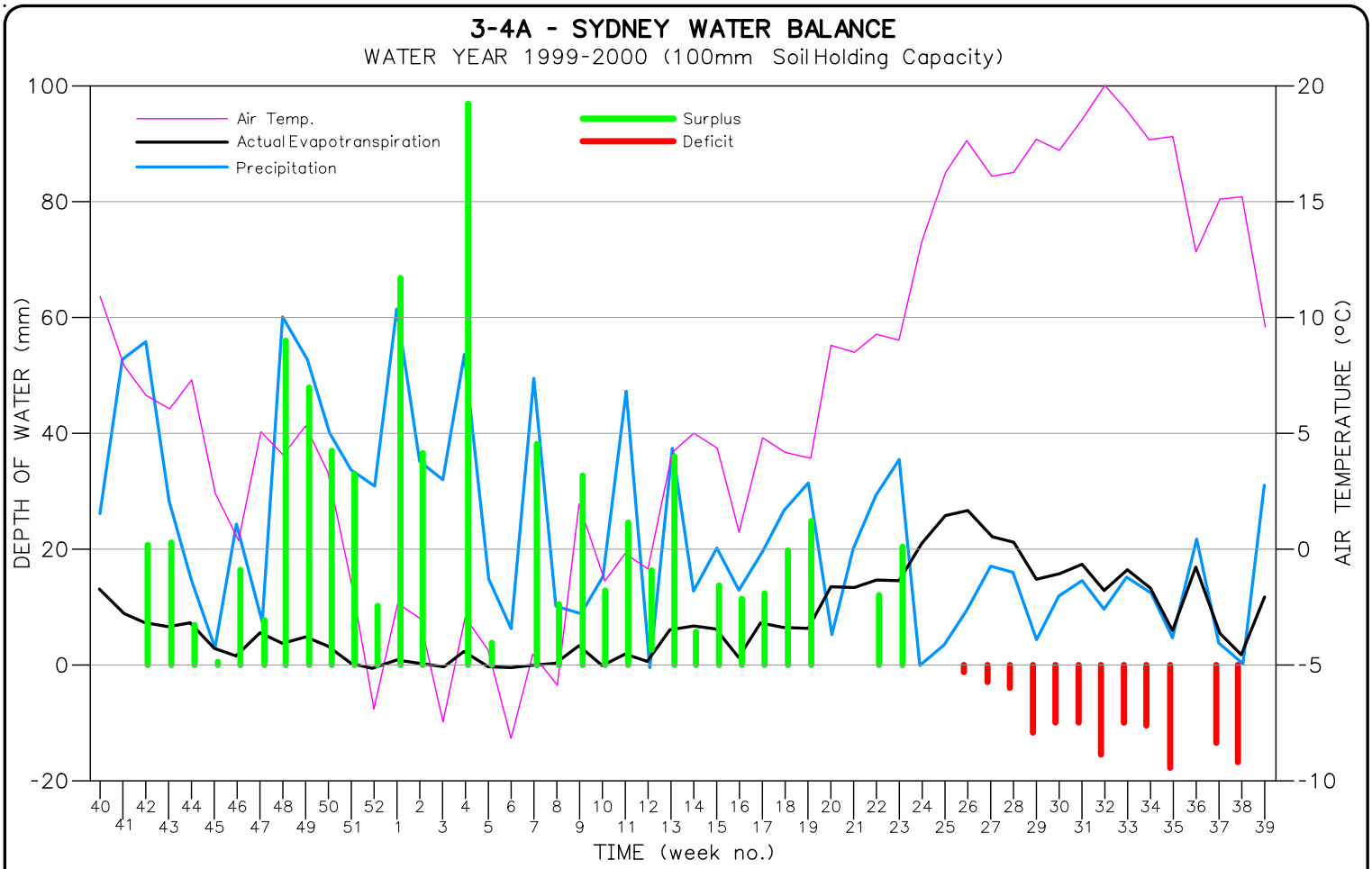

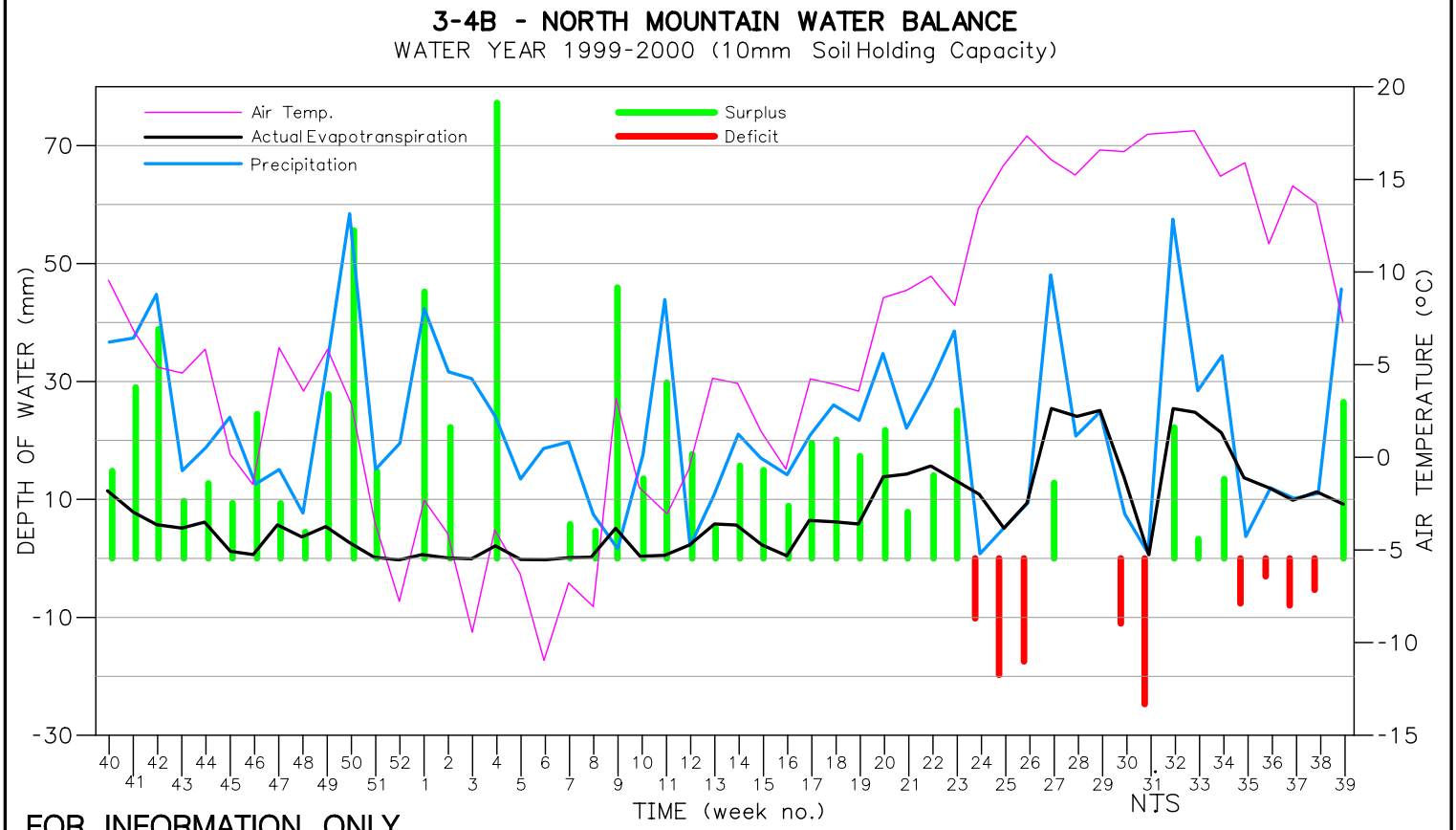

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Proj. STATE OF ENVIRONMENT
BRAS D'OR LAKES WATERSHED
FRESH WATER RESOURCES

Dwg. **WATER BALANCE DIAGRAMS FOR LOWLAND & HIGHLAND REGIONS**

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Dwg. Standards Chk. By:	Dwg. No. **FIGURE 3-4**
Designed By: FEB	Dwg. Design Chk. By: FEB / Rev. 0

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Lowland (100 mm water holding capacity) and Highland Regions (10 mm) are shown in Figure 3-4 for the 1999-2000 Water Year. Both show a large volume of precipitation (1160 to 1194 mm) and low evapotranspiration loss. This resulted in a large annual water surplus ranging from 757 mm (65% of precipitation) in the Highland Region, to 758 mm (63%) in the Lowland Region.

The surplus arrives over nine months in two distinct wet seasons. During winter/early spring (January to May inclusive) air temperatures are below freezing and the surplus goes into storage as snow, depending upon melt events, which are more frequent over the Lowland Region. Warming trends in March through May release the snowpack storage and eliminate frost cover, creating the Spring Recharge Period, feeding streams and groundwater. During late fall (October to December inclusive), precipitation occurs mostly as rain from the hurricanes and Nor'easters, evapotranspiration loss is diminishing and frost cover is absent, creating the Fall Recharge Period. During the summer, evapotranspiration loss increases creating deficit conditions, low streamflow and groundwater levels.

The differences between the Highland and Lowland Regions water balance during one year of available data indicate a greater, longer duration deficit condition (125 mm) in the Lowland than the Highland (111.5 mm).

It would appear from this one year of data that the water balance in both regions is similar. The major difference focuses around the colder winter weather, with only minor melt events in the Highlands. This allows more of the surplus to remain in storage as snow, accumulate and then run off quickly, later in May.

3.10 Precipitation Chemistry

The chemistry of the Island's precipitation has been sporadically monitored in the past by Underwood (1984) and Baechler (1986); none were located within the Watershed, none are active.

The chemical signature for precipitation reveals a sodium-chloride type water (Figure 3-5B) during the winter, evolving toward a calcium-sulfate/bicarbonate type in the summer. Total dissolved solids (TDS) ranged from 8 to 14 mg/L. All five metals monitored for exhibited detectable concentrations. The influence of the sea is felt in the chloride concentrations, which decrease with distance from the Ocean. The decline found in Cape Breton (Underwood, 1981) was similar to that found elsewhere in Nova Scotia and along the Atlantic Seaboard (Figure 3-5C).

FIGURE 3-5A WIND ROSE FOR SYDNEY AIRPORT

after Wilson, 1965

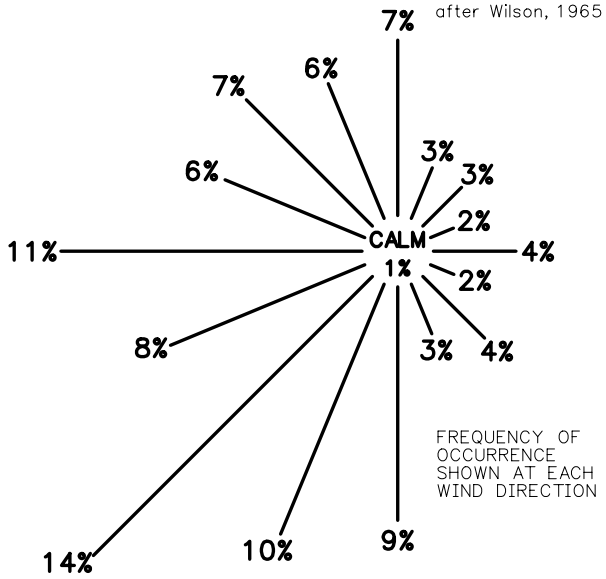

FIGURE 3-5B TRILINEAR DIAGRAM OF PRECIPITATION CHEMISTRY

after Baechler, 1986

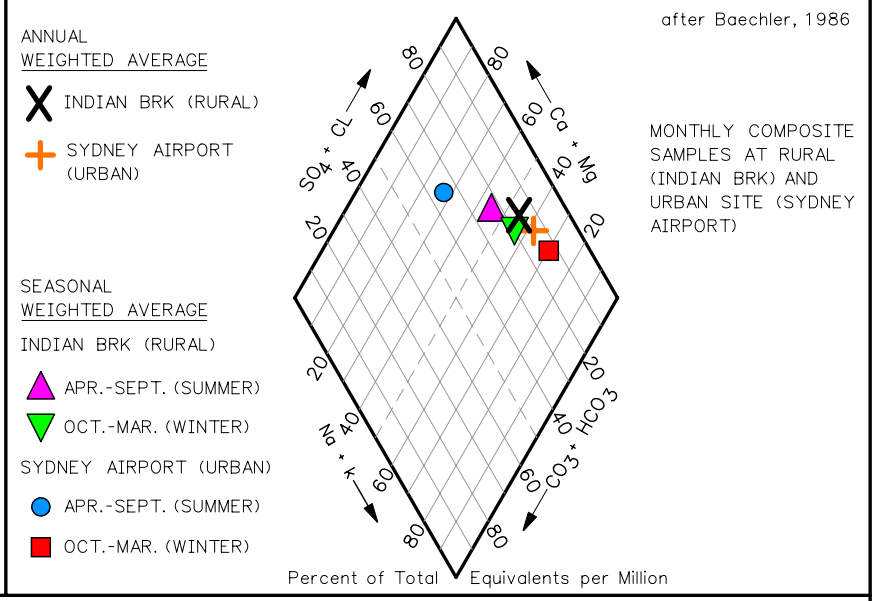

FIGURE 3-5C THE RESPONSE OF PRECIPITATION CHLORIDE CONCENTRATIONS TO DISTANCE FROM THE OCEAN

after Underwood, 1984

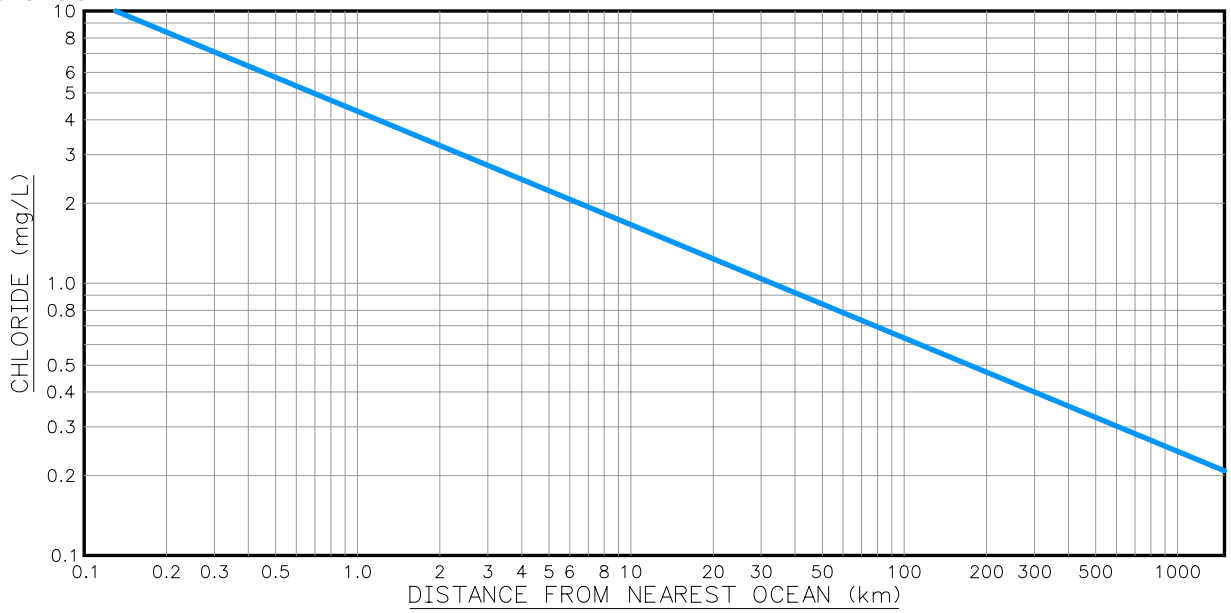

FIGURE 3-5D

(Underwood, 1984)

AVERAGE ANNUAL pH, FALL 1977 THROUGH 1980 WET PLUS WINTER BULK SAMPLES

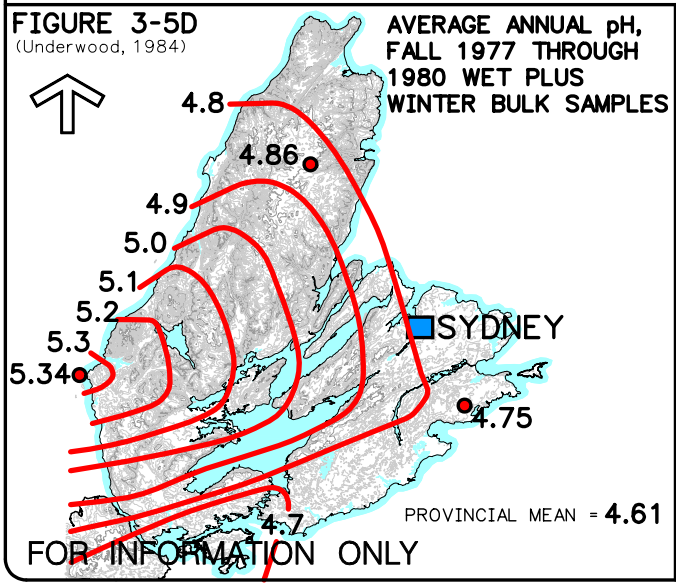

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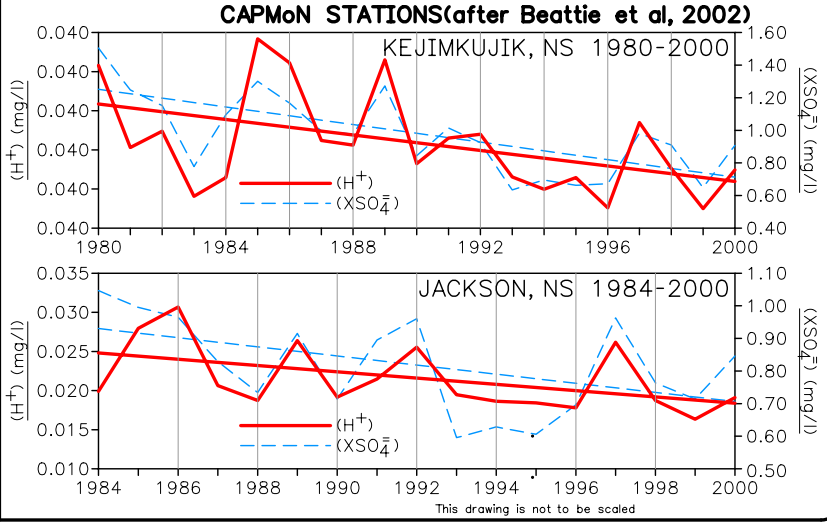
FIGURE 3-5E TRENDS IN ANNUAL AVERAGE HYDROGEN ION CONCENTRATION AT TWO NOVA SCOTIA CAPMoN STATIONS(after Beattie et al, 2002)



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Proj. STATE OF ENVIRONMENT BRAS D'OR LAKES WATERSHED FRESH WATER RESOURCES

Dwg. ELEMENTS OF PRECIPITATION CHEMISTRY

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Dwg. Standards Chk. By:	Dwg. No. FIGURE 3-5
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Due to the prevailing westerly winds (Figure 3-5A), the province lies within the "airsheds" of many densely populated, highly industrial areas on the eastern US Seaboard and the St. Lawrence Valley-Great Lakes region. This places the Watershed in a position conducive to the receipt of potential acids and other contaminants from long-range transport of air pollutants (LRTAP). Further, it lies at the downwind sector of the province and is, therefore, in receipt of provincial emissions.

The average annual pH (5.0 to 5.2) was less than the 5.7 equilibrium value, indicating that acidity was controlled by more than just atmospheric carbon dioxide in equilibrium with precipitation. The lowest monthly composite pH's recorded at the rural site was 4.8 (Baechler, 1986), which was in agreement (Figure 3-5D) with work by Underwood (1981).

3.11 Climatic Trends

Globally, cold conditions commenced in the early 1700's and continued through to approximately the late 1800's (Figure 2-6C), known as the "climatic worsening". Around 1890, temperatures began to rise, culminating in a worldwide peak (Figure 2-6D) in the 1940's (Lamb, 1985). This was followed by a decline through until the 1990's, when conditions appear to be reversing. Climate records from Sydney since 1870 (Figure 3-6) support this global trend for the Watershed.

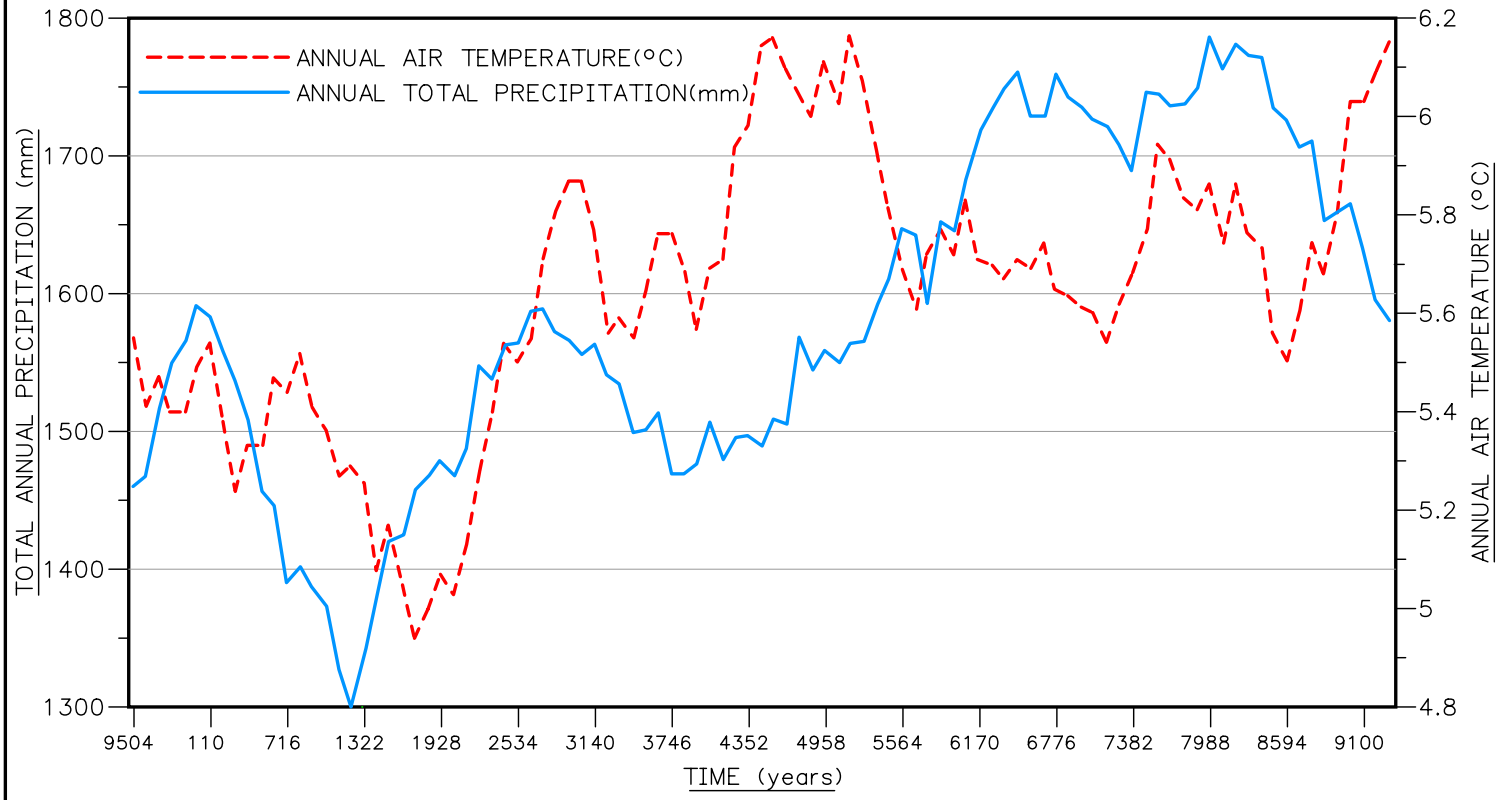
The multiple forces, which interweave to create the Watershed's variable climate, have created both short (one to three year) and longer term (20 to 30 year) cycles within the last 110 years of records at the Sydney Airport.

A Quasi Biennial Oscillation (QBO) was noted by Burroughs (1992) as a world wide meteorological phenomenon with a pulse slightly in excess of two years. The same QBO is randomly present at Sydney (Baechler, 1999) in both precipitation and air temperature (Figure 3-7) during five notable intervals; the longest being between 1967 and 1983.

Longer term decadal cycles (Figure 3-6A) were determined by smoothing out the QBO fluctuations with 10 year moving means (Baechler, 1999). There is an overall trend of increasing precipitation and reduced air temperature commencing in the mid to late 1950's, with air temperature exhibiting a more complex cycling. The total annual precipitation exhibited a rising trend starting in the late 1950's, which rose approximately 275 mm, to peak in the mid 1980's. Since that time, there has been a falling trend of approximately 100 mm. Figure 3-6B separates precipitation into snowfall, with peak

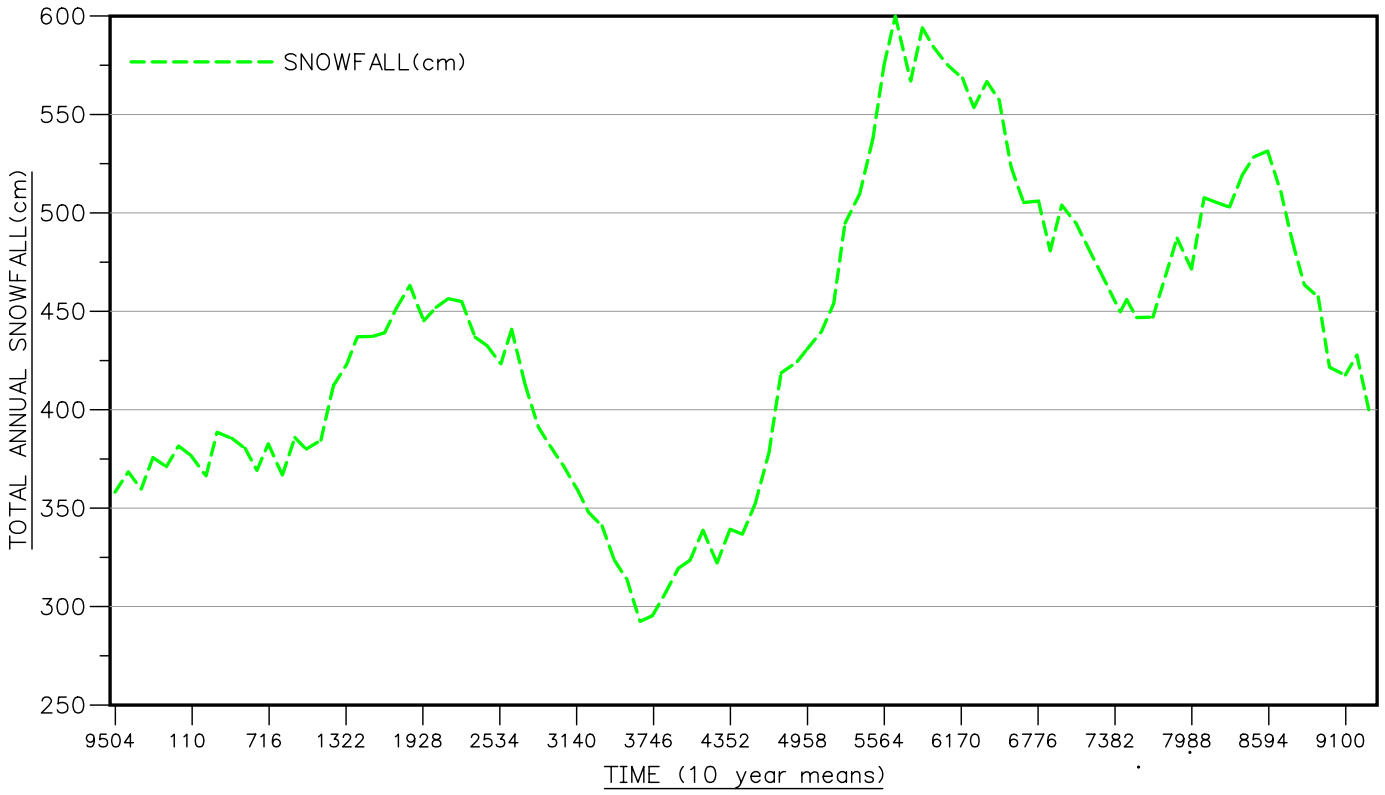
FIGURE 3-6 MOVING 10 YEAR MEANS - SYDNEY AIRPORT: 1895-2002

3-6A - TOTAL ANNUAL PRECIPITATION & AIR TEMPERATURE



NOTE: 9504 REFERS TO THE PERIOD 1895 TO 1904

3-6B - SNOWFALL



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Dwg. SYDNEY AIRPORT - 1895-2002
MOVING DECADAL MEANS ANALYSIS

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Dwg. Standards Chk. By:	Dwg. No. FIGURE 3-6
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e:\5810001\\cont01\Fig3-7_AnnualPrecipTemp.DGN

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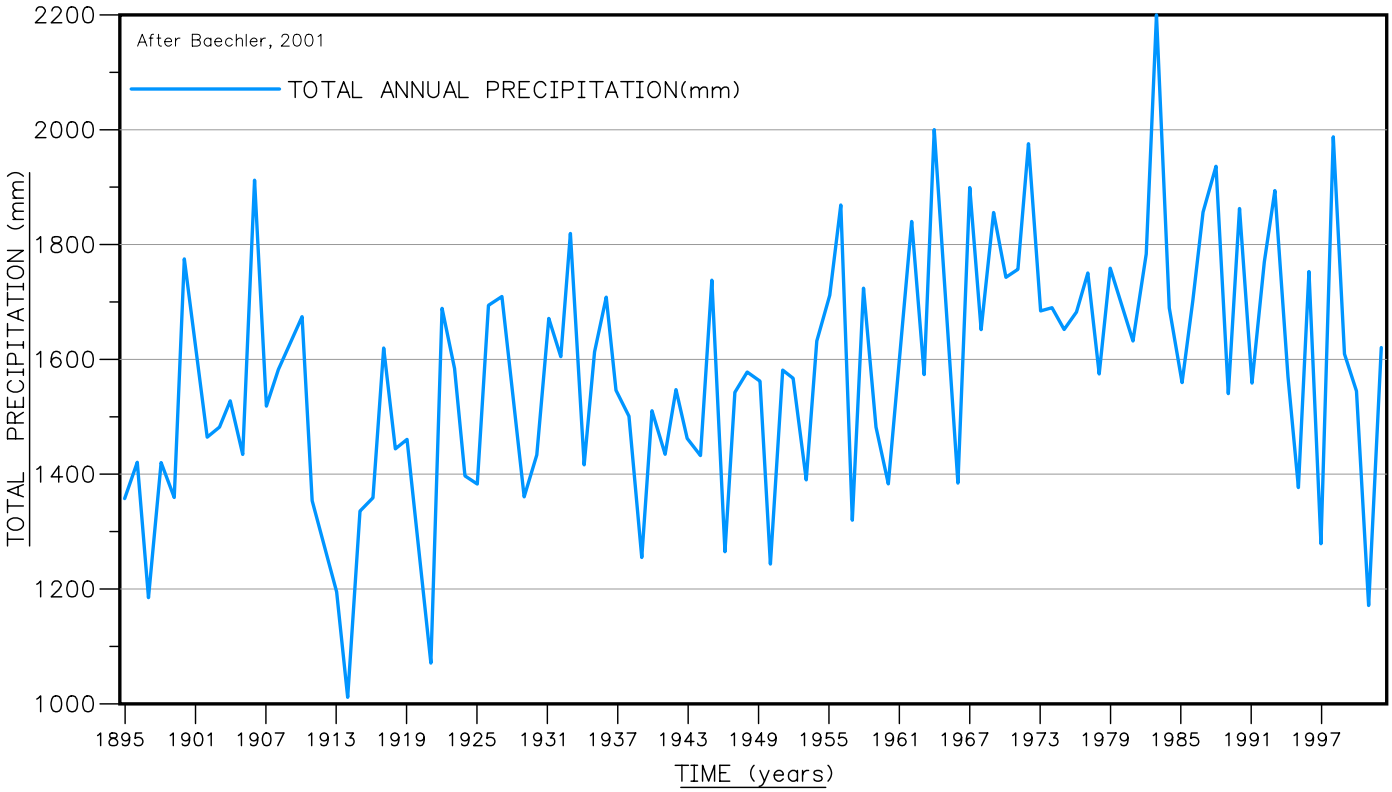
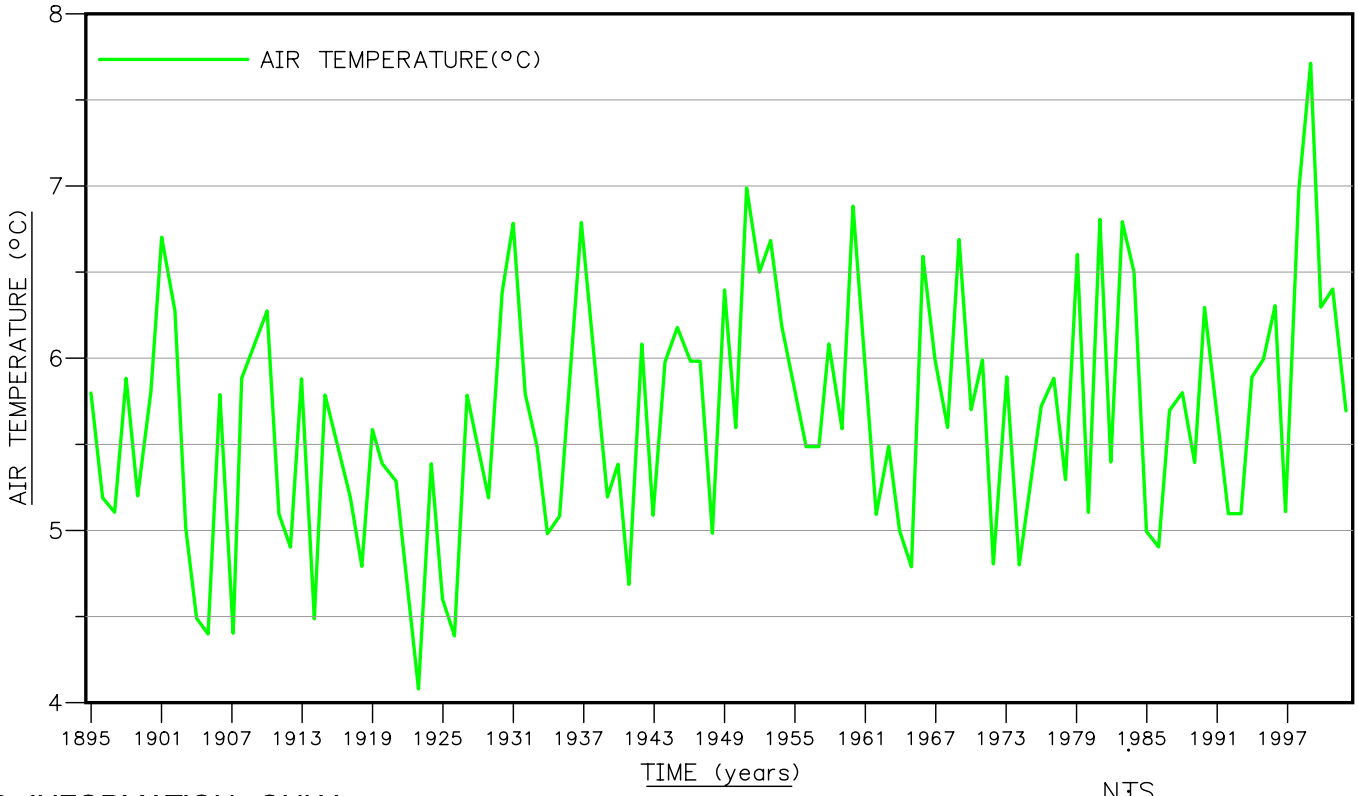
FIGURE 3-7 QUASI BIENNIAL OSCILLATIONS - SYDNEY AIRPORT - 1895 - 2002

3-7A - TOTAL ANNUAL PRECIPITATION



3-7B - AIR TEMPERATURE



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Proj. STATE OF ENVIRONMENT
BRAS D'OR LAKES WATERSHED
FRESH WATER RESOURCES

Dwg. SYDNEY AIRPORT - 1895-2002
QBOin ANNUAL PRECIPITATION
& TEMPERATURE

Drawn By: NEB	Proj. No. 5810-001.1
Dwg. Standards Chk. By:	Dwg. No. FIGURE 3-7
Designed By: FEB	Dwg. Design Chk. By: FEB / Rev. 0

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snowfalls occurring in the 1960's (Baechler, 1999). Overall, the annual changes appear to be generally related to changes in rainfall during the fall and early to mid winter.

Figure 3-8A uses the winter of 1998-1999 to represent the milder winters of the 1980's and 1990's at Sydney. Figure 3-8B uses the 1963-1964 winter to represent the cold winters within the time of high snowfall in the early 1960's. These two thermographs exhibit the influence of above freezing episodes and rainfall during mild winters on minimizing snow cover and spring melt.

Routine monitoring of precipitation chemistry has been on going only since 1975 in Atlantic Canada. The nearest active site is a provincially operated station at Sherbrooke, some 100 km southwest of the Watershed. Since approximately the 1950's, there has been a continued decrease in pH through to the late 1970's (Underwood, 1979). Between 1980 and 1998, total US and Canadian sulphur dioxide emissions declined by approximately 29%. This resulted in a statistically significant linear decline in sulphate concentration of 24 to 54% at the five Environment Canada CAPMON Atlantic Canadian Monitor Sites. However, linear decreases in hydrogen ion concentration were not as large, ranging from 15 to 39% (Figure 3-4E) (Beattie et al, 2002).

3.12 Summary

The climate of the Bras d'Or Lakes Watershed is governed by global and continental scale systems being drawn toward, then converging over the Watershed, only to be modified by the sea and rugged highlands to create a constantly changing "weatherscape". The convergence of these continental systems also places the Watershed within the airshed of heavily industrialized emissions in North America. As the rains deluge the Island's waterscape, they bring with it the dissolved remnants of a continent's outpourings.

4.0 HYDROSTRATIGRAPHIC UNITS (BUILDING BLOCKS OF THE WATERSCAPE)

4.1 Introduction

Hydrostratigraphic units (HUs) are the building blocks which, when combined in various combinations, create the *matrix* of the waterscape through which water flows.

e:\581000111\cont01\FIG3-8_WinterTherm.DGN

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FIGURE 3-8A MILD WINTER THERMOGRAPH

SYDNEY AIRPORT: 1998-1999

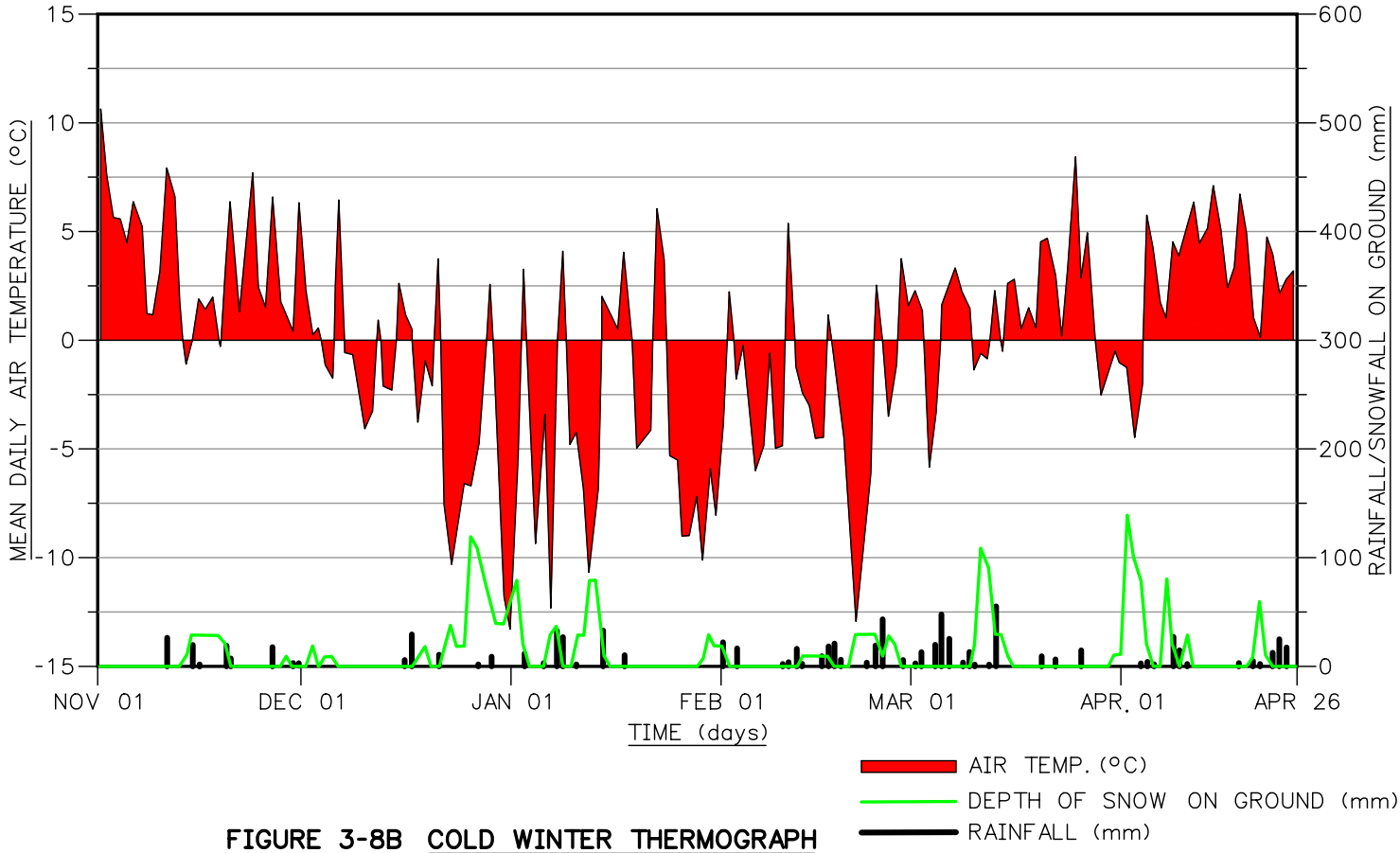
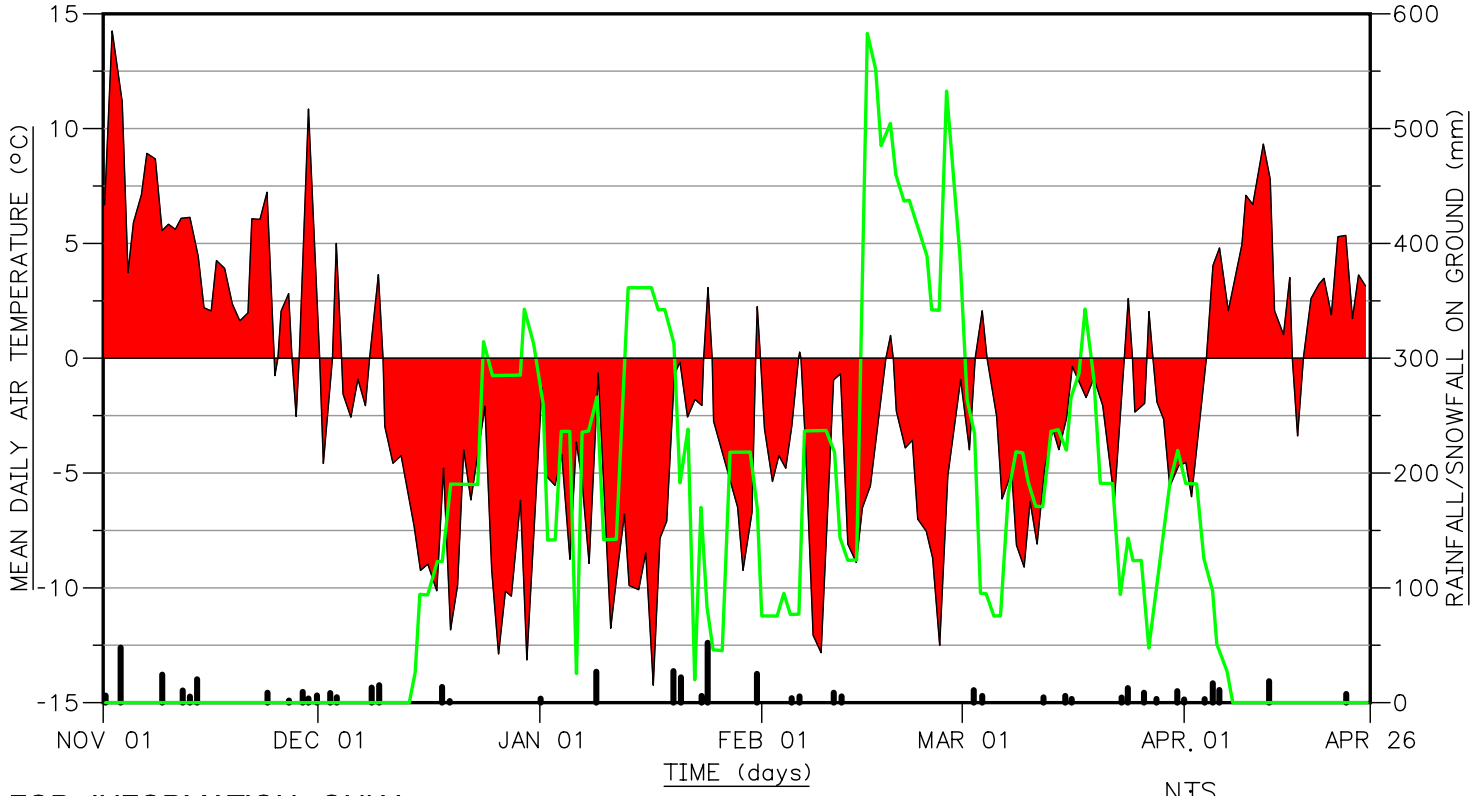


FIGURE 3-8B COLD WINTER THERMOGRAPH

SYDNEY AIRPORT: 1963-1964



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Dwg. CHANGES IN WINTER THERMOGRAPHS BETWEEN 1960's & 1990's AT SYDNEY

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Dwg. Standards Chk. By:	Dwg. No. FIGURE 3-8
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They are geological units exhibiting similar properties that control the occurrence, quantity and quality of water. A total of 12 create the Bras d'Or Lakes Watershed as summarized from Baechler et al (in preparation). Mapping for this report is intended for use at a scale of 1:250,000.

The ability to transmit water is defined in the following discussion by transmissivity (T) in m^2/day, as well as hydraulic conductivity (K) in centimetres per second (cm/sec). Safe yield is defined as a 20 year well yield. Ten primary indicator parameters provide a chemical signature of the inorganic chemistry, augmented with others were necessary. Zones of naturally occurring mineralization and hydrocarbons are noted, which may locally degrade water quality.

4.2 Igneous Metamorphic Hydrostratigraphic Unit

This HU encompasses both plutonic and volcanic igneous rocks, as well as adjacent metamorphic rocks (Figure 4-1). These erosion resistant rocks underlie seven highland areas including the Cape Breton Highlands, Sporting Mountain, Boisdale Hills, East Bay Hills, North Mountain, Kellys Mountain and Creignish Hills.

Plutons encompass molten igneous rocks, mostly granites, injected into immense magma chambers deep within the earth's crust by the collision of continental plates within Time Line 1. Volcanic igneous rocks were created through lava flows or "pyroclastics" blown out during volcanic eruptions fed by magma from the plutons. This unit also includes surrounding rocks metamorphosed by heat and pressure, encompassing distinctive beds of marbles within the Georges River Metamorphic Suite.

Transmissivities of these rock types ranged from 0.1 to 21.6 m^2/d, resulting in Ks ranging from 1.6×10^{-4} to 2.0×10^{-5} cm/sec. Safe yields ranged from 2.7 to 110 Lpm, averaging 40 Lpm.

Groundwater is generally a fresh (TDS 38 to 225 mg/L), soft to moderately hard, corrosive, sodium/calcium-bicarbonate type water (Figure 4-1B), with an alkaline pH (6.8 to 9.4). Nutrients occur as low concentrations of total organic carbon (1 to 4 mg/L); iron (<0.02 to 0.9 mg/L) and manganese (<0.01 to 0.25 mg/L) are at relatively low concentrations. This can be altered by localized zones of natural mineralization. The average uranium content of the Island's granitic rocks suggest a low potential to host uranium deposits. Low-grade uranium deposits may be formed in the metamorphosed country rock, as noted within black shale horizons in a narrow basin stretching the length of the Boisdale Hills (Nova Scotia Department of Mines and Energy, 1982). The

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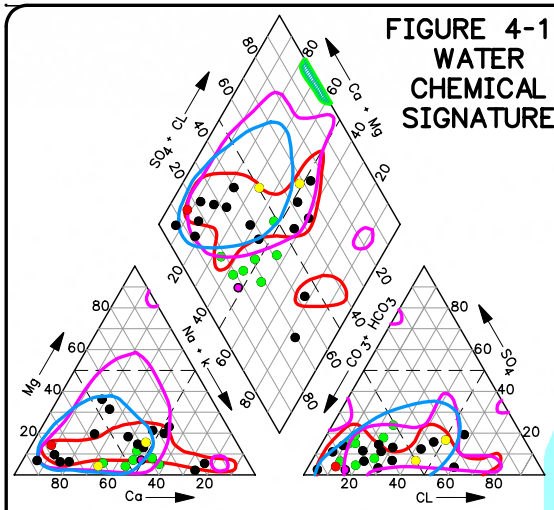
FIGURE 4-1B WATER CHEMICAL SIGNATURE



LEGEND:

- CAPE BRETON ISLAND

MINI CASE STUDIES

- KELLY'S Mtn. PLUTON
- BLACK BROOK PLUTON
- GEORGES RIVER MARBLE
- FISSETT BROOK VOLCANICS

ENVELOPE OF SAMPLES FROM MAINLAND STUDIES

ENVELOPE FOR BRINES IN CRYSTALLINE ROCKS; after Frape et al. 1987)

BRAS D'OR LAKE WATERSHED

IGNEOUS VOLCANIC-METAMORPHIC HYDROSTRATIGRAPHIC UNITS(IvM-HU)

IGNEOUS PLUTONIC HYDROSTRATIGRAPHIC UNITS (Ip-HU)

SHADED RELIEF IMAGE OF CAPE BRETON COURTESY OF NS DEPARTMENT OF NATURAL RESOURCES, MINERAL RESOURCES BRANCH DIGITAL PRODUCTS

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FIGURE 4-1A

KELLY'S MOUNTAIN

BOISDALE HILLS

CREIGNISH HILLS

EAST BAY HILLS

NORTH MOUNTAIN

SPORTING MOUNTAIN

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Dwg.

EXTENT & CHEMISTRY OF THE IGNEOUS METAMORPHIC HYDROSTRATIGRAPHIC UNIT
(After Baechler et al, in progress)

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Dwg Standards Chk. By:	Dwg. No. FIGURE 4-1	
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Georges River marble hosts metallic deposits including zinc and tungsten near Marble Mountain, and tungsten-molybdenum-copper at Whycocomagh Mountain (Chatterjee, 1980a, b).

In summary, this HU is characterized by generally low transmissivity. Discrete zones of higher transmissivity can be overprinted by localized fault zones (Section 4.7) and karst development in the marble units. This HU generally exhibits a low permeability, with water wells producing barely enough (5 Lpm) potable water for a domestic water supply. Water quality is generally acceptable with sporadically elevated iron, manganese and uranium.

4.3 Horton Hydrostratigraphic Unit

The first sediments deposited in the inter-mountain basins formed the Horton Group (Figure 4-2), principally along the north and central areas. It incorporates conglomerates and sandstones deposited in alluvial fan-braided stream environments positioned near steep, fault bounded, basin margins along mountain fronts.

Transmissivity ranges from 0.8 to 35.8 m^2/d, averaging 12.7 m^2/d, resulting in Ks ranging from 8.0 x 10^{-4} to 1.7 x 10^{-5} cm/sec. Safe yields ranged from 58 to 387 Lpm, averaging 167 Lpm.

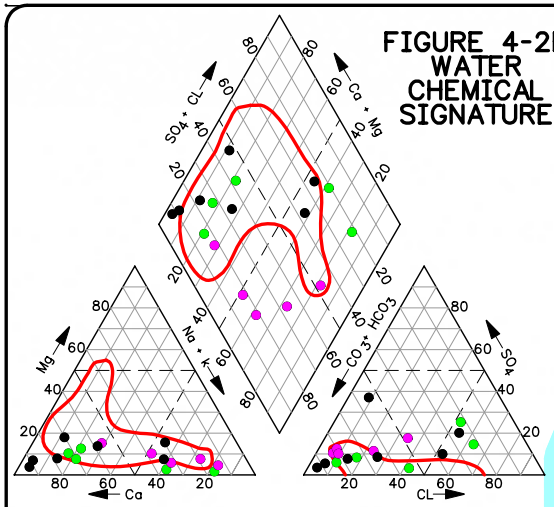
The groundwater exhibits a wide variability in typing (Figure 4-2B). It can be characterized as a fresh (TDS 57 to 582 mg/L), soft to moderately hard, corrosive to encrusting, calcium-bicarbonate, sodium-bicarbonate and mixed sodium/calcium-bicarbonate/chloride type water. The pH is alkaline (7.0 to 8.8) and nutrients are primarily total organic carbon (<0.5 to 5.7 mg/L). Iron (<0.01 to 0.21 mg/L) and manganese (<0.01 to 0.172 mg/L) are at relatively low concentrations.

Fine-grained rocks of this HU form excellent hydrocarbon source rocks and reservoirs (Ryan, 2001). There is significant potential for metallic deposits (copper, lead and zinc) hosted in Horton sediments, especially when it is in contact with the basal Windsor Group (Forgeron, 1980). It is also considered a possible host for uranium mineralization (Giles, 1991).

In summary, this HU is characterized by moderate transmissivity ranging over one order of magnitude. Discrete zones of higher transmissivity can be overprinted by localized faulting (Section 4.7). It generally provides acceptable quantity and quality of potable

FIGURE 4-2A

FIGURE 4-2B
WATER
CHEMICAL
SIGNATURE



LEGEND:
- CAPE BRETON SAMPLES

MINI CASE STUDIES
- COXHEATH
- BADDECK
- ENVELOPE ENCOMPASSING GROUNDWATERS SAMPLED ON THE MAINLAND

HORTON HYDROSTRATIGRAPHIC UNIT(H-HU)

BRAS D'OR LAKE WATERSHED

BADDECK

WHYCOCOMAGH

ESKASONI

ATLANTIC OCEAN

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Dwg.
EXTENT & CHEMISTRY OF THE HORTON HYDROSTRATIGRAPHIC UNIT
(After Baechler et al, in progress)

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Dwg Standards Chk. By:	Dwg. No. FIGURE 4-2	
Designed By: FEB	Dwg Design Ckd By: FEB	Rev. 0

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water for at least domestic purposes. The water supply for the Village of Whycocomagh and the Highland Village in Iona is drawn from this aquifer.

4.4 Windsor/Mabou Hydrostratigraphic Unit

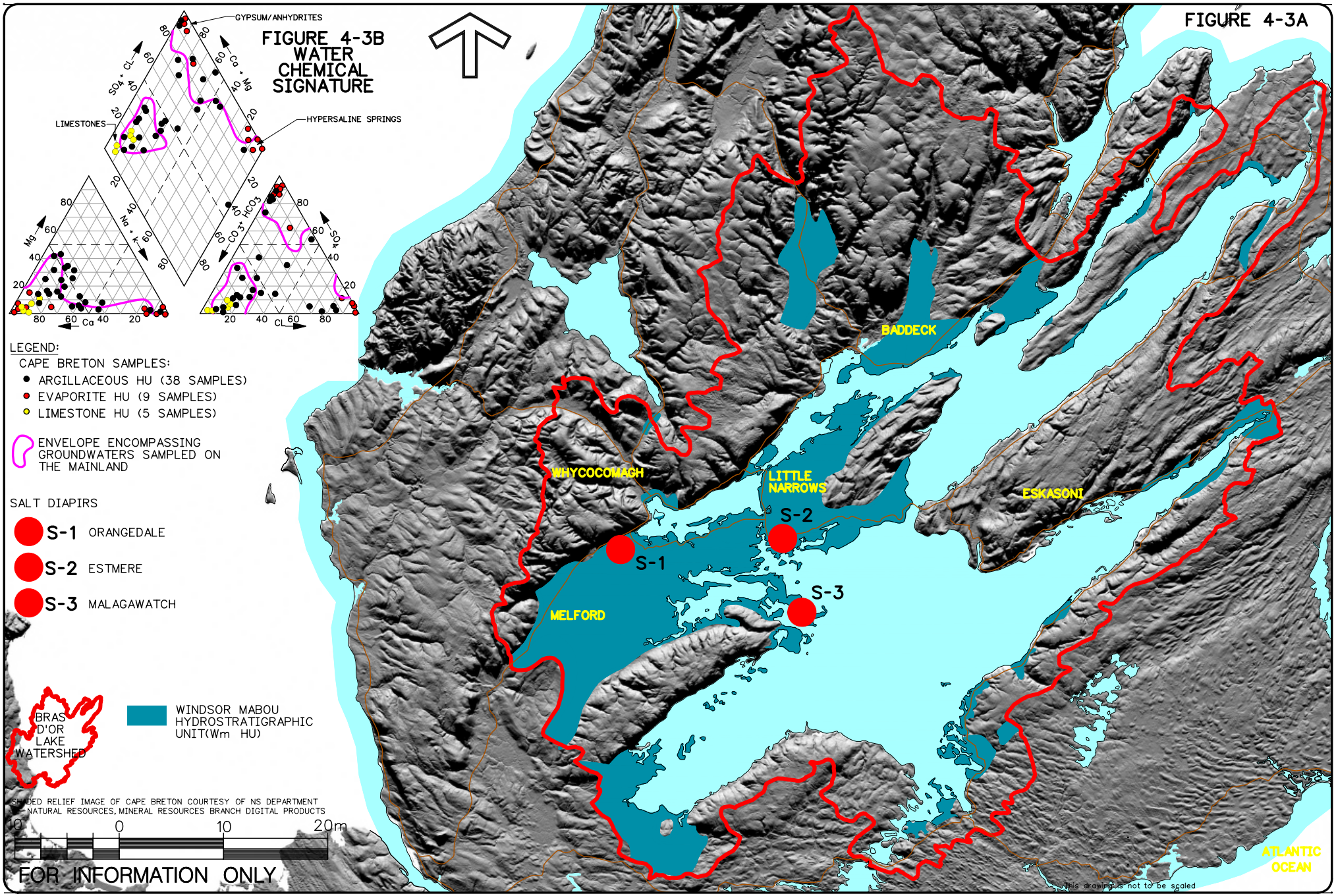
Marine sediments of the Windsor and Mabou Groups were deposited over the Horton as the basins flooded five times by the rise and fall of global sea level (Calder, 1998). Tropical seas dominated the first two cycles, resulting in extensive evaporite deposits of salt gypsum and potash. With the last recession, the basins evolved into a river-floodplain-lake environment in which shales, mudstones and siltstones of the Mabou Group were deposited.

This HU (Figure 4-3) underlies the present day lowlands, mostly around the Bras d'Or Lakes. It has been subdivided into three sub-units. The Evaporite (WM_E HU) is the largest encompassing primarily gypsum and salt deposits. Salt diapirs have been documented (Figure 4-3) at Estmere, Malagawatch (Giles, 2003) and Orangedale (Cook et al, 2003), as well as inferred at Kempt Head, Bucklaw, Seaview and Dundee (Boehner, 1986, 2002). Most karst (sinkhole) formation has been wiped out by glaciation, although active surface karst has been documented around Melford, River Denys and Little Narrows. A regionally extensive limestone (WM_L HU) is found at the base of this HU. The Argillaceous (WM_A HU) includes interbedded mudstone, shale, siltstone, limestones and sandstones with minor evaporates.

Transmissivity within the Argillaceous HU ranges from 2.9 to 17.7 m^2/d, averaging 7.3 m^2/d, resulting in Ks ranging from 1.2×10^{-3} to 2.0×10^{-4} cm/sec. Safe yields ranged from 9.6 to 220 Lpm, averaging 73 Lpm. Literature values (Castany, 1984) provided a transmissivity range from 100 to 11,000 m^2/d for fissured and karstic limestones and evaporates.

The groundwater chemistry exhibits a wide variability given the range in lithology. Overall, it can be characterized as a fresh to hypersaline (TDS 77 to 50,000 mg/L), soft to extremely hard, corrosive to encrusting water. The typing ranges between three end members of calcium sulfate, sodium chloride and calcium carbonate (Figure 4-3B). The pH is generally alkaline (6.5 to 8.7) and nutrients are primarily as total organic carbon (<0.5 to 22 mg/L). Iron (<0.2 to 2.7 mg/L) and manganese (0.01 to 2.5 mg/L) exhibited variable concentrations.

The contact between the limestone and the underlying Horton has been one of the more prospective exploration targets for natural mineralization. This includes carbonate-hosted



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Dwg.
EXTENT & CHEMISTRY OF WINDSOR MABOU HYDROSTRATIGRAPHIC UNIT
(After Baechler et al, in progress)

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base metal, silver, celestite and barite deposits (Patterson, 1991). Salt Diapir activity forms a variety of structural traps for gas and oil reservoirs, which have become a target for oil and gas exploration.

In summary, this HU is characterized by highly variable transmissivity ranging over two and a half orders of magnitude. The evaporites, siltstones and shales exhibit generally low yields of non-potable, very hard, salty water, difficult to treat. The limestone units can exhibit larger yields with relatively good water.

4.5 Cumberland Hydrostratigraphic Unit

Following retreat of the oceans, another mountain building period took place. The erosion of these mountains deposited a third package of sediment in the regenerated basins, forming the Cumberland HU. As the basins filled, the braided rivers deposited the sandstones and conglomerates of the Lower Morien (C_{LM}) HU (Figure 4-4), primarily under Boularderie Island and near St. Peter's.

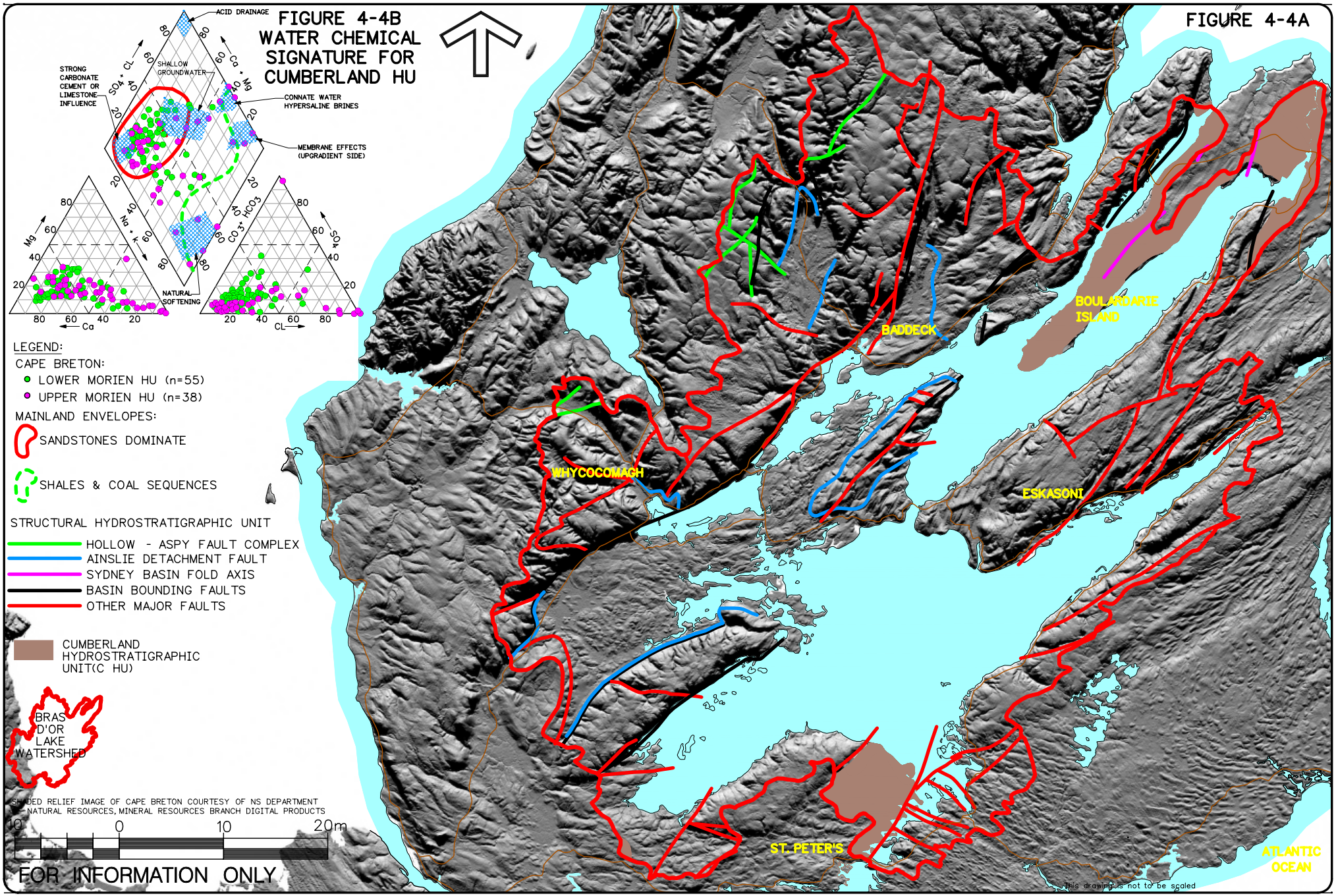
Transmissivity ranges from 1.3 to 522 m^2/d, averaging 72.9 m^2/d, resulting in Ks which average 1.8 x 10^{-3} cm/sec. Safe yields ranged from 2.7 to 1884 Lpm, averaging 594 Lpm.

Although water chemistry is variable, there is a dominant core area considered to represent "normal" conditions for the aquifer. It can be characterized as a fresh (TDS average 129 mg/L), soft to hard, primarily corrosive, calcium-bicarbonate type water (Figure 4-4B). The pH is generally slightly alkaline (6.3 to 8.1) and nutrients are at non-detectable to low concentrations, primarily as total organic carbon (average 1.95 mg/L). Iron (average 0.8 mg/L) and manganese (average 0.49 mg/L) are usually at relatively low concentrations, although zones of elevated concentrations do exist. The contact between the Cumberland and Windsor/Mabou HUs is a target for sulphides and base metals mineralization.

In summary, this HU exhibits moderate to high transmissivities. However, discrete zones of higher transmissivity are overprinted through localized fault and fold zones (Section 4.7). It forms one of the best potable water aquifers within the Watershed.

4.6 Structural Hydrostratigraphic Unit

This HU comprises the zones where massive folding and faulting of the bedrock has occurred, which are kilometres in scale (Figure 4-4). The forces that created these zones



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Dwg.
EXTENT & CHEMISTRY OF CUMBERLAND & STRUCTURAL HYDROSTRATIGRAPHIC UNITS
(After Baechler et al, in progress)

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were responsible for widespread fracturing of the bedrock, which provides their ability to transmit water. However, this HU focuses on the "epicenter" of the tectonic activity where there may have been sufficient change to warrant a special designation. Tectonically, Cape Breton is not highly active at present, so the creation of new faults and folds, or rejuvenation of old systems is not expected.

Three broad types of structure are present within the Watershed. Basin Bounding Faults comprise linear, generally northeast trending, extensional faults positioned along the edge of the Carboniferous basins. Salt Diapirism, within the Windsor extend upward some 0.9 to 1.5 km, penetrating, warping and fracturing overlying Carboniferous clastic strata for out to 2 km from the margins (Davison, 2005). The Ainslie Detachment Fault was triggered by a regional evaporite controlled, bedding-parallel gravity slide near the base of the Windsor Group.

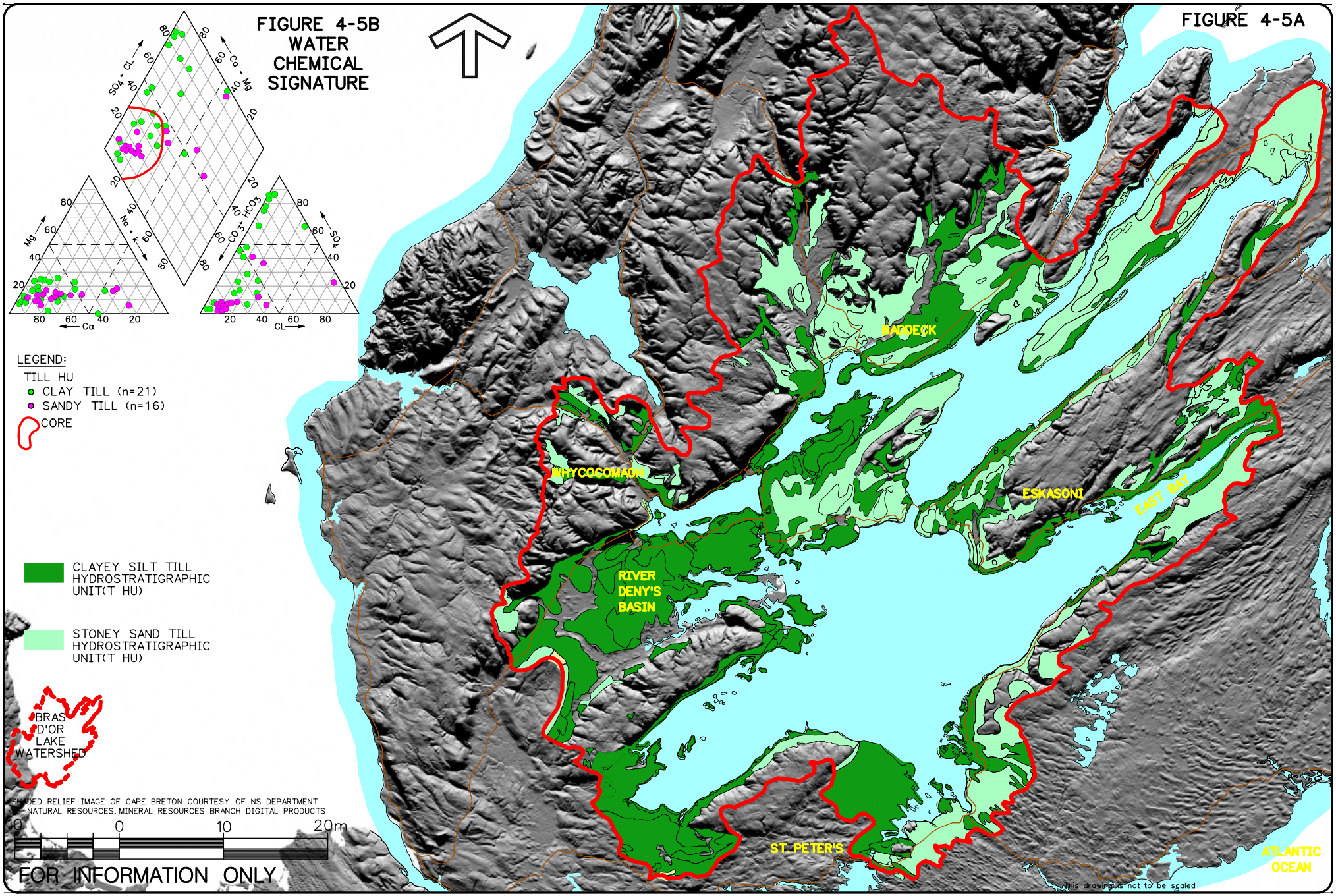
The Structural HU can exhibit a wide variety of hydraulic characteristics including complete hydraulic connection from one side to the other, a permeable zone of preferential flow and an impermeable barrier. Experience suggests many faults are hydraulically active to some extent, regardless of age.

The chemistry of waters from the Structural HU generally mimics that of the surrounding HUs. There is a link between the Ainslie Detachment and regional lead-zinc mineralization.

4.7 Till Hydrostratigraphic Unit

The last glacial advance produced a wide variety of unconsolidated deposits overlying the bedrock. Till is the most widespread of these deposits (Figure 4-5). It is generally present over the uplands and lowlands, but absent over the highlands. Over the more easily erodible sedimentary lowlands it is thicker, more extensive, lithologically diverse and finer textured, with fewer cobbles and boulders. Sequences of multiple tills are common along the north side of East Bay, as well as in the River Denys Basin (Stea et al, in preparation).

It has been subdivided into a Stony Sand (T_S HU) and Clayey Silt Till (T_C HU). The former comprises a gray to brown stony sand deposit thin enough to reveal underlying bedrock relief (Grant, 1994). The latter is a "till blanket" more than 5 metres thick. It is relatively fine-grained, with few or no cobbles and boulders (Stea et al, in preparation).



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EXTENT & CHEMISTRY OF TILL HYDROSTRATIGRAPHIC UNITS
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The T_S HU, exhibits an average K of 6.1 x 10^{-5} cm/sec; the T_C HU a range of 1x10^{-5} to 1x10^{-7} cm/sec.

The chemistry of both exhibits a wide variability. The core chemistry is a fresh (TDS 91 to 291 mg/L), soft to very hard, corrosive to encrusting, calcium-bicarbonate type water (Figure 4-5B). The pH is generally alkaline (7.1 to 8.2) and nutrients are at non-detectable to low concentrations. Total organic carbon (1 to 19 mg/L) is quite variable, but generally <5 mg/L, probably attributable to the shallowness of the wells and, therefore, proximity to the soil horizon. Iron (0.02 to 1.12 mg/L) and manganese (<0.01 to 2.2 mg/L) are usually at relatively low concentrations. The TDS and alkalinity for the T_C HU exceeds that for the T_S HU, attributable to the underlying Windsor bedrock from which it is predominately derived.

This HU is usually not a target for water supply, except for occasional dug wells. Its importance stems from the control it exerts on directing precipitation, more as overland flow into streams. It also forms a protective layer for bedrock aquifers, hence it is critical to water resources protection.

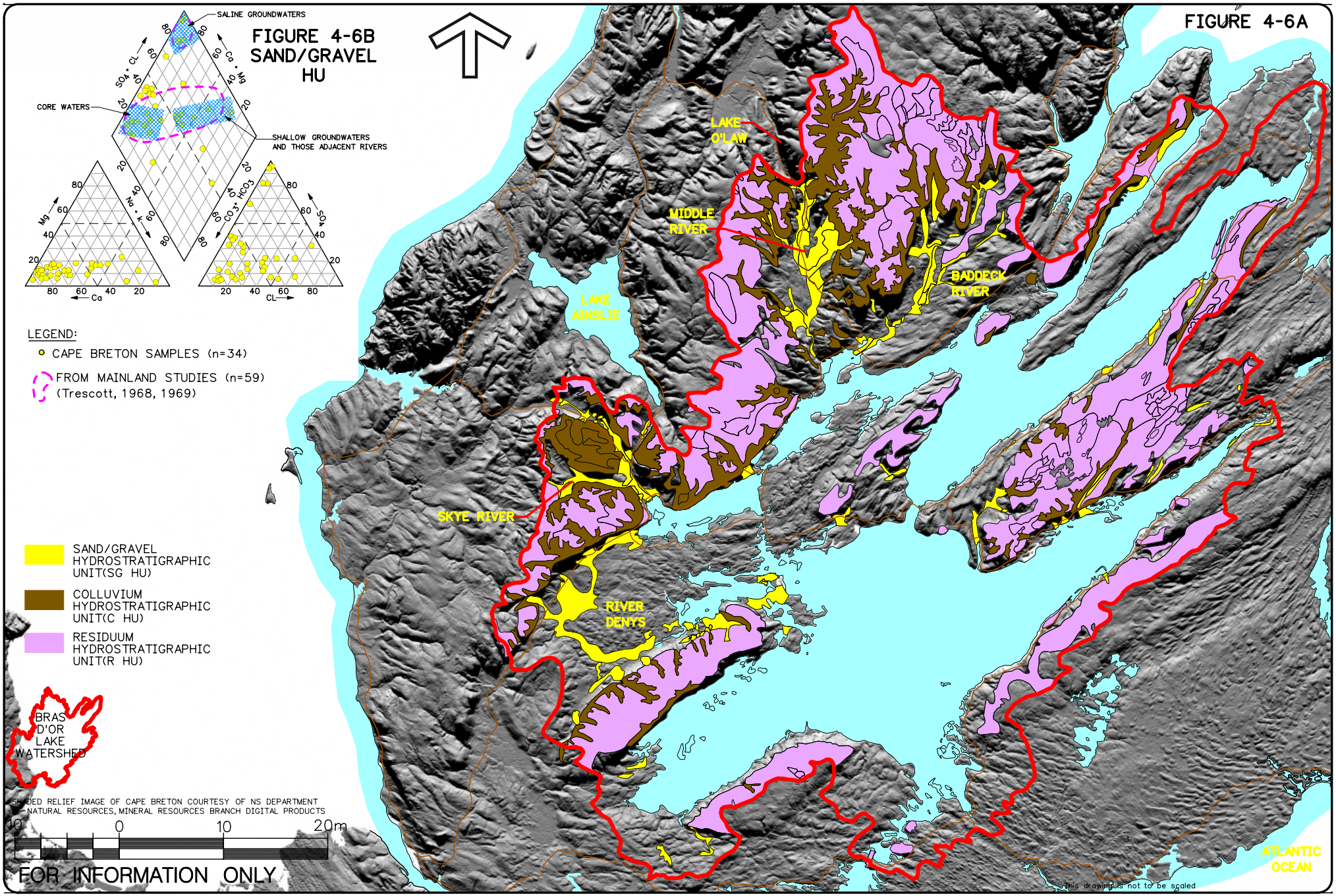
4.8 Sand/Gravel Hydrostratigraphic Unit

This HU encompasses sand and/or gravel formed primarily by glacial meltwater streams. Only the largest are mappable at the scale designated for this report (Figure 4-6). The most extensive deposits are found in the Middle, Denys, Skye and Baddeck River valleys.

Underlying some of these outwash plains are river channels deeply incised into the bedrock surface, with maximum proven depths of some 15 metres below present sea level. These have been documented at Melford (ADI, 2001), Orangedale (Stea et al, 2003) and Lake O'Law (Montreal Engineering Co. Ltd., 1979).

Transmissivity ranges from 2.6 to 1181 m^2/d, averaging 200 m^2/d resulting in Ks ranging from 1.3 x 10^{-1} to 2.5 x 10^{-3} cm/sec, averaging 4.0 x 10^{-2} cm/sec. Safe yields ranged from 4.6 to 1189 Lpm, averaging 345 Lpm.

The groundwater chemistry exhibits wide variability. A core calcium bicarbonate typing (Figure 4-6B) is prevalent, which is characterized as a fresh (TDS average 157 mg/L), soft to very hard, primarily corrosive, calcium-bicarbonate type water. The pH is generally alkaline (6.9 to 8.1) and total organic carbon remains fairly low (<0.5 to 5 mg/L). Iron (<0.1 to 3.4 mg/L) and manganese (<0.01 to 1.1 mg/L) are usually at



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EXTENT & CHEMISTRY OF SAND/GRAVEL, COLLUVIUM AND RESIDUUM HYDROSTRATIGRAPHIC UNITS

(After Baechler et al, in progress)

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relatively low concentrations. Deeper wells exhibit calcium-sulfate type waters with very high TDS (1000 to 2500 mg/L), due to underlying Windsor/Mabou HU.

This HU exhibits a high, but variable transmissivity ranging over three orders of magnitude. Generally, it is one of the top producing aquifers, exhibiting good quantity and quality groundwater for wells, and is important in contributing flow to adjacent streams.

4.9 Colluvium Hydrostratigraphic Unit

This unit includes loose debris accumulated at the base of steep slopes by rockfalls and landslides. They are generally very permeable deposits comprising sand, gravel and boulder sized material (Figure 4-6), primarily around the edge of the highlands and uplands (Grant, 1994). They are not used for water supplies due to the inhospitability of the terrain.

Based upon visual field observations and literature review, an estimated K ranges from 10^{-1} to > 1 cm/sec.

4.10 Residuum Hydrostratigraphic Unit

This unit encompasses broken, disintegrated bedrock and localized thin, stony sand till found over the highlands (Figure 4-6). It represents a thin, very permeable unit overlying igneous and metamorphic rocks, which control infiltration and surface runoff.

It consists of Residuum, which ranges from broken, to disaggregated and disintegrated rock, including felsenmeer (rock rubble), grus (sandy debris), sapprolite (weathered paleo soils) and rock rooted insitu (chemically altered, but coherent and not texturally disintegrated). It occurs to depths of 2 to 3 metres (Grant 1994).

Literature estimates (Clow et al, 2003) suggest a K ranging from 1.1 to 3.9 x 10^{-1} cm/sec.

Generally, the groundwater is a fresh (TDS 24 to 35 mg/L), soft, corrosive, sodium-chloride type water with pH of 5.8 to 6.0, alkalinities of 2 to 5 mg/L and TOC of <1 to 10 mg/L. Metals were mostly non-detectable; iron ranged from 0.07 to 0.9 mg/L and manganese from 0.02 to 0.08 mg/L (Nolan Davis, 1989a).

4.11 Organics Hydrostratigraphic Unit

Wetlands constitute unusual landforms as they are formed of biological material predominantly shaped by biological processes, rather than rock. They include bogs, fens, swamps and salt marshes. They have arisen because the Island's maritime climate sustains abundant precipitation and low evaporation. Most are localized, only the largest appear on Figure 4-7.

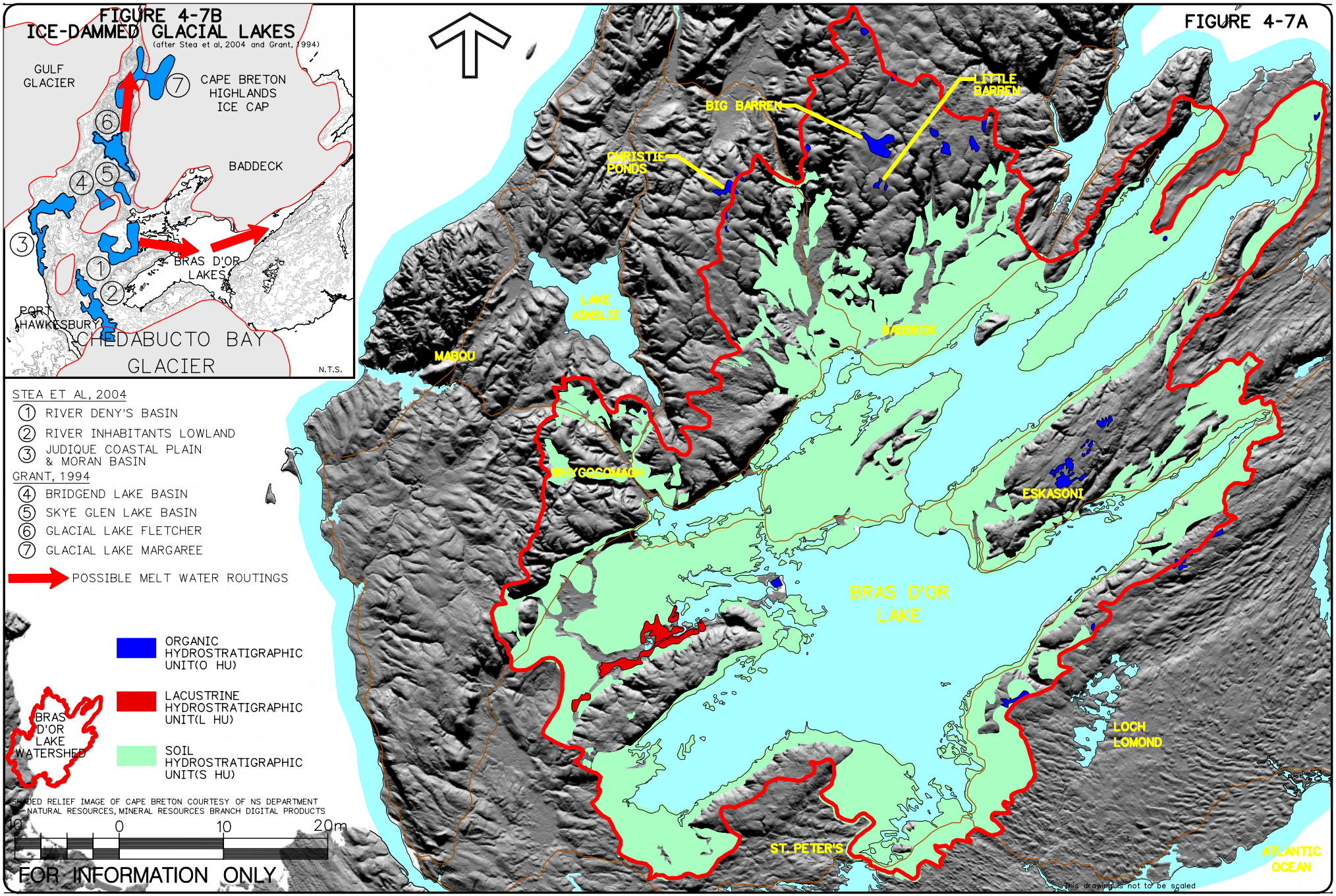
Three wetlands have been investigated within the Watershed by Nova Scotia Department of Natural Resources, identified on Figure 4-7 as Big Barren (X87-3), Little Barren (X87-2) and Christie Ponds (X70-1G) (Anderson et al, 1988). They range in areal extent from 200, 41 to 111 hectares, respectively. While relatively large in spatial coverage, they are all relatively thin with maximum depths of 3.7, 2.1 and 2.8 metres, respectively.

This HU is divided hydrogeologically into two components. The upper, very permeable, unhumidified zone comprises fibrous peat or peat moss, living plants, microbes and other biota. With depth, humidification results in a fairly homogeneous muck, with relatively low permeability and porosity (Price, 1992). Boelter (1965) and Ivanov (1981) found the highest K (3.8×10^{-2} cm/sec) in the upper active layer. The lowest (7.5×10^{-6} cm/sec) were found in the sapric zone, where the peat is highly decomposed and dense.

Four samples of drainage from a fen identified as Big Barren on the Cape Breton Highlands recorded a fresh (TDS 12 to 62 mg/L), soft, corrosive, highly colored (12 to 320 TCU), mixed sodium, calcium-bicarbonate/chloride type water, with a pH of 5.0 to 7.3. Nutrients were non-detectable, except for low levels of nitrogen as nitrate and total organic carbon (2.3 to 10 mg/L). Metals were all non-detectable, except for iron (1.2 to 9.2 mg/L) and manganese (0.2 to 1.4 mg/L).

4.12 Lacustrine Hydrostratigraphic Unit

This unit comprises silt and clay deposited in ice dammed lowland lakes, created during glacial retreat. The Watershed's topography favored the development of glacial lakes because of narrow, highland-bordered outlets, which were easily blocked by ice sheets.
Grant (1994) and Stea et al (2003) outlined the presence of seven ice-dammed glacial lakes in the southwestern lowlands (Figure 4-7B), two of which were within the Watershed, namely Skye Glen and River Denys Basin. These were created by the presence of an ice sheet along the western coast of the Island (Gulf Glacier), which dammed up rivers flowing into the Gulf of St. Lawrence from the Cape Breton Highlands and Chedabuctou Bay glaciers. Depending upon the timing and extent of these ice



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Dwg.
EXTENT OF ORGANIC, LACUSTRINE AND SOIL HYDROSTRATIGRAPHIC UNITS
(After Baechler et al, in progress)

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masses, the lakes either flowed out the present Southwest Margaree along the shore to Cheticamp and into the Gulf, or through the present Bras d'Or Lakes to the Atlantic Ocean.

As much as 50 metres of fine-grained silt and clay were deposited in the Denys Basin (Stea et al, 2003a). Four glacial lacustrine units were found at depth, created during the former interglacial and the last glacial advance and retreat.

K values of the Moran clay provided values of 1×10^{-8} and 9×10^{-9} cm/sec (Stea et al, in preparation). Due to the low permeability of these deposits, they are not used for water supply.

4.13 Soil Hydrostratigraphic Unit

Soils were developed over the top metre of the glacial deposits, since ice retreated some 10,000 years ago. Initially, this was a function of freeze-thaw action due to the adverse climate. Later this was augmented by vegetation and microorganisms, as they took hold over the landscape. These processes resulted in the formation of a soil profile.

Podzol soils cover the largest areal extent (Cann et al, 1963). The A horizon is generally comprised of a thin organic surface layer of partly decomposed organic matter and bleached light colored layer from which alkali clay, iron and aluminium compounds have been leached out by infiltrating rainwater. The underlying B horizon is dark coloured and usually finer in texture in which organic matter and sesquioxides are the main accumulation products, leached from the A horizon. It can become notably cemented by one, or a combination of Duripans, Fragipans, Ortsteins and Ironpans, due to cementation by silica, iron, manganese and/or a high percentage of silt or very fine sand. The C horizon represents unweathered glacial parent material.

For Podzols under forest conditions, the three soil types overlying the T_S HU exhibit values ranging from 1.4×10^{-2} to 1.9×10^{-3} cm sec for the A and B horizons. A similar range was provided for the T_C HU. Gleyed Podzols were similar, although could exhibit a lower range in the A and B horizons down to 5.6×10^{-5} cm/sec in soils over the latter (Webb, pers comm).

This thin HU at the ground surface is not used for water supplies, but is critically important in directing rainfall and snowmelt into stream runoff and groundwater recharge.

4.14 Summary

The best aquifers for supplying potable groundwater are the Cumberland (C_{LM} HU, Horton and Sand/Gravel HUs. The two poorest aquifers, due to low yield and/or poor quality water, are the Windsor/Mabou and Clayey Silt Till HU. Both of these occur together and form most of the north and central shorelines of the Lakes; mostly where settlement is occurring.

5.0 HYDROLOGICAL SETTINGS (PAINTING THE WATERSCAPE)

5.1 Introduction - A Systems Approach

The key to managing the Island's freshwater resources is to be able to map the *occurrence, quantity and quality* of water as it sifts through the waterscape.

To date, our knowledge of the Bras d'Or waterscape has grown by studying "bits and pieces" through site-specific projects, while disregarding the ecosystem as a whole; it has looked at the "trees" rather than the "forest". However, the fact that the real world is immensely complex becomes apparent when trying to put the "bits and pieces" together; when turning from "analysis" to "synthesis" (White et al, 1984).

> *"We are all too inclined, I think, to walk through life with our eyes closed. There are things around us and right at our very feet that we have never seen, because we have never looked. We should not keep forever on the public road, going only where others have gone; we should leave the beaten track occasionally and enter the woods. Every time you do that you will be certain to find something you have never seen before. Of course, it will be a little thing; but do not ignore it. One discovery will lead to another, and before you know it you will have something worth thinking about to occupy your mind, for all really big discoveries are the results of thought."* Alexander Graham Bell

To synthesize an integrated picture of the waterscape a framework is needed - an operating manual so to speak - to show how it works when water (Chapter 3.0) is pumped through the HUs (Chapter 4.0). Such a framework is provided by the concept of "systems" (Chorley et al, 1971 and Christopherson, 1997)), three of which are critical for this assessment including:

Morphological System

This comprises the arrangement of climate (Chapter 3.0), HUs (Chapter 4.0) and topography to create Hydrological Settings. It describes all the elements of a waterscape that control the movement of ground and surface waters. It is a mappable unit with common hydrological characteristics. The Biophysical Land Classification System previously applied to Cape Breton (Nova Scotia Museum, 1997) was subsequently refined with the Ecological Land Classification by Neily et al (2003). Both approaches provided a good base to build upon. However, to manage fresh water resources, Baechler et al (in preparation) modified those descriptors to include Hydrological Settings.

Cascade System

The drainage basin forms the most convenient cascade system. It provides a unit of the earth's surface within which a balance can be struck in terms of inflow and outflow of moisture and energy through rivers and groundwater (Leopold et al, 1964). The alphanumeric Watershed identification system employed by Maritime Resource Management Service (1980) was retained and coupled with the local name. For this scale of mapping it was assumed that surface Watersheds approximate groundwater Watersheds.

Process-Response-Control Systems

These represent the interaction of the Morphological and Cascade systems as they mutually adjust themselves to changing input-output within a particular drainage basin through the:

Hydrological Cycle - the movement of water;
Geochemical Cycle - the movement of chemicals; and
Debris Cycle - the movement of sediment.

The remainder of this section delineates Hydrological Settings then models how water, chemicals and sediment flow through indicator drainage basins selected to be representative of each district. This approach is best described by LeGrand et al (2000) where:

> *The focus is on using generalizations and inferences with existing information to draw conclusions from imprecise and incomplete information. It is not equation based, but, instead a rule-based system of inferences.*

The waterscape was divided into six Hydrological Regions and 11 Districts. The first four Regions include the Highland, Mountain Flank, Foothills and Lowlands, which isolate specific settings. The Canyon and Bras d'Or Marine Regions combine a number of Districts from the first four Regions into a special setting. Conceptual models are provided to illustrate distinctive characteristics.

5.2 Highland Hydrological Region

5.2.1 Overview

This Region encompasses some 30% of the Watershed (Figure 5-1A), including the Cape Breton Highlands and isolated remnants protruding above the lowlands. It has been subdivided into the Peneplain, Mountain Crest and Mountain Valley Hydrological Districts. Distinctive elements incorporate the underlying Igneous Metamorphic HU, draped with Residuum HU at high elevations, under a harsh climate with a high water surplus.

5.2.2 Districts

The *Peneplain Hydrologic District* comprises most of the Cape Breton Highlands, as well as Gairloch Mountain, covering some 10% of the Watershed (Figure 5-1B). Distinctive features comprise an expansive, bedrock controlled, low relief plain, at high elevation (300 to 450 metres) under the influence of the snowbelt. Wetlands (Organic HU) occur in local depressions and in occasional widespread barrens.

The *Mountain Crest District* (Figure 5-1A and 5-2A) comprises six highland ridges at lower elevations (100 to 300 metres) covering some 16.5% of the Watershed (Figure 5-1A). These include the Creignish Hills, North Mountain, Sporting Mountain, East Bay Hills, Boisdale Hills and Kellys Mountain. The crests take the form of long linear ridges, rather than a peneplain, positioned inland out of the snowbelt. They are bounded by steep slopes, with rounded crests and cross cut by gullies and ravines. Marbles of the IM HU are present with relict karst. Minimal wetlands are present, except on the Boisdale Hills.

The *Mountain Valley District* (Figure 5-1A and 5-2B) comprises large, deeply incised, "V" shaped, steep sloped, high gradient stream valleys dissected into the previous two Districts. It also includes steep slopes descending to the sea. Combined, it covers some 3.4% of the Watershed. The low relief and presence of Residuum and Organic HUs over the Peneplain are replaced with the Colluvium HU and steep valley walls, as well as high gradient streams with waterfalls. Microclimates are expected.

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FIGURE 5-1B HIGHLAND REGION PENEPLAIN DISTRICT CONCEPTUAL HYDROLOGIC MODEL

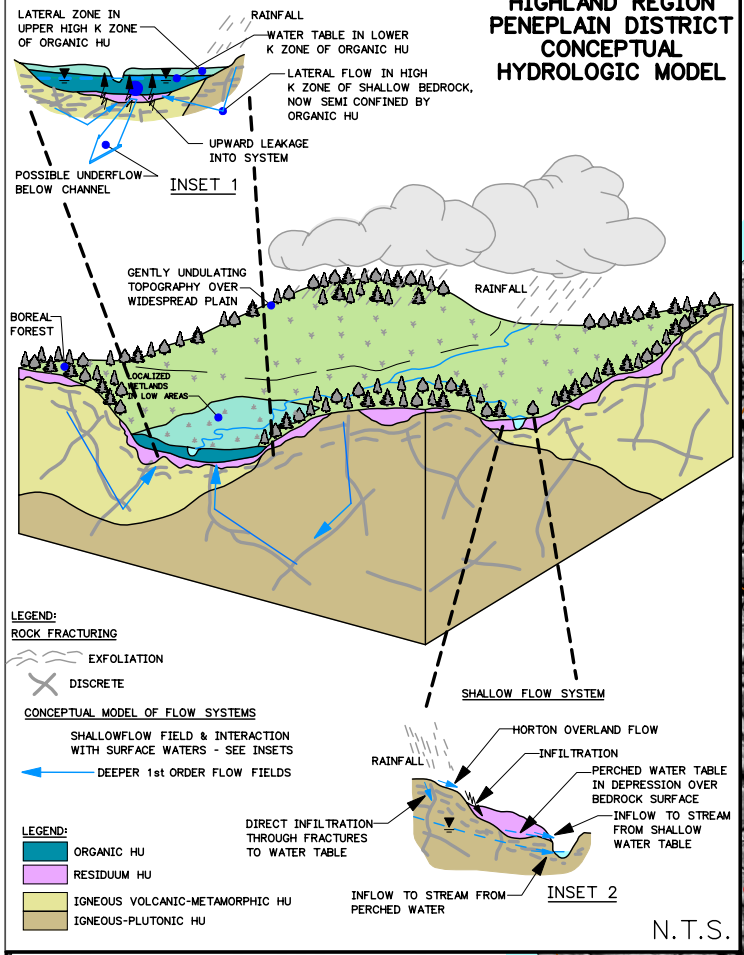
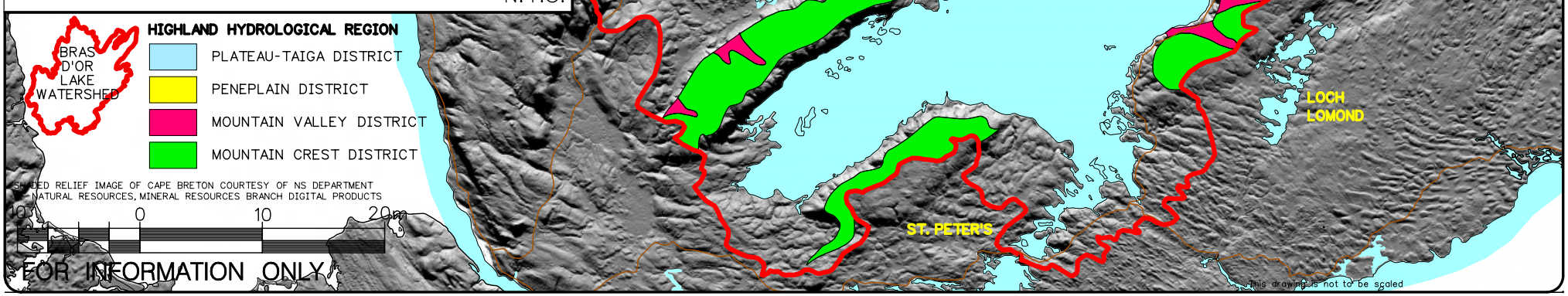


FIGURE 5-1A



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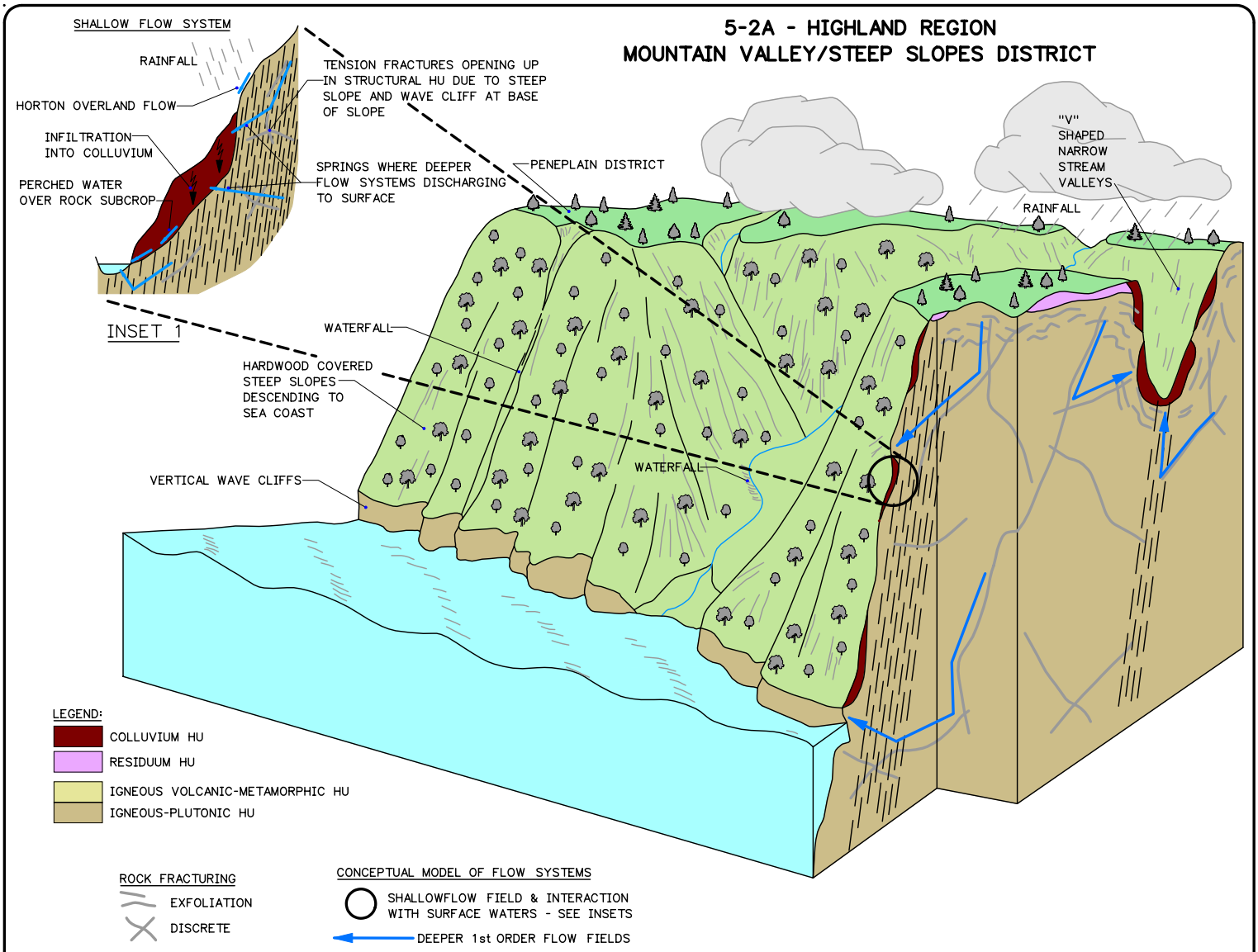

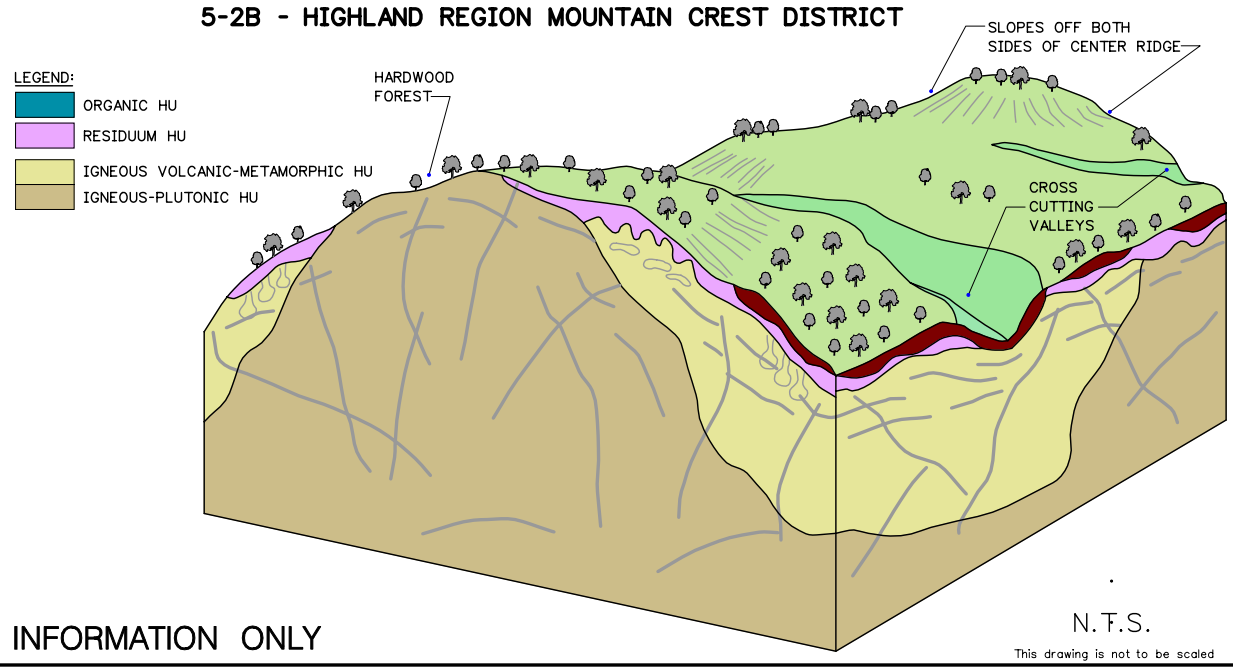

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FRESH WATER RESOURCES

Dwg. **CONCEPTUAL MODELS FOR MOUNTAIN CREST AND MOUNTAIN VALLEY HYDROLOGIC DISTRICTS**
(After Baechler et al, in preparation)

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Dwg. Standards Chk. By:	Dwg. No. **FIGURE 5-2**
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5.2.3 Hydrologic, Geochemical, Debris Cycles

Minimal information is available within the Watershed to document conditions in this Region. What is known derives from six years of monitoring on Alder Brook (data courtesy of Georgia Pacific Canada Inc.), draining the Creignish Hills (Mountain Crest) and sporadic sampling of Big Barren Brook (Peneplain) by Baechler et al (in preparation). Discussion of climatic conditions (Chapter 3.0) and HUs (Chapter 4.0) were derived from studies predominately outside the Watershed. Block diagrams (Figures 5-1B and 5-2) conceptualize the present understanding of groundwater, streams and their interaction.

The arrangement of low permeable bedrock overlain by relatively high permeable, thin Residuum HU with a high water surplus is expected to result in shallow water tables, usually in the upper part of the unconfined Igneous Metamorphic HU. There is no overburden to act as a recharge source for the bedrock during dry periods. Toth's (1970) first order (local) flow systems are expected to dominate the waterscape, governed by discrete subvertical fractures at depth and a horizontal high permeable zone near the bedrock surface. Localized relict karst can occur in the Mountain Crest District. The steep slopes and depth of incision associated with the Mountain Crest and Valley Districts is expected to generate better, well drained sites than the Peneplain as a result of: greater surface runoff, greater driving head in the groundwater flow field and possibly lowered water tables in the recharge area. Intersection of Toth's (ibid) second or third order (intermediate and regional) flow systems within the walls of Mountain Valleys is possible.

Streams are of low order and ephemeral. Over the Peneplain District they exhibit low gradients, with little erosive power. Gradient and erosive power increases in the Mountain Crest and Valley Districts with numerous waterfalls. Minor glacial lakes are present, formed primarily as basins scoured out by ice movement. Small wetland lakes are also present within the Peneplain District. Three lakes have undergone a preliminary assessment by Nova Scotia Department of Natural Resources including Belle and Snake Cat Lakes in the Peneplain District within the headwaters of the Baddeck River, as well as Loon Lake in the Boisdale Hills Mountain Crest District. All were relatively small in area (22 to 103 hectares), shallow (3 to 6 metre maximum depth), with a slightly acidic pH (6.3 to 6.8) and no summer thermal gradient.

Groundwater stream interaction (GWSI) is expected to be governed by inflow from: a) an intermittent shallow perched water table system over the bedrock; b) the water table in the shallow bedrock; and/or c) the interflow zone within the wetlands. The perched water

table may coalesce with the main water table during times of high water surplus. Over the steep slopes of the Mountain Valley and Crest Districts the high permeability of the Colluvium HU ensures total infiltration. Groundwater discharges to streams as springs at the toe-of-slope from the Colluvium HU, as well as from deeper flow systems discharging out of the valley wall.

The geochemistry is controlled by the rock matrix of the dominant Igneous Metamorphic HU, which is essentially insoluble, except in the localized regions where marbles exist. Stream chemistry is expected to be similar, exhibiting dilute sodium-chloride type water, gradually transitioning to calcium-bicarbonate water, especially where marbles are present. Monitoring of Alder Brook on a first order (shreve) channel with a 1.1 km^2 drainage basin, illustrates the latter case where TDS varies from 25 to 200 mg/L, with an inverse relationship with streamflow (Figures 5-3A and B), due to groundwater baseflow. The pH is slightly alkaline, ranging from 6.7 to 8.1 (Figure 5-3A). The water is a soft, corrosive, mixed calcium/sodium–sulfate/chloride/bicarbonate type. Nutrients are comprised solely of organic carbon (1 to 2.4 mg/L). Iron (usually <0.02 mg/L) and manganese (<0.002 to 0.012 mg/L) are at low concentrations. Figure 5-3C notes that total coliform (10 to greater than 2000/100 ml) and fecal e.coli coliform (absent to greater than 800/100 ml) bacteria are naturally occurring and peaking during summer months.

The extent of wetlands in the Peneplain District is expected to create coloured water systems due to elevated organic carbon. In Big Barren Brook, colour ranges from 65 to 320 TCU with organic carbon of 9 to 10 mg/L. Iron (1.2 to 9.2 mg/L) and manganese (0.15 to 1.4 mg/L) are at elevated concentrations. Due to the absence of wetlands, the Alder Brook Watershed is a clear water stream (colour <5 to generally less than 10 TCU, Figure 5-3D).

The Debris Cycle, as characterized by Alder Brook, notes naturally low suspended sediment (<2 to 14 mg/L) and turbidity (<0.5 to 2.5 NTU) (Figure 5-3E). Stream sediment geochemistry surveys (Nova Scotia Department of Mines and Energy, 1991) noted elevated (> 90 percentile) naturally occurring concentrations of specific metals in the Highland Region. Of note were the Creignish Hills (copper, lead, zinc, silver, mercury and nickel), Cape Breton Highlands (copper, zinc, silver, arsenic, mercury, uranium, nickel, cobalt and molybdenum) and Boisdale Hills (lead, zinc, iron, manganese, uranium, nickel, cobalt and molybdenum).

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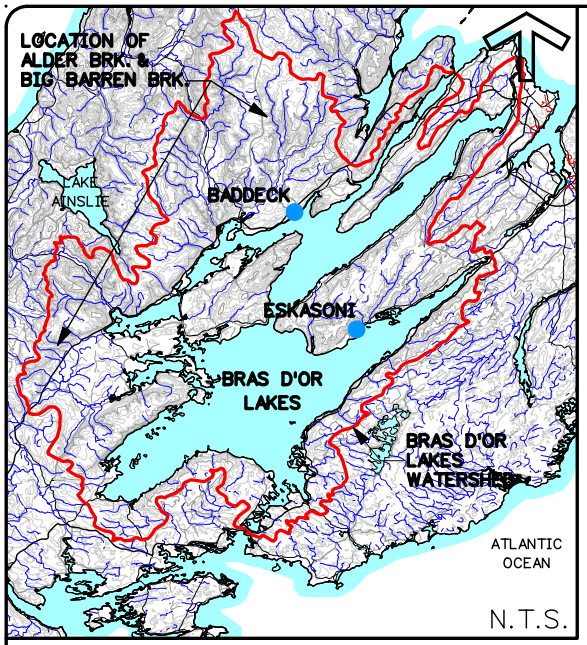

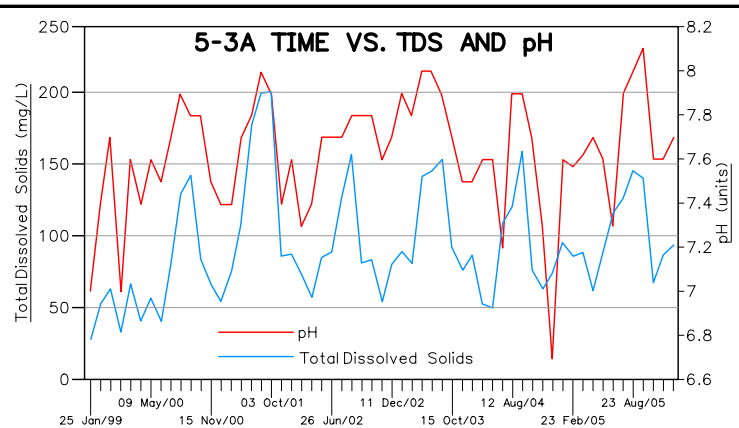

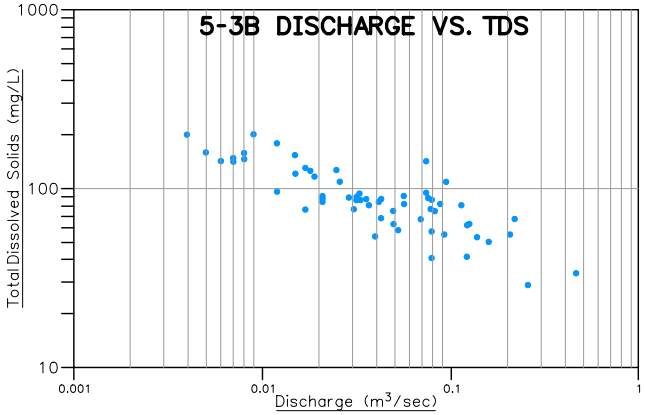

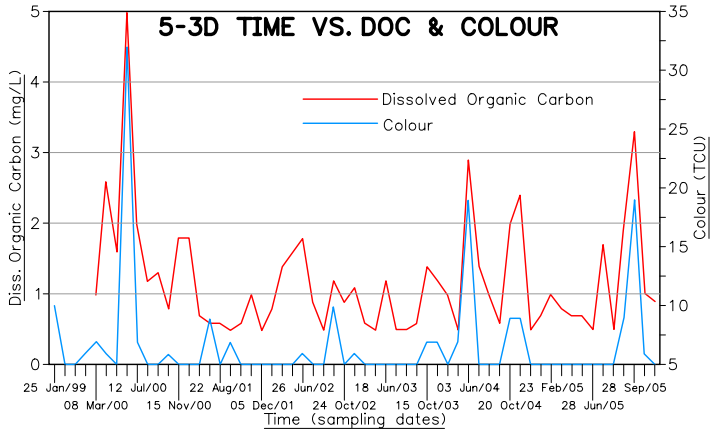

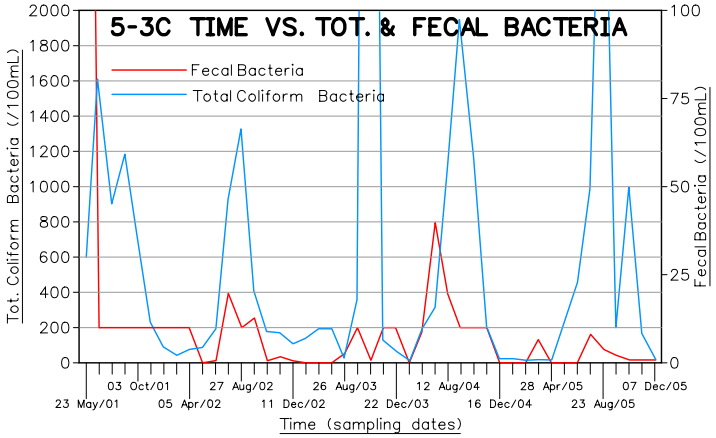

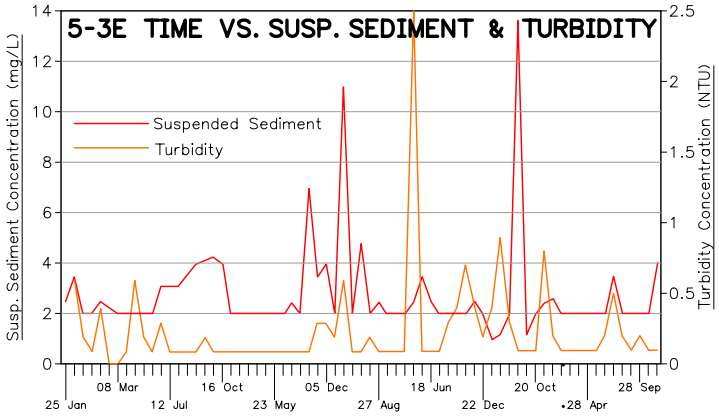

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Dwg.

HIGHLAND REGION
FLOW CHEMISTRY AND SEDIMENT
ALDER BROOK
(Data Courtesy of Georgia Pacific Canada Inc.)

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Dwg Standards Chk. By:	Dwg. No. **FIGURE 5-3**	
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5.3 Mountain Flank Region

5.3.1 Overview

This Region forms the contact between the basement complex (representing the former mountains) and the adjacent sedimentary basins, providing the transition between Highland and Lowland Regions. It encompasses some 24% of the Watershed in generally northeast-southwest oriented narrow linears, 1 to 2 km in width (Figure 5-4). This region is the most complex and forms the more spectacular scenic vistas on-Island. It has been subdivided into the Horton, Evaporite and Fault Hydrological Districts.

Distinctive features comprise a steeply dipping contact between the Igneous Metamorphic HU (basement complex) and a variety of sedimentary rock HUs, usually separated by a major fault boundary (Structural HU). In two Districts, the contact is marked by a steep, high fault scarp transition slope, marked by bare rock or covered by Colluvium and/or Sand/Gravel HUs; occasionally deeply dissected by Mountain Valleys. Climatic conditions reflect attributes of both the Highland and Lowland regimes.

5.3.2 Districts

Within the *Horton District*, the Horton and at times Cumberland (Lower Morien) HUs lie adjacent the Basement Complex (Figure 5-5A). It is the least complex of the three Districts, covering 12.6% of the Watershed. The similarity in erosivity between the bedrock units results in the absence of a steep transition slope; replaced by a gently undulating slope, exemplified by the south side of South Mountain. Basin bounding faults may be present at depth.

The *Evaporite District* comprises easily erodible rocks of the Windsor/Mabou (Evaporite) HU juxtaposed against the resistant high relief of the basement (Figure 5-5B), comprising 9.6% of the Watershed. This creates an abrupt change in topographic relief, along a steeply dipping, fault bounded transition slope, possibly augmented by highly fractured sandstones of the Horton HU. The fault scarp exhibits permeable Colluvium and Sand/Gravel HUs. A thick Clayey Till HU is present over the Windsor/Mabou HU, with the bedrock subcrop exhibiting hydraulically inactive, as well as active karst. Representative examples include the southern boundary of the Creignish Hills and the area surrounding North Mountain.

The *Fault District* (Figure 5-5C) is by far the most complex setting comprising 1.8% of the Watershed. It derives its name from the presence of up to three types of faulting,

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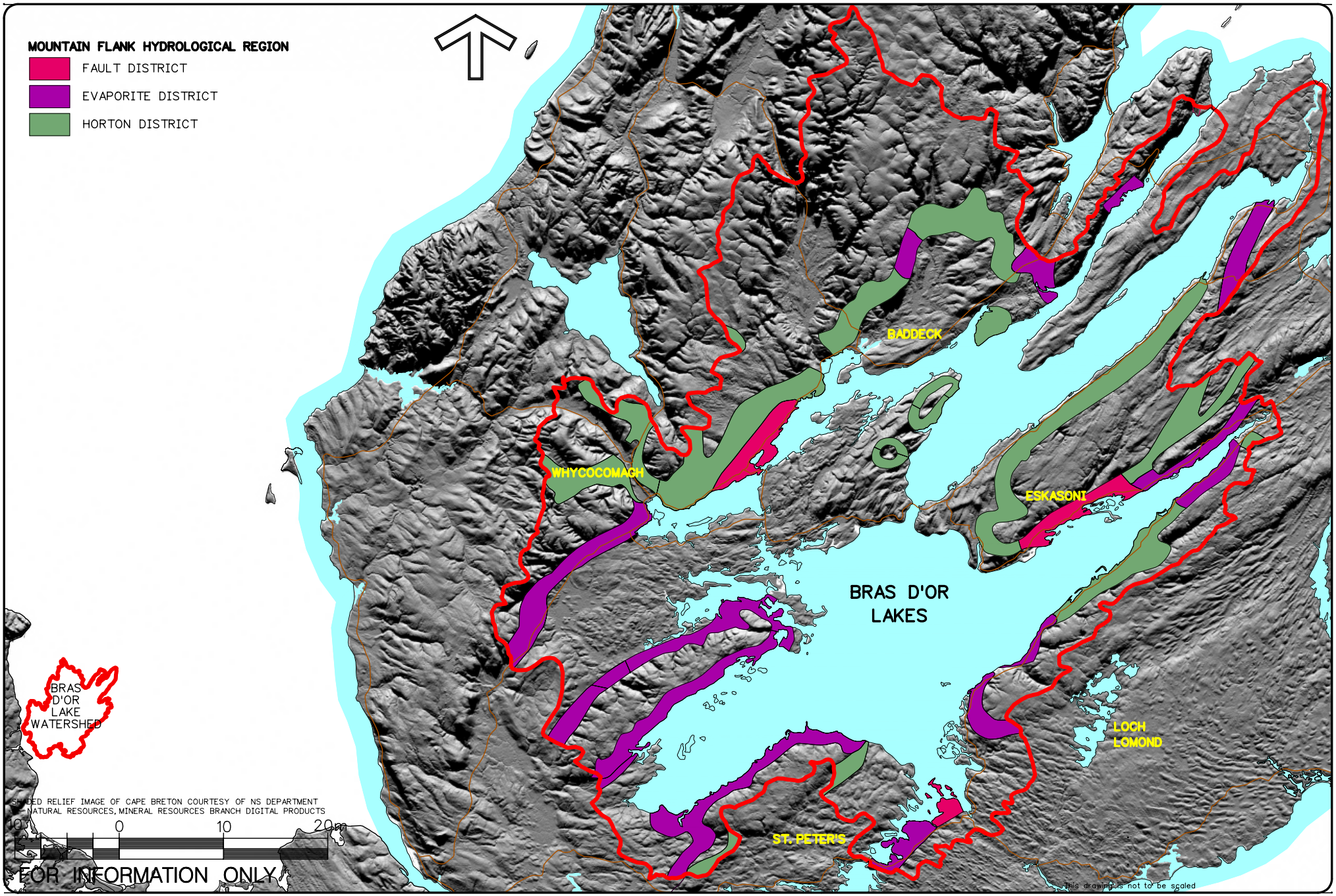

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Dwg.
MOUNTAIN FLANK HYDROLOGICAL REGION DISTRICTS
(After Baechler et al, in preparation)

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Dwg Standards Chk. By:	Dwg. No. FIGURE 5-4	
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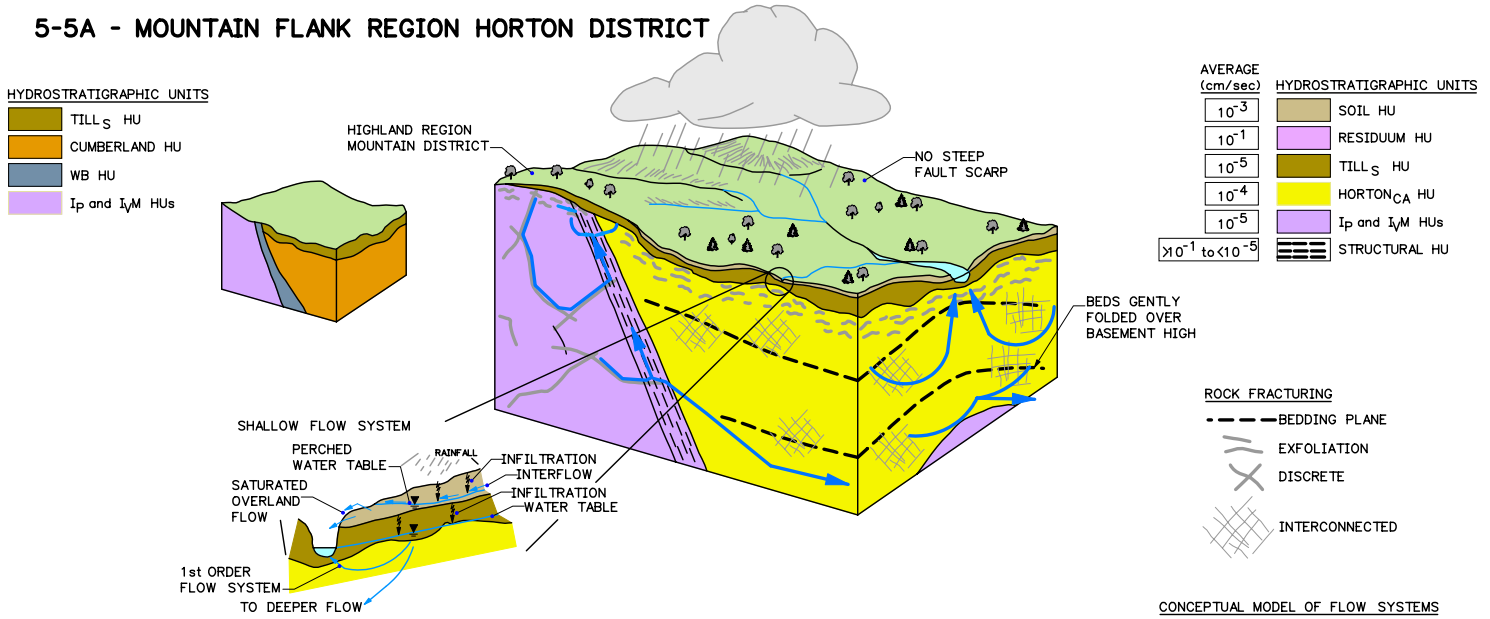
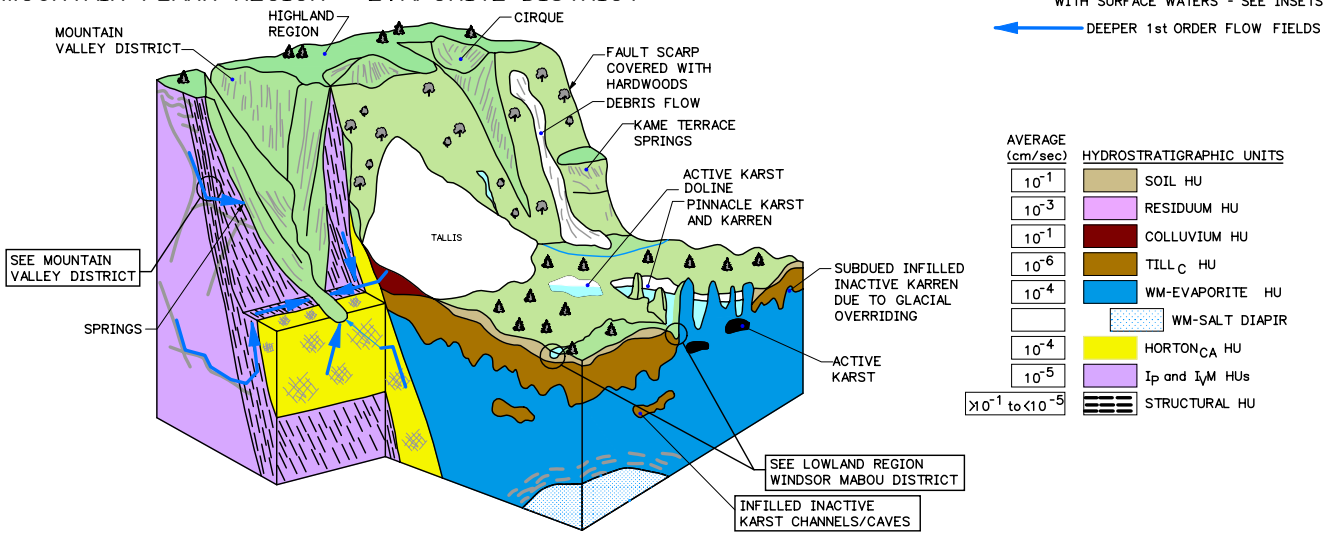
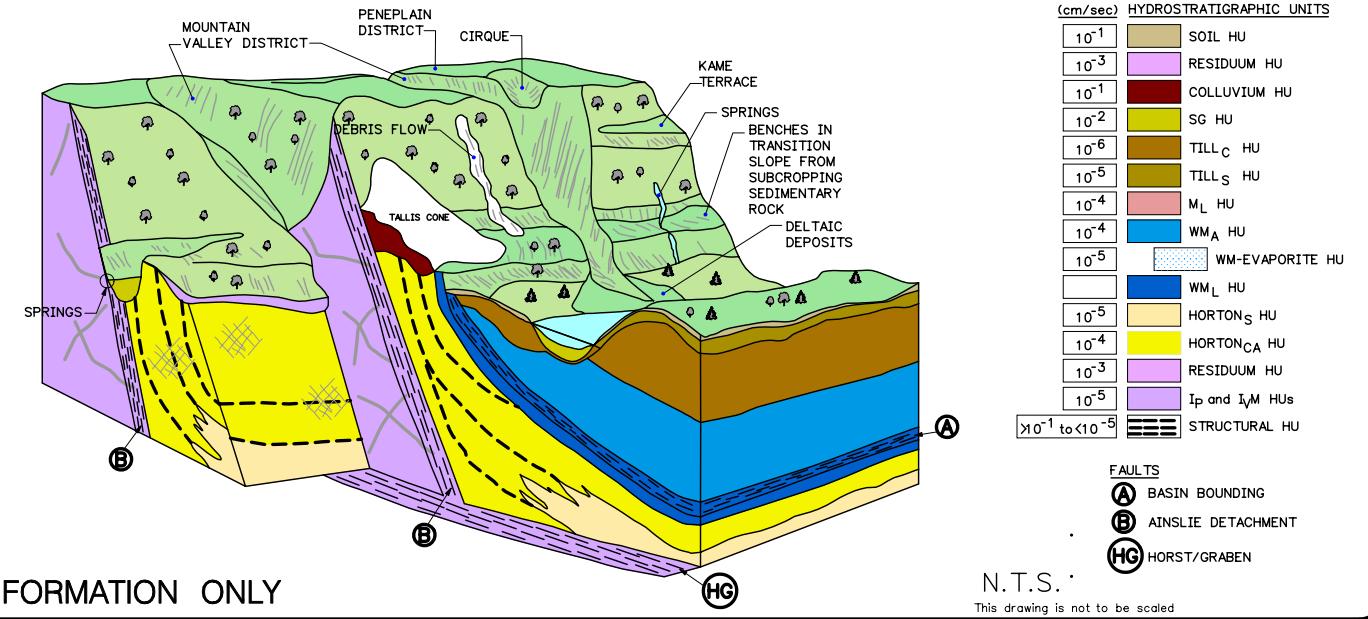
5-5A - MOUNTAIN FLANK REGION HORTON DISTRICT



5-5B - MOUNTAIN FLANK REGION - EVAPORITE DISTRICT



5-5C - MOUNTAIN FLANK REGION - FAULT DISTRICT



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Dwg. **CONCEPTUAL MODELS FOR MOUNTAIN FLANK REGION HORTON, EVAPORITE & MOUNTAIN FAULT HYDROLOGIC DISTRICTS**
(After Baechler et al, in preparation)

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Dwg. Standards Chk. By:	Dwg. No. **FIGURE 5-5**	
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rapid lithologic changes and upwarping of adjacent sedimentary rock along the basin bounding fault. The Ainslie Detachment has moved the evaporite sequence farther down basin leaving the Windsor/Mabou (Argillaceous) HU in its place. The steep transition slopes form along both basin bounding, as well as offset horst and graben faulting. The slope is potentially marked by kame terraces, cut by gorges, debris slides and talus cones exhibiting a wide variety of Colluvium HU. The toe-of-slope can exhibit a variety of lakes, river valleys and alluvial fans. A wide variety of scenarios are depicted, not all of which may be present at any one site. Larger examples include the Big Bras d'Or Channel, the Georges River valley and Boisdale Hills near Eskasoni.

5.3.3 Hydrological, Geochemical and Debris Cycles

No information is available within the Watershed to document conditions in this Region. Discussions of climatic conditions (Chapter 3.0) and HUs (Chapter 4.0) were derived from studies primarily outside the Watershed. Block diagrams (Figures 5-5A through C) conceptualize the present understanding of groundwater, streams and their interaction.

The configuration of low permeable bedrock overlain at steep angles by permeable Colluvium and Sand/Gravel HUs along a faulted transition slope, then covered at the base by a variety of sedimentary HUs is expected to result in high diversity of complicated conditions. Within the Horton District the groundwater flow field moves from low to high permeable HUs over a widespread area, under a relatively low driving head. In the Evaporite District, groundwater flow moves from one low permeable unit to another under a high driving head, separated with a possibly highly permeable, steeply dipping fault. Within the Fault zone anything is possible.

Intermediate and Regional flow systems are expected to dominate the waterscape, governed by discrete fractures at depth and a high subvertical permeable zone along the contact. The exposed transition slopes associated with the Evaporite and Fault Districts is expected to generate better, well drained sites than the Horton as a result of: greater surface runoff; less groundwater recharge; greater driving head; and possibly lowered water tables in the recharge area. Intersection of deep regional order flow systems is possible with upwelling along the faults, especially where bounded and confined by much lower permeable Windsor/Mabou (Evaporite) HU and intersected by deeply incised Mountain Valleys.

Streams are of low order and expected to be perennial for the most part. Gradient and erosive power is high over the transition slope in the Evaporite and Fault Districts, then reduces dramatically at the toe-of-slopes. Lakes can potentially be present at the toe-of-

slope, created by differential erosion of fault zone and/or the Windsor/Mabou HU, as well as by solution as karst lakes. Two lakes have undergone a preliminary assessment y Nova Scotia Department of Natural Resources including Gillis and McAdam Lakes adjacent the Coxheath Hills Mountain Crest District. Both are small (31 to 45 hectare), but relatively deep (10 to 23 metres maximum depth), with a near neutral pH (7.1 to 7.5) and a distinct thermal gradient in the latter (no information available on the former).

GWSI is expected to be governed by the high permeability of the Colluvium and Sand/Gravel HUs, which ensures total infiltration. Groundwater discharges to streams as springs at the toe-of-slope from the Colluvium HU, as well as the deeper flow systems discharging out of the valley wall at a variety of elevations. Hydraulically active fault zones and fractured Horton HU within the Evaporite and Fault Districts can potentially form a major source of groundwater recharge for deep basin aquifers and/or could act as regional discharge zones allowing deep basement flow, including evaporite brines to discharge to surface (i.e., Bucklaw). It also has the potential for forming the greatest area for shallow direct GWSI, especially where Mountain Valleys transect the transition slope.

The initial geochemistry at the inflow to this Region is controlled by the relatively insoluble rock matrix of the dominant Igneous Metamorphic HU. Stream chemistry is expected to exhibit dilute sodium-chloride type water, gradually transitioning to calcium-bicarbonate water, especially in areas of marbles. However, by the end of the Region it changes dramatically, especially over the Evaporite and Fault HUs due to GWSI.

5.4 Foothills Hydrological Region

5.4.1 Overview

This Region is characterized by uplands, underlain by the Horton HU, as the waterscape rises into the Highlands, hence the foothills designation. It covers 3.6% of the Watershed, primarily over the northwest corner (Figure 5-6A). It has not been subdivided into Districts.

Distinctive features (Figure 5-6B) comprise a heavily dissected, high relief plateau with well-rounded slopes at moderate elevations (300 to 350 metres), underlain by the Horton HU and covered with a continuous blanket of Sandy Till HU, positioned within the southern extent of the snowbelt. The area is on the uptilted side of the peneplanation surface and has been deeply eroded. In localize areas domed hills occur that may conceal blocks of basement rock underneath, such as at Hunters Mountain and Salt Mountain.

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FIGURE 5-6B
FOOTHILLS REGION CONCEPTUAL HYDROLOGIC MODEL

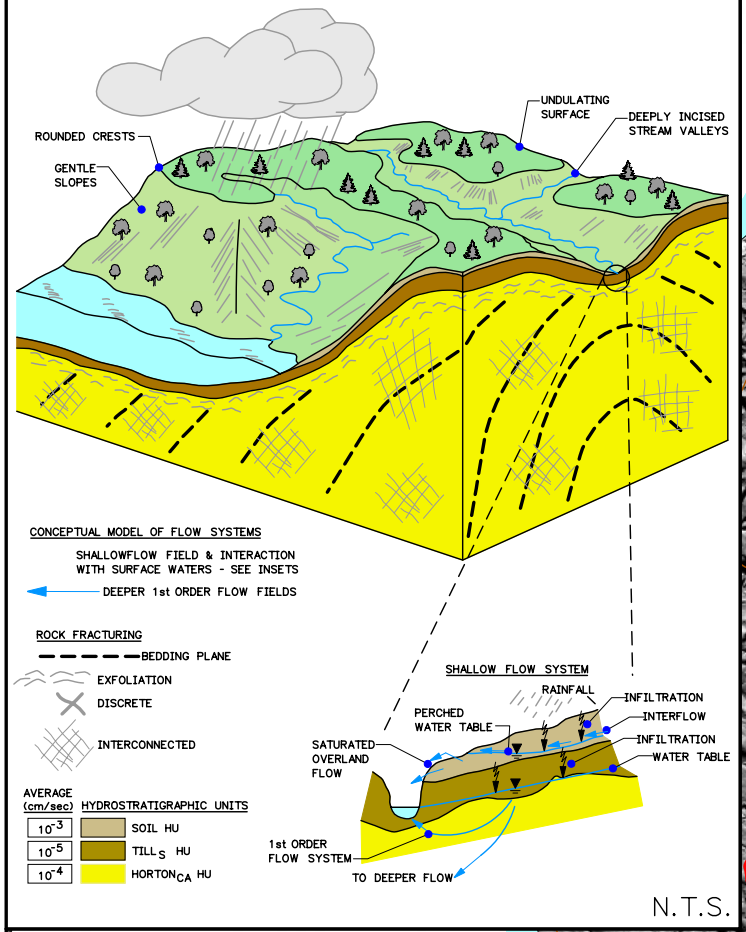
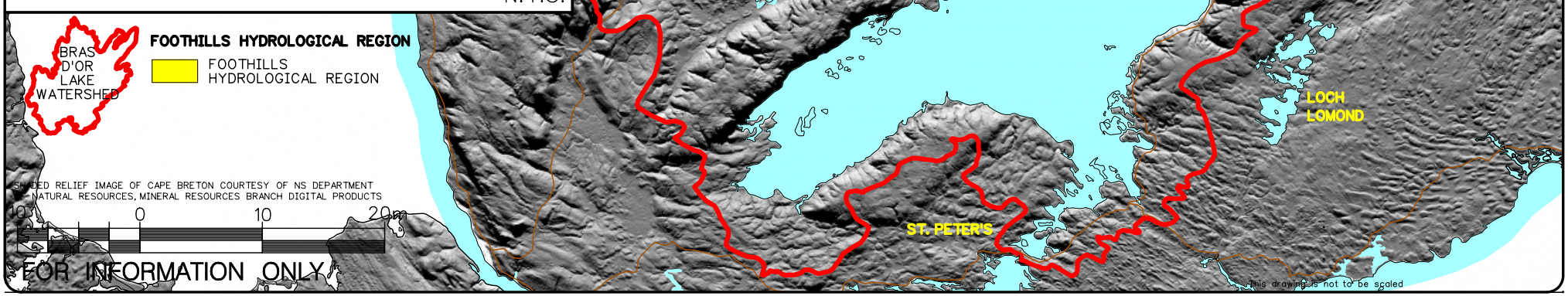


FIGURE 5-6A



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Dwg.
FOOTHILLS HYDROLOGICAL REGION AND CONCEPTUAL MODEL
(After Baechler et al, in preparation)

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The District is dissected by faults that lie predominantly northeast southwest, parallel to fold direction typical of Carboniferous Basins.

5.4.2 Hydrological, Geochemical and Debris Cycles

Minimal information is available within the Watershed to document conditions in this Region. What is known is derived from sporadic monitoring of the Humes River (Baechler et al, in preparation). Discussion of climatic conditions (Chapter 3.0) and HUs (Chapter 4.0) were derived from studies outside the Watershed. A block diagram (Figure 5-6B) conceptualizes the present understanding of groundwater, streams and their interaction.

The configuration of homogeneous, moderately permeable Horton HU under ridges and valleys within a region of high water surplus is expected to result in high water table conditions, usually in the upper part of the unconfined Horton HU. The Sandy Till HU is present to act as a recharge source for the bedrock during dry periods. Local flow systems are expected to dominate the waterscape, governed by well interconnected fracture network at depth and a horizontal, high permeable zone near the bedrock surface. The moderate slopes and depth of incision is expected to generate well drained sites.

Streams are of low to moderate order, both perennial and ephemeral. They exhibit a dominant trellised pattern, due to rock structure with a secondary dendritic pattern. Over the valley floors they are underfit and exhibit a straight to slightly meandering pattern.

GWSI is expected to be governed by: a) interflow and storm saturated overland flow in the Soil HU perched over the Till HU; b) the water table usually at or near the bedrock surface; and/or c) semi-confined artesian conditions in the upper highly fractured zone of the bedrock.

The geochemistry is controlled by the rock matrix of the dominant Horton HU with its soluble cementation. Stream chemistry is expected to be, therefore, similar to the Horton HU exhibiting a calcium-bicarbonate type water. Two years of monitoring in the Humes River noted a fresh (TDS 20 to 55mg/L), soft, corrosive type water with a neutral pH (6.7 to 7.3). Nutrients were generally non-detectable, except for organic carbon (2.1 to 6.8 mg/L). It ranges from a clear to slightly coloured water system (colour 15 to 35 TCU). Iron (0.06 to 0.09 mg/L) and manganese (non-detect to 0.005 mg/L) are at low concentrations. Low turbidity (0.2 to 1.0 NTU) characterizes the Debris Cycle.

5.5 Lowland Hydrological Region

5.5.1 Overview

This Region covers the largest area of the Watershed (35.3%), positioned primarily within the central core (Figure 5-7), nestled between the Highlands and the Bras d'Or Lakes. It exhibits the most variability, being divided into five Hydrological Districts including Sedimentary Plain, Windsor Lowlands, Karst, Alluvial Valley and Estuarine.

Distinctive features comprise a low lying, gently undulating plain, underlain by a variety of sedimentary bedrock HUs, overlain primarily with Till HU with localized Sand/Gravel HU. It is influenced by a coastline of submergence, which has dissected the Region with deeply indented salt water embayments. The climate is dominated by the Eastern Nova Scotia Climatic Region.

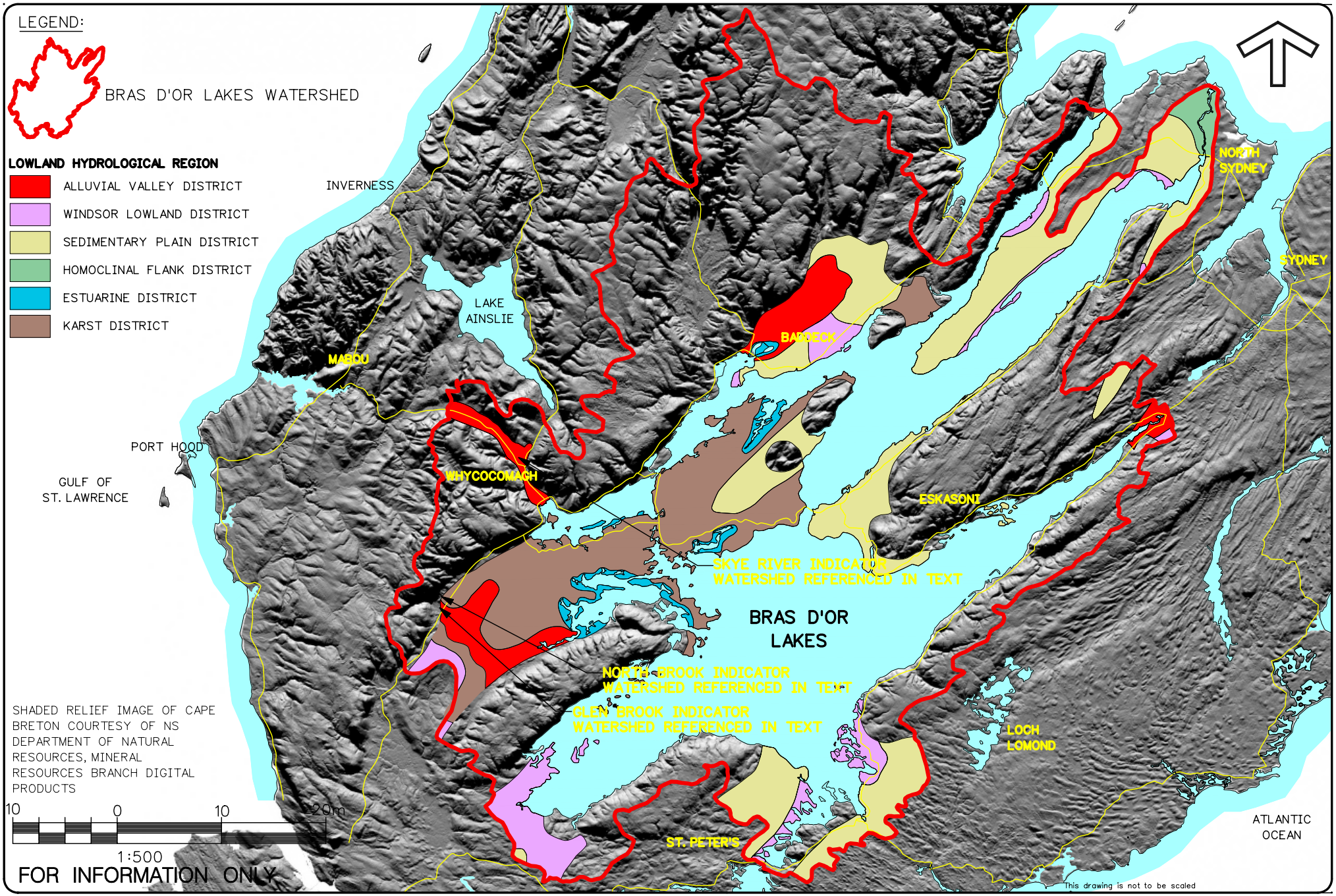
5.5.2 Districts

The *Sedimentary Plain District* (Figure 5-8A), comprising 14.7% of the Watershed, is characterized by underlying, conglomerates and sandstones of the Cumberland (Lower Morien) and Horton HUs, overlain by a thin continuous blanket of Sandy Till HU and localized wetlands. The competent bedrock is well fractured by extensive folding. Hills are smooth, rounded and bedrock controlled, with minor dissection by low order streams.

The *Windsor Lowlands (*Figure 5-8B), comprising 4.4% of the Watershed, exhibits a topography similar to the Sedimentary Plain, but distinctive in its lower elevation, drift controlled relief, and underlying Windsor-Argillaceous HU, covered with a thick blanket of Clayey Till and at times Lacustrine HUs. Localized karst is present with limestones and evaporites, but usually inactive having been infilled with glacial debris. The primarily incompetent rocks are shallow dipping and not folded.

The *Karst District* (Figure 5-9A), comprising 10.5% of the Watershed, also exhibits a low lying, drift controlled plain of low relief similar to the Windsor Lowland. However, its distinctive character derives from the dominance of evaporites (salt, gypsum, anhydrite and potash) of the Windsor/Mabou (Evaporite) HU. As a result, relict and active karst dominate, with salt diapers warping the formation.

Four notable valleys comprise the *Alluvial Valley District* (Figure 5-9B), comprising 4.2% of the Watershed. They are carved into the above three Districts within the Skye, Denys, Baddeck and Middle Rivers. They exhibit gently sloped smooth valley flanks



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LOWLAND HYDROLOGICAL REGIONS & DISTRICTS
(After Baechler et al, in preparation)

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Dwg Standards Chk. By:	Dwg. No. **FIGURE 5-7**	
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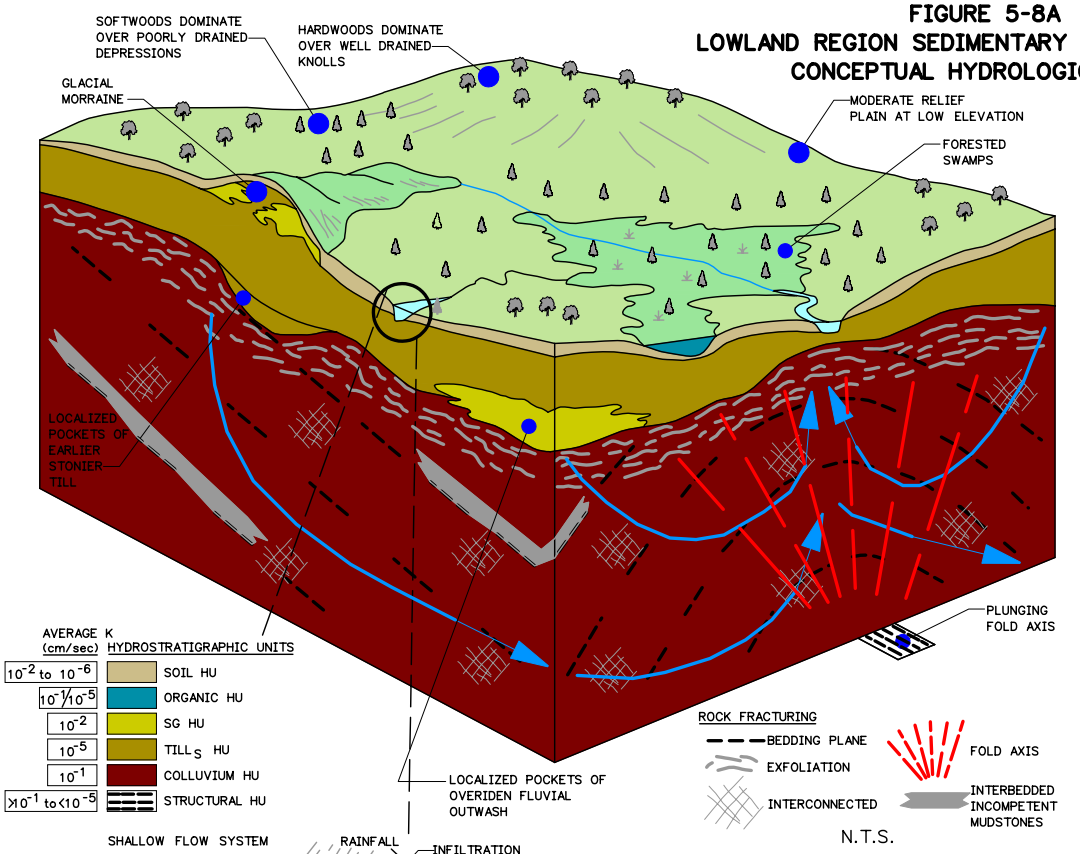
FIGURE 5-8A
LOWLAND REGION SEDIMENTARY PLAIN DISTRICT CONCEPTUAL HYDROLOGIC MODEL



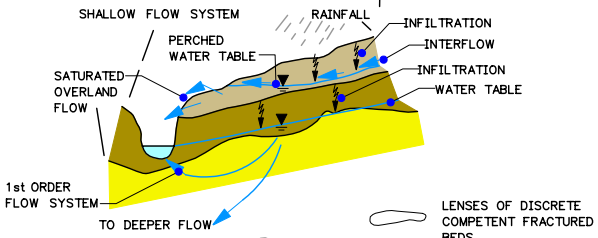
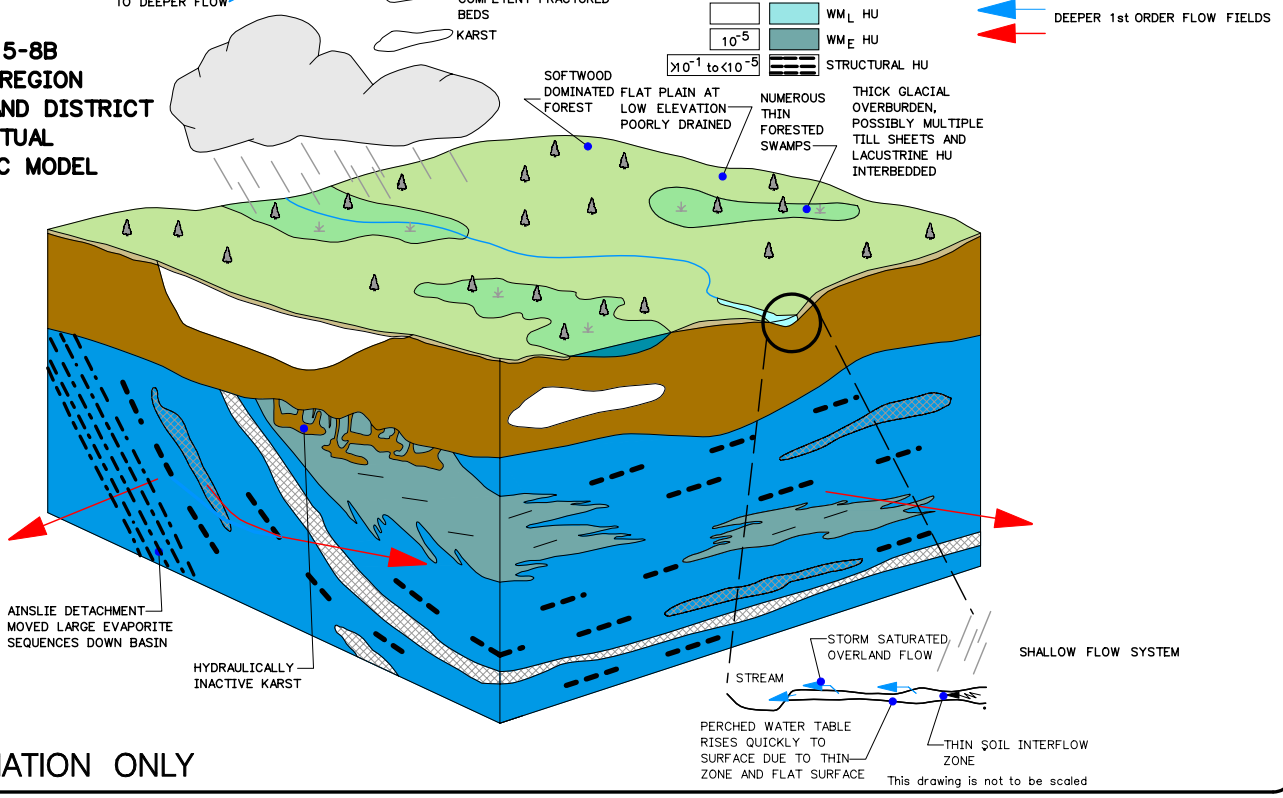


FIGURE 5-8B
LOWLAND REGION WINDSOR LOWLAND DISTRICT CONCEPTUAL HYDROLOGIC MODEL



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Dwg. LOWLAND REGION CONCEPTUAL MODELS FOR SEDIMENTARY PLAIN & WINDSOR LOWLAND HYDROLOGICAL DISTRICTS
(After Baechler et al, in preparation)

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Dwg. Standards Chk. By:	Dwg. No. FIGURE 5-8
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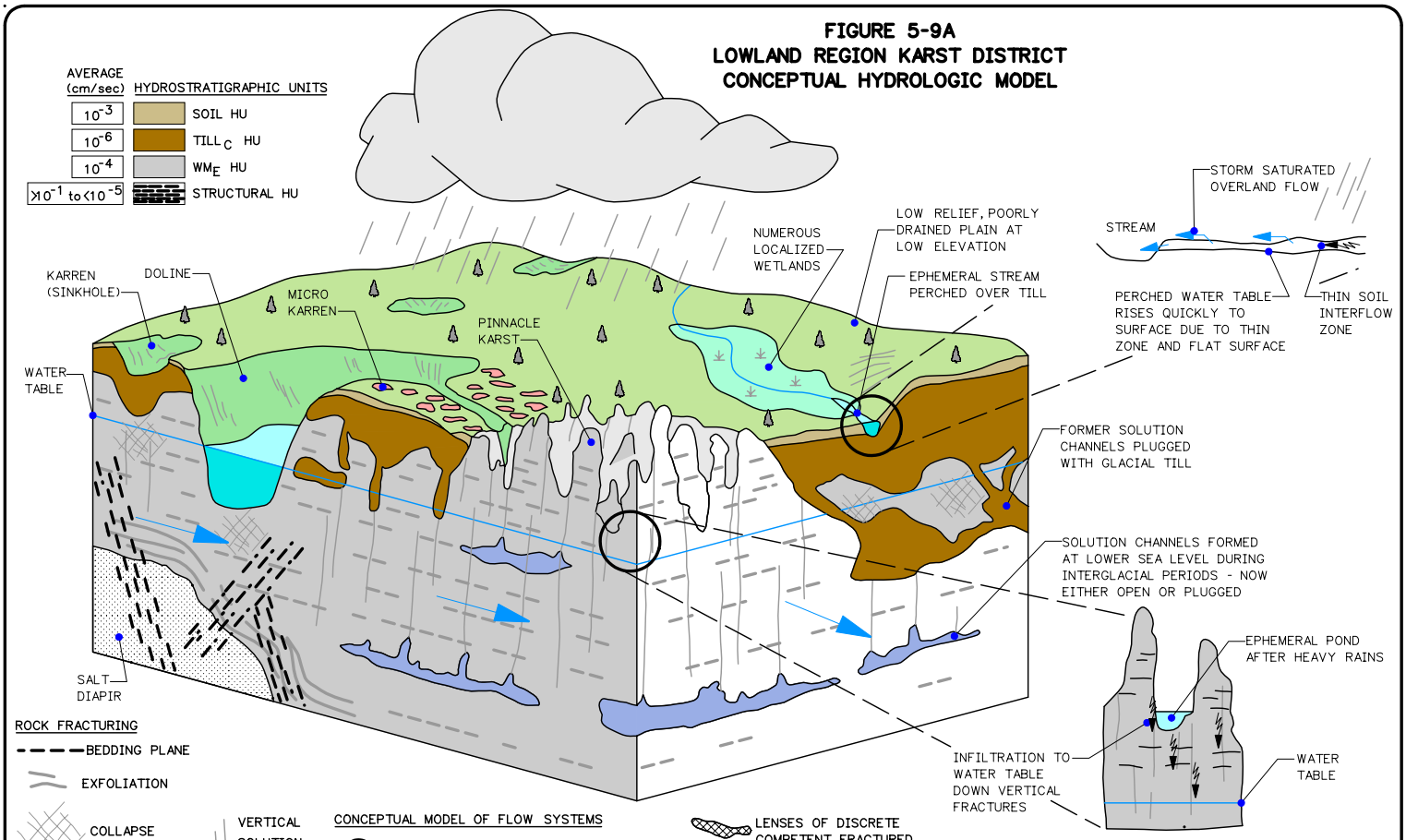
FIGURE 5-9A
LOWLAND REGION KARST DISTRICT
CONCEPTUAL HYDROLOGIC MODEL



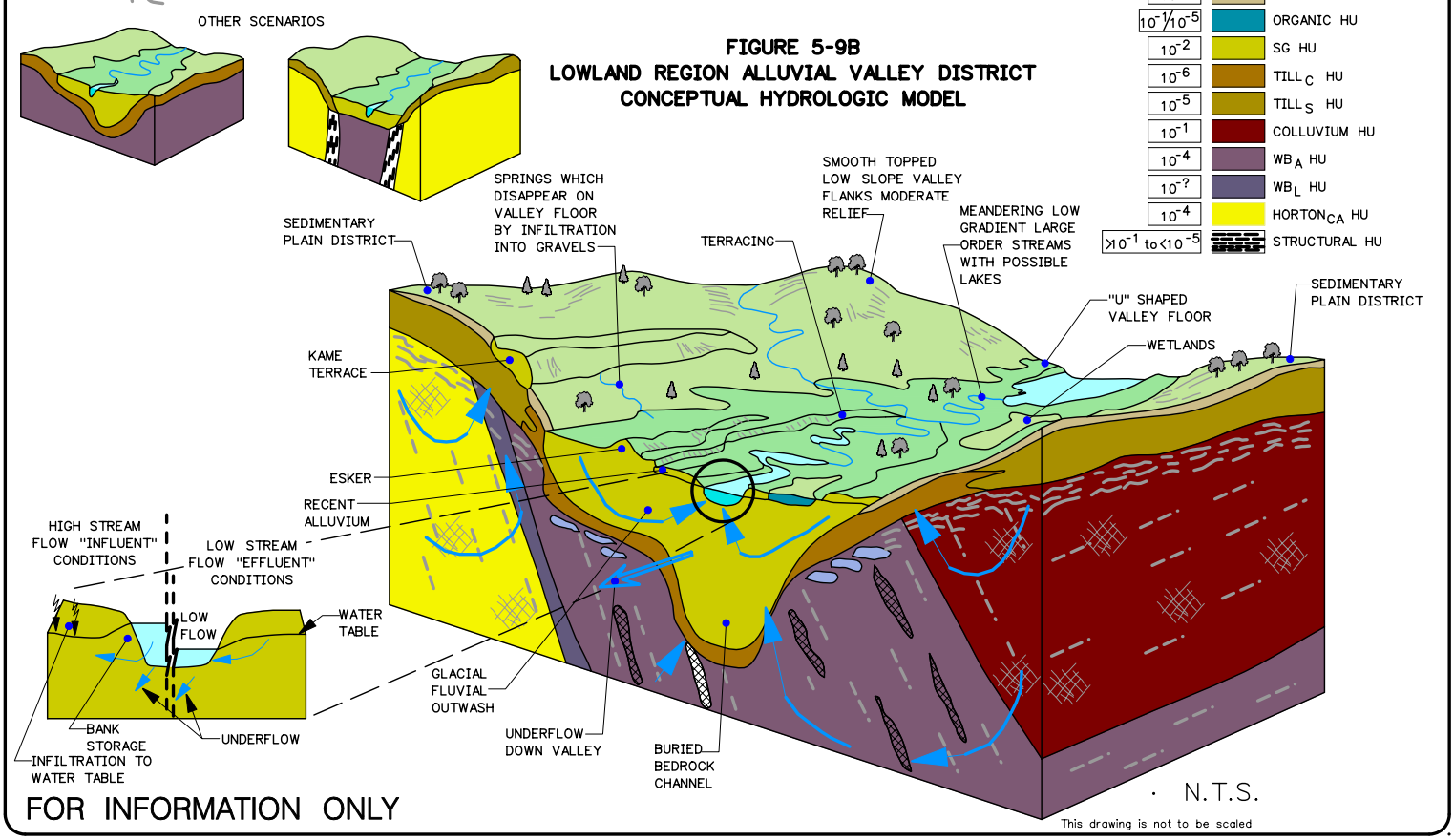


FIGURE 5-9B
LOWLAND REGION ALLUVIAL VALLEY DISTRICT
CONCEPTUAL HYDROLOGIC MODEL

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FRESH WATER RESOURCES

Dwg. **LOWLAND REGION CONCEPTUAL MODELS FOR KARST & ALLUVIAL VALLEY HYDROLOGICAL DISTRICTS**
(After Baechler et al, in preparation)

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Dwg. Standards Chk. By:	Dwg. No. FIGURE 5-9
Designed By: FEB	Dwg. Design Chk. By: FEB / Rev. 0

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bounding wide flat valley floors underlain by large glacial-fluvial outwash (possibly encompassing infilled buried bedrock channels). The valley floor exhibits large meandering rivers within broad, at times terraced floodplains, underlain by the Windsor/Mabou HU. The valley flanks are usually comprised of more resistant Cumberland or Horton HU.

The smallest District is the *Estuarine District*, comprising only 1.1% of the Watershed, sometimes referred to as Barachois Lakes. It combines enclosed, low energy, brackish water environments usually constrained by bay mouth bars seaward and low surrounding topography landward.

5.5.3 Hydrological, Geochemical and Debris Cycles

Minimal information is available with the Watershed to document conditions in this Region. What is known derives from six years of monitoring in the Karst and Alluvial Valley Districts within the River Denys Watershed (data courtesy of Georgia Pacific Canada Inc). Discussion of relevant climatic conditions (Chapter 3.0) and HUs (Chapter 4.0) were derived from studies mostly outside the Watershed. Block diagrams (Figures 5-8 and 5-9) conceptualize the present understanding of groundwater, streams and their interaction.

5.5.3.1 Sedimentary Plain Hydrological District

The configuration of HUs (Figure 5-8A) within the Sedimentary Plain District produces a highly permeable relatively homogeneous bedrock HU, under a thin, continuous, low permeable Sandy Till HU. Although similar in some respects to the Foothills Region, both the larger driving heads and elevated water surplus of the snowbelt are absent. Local flow systems are expected to dominate the waterscape, governed by discrete subvertical fractures at depth, a higher horizontal permeable zone near the bedrock surface and an overburden that acts as a reservoir recharge source for the bedrock during dry periods.

GWSI is expected to be governed by: a) interflow and storm saturated overland flow within the Soil HU; b) the water table in the Till-Shallow bedrock; and c) flowing artesian conditions from the first order flow systems. Streams are for the most part perennial. Numerous glacial lakes are present, primarily of glacial origin, formed either as a basin scoured out by ice movement or by interruption of original drainage by till. One lake underwent a preliminary assessment by Nova Scotia Department of Natural

Resources. Scotch Lake is a small (2.8 hectare), shallow (maximum depth of 5 metres) lake with a near neutral pH (7.3) and no thermal gradient.

5.5.3.2 Windsor Lowland and Karst Hydrological Districts

Within the Windsor Lowland and Karst Districts (Figures 5-8B and 5-9A), the distinctive thick, low permeable overburden and bedrock, coupled with low relief is expected to minimize recharge and maximize runoff. Deeper regional flow fields are expected to be directed to the Bras d'Or Lakes rather then minimally incised streams. Localized, discrete, flow fields are associated with active karst. GWSI is governed by interflow in the shallow Soil and Organic HUs and active karst. Streams are for the most part ephemeral which, within karst systems, can disappear underground then reappear some distance away. Lakes are primarily of solution origin comprising dolines from karst formation.

Natural aspects of the Geochemical and Debris Cycles are available from six years of monitoring at indicator streams (Figure 5-7) at North Brook (Karst District). Stream and groundwater chemistry are strongly controlled by the rock matrix of the dominant Windsor/Mabou (Evaporite) HU with its wide variety of soluble salts. A first order (shreve) channel of North Brook with a drainage area of 1.8 km^2 exhibited a fresh to brackish (TDS 400 to 1850 mg/L), very hard, calcium-sulfate type water with a moderate to alkaline pH (7.2 to 8.2; Figure 5-10A). The former shows an inverse relationship with stream flow (Figure 5-10B), due to a large continuous baseflow. Figure 5-10C notes that total coliform (non-detect to 4300/100ml) and fecal (e.coli) coliform (non-detect to 120/100 ml) bacteria are naturally present, peaking during the summer months. Total nutrients are in the range of 1.8 to 7.7 mg/L, dominated by carbon, with consistently no phosphorous. Iron (usually <0.2 mg/L) and manganese (0.042 to 0.14 mg/L) are at non-detectable to low concentrations.

The Debris Cycle is characterized (Figure 5-10D) by low suspended sediment (usually less than 10 mg/L) and turbidity (usually less than 4 NTU). There is no apparent relationship to flow rate.

5.5.3.3 Alluvial Valley Hydrological District

The Alluvial Valley District (Figure 5-9B) comprises different components of the previous three Districts. The elevated relief provides the greatest driving head within this Region. These gradients are modified by the high, relatively more permeable bedrock-sandy Till HU underlying the valley flanks, juxtaposed against the relatively low

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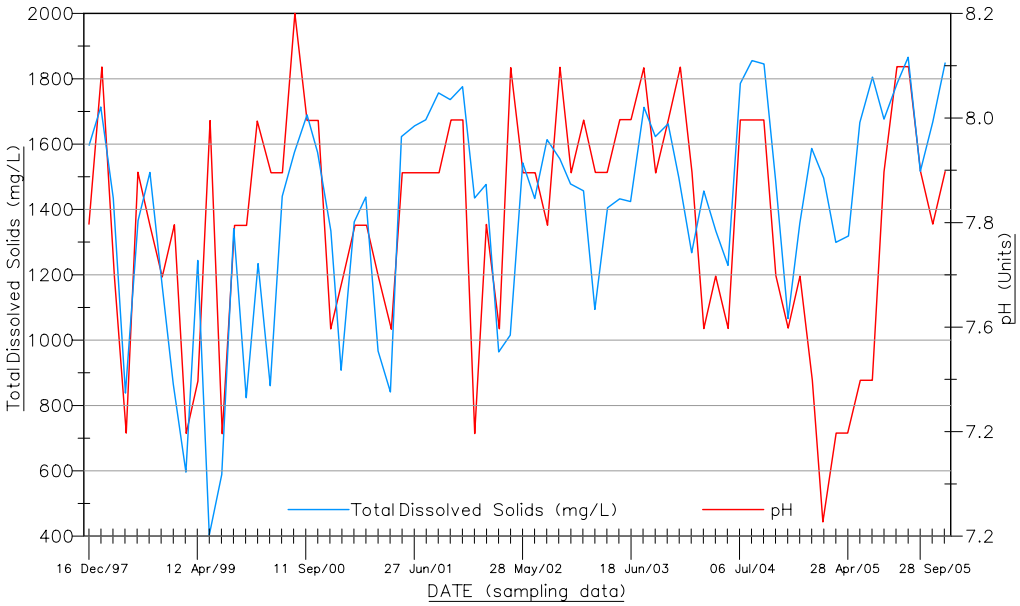
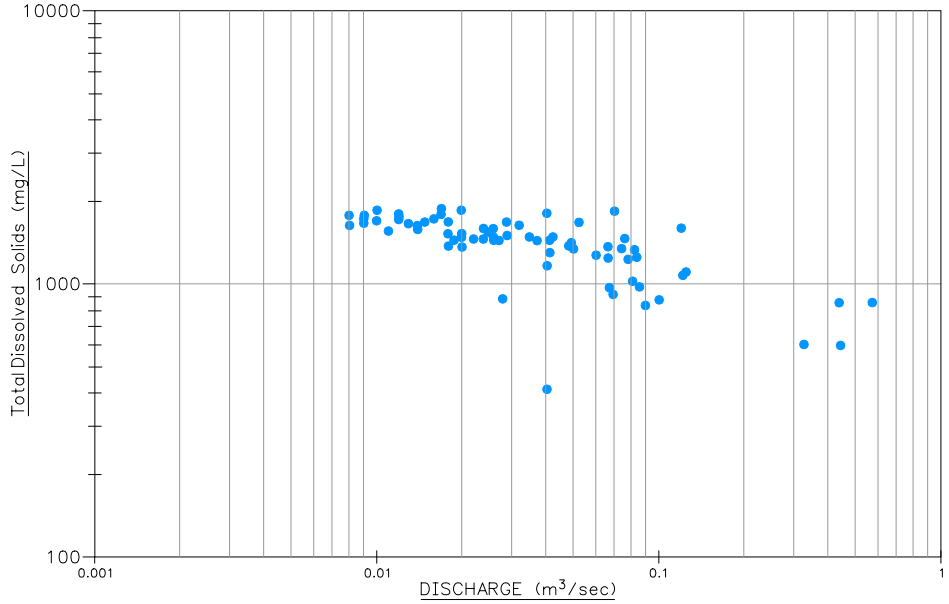
FIGURE 5-10 STREAM INDICATOR CHEMISTRY LOWLAND REGION - KARST DISTRICT

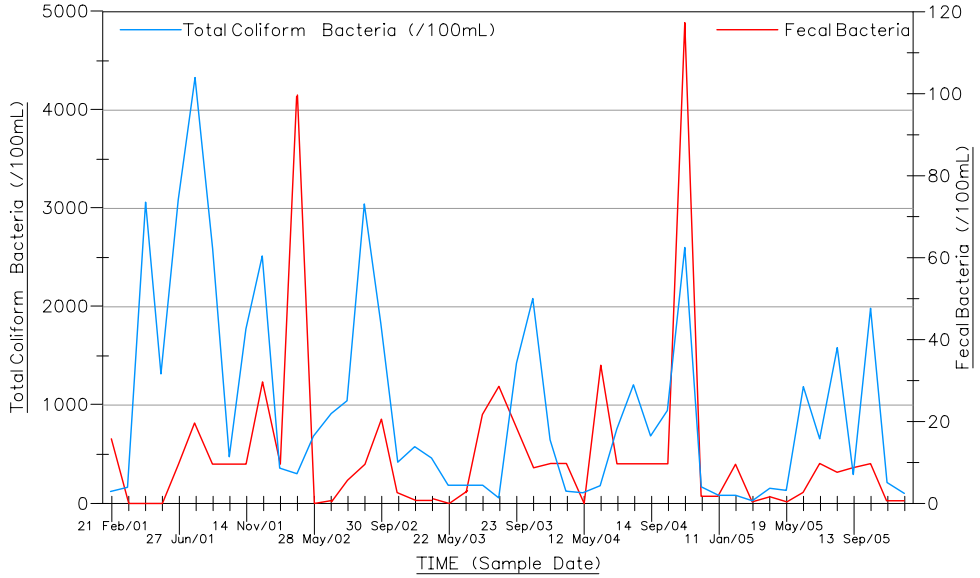
5-10A - TIME VS. TDS AND pH



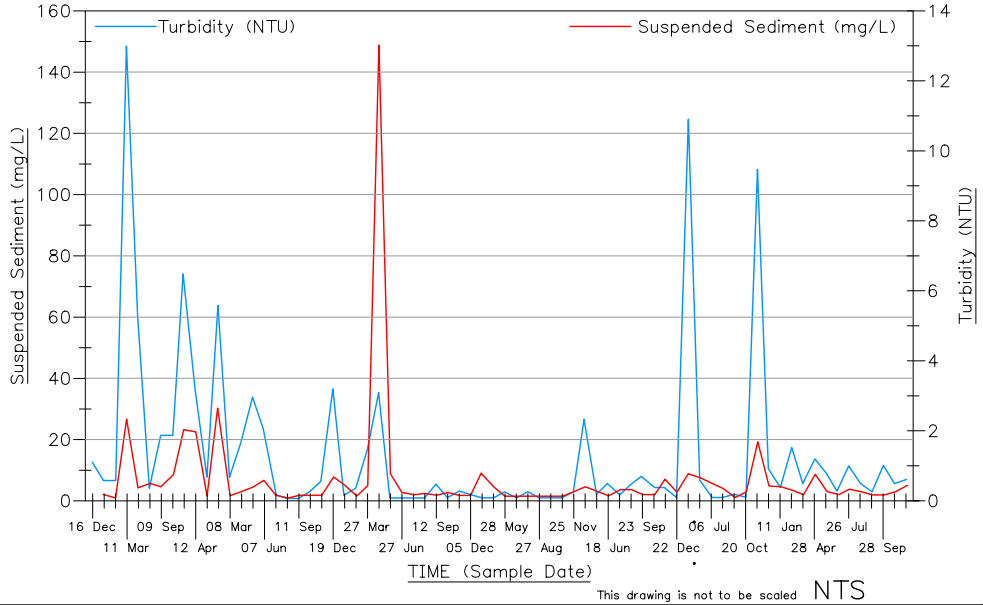
5-10B - DISCHARGE VS. TDS



5-10C - TIME VS. TOTAL AND FECAL BACTERIA



5-10D - SUSPENDED SEDIMENT & TURBIDITY



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STREAM INDICATOR CHEMISTRY
LOWLAND REGION
KARST DISTRICT
(Data courtesy of Georgia Pacific Canada Inc.)

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Dwg Standards Chk. By:	Dwg. No. **FIGURE 5-10**	
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permeability of the Windsor/Mabou (Argillaceous) and thick Clayey Till HUs under the valley floor. This configuration separates the high permeability valley flanks from the Sand/Gravel HU outwash directly underlying the valley floor.

GWSI is governed by the dynamic, rapid interaction between large order perennial rivers and the water table within long, linear Sand/Gravel HU positioned adjacent and under the channels. This provides for high baseflows during summer low flows and dampening of storm peaks. Only minor lakes occur over the valley floor, more as Oxbow Lakes in cut off river meanders. In all instances, this District drains into an Estuarine District prior to entering the Bras d'Or Lakes.

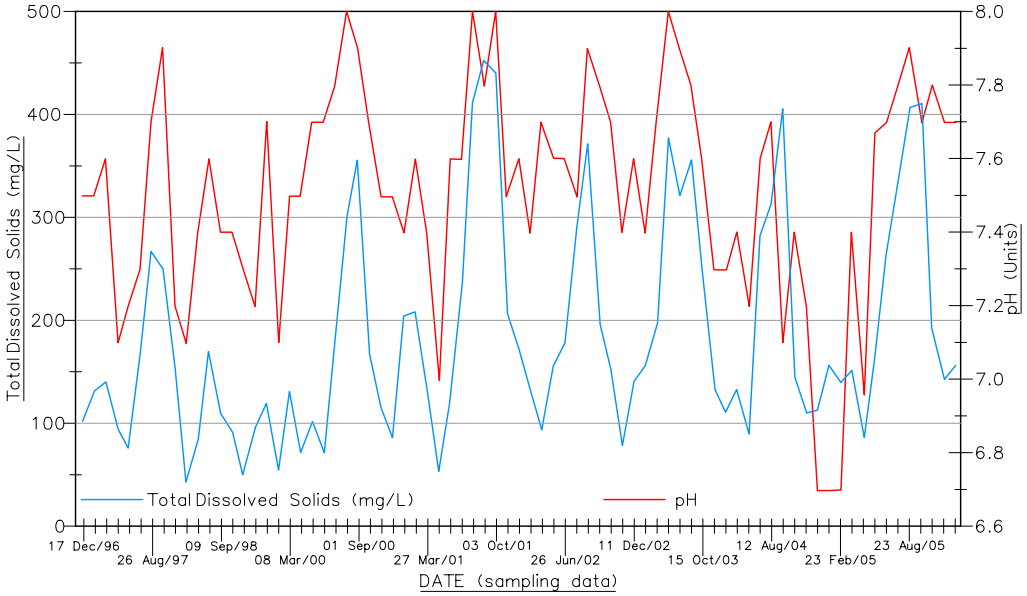
Natural aspects of the Geochemical and Debris Cycles are available from six years of monitoring Glen Brook near Melford (data courtesy of Georgia Pacific Canada Inc.). This is a ninth (shreve) order channel with a drainage area of 16.8 km^2. The channel meanders across a wide, three terraced valley floor. Although underlain by the Windsor/Mabou (Evaporite) HU the 30 plus metre cover of Sand/Gravel HU limits its effect. The water is characterized by a low to moderate TDS (50 to 450 mg/L; Figure 5-11A), with an inverse relationship with stream flow (Figure 5-11B), due to a large continuous baseflow provided by the Sand/Gravel HU. The water is generally a non-coloured, corrosive, soft to hard, mixed calcium/sodium-sulfate/bicarbonate type with alkaline pH (6.7 to 8.0; Figure 5-11A). Nutrients are in the range of 0.6 to 3.4 mg/L, dominated by carbon, with consistently no phosphorous. Iron (usually <0.02 mg/L) and manganese (usually <0.01 mg/L) are at low to non-detectable concentrations. Total coliform (non-detect to 2500/100 ml) and fecal (e.coli) coliform (non-detect to >100/100 ml) bacteria are naturally present, peaking in summer months (Figure 5-11C).

The Debris Cycle is characterized (Figure 5- 11D) by low suspended sediment (usually less than 10 mg/L) and turbidity (usually less than 4 NTU). There is a slight relationship to flow rate resulting from the high erodible channel banks comprised of loose sand and gravel.

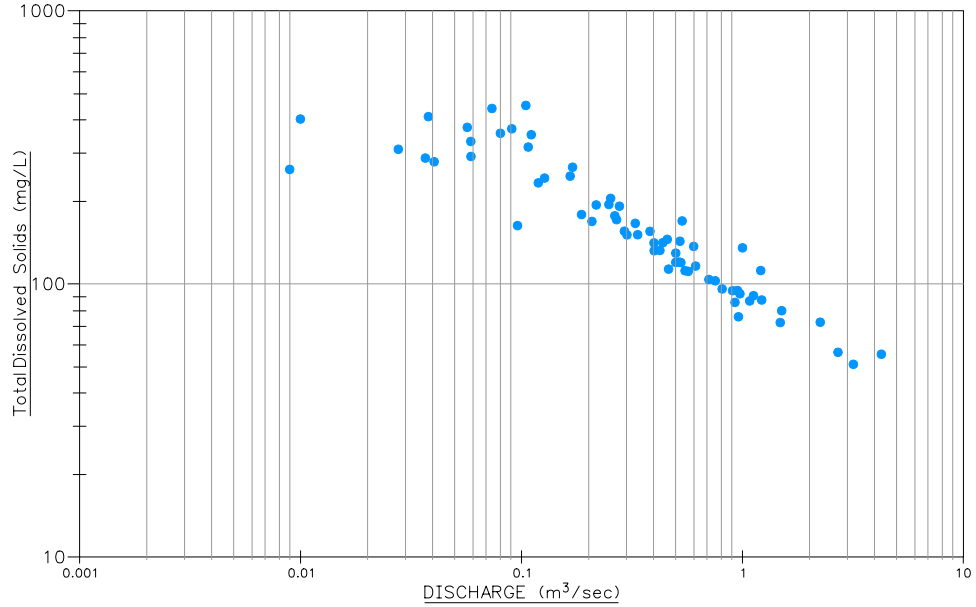
Stream sediment geochemistry surveys (Nova Scotia Department of Mines and Energy, 1991) noted elevated (>90 percentile) concentrations of specific metals in the Lowland Region. Of note were the Iona Peninsula (zinc, mercury, iron, arsenic, nickel, cobalt, gold and chromium) and River Denys (silver, mercury, molybdenum, chromium, tungsten and gold).

FIGURE 5-11 STREAM INDICATOR CHEMISTRY LOWLAND REGION - ALLUVIAL VALLEY DISTRICT

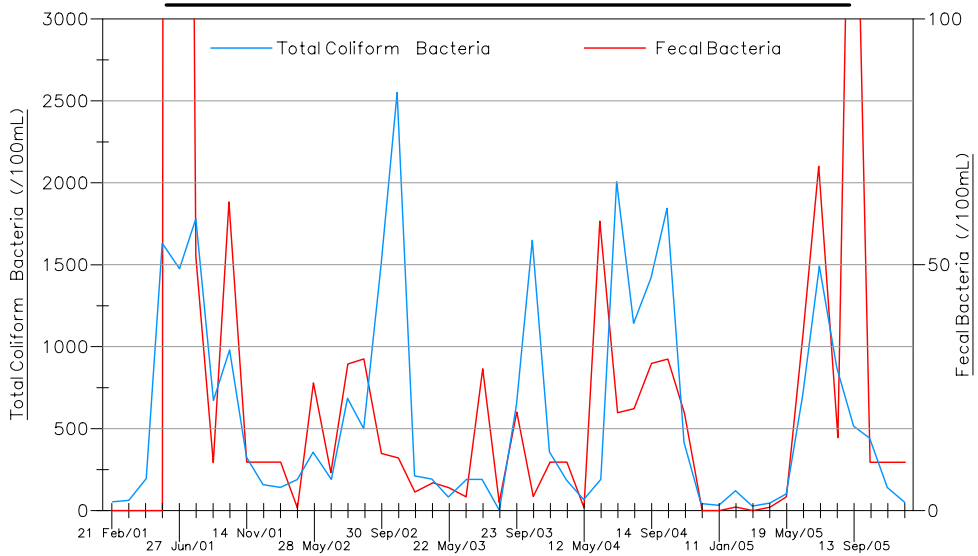
5-11A - TIME VS. TDS AND pH



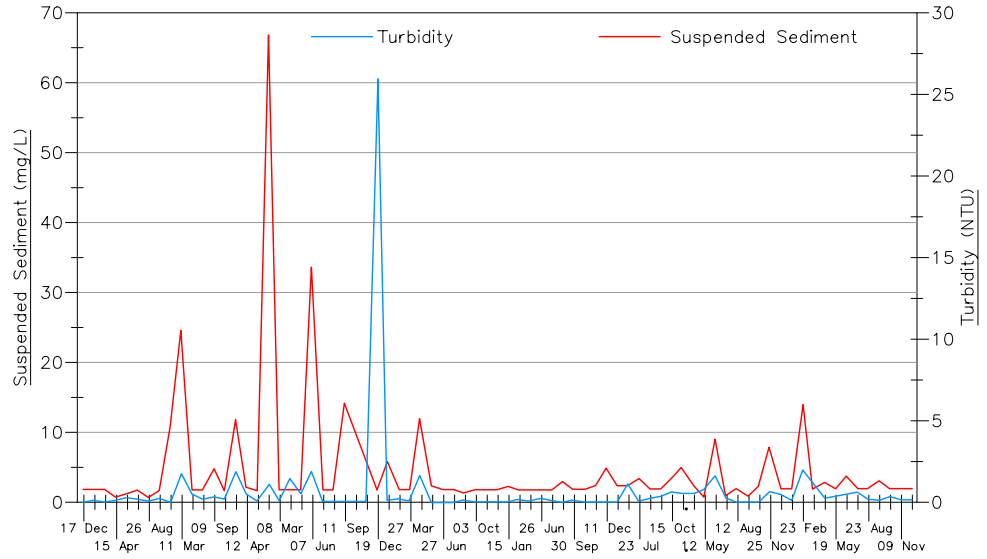
5-11B - DISCHARGE VS. TDS



5-11C - TIME VS. TOTAL AND FECAL BACTERIA



5-11D-GLEN BROOK STATION 1: SUSPENDED SEDIMENT & TURBIDITY



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Dwg.
STREAM INDICATOR CHEMISTRY
LOWLAND REGION
ALLUVIAL VALLEY DISTRICT
(Data courtesy of Georgia Pacific Canada Inc.)

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Dwg Standards Chk. By:	Dwg. No. FIGURE 5-11	
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5.5.3.4 Estuarine Hydrological District

The Estuarine District does not include the entire shoreline where land meets sea; rather it represents a very dynamic setting where brackish barachois lakes are formed along the coast of the Bras d'Or Lakes, surrounded landward by both low relief and groundwater driving head. The setting can be defined by a wide variety of configurations utilizing a number of HUs. This is further complicated by the fluctuation in the position of the salt-fresh water interface governed by seasonal fluctuations and rainstorm events. Finally, the outer seaward boundary is constantly changing due to sea level rise and long shore drift from wave and current action. The combination of these processes can include the deltaic environments at the mouths of Middle and Baddeck Rivers, as well as large irregular shaped embayments formed by drowned river valleys resulting from sea level rise (i.e., Denys Basin). It may also include small embayments protected by baymouth gravel barrier bars cut at times with channels. In each of these settings the glacial till, which protects the bedrock aquifer, may have been partially or fully eroded by wave action, allowing a direct interconnection between the deeper bedrock flow systems and the barachois.

One Barachois Lake identified as Amaguades near Eskasoni underwent a preliminary assessment by Nova Scotia Department of Natural Resources. This 85 hectare lake exhibited a shallow depth (maximum 5 metres) with and alkaline pH (7.7) and a summer thermal gradient.

5.6 Canyon Hydrological Region

5.6.1 Overview

The Middle River is one of two settings within the Watershed that forms such a unique grouping of various Districts from each of the former Regions that it warrants its own Region designation. For the purpose of this mapping effort the Middle River deeply incised into the Highlands, is defined as a Canyon Region (Figure 5-12), comprising 7.6% of the Watershed. Canyons predate the last glaciation and have been carved into the waterscape over approximately the last 65 million years (Grant, 1994).

The key distinctive features (Figure 5-13) comprise large river systems, deeply incised into and bounded by the Igneous Metamorphic HU underlying the Highland Region and the associated snowbelt. The Mountain Flank Region forms the Canyon walls, dropping the waterscape down to a broad Lowland Region, which exhibits large order rivers

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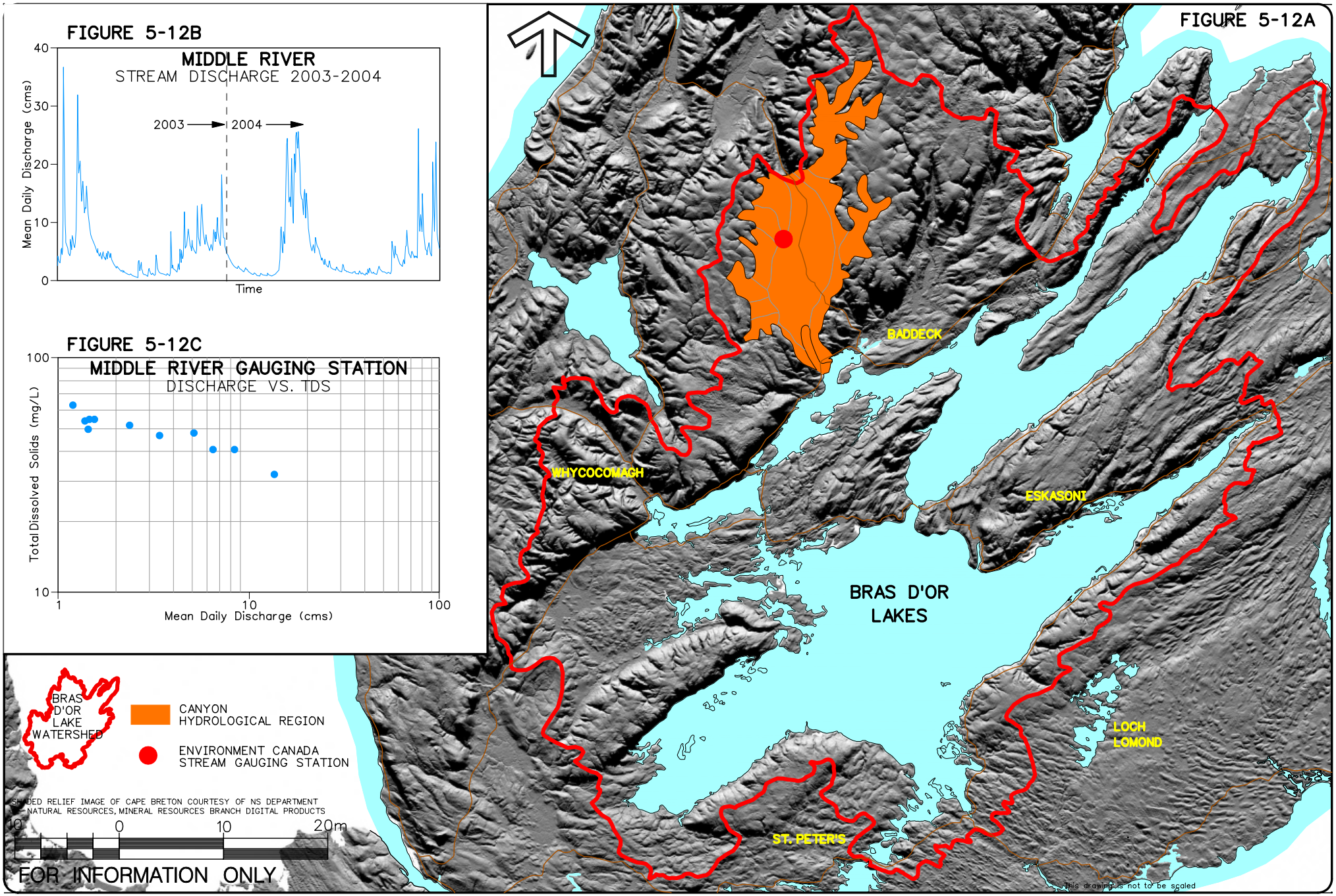
FIGURE 5-12B

FIGURE 5-12C

FIGURE 5-12A



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Dwg.

CANYON
HYDROLOGICAL REGION
(After Baechler et al, in preparation)

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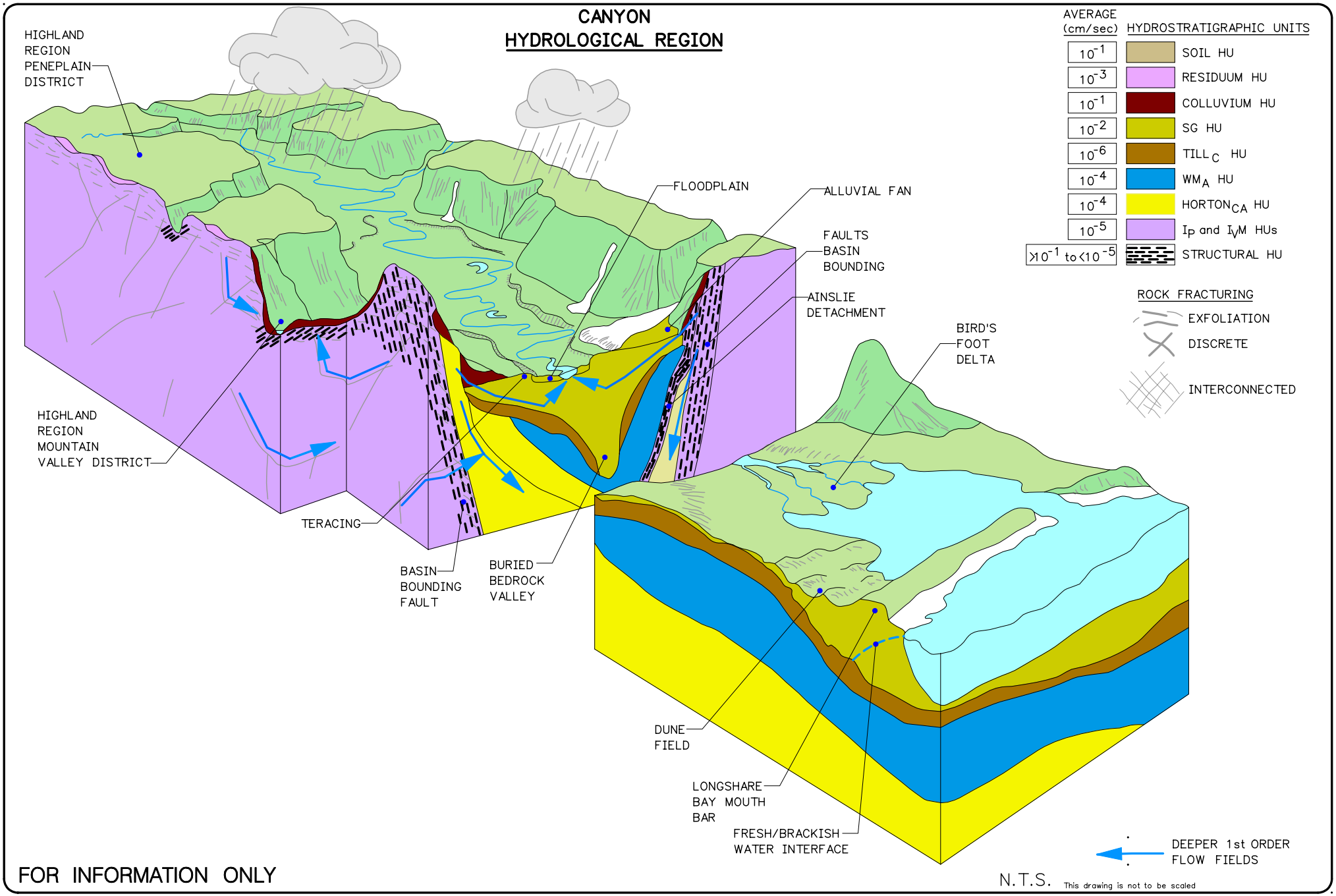

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CANYON HYDROLOGICAL REGION
(After Baechler et al, in preparation)

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Dwg Standards Chk. By:	Dwg. No. **FIGURE 5-13**
Designed By: FEB	Dwg Design Ckd By: FEB / Rev. 0

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meandering across a wide "U" shaped valley floor, characterizing an Alluvial Valley District. Microclimate effects are expected to be present.

5.6.2 Hydrological, Geochemical and Debris Cycles

The conceptual nature of flow within the Canyon Region has been discussed previously for the Highland Region-Peneplain District, Mountain Flank Region-Evaporite District and Lowland Region-Alluvial Valley District. A block diagram (Figure 5-13) conceptualizes the present understanding of groundwater, streams and their interaction.

One unique attribute of the Middle River Canyon is its possible physical link to the northeast Margaree River Canyon through the Lake O'Law mountain pass. Hydrogeological assessments in the Margaree end of the pass (Montreal Engineering Co, Ltd., 1979) suggests it is underlain by a large Sand/Gravel HU, which could provide a hydraulic connection between the two Canyons and, therefore, Watersheds.

Minimal information is available within the Watershed to document conditions in this Region. What is known has been discussed in the relevant sections for Hydrological Districts defined above. Recently, a stream gauge was installed in the Middle River Watershed (provincial designation 1FF-2) on a 119th (shreve) order reach draining 116.8 km^2, or 36% of the Watershed. It provided one and half years of flow data up to December 2004 (Figure 5-12B). The hydrograph is characterized by dual peak flows in spring, from March through May. The early peak represents earlier snowmelt in the Lowlands, the latter the later highland melt peak. The river is perennial with baseflow in summer and mid winter provided by inflow from underlying bedrock and/or Sand/Gravel HUs. Fall rains create numerous peaks and overall rising streamflow. The annual mean daily flow in 2004 was 4.9 cubic metres per sec (cms), creating a runoff coefficient of 0.04 cms/km^2. Maximum monthly average mean daily flows occurred in April (12.03 cms) and May (13.50 cms), with minimums in July (1.93 cms) and August (1.35 cms). Mean daily flows peaked at 25.4 cms (May) with minimum baseflows of 1.08 cms (August).

Sporadic water quality sampling by Baechler et al (in preparation) and Environment Canada further downstream in the 1970s indicated a fresh (TDS 32 to 55 mg/L), soft, corrosive, non-coloured (colour 5 to 16 TCU), slightly alkaline water (pH 6.9 to 8.2). TDS shows an inverse relationship to discharge (Figure 5-12C), reflecting a strong groundwater baseflow component. During low flow with maximum groundwater input it is a calcium-bicarbonate type water, which under high flow changes to a mixed sodium/calcium-chloride/bicarbonate type water. Nutrients appear as total organic

carbon (0.8 to 2.6 mg/). Iron (<0.1 to 0.03 mg/L) is at low to non-detectable levels, manganese is always non-detectable. During low summer flows, total coliform bacteria range from 144 to 470/100 ml with 2 to 4/100 ml fecal (e. coli) coliform.

5.7 Bras d'Or Marine Hydrological Region

5.7.1 Overview

The sea floor of the Bras d'Or Lakes (Figure 5-14) is the second of two settings within the Watershed which form such a unique grouping of various Hydrologic Districts within the Lowland Region as to warrant its own Region designation. While seemingly unorthodox to describe this setting as part of "Watershed", it is important to recognize:

1. The recognition of the importance of such settings is attaining more recognition (Fisher, 2005).

2. From approximately 10,000 to 5,000 years ago what is now sea floor was forested land exposed to rain prior to inundation by the sea. During this time, fresh water drained through the streams (Figure 5-14B) to lakes and recharged the aquifers. While the streams no longer exist, fresh groundwater could still exist in the aquifers. This seawater intrusion has presently created approximately 1,000 km of shoreline where salt water interfaces with fresh water.

3. While present day streams discharge fresh water into the Bras d'Or Lakes at sea level, deep groundwater flow systems recharging on land will discharge their fresh water up through the sea floor, which lake water budgets must account for.

4. While humans do not directly utilize this water resource, the impact of varying groundwater quality discharging through the sea floor could impact benthic aquatic life ecosystems.

5. This area, in plan view, comprises some 1085 km^2 or 43% of the land based watershed (2512 km^2). It, therefore, comprises a significant portion of the overall 3597 km^2 Bras d'Or Lakes and Watershed.

Distinctive features combine the Windsor Lowland, Karst, Alluvial Valley and Estuarine Districts of the Lowland Region, overlain by a progressively increasing head of saline water (at two thirds the salinity of sea water), with low tidal amplitude. Further definition of these settings will be possible once detailed marine bathymetry (Dr. J.

Shaw) is available from the Bedford Institute of Oceanography mapping effort. A conceptual model is provided in Figure 5-15.

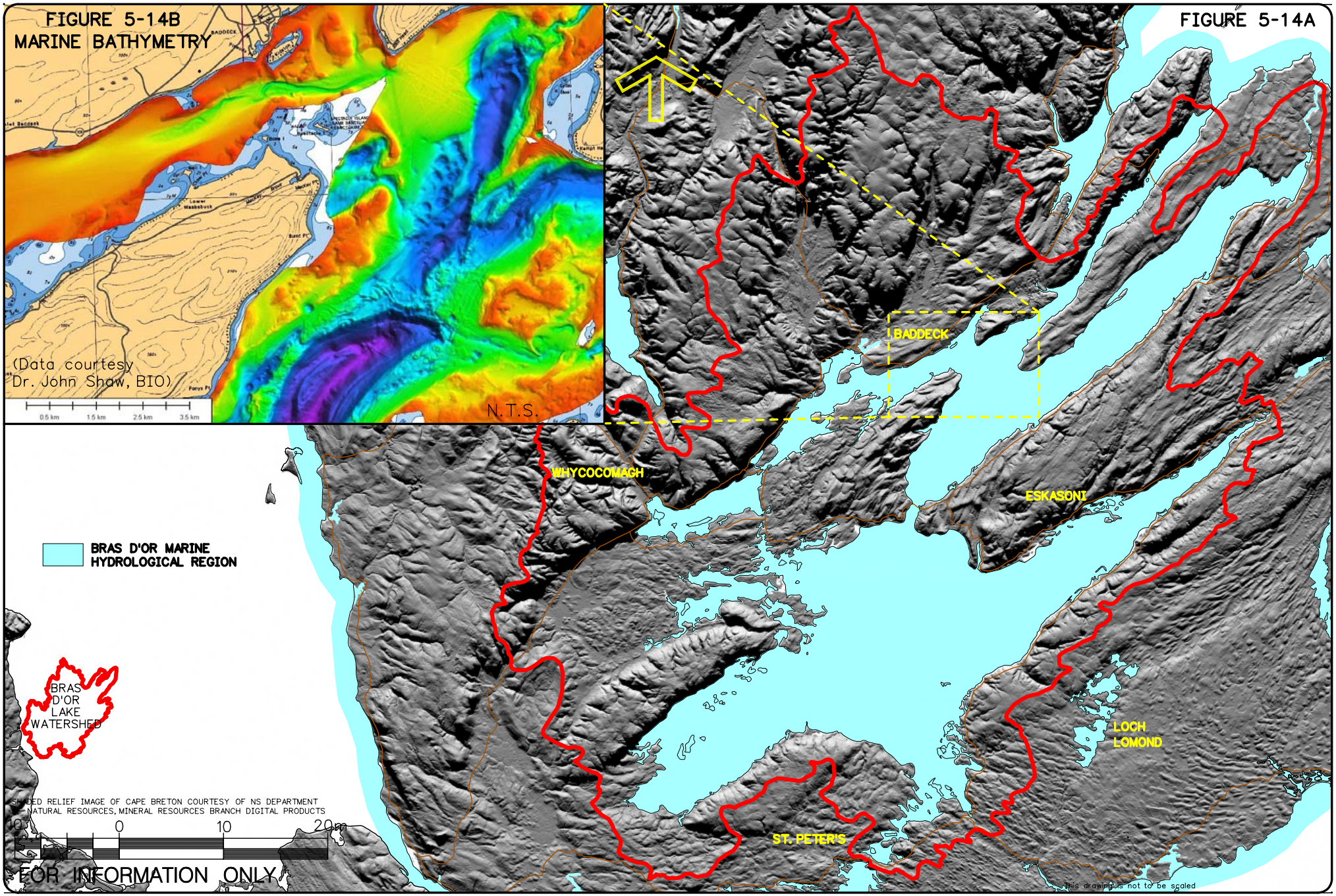
The impact of the Karst District maybe seen in the linear deep water trough of St. Andrews Channel and depressions in the Great Bras d'Or Channel southwest and west of Kempt Head (Figure 5-14B). These depressions generally coincide with the projected outcrop of Windsor/Mabou Evaporite HU. The deep water features, therefore, maybe a large scale solution trench–karst system attributed to dissolution and solution collapse of evaporites (Boehner, 1985).

Rising sea level (Section 2.6) has created a number of changes to the natural flow systems as described in the relevant District sections. The rising sea level creates a compression effect, somewhat similar to glacial overriding. This can be expected to gradually seal off horizontal to subhorizontal fractures in the near bedrock subcrop zone, thereby reducing the bulk permeability of the bedrock.

Depending upon the rate of sea level rise and topography, the overlying, usually clayey Till HU may have been eroded off by wave and current action exposing the bedrock HUs to direct contact with the sea. Initially after submergence the driving head of fresh water would probably exceed that of the shallow sea, allowing "fresh" water discharge to the near shore zone in exposed areas, seaward of high relief land with high driving heads. Where the Till HU was not eroded, its aquitard characteristics (coupled with deposition of marine clays) may act to keep the groundwater flow field and lake water separated.

With continued submergence, hydraulic head would not be the sole driving force for groundwater flow fields. The presence of seawater would allow density and chemical/ osmotic gradients to begin to play a role, possibly allowing flow from the sea down into the exposed fresh water bedrock aquifers. The extent of such salt water intrusion would be governed by upwelling gradients of fresh water, and the possible elevated salinity of groundwaters passing through evaporite deposits. With increasing submergence, the weight of overlying water may collapse till/bedrock caps over active solution channels, creating new karst and direct connection.

At depth, salt diapir activity may allow intense fracturing of the adjacent bedrock forming a high vertically permeable zone. This could potentially allow upward transport of deep basin brines and hydrocarbons into the bottom of the lake, driven by lithostatic compaction, tectonism, thermal gradients and diffusion processes.



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STATE OF ENVIRONMENT
BRAS D'OR LAKES WATERSHED
FRESH WATER RESOURCES

Dwg.

BRAS D'OR MARINE
HYDROLOGICAL REGION
(After Baechler et al, in preparation)

Drawn By: NEB	Proj. No. 5810-001.1	
Dwg Standards Chk. By:	Dwg. No. FIGURE 5-14	
Designed By: FEB	Dwg Design Ckd By: FEB	Rev. 0

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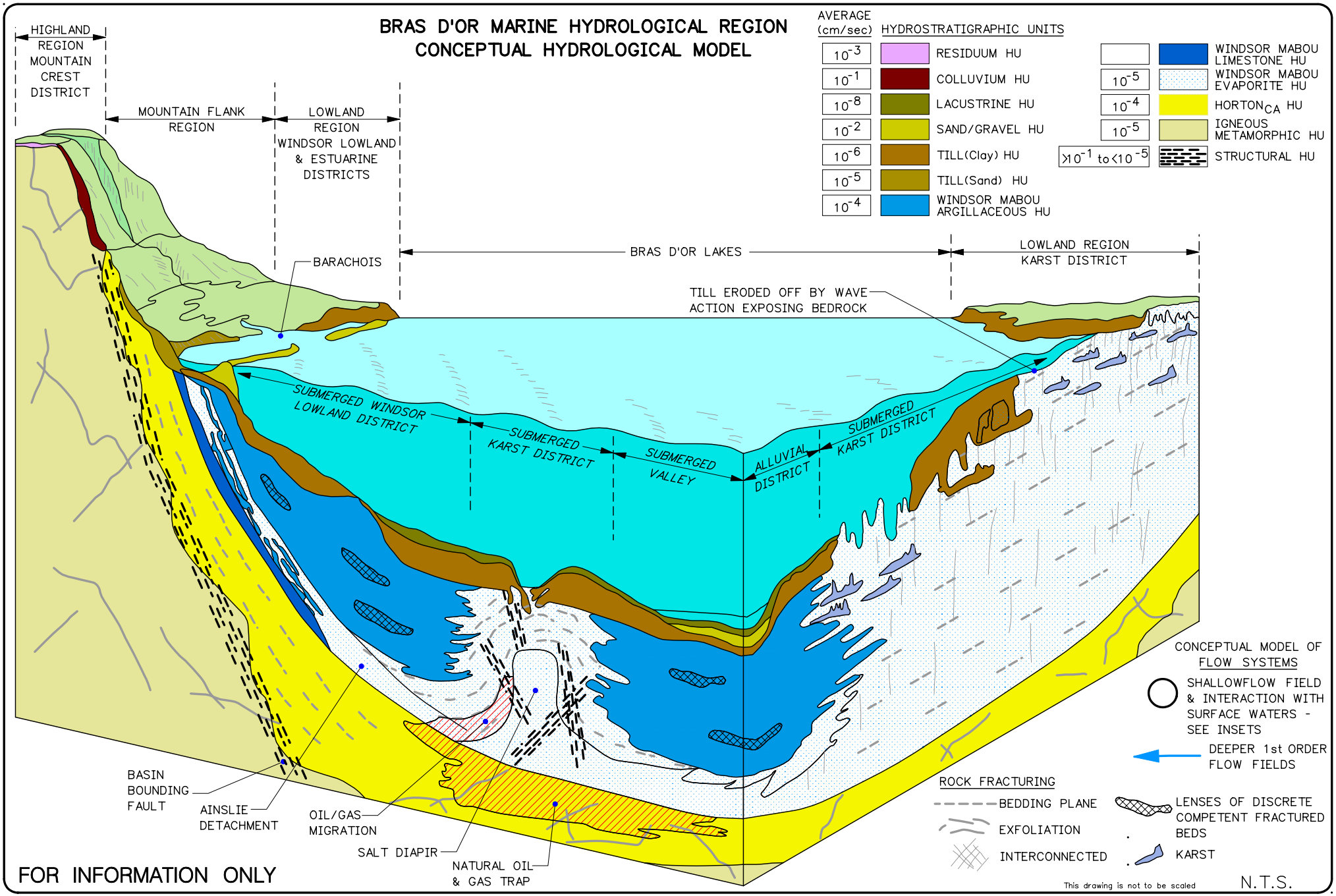

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Proj.
STATE OF ENVIRONMENT
BRAS D'OR LAKES WATERSHED
FRESH WATER RESOURCES

Dwg.
BRAS D'OR MARINE HYDROLOGICAL REGION CONCEPTUAL HYDROLOGICAL MODEL
(After Baechler et al, in preparation)

Drawn By: NEB	Proj. No. 5810-001.1
Dwg Standards Chk. By:	Dwg. No. **FIGURE 5-15**
Designed By: FEB	Dwg Design Ckd By: FEB / Rev. 0

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Sea level has generally not risen sufficiently to override the subcrop of the Horton and basin bounding faults, except perhaps south of Eskasoni. Therefore, these areas still allow recharge of deep basin aquifers with fresh groundwaters.

The rising sea level, with its associated currents, tidal action erosion of wave cut cliffs and long shore sediment transport, has created a number of unique local Estuarine Districts or Barachois Lakes.

Diurnal changes in sea level within the lakes are not large and, therefore, not expected to create noticeable changes in the flow field. Tides outside the lakes are mixed semi-diurnal, but the tide wave is attenuated as energy is dissipated through the Bras d'Or Lakes, being in the range of 0.25 metres at Baddeck, 0.15 metres at the Barra Straits and a few centimetres at lake end near St. Peter's (Gadus and Assoc, 2001).

6.0 GAP ANALYSIS (REFLECTIONS ON OUR PORTRAIT OF THE WATERSCAPE)

6.1 Human Impacts, Driving Forces, Pressures and Responses

As noted in Section 1.0, identifying changes to the natural state of the fresh water environment resulting from human stressors was not part of the scope of this project. Relevant assignments have been allocated to others to fill those data gaps, including land use, forestry, planning, transportation, tourism, etc.

However, once those driving forces and pressures have been identified, there has been no effective monitoring of streams or groundwater to form a source of information to quantify the impact. Within the Lakes, monitoring for bacterial levels to support shellfish closures allowed preliminary impacts to be determined. No such indicator parameter is available throughout the Watershed. Impacts from site-specific operations, such as mining at Melford, Little Narrows and Marble Mountain are being assessed by on-going compliance and environmental effects monitoring programs as required in permitting from Nova Scotia Environment and Labour.

Based upon the SOE reporting format, a "Response" related to filling necessary data gaps is outlined below.

6.2 Research and Monitoring

6.2.1 Baseline Natural Conditions

In order to effectively manage the fresh water resources, it is necessary to understand its natural occurrence, quantity, and quality; and how this varies with time and human impacts. A number of data gaps exist in our knowledge concerning the movement of water, chemicals and sediment critical to this analysis. It is, therefore, considered of paramount importance to develop monitoring and research programs in order to acquire the relevant data.

The existing data for the Hydrological, Geochemical and Debris Cycles (Section 5.0) were assessed to determine if "sufficient" information and knowledge was available. The determination of what constituted "sufficient" for the purposes of this report was defined as:

> TEMPORAL – "sufficient" data constituted the ability to determine at least seasonal fluctuations and annual averages.
>
> SPATIAL – "sufficient" data constituted the ability to define temporal data for specific Hydrological Regions and Districts.

The baseline gap analysis focused on answering questions concerning the natural state of the fresh water resource to determine how the waterscape works. It was designed as a first step to identify major questions that required answering, not to design each program. This method of approach is summarized by Gerard (1965):

> *"In science we commonly think that quantitative precession is our great strength…. but before measurements can be meaningful, they must be directed to the right things and even in science, finding these things is the major achievement."*

At this draft stage of reporting the authors' believe the following questions require answering:

Re: Total Fresh Water Input

1. What is the annual input of precipitation to the Bras d'Or Lakes Watershed?

2. How does it vary with seasons? between Highland and Lowland Regions? between rain, snow and snowpack?
3. What is the chemical characteristic of precipitation and dust fallout?
4. Are there inter-basin transfers of water from the Mabou, Lake Ainslie, Northeast Margaree and/or Sydney River Watersheds into the Bras d'Or Lakes Watershed through connecting groundwater reservoirs?

Re: Replenishable Resource

1. What is the replenishable fresh water resource (total input minus evapotranspiration loss)?
2. What is the appropriate water balance to characterize Lowland and Highland Regions?
3. What is the rate of groundwater recharge within the various Hydrological Districts?
4. How much of the replenishable resource resides in streams; how much in groundwater?

Re: Storage

1. How much potable water resides in storage within groundwater reservoirs?
2. How much water resides in storage within streams and lakes?

Re: Climate Change

1. Climate change is on going (Section 3.11). How is this taking place, i.e., variations in season, recurrence intervals, as rain or snow, in chemistry, melting of snowpack etc.?
2. What impacts are these changes making in the chemical and physical properties of groundwater, streams and lakes?

Re: Aquatic Life

1. What streams provide optimum habitat for aquatic life (salmon, trout) and why?
2. How much water must remain in streams during low summer flows to provide suitable habitat?
3. How does GWSI affect flow and chemistry in streams within different Hydrological Districts and could that interaction effect habitat?
4. What influence is climate change having on aquatic life?

Re: Limnology of the Bras d'Or Lakes

1. What is the annual rate of fresh water entering the Lakes through groundwater and streamflow?
2. What is its quality?
3. Where does groundwater-lake interaction occur?

Re: Potable Water Resource

1. Which of the HUs can be considered as water supply aquifers that can support major development and/or individual households?
2. What are groundwater quality limitations with storage and depth?
3. Which HUs cannot provide potable water and require consideration of streams and/or cisterns?
4. How should safe yield be determined to ensure withdrawals minimize ecosystem impact?
5. What are appropriate requirements to maintain aquifer specific water well infrastructure sustainability? What is the present condition of private water well infrastructure?

Re: Waste Disposal

1. Which HUs and Hydrological Settings can be considered for disposal of wastes (septic, landfills, sewage lagoons, others) using natural attenuation?

Re: Sedimentation

1. What overburden HUs are most susceptible to erosion and require stringent sediment erosion control regulations?
2. What metals and nutrients are tied up in overburden and stream sediment and are being transported into the Bras d'Or Lakes?

Monitoring programs designed to answer these questions should include consideration of:

1. Climatic conditions: This would require at least one location in the lowlands at Baddeck (upgrade the existing station) and one new one in the Highlands, in the headwaters of the Middle and Baddeck Rivers. Parameters to be monitored would include air temperature, snowfall, rainfall, total precipitation, depth of snow and chemistry (both wet and dry fallout).

2. Groundwater/streams/lakes/wetlands: This would require selecting indicator natural Watersheds characteristic of the Hydrological Districts. These conditions could then be extrapolated to the remainder of each District within the Bras d'Or Watershed. Each Watershed would be instrumented to monitor streamflow, groundwater head levels, water chemistry, suspended sediment and bed sediment geochemistry.

3. Fresh water input to Bras d'Or Lakes: Stream gauging stations would be installed at the mouths of selected large rivers draining a variety of Regions and Districts to characterize flow and chemistry.

6.2.2 Determining the Extent of Human Impacts

A special set of research programs will be required to investigate the impacts of specific human pressures as delineated in other reports identified in Section 6.1. At this draft stage, the author's view as to the main questions that could potentially need addressing is as follows:

1. Agriculture: What are the chemical/microbiological impacts of agricultural activities in the Skye River Valley, Boularderie Island, etc.?

2. Forestry: What are and were the physical and chemical impacts of forest cutting activities and spring budworm infestations in the Highland and Gariloch Mountain areas?

3. Tourism: What are the impacts associated with increased water demands required to meet tourism requirements, i.e., Baddeck, golf courses, ski hill, campgrounds, cosmetic landscaping, contaminant sources?

4. Highways: What are the impacts associated with de-icing compounds and road wash runoff?

5. Urbanization/Subdivisions: What are the impacts associated with population growth, i.e., Baddeck, subdivisions, linear shoreline development?

6.2.3 Geoindicators

In an attempt to deal with larger ecosystems, SOE reporting has been developed to test new approaches to and policies for ecosystem management. One main goal of SOE

reporting is to identify and communicate to decision makers trends in key environmental signals, especially changes that warn of impending thresholds that require changes to policy, institutions and human behaviour (Berger, 1996).

Just as a physician gauges human health by monitoring a patient's vital signs, so those for judging ecosystem health need vital signs, or indicators, to determine whether things are stable or changing.

To date, most SOE reports have dealt with obvious and important biological and chemical parameters relating to pollution and biodiversity. What seems to have been forgotten in the search for indicators is the role played by natural physical processes that operate whether or not living organisms are present.

Geoindictors are measures of surface and near surface geological processes and phenomena that vary significantly over periods less than 100 years and that provide information that is meaningful for ecosystem management. They measure both catastrophic events and those that are more gradual, but evident within a human lifespan. They need to be high-resolution measures of short-term changes in the geological environment (Berger, 1996).

The data gaps in our knowledge of the Bras d'Or Waterscape limits the ability to delineate appropriate geoindicators. Palaeohydrology (Section 2.0) provides some aid in tracking changes in potential geoindicators with time, to provide baselines against which human induced and natural stresses can be assessed more thoroughly.

At this draft stage of reporting, it is the author's view that consideration should be given to at least using total precipitation, sea level, snowpack, water level and major ion chemistry in groundwater reservoirs, as well as stream flow in select Hydrologic Districts as Geoindicators. It is hoped that more will be added as the research and monitoring outlined in Section 6.2 proceeds.

6.3 Establishing Priorities

To acquire sufficient data to fill these gaps will require a notable commitment of time and monies. It is, therefore, recommended that priorities be established. Each year a few programs should be initiated allowing for data acquisition over the long-term. This would also allow capacity building within CEPI/UINR to install, monitor, maintain and analyze the information as it becomes available.

Priorities could be established based upon, but not limited to the following guidelines:

1. Assess which data we "want to know" and which "we need to know" to facilitate short, intermediate and long-term water resources management goals as defined by CEPI.

2. Define the most valuable portions of the environment within the Watershed to provide a focus for efficient utilization of time and monies for monitoring, i.e., drinking water, salmon.

3. Select Watersheds important to integrate with marine water quality and budget analyses.

4. Require Environmental Impact Assessments for new development, incorporating their monitoring programs into this overall resource management, as has been successful with Georgia Pacific's Melford mine.

5. Determine which data gaps could temporarily be filled by extrapolating data from outside the Watershed.

6.4 Establish a Database

To be effective, the development of management strategies must be based on all the up-to-date factual data available. This implies development of an effective, digital data gathering, storage and retrieval system, especially given the large volume of data pertinent to the water resources. The database must be independent of time (i.e., must be continually updated). It must be set up on a large-scale basis so as to allow flexibility in scale of study and should be easily accessed by independent users.

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