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Coast of Bays Metrics: Geography, Hydrology and Physical Oceanography of an Aquaculture Area of the South Coast of Newfoundland

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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LIST OF ACRONYMS

Acronym	Name	Description
BB	Belle Bay	Major bay of interest
BBE	Belle Bay East	Along-channel transect (Fortune Bay - Belle Bay region)
BB-MB	Belle Bay - Mal Bay	Along-channel transect (Fortune Bay - Belle Bay region)
BBW	Belle Bay West	Along-channel transect (Fortune Bay - Belle Bay region)
BDE	Bay d'Espoir	Major bay of interest
BDE-DA	Bay d'Espoir Development Association	Local society promoting economic development
BDE-E	Bay d'Espoir - East	Main arm of Bay d'Espoir fjord, located to the east; also used as a main axis
BDE-W	Bay d'Espoir - West	Main arm of Bay d'Espoir fjord, located to the west; also used as a main axis
BIO	Bedford Institute of Oceanography	Federal research facility (Canada)
CB	Connaigre Bay	Major bay of interest
CCOG	Canadian Council on Geomatics	Federal-provincial-territorial consultative body (Canada)
CD	Chart Datum	Vertical datum corresponding to, in this study, the low water level mark, large tides
CDEM	Canadian Digital Elevation Model	Three dimension terrain representation, produce by the Canadian Council on Geomatics
CGVD28	Canadian Geodetic Vertical Datum of 1928	Vertical datum
CHS	Canadian Hydrographic Service	Federal hydrographic office (Canada)
CP	Connaigre Peninsula	Broad region encompassing Connaigre Bay, Harbour Breton- Northern Arm and Great Bay De l'Eau
CTS	Coastal Time Series	Inventory of coastal and freshwater temperature time series data maintained by the Ocean Science Division at the Bedford Institute of Oceanography
DGPS	Differential Global Positioning System	Satellite navigation system enhanced by ground-based reference station(s)
DO	Dissolved Oxygen	Seawater characteristic/parameter
EB	East Bay	Along-channel transect (Hermitage Bay - Bay d'Espoir region)
FB	Fortune Bay	Major bay in study area; also a transect of the Fortune Bay - Belle Bay region
FB-BB	Fortune Bay - Belle Bay	Region encompassing Fortune Bay and Belle Bay
FB-LH	Fortune Bay - Long Harbour	Along-channel transect (Fortune Bay - Belle Bay region)

Acronym	Name	Description
GBDE	Great Bay de L'Eau	Major bay of interest in this study; also a major channel of Connaigre Peninsula region
GBDE-E	Great Bay de L'Eau – East	Main arm of Great Bay De l'Eau, located to the east; also used as a main axis
GBDE-W	Great Bay de L'Eau – West	Main arm of Great Bay De l'Eau, located to the west; also used as a main axis
HB	Hermitage Bay	Along-channel transect (Hermitage Bay - Bay d'Espoir region)
HB-BDE	Hermitage Bay - Bay d'Espoir	Region encompassing Hermitage Bay and Bay d'Espoir
HB-NA	Harbour Breton - Northeast Arm	Major bay of interest in this study; also a major channel of Connaigre Peninsula region
HS	Hydrometric station	Hydrometric stations located within the study area (i.e., places where river flow are or were being measured)
HWL	High Water Level	Vertical datum corresponding to the high water level mark, large tides
IDW	Inverse Distance Weighting	Deterministic method multivariate interpolation technique
LaP-UBDE	Lampidoes Passage - Upper Bay d'Espoir	Along-channel transect (Hermitage Bay - Bay d'Espoir region)
LBDE	Lower Bay d'Espoir	Along-channel transect (Hermitage Bay - Bay d'Espoir region)
LBDE-NB	Lower Bay d'Espoir - North Bay	Along-channel transect (Hermitage Bay - Bay d'Espoir region)
LCB	Lower Connaigre Bay	Along-channel transect (Connaigre Peninsula region)
LiP	Little Passage	Along-channel transect (Hermitage Bay - Bay d'Espoir region)
MBES	Multibeam Echosounder	Sonar sounding system
MCF	1,000,000 Cubic Feet	unit of volume (imperial system)
MHWL	Mean High Water Level	Vertical datum corresponding to the high water level mark, mean tides
MSL	Mean Sea Level	Vertical datum corresponding to the water level between high tides and low tides
MSRL	Marine Science Research Laboratory (Memorial University of Newfoundland)	Academic research facility (presently Ocean Science Centre)
NAD83	North American Datum of 1983	Horizontal coordinate system
NRCan	Natural Resources Canada	Federal government department (Canada)
NTDB	National Topographic Database	Inventory of digital vector datasets that cover the Canadian landmass
NTS	National Topographic System	Natural Resources Canada general purpose topographic map system
NWC	Northwest Cove	Aquaculture overwintering site located in Bay d'Espoir
OCP	Outer Connaigre Peninsula	Along-channel transect (Connaigre Peninsula region)

Acronym	Name	Description
ODI	Ocean Data Inventory	Web accessible inventory of ocean current, temperature and salinity time series data maintained by the Ocean Science Division at the Bedford Institute of Oceanography
RB	Roti Bay	Aquaculture overwintering site located in Bay d'Espoir
ROFI	Region Of Freshwater Influence	Area where freshwater runoff (or input) dominates the effect of buoyancy input on coastal waters over (local) solar heating
SBES	Single Beam Echosounder	Sonar sounding system
SC	Ship Cove	Aquaculture overwintering site located in Bay d'Espoir
TG	Tide Gauge	Tide gauges (places where the water level has been measured to determine tidal constituents)
UCB	Upper Connaigre Bay	Along-channel transect (Connaigre Peninsula region)
UTM	Universal Transverse Mercator	Horizontal coordinate system
WGS84	World Geodetic System of 1984	Horizontal coordinate system
yd	year day	Unit of time defined as day numbers from January 1st of the year being considered. January 1st being equal to 1, January 2nd to 2, etc.

ABSTRACT

Upon a recent rapid increase of the finfish aquaculture industry in the Coast of Bays, an area of the South Coast of Newfoundland (nine-fold production growth from 2003 to 2013), Fisheries and Oceans Canada (DFO) carried out a research project to better understand the physical oceanography of the area. This report is the first of a series aiming to provide an oceanographic knowledge baseline of the Coast of Bays (i.e., data and analyses) to help manage and ensure the sustainable growth of the aquaculture industry. Bathymetric, topographic and hydrologic data as well as sea water temperature, tides and wind data were used to determine the geographic, hydrologic and oceanographic characteristics of the area. The area includes five major bays where the aquaculture activities are currently occurring or planned.

The results of these analyses indicate that the Coast of Bays area can be divided in three regions of distinct geographic, hydrologic and oceanographic characteristics: a deep, long and narrow fjord subject to large runoff (Bay d'Espoir), a deep and wide bay subject to less but still significant runoff (Belle Bay) and a shallower region, more exposed to the open ocean and subject to very small runoff (Connaigre Peninsula). The annual average freshwater discharge was found to be about 252 m^3/s in Bay d'Espoir, about 71 m^3/s in Belle Bay and about 10 m^3/s in the Connaigre Peninsula and characterised by a strong seasonal cycle with a large spring freshet (April-May), a low in summer (July-August) and smaller peak in late-fall/early-winter (November-December). Tides are semi-diurnal and small, with a range of about 2 m (large tides). Thus, and due to the large volumes of the bays considered, flushing times due to tides only are large and unequal, varying from about 30 days in the Connaigre Peninsula to about 70 days in Bay d'Espoir and Belle Bay. The study area is also characterized, as a whole, by a strong heating and cooling seasonal cycle with sea-surface (0-20 m) water temperature amplitude of about 7^{o}C. Differences among the three regions in terms of seasonal cycle amplitudes and phases as well as monthly statistics and vertical mixing estimates were found and suggest a potential effect of the freshwater input on thermal stratification. The wind climate of the area is also strongly seasonal with prevailing and strong winds from the west-northwest/northeast in winter/spring (about 35-45 km/h median speed) and prevailing and much weaker winds from the southwest in summer (about 20-30 km/h median speed). Finally, bathymetric characteristics were used to delineate the area in basins which can be used, in conjunction with other relevant factors, for aquaculture zoning management purposes.

Data used and presented in this report are available at the Government of Canada's Open Data website.

Mesures de la Coast of Bays: géographie, hydrologie et océanographie physique d'une zone aquacole de la côte sud de Terre-Neuve

RÉSUMÉ

À la suite d'une augmentation récente et rapide de l'industrie aquacole dans la Coast of Bays, une région de la côte sud de Terre-Neuve (production multiplié par 9 de 2003 à 2013), Pêches et Océans Canada a mené un projet de recherche pour mieux comprendre l'océanographie physique de la zone. Ce rapport est le premier d'une série visant à fournir une base de connaissances océanographiques de la région (données et analyses) afin d'aider à gérer et assurer la croissance durable de l'industrie aquacole. Des données bathymétriques, topographiques et hydrologiques ainsi que des données sur la température de l'eau de mer, la marée et le vent ont été utilisées pour déterminer les caractéristiques géographiques, hydrologiques et océanographiques de la zone. La zone comporte cinq grandes baies où les activités aquacoles sont actuellement en cours ou prévues.

Les résultats de ces analyses indiquent que la Coast of Bays peut être divisée en 3 régions de caractéristiques géographiques, hydrologiques et océanographiques distinctes: un fjord profond, long et étroit soumis à un ruissellement important (Bay d'Espoir), une baie profonde et large (Belle Bay) et une région moins profonde, plus exposée à l'océan et soumise à un ruissellement très faible (Connaigre Penninsula). L'apport annuel moyen en eau douce est estimé à environ 252 m^3/s dans Bay d'Espoir, environ 71 m^3/s dans Belle Bay et environ 10 m^3/s dans la péninsule de Connaigre. Cet apport est fortement saisonnier avec une grande crue printanière (avril-mai), un débit faible en été (juillet-août) et une deuxième crue, plus petite, à la fin de l'automne - début de l'hiver (novembre-décembre). Les marées sont semi-diurne et petites, ayant un marnage d'environ 2 m (grandes marées). De ce fait, et en raison de leur grands volumes, le temps de renouvellement des eaux des baies considérées dues aux marées seules est grand et inégal, variant d'environ 30 jours dans la péninsule de Connaigre à environ 70 jours dans Bay d'Espoir et Belle Bay. La zone d'étude est également caractérisée, dans son ensemble, par un fort cycle saisonnier de réchauffement et de refroidissement avec une amplitude annuelle de la température de la surface de la mer (0-20 m) d'environ 7^{o}C. Des différences entre les trois régions en termes d'amplitudes et de phases du cycle saisonnier, ainsi que de leurs statistiques mensuelles et estimées de mélange vertical suggèrent un effet potentiel de l'apport d'eau douce sur la stratification thermique. Le climat du vent de la région est également très saisonnier avec des vents d'ouest-nord-ouest / nord-est dominants et forts en hiver / printemps (environ 35-45 km / h vitesse médiane) et les vents dominants et beaucoup plus faibles venant du sud-ouest en été (20 à 30 km / h de vitesse médiane). Enfin, les caractéristiques bathymétriques ont été utilisées pour délimiter la zone dans les bassins pouvant être utilisés, en parallèle avec d'autres facteurs pertinents, pour la gestion du zonage de l'aquaculture.

Les données utilisées et présentées dans ce rapport sont disponibles au le site Web des données ouvertes du gouvernement du Canada.

INTRODUTION

As any living organism, finfish and shellfish cultured in the ocean interact with and depend on their physical environment. The physical environment determines the kind of species that can be cultured and how they can be cultured (e.g., technology used), but also affect their general health and well-being. Atlantic salmon, for instance, cannot survive in water temperature below -0.7^{o}C to -0.8^{o}C (Saunders et al. 1975, Fletcher et al. 1988 and Elliott and Elliott 2010) and temperature <1^{o}C or >16^{o}C are unfavorable for growth (Saunders et al. 1975, Saunders 1995). Optimum growth temperature range is reported to be between 8-12^{o}C (Sanders 1995) and lethal upper temperature was found to be in the vicinity of 23^{o}C (Priede 2002) to 28^{o}C (Elliott 1991, Jonsson and Jonsson 2011). The introduction of aquaculture activities can also affect the environment through organic loading (e.g., Brown et al. 1987, Wildish and Pohle 2005, Hamoutene et al. 2015), chemical input (e.g., Armstrong et al. 2005, Burridge et al. 2010, Fitridge et al. 2012, Guardiola et al. 2012, Page and Burridge 2014, Page et al. 2015), enhanced turbidity and/or decrease of water quality (e.g. Hargrave 2003, Price et al. 2015), wild species genetic interactions, space competition or disease introduction (e.g., Fisheries and Oceans Canada 2006, Johansen et al. 2011).

Thus for the understanding of the complex interaction between aquaculture and the environment a sound knowledge of the physical features of the environment is imperative. For instance, currents (speed and direction), water column stratification and turbulences, bottom topography and water temperature are all critical parameters to estimate the dispersion and fate of sediment load from aquaculture farms (e.g., Cromey et al. 2002, Cromey and Black 2005, Symonds 2011, Chang et al. 2014a). Flushing time, itself a result of physical forces such as the tide, wind and freshwater inflow acting on the water column is necessary to estimate dissolved oxygen (DO) depletion (e.g., Trites and Petrie 1995, Page et al. 2005a), eutrophication potentials (e.g., Trites and Petrie 1995, Reid 2007) and more generally to estimate the ecological holding capacity (for salmon) or carrying capacity (for molluscs) in farming areas (e.g., Sowles 2005, Gallardi 2014). The ocean currents, induced by the tides, winds and other physical forces, must be known (e.g., using in-situ measurements) or accurately estimated (e.g., using numerical models) to suitably assess the dispersion of waterborne diseases (e.g., Page et al. 2005b, Foreman et al. 2015), parasites (e.g., Amundrud and Murray 2009, Stucchi et al. 2011) and chemical treatments (e.g., Page et al. 2015).

The work described in this report is the first stage of a study on the physical oceanographic environment and water exchange in several bays of the South Coast of Newfoundland (here after referred to as the ‘Coast of Bays’, Figure 1) where the vast majority of the salmonid aquaculture industry of the province is currently operating and rapidly expanding (Department of Fisheries and Aquaculture 2014a). The rapid expansion of aquaculture activities (from 2,600 t in 2003 to 22,196 t in 2013, or about 9 fold in 10 years, of salmonid production) represents a significant challenge with respect to fish health, site selection and economic considerations. To minimize the effects of potential issues such as, for example, the spread of diseases and parasites, a number of coastal zone management policies has been developed and implemented by the major countries producing salmonids: “Farm Management Areas” (FMAs) in Scotland (Scottish Salmon Producers Organisation 2015), “Single Bay Management” in Ireland (Jackson 2011), “group of concessions” or “barrios” in Chile (Clément 2013) and Bay Management Areas (BMAs) in New Brunswick, Canada (Chang et al. 2014b). Norway, the leading country in salmon farming, both in terms of production and historical breakthroughs, has implemented and is continuously developing a set of policies based on coastal zone management (“LENKA”, Ibrekk et al. 1993) and continuous monitoring management (“MOM”, Stigebrandt et al. 1997, Stigebrandt et al. 2004) to be superseded with an even more cohesive management system named “MOLO” (Lundebye 2013). All of those international and national policies rely substantially on physical environment considerations; the water exchange between farms being a key aspect in diseases and parasites spreading. In Newfoundland and Labrador (NL), the provincial Department of Fisheries, Forestry and Agrifoods (formerly the Department of Fisheries and Aquaculture), the regulatory body, together with the finfish industry recently implemented a BMAs policy, similar to that of New Brunswick, to better manage the growth and ensure sustainability of aquaculture activity in the Coast of Bays (Department of Fisheries and Aquaculture 2014b). The BMAs policy established in New Brunswick consists in implementing single-year-class farming and in partitioning salmon farm areas into Management Areas based on a combination of oceanographic, fish health and business considerations (Chang et al. 2014b). The oceanographic considerations rely largely on potential for water exchanges between farm sites based on tidal excursions; with the underlying objective of minimizing the connections among farms to reduce risks of cross-contaminations (Chang et al. 2007). However, scientific basis for defining those BMAs in Newfoundland is limited as there is little understanding of the oceanography.

The study area (Figure 1) is located on the continental shelf of the South Coast of Newfoundland, Canada and is characterized by complex bathymetry with a deep and large channel to the west (Hermitage Bay - HB) connecting a two-armed fjord (Bay d’Espoir - BDE) to the ocean and a long and deep fjord-like embayment to the east (Fortune Bay - FB). The head of FB opens on its northwest side to form a fairly large embayment (Belle Bay - BB), which features deep channels and a central shallow bank. Between FB and HB, the triangular Connaigre Peninsula (CP) features two fairly large and open bays, Connaigre Bay (CB) to the west and Great Bay De l’Eau (GBDE) to the east, and a narrow inlet, Harbour Breton - Northeast Arm (HB-NA).

The geography and oceanography of the area were studied in the mid-1970s to early 1980s as part of aquaculture farming feasibility studies (Taylor 1975; Marine Sciences Research Laboratory (MSRL) 1980, Bay d'Espoir Development Association (BDE-DA) 1984) with a primary focus on BDE. Oceanographic studies were extended by researchers from Memorial University of Newfoundland from the mid to late 1980s (de Young 1983, Richard and Hay 1984, de Young and Hay 1987, Hay and de Young 1989, White and Hay 1994). In the late 1990s and early-2000s, there were a number of studies on the marine environment of BDE, providing new oceanographic data (Tlusty et al. 1999, Tlusty et al. 2000, Pepper et al. 2003ab, Pepper et al. 2004, Anderson et al. 2005 and Tlusty et al. 2005). Aspects of the coastline geography of the study area were also assessed during that same period (Catto et al. 2003). In recent years, renewed interest in the area’s oceanography arose from the rapid development of the aquaculture industry (Ratsimandresy et al. 2012, Salcedo-Castro and Ratsimandresy 2013, Currie et al. 2014).

However, and despite the number of studies completed in the area, no comprehensive overview of the physical environment has been attempted since the MSRL (1980) and BDE-DA (1984) reports and very little, if any, information has been published on the new regions of aquaculture development including BB and the CP. The five major bays of the study area where the aquaculture industry is currently present and expanding are considered: BDE, BB, CB, HB-NA and GBDE. The main parameters provided are inspired from previous work undertaken in the Maritime Provinces in the 1990s by Gregory et al. (1993). The following parameters are presented:

- Geographic: areas, perimeter, length and width, volumes, depths, width and area at the mouth of the bay and watershed area;
- Hydrological: average monthly freshwater discharges into the bay; and

- Oceanographic: Regions Of Freshwater Influence (ROFI; Simpson 1997), tidal ranges, tidal volumes, tidal currents at the entrance and flushing time estimates of the bay.

In addition to the above parameters a detailed description of the bathymetry as well as an initial assessment of the 0-20 m seawater temperature and wind climate are provided. The description of the bathymetry includes the main channels' morphology as well as basic metrics of the main basins and sills identified. The main purpose of this report is to provide a comprehensive physical description and baseline data of the study area for advice provision for aquaculture management not only to study water exchanges but also on aspects such as, but not limited to, site selections and carrying capacity.

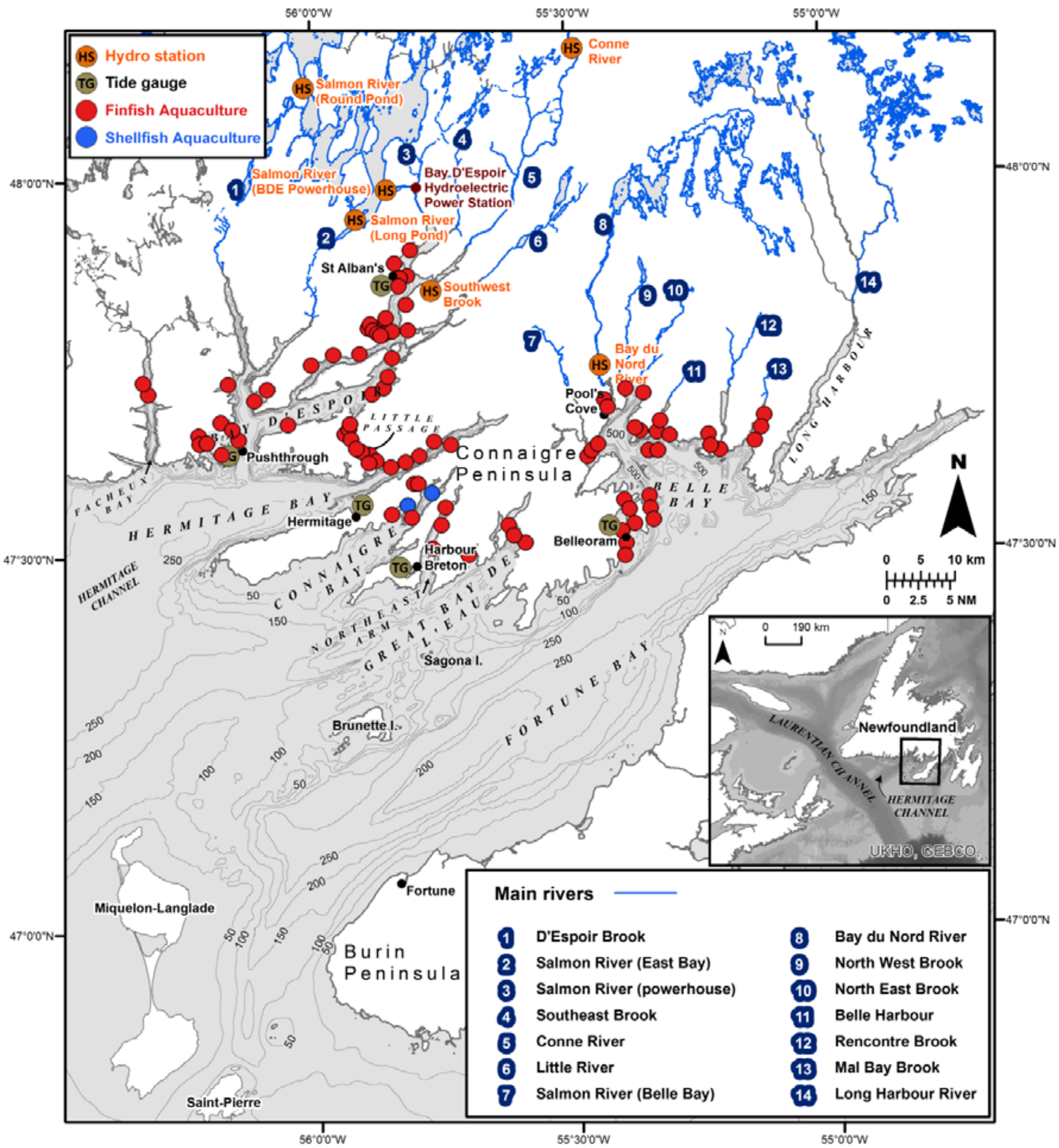


Figure 1: Study area with the locations of the aquaculture licences (as of November 2015; [Department of Fisheries and Aquaculture 2015a](#)), main rivers and the stations where river flow (HS) and tide gauge (TG) archived data are available.

MATERIAL AND METHODS

DATA COLLECTION

Bathymetry

The bathymetry data used for this study were provided by the Canadian Hydrographic Service (CHS). The resolution of the data varied throughout the region from very coarse to fine scale (Figure 2):

- More than 500 m in Outer GBDE and outer-west of HB-NA (collected in 1960-61), portions along the northern shore of the Burin Peninsula, and the eastern shore of St. Pierre Island (1950s), all collected using a Single Beam Echosounder System (SBES) and positioned by sextant;
- 300 to 500 m at the mouth of Fortune and Hermitage Bays as well as around the St. Pierre and Miquelon archipelago and the Long Harbour estuary, collected using SBSE/sextant (1952-61);
- Approximately 150 m in much of FB (1952, using SBSE/sextant and 1980-81, using SBES/MiniRanger ultrasonic level transmitter), Facheux Bay and portions of Hermitage Bay (1955, using SBSE/sextant), Southwest Arm (HB-NA) (1960, using SBSE/sextant), Inner GBDE (1961, using SBSE/sextant), and Roti Bay and edges of BDE (1950-60s, using SBSE/sextant);
- 50-100 m in a small area southwest of Brunette Island, FB (1996) collected using Multibeam Echosounder (MBSE) and Differential Global Positioning System (DGPS);
- 30-50 m in the central and southwest portion of BB, Little Passage as well as parts of Hermitage Bay (1990s) and areas surrounding Brunette Island (2007), all collected using MBSE/DGPS;
- 15-30 m in BDE, HB-NA and a swath running south from the CP (south of CB and HB-NA) to St. Pierre (1990s using MBES/DGPS);
- Less than 15 m in Southwest Arm (Harbour Breton) (1960), collected using SBSE/sextant;
- And approximately 2 m in the north to northeast portion of BB (2006), CB (2010) as well as portions of Hermitage Bay, GBDE and HB-NA (2013), collected using MBSE/ DGPS.

Data points consisted of decimal degree longitude and latitude (World Geodetic System of 1984, WGS84, horizontal datum) and depth recorded in meters. Using the ArcGIS 10.0 Spatial Analyst toolset, an Inverse Distance Weighting (IDW) interpolation was used to produce a gridded raster surface of the study area's bathymetry. The extent of the IDW surface was determined by an analysis mask produced from a coastline polygon shapefile which had been assembled from the Natural Resources Canada's (NRCan) National Topographic System (NTS) 1:50,000 map-sheets. To enable use in spatial analysis, the resulting layer was projected from the initial WGS84 datum to a 2-dimensional Cartesian coordinate system, the Universal Transverse Mercator (UTM) projection, zone 21 north. The vertical datum used, Chart Datum (CD), was kept as provided by CHS.

Following cartographic equations presented by Hengl (2006) for grid resolution based on the density of sample points, a grid of 20 m resolution was selected for the interpolation. Given the great heterogeneity of the data sources and their resolutions, we estimate the accuracy of the interpolated dataset to be of the order of 1 m on the vertical, overall (i.e., it can be larger or smaller depending of the area looked at, being generally better in areas surveyed recently with modern equipment, as described above and as illustrated in Figure 2).

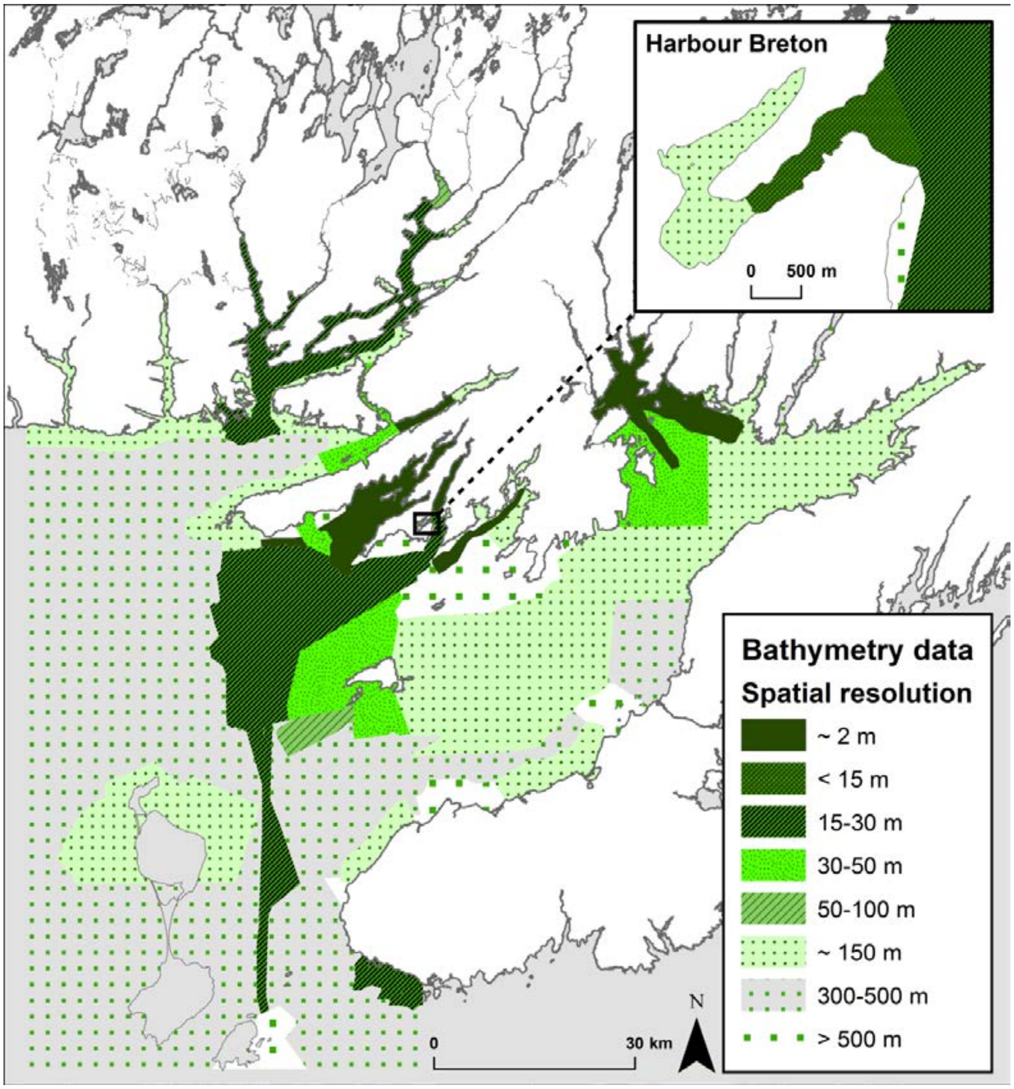


Figure 2: Study area bathymetric surveys coverage and spatial resolution.

Topography

The Canadian Council on Geomatics' (CCOG) [Canadian Digital Elevation Model (CDEM) data] (NRCan 2014) was downloaded for our study area (46° 45' 10" to 48° 10' 48''N, 54° 38'58" to 56° 29' 36"W). The CDEM is a high resolution (0.75 arc-second) gridded dataset of integer values derived from the National Topographic Database (NTDB). It should be noted that due to the various types of source data (i.e., land-based or remote sensing), the elevation provided can be either ground or reflective surface elevations (e.g., top of buildings, trees, structures and other objects) depending on the location and that the dataset was available as integer values, leading to a vertical resolution of 1 m (NRCan 2013a). Horizontal and vertical datum used by the CDEM are the North American Datum 1983 (NAD83) and Canadian Geodetic Vertical Datum 1928 (CGVD28), respectively. To merge this topographic dataset with the bathymetry data, the CDEM was resampled to a 20 m resolution grid projected to UTM zone 21 with a WGS84 horizontal datum and elevation values were converted to CD using (adding) a constant of 1 m.

The 1 m constant is based on the results of the tidal analysis giving a range, large tides, of the order of 2 m for the Coast of Bays area and described in more detail below.

Coastline and rivers

The coastline data are from a polygonal shapefile which was obtained from the NRCan NTS series 1:50,000 mapsheets vector data mentioned above. It has a WGS84 horizontal datum and Mean Sea Level (MSL) vertical datum, the latter considered equivalent to the CGVD28 vertical datum used by the above mentioned CDEM in this study. The coastline polygon was projected to UTM 21 North and analysis masks representing the bays and basins described in the present document were produced from this polygon. These masks were used as boundaries for the analyses to obtain the desired metrics. The dataset resolution was found to be about or higher than 50 m, overall, in our study area.

CCOG National Hydrographic Network data were extracted from NRCan CanVec+ data acquired at geogratis.ca to provide a rivers shapefile (NRCan 2014b). The names used in labelling the rivers were taken primarily from 1:250,000 scale maps of insular Newfoundland (Department of Environment and Conservation 2007). Any names not found within this document were obtained with Google Maps. The river shapefile was used along with the topography data to derive watershed areas around each of the bays of interest.

River flow statistics were obtained from Environment Canada's water survey website. Archived data from the six available stations located within our area of interest were downloaded (Bay du Nord at Big Falls, Salmon River at Powerhouse, Salmon River at Long Pond, Salmon River at Round Pond, Conne River and Southwest Brook, all labeled HS in Figure 1). Of those six stations, three are currently being monitored (Bay du Nord, Conne River and Southwest Brook) and three are discontinued (all the Salmon River stations). The statistics were used along with the watersheds to derive freshwater discharge rates into the bays (see below for the methodology).

Tides

Tidal constituents were compiled by the CHS (Appendix A(ii)). Five stations with archived data were available (Belleoram, Harbour Breton, Hermitage, Pushthrough and St. Alban's on map, Figure 1). For each station, a tidal analysis was run to derive a 19-year prediction from which mean and large tidal ranges and associated water levels (Mean High Water Level, MHWL, and High Water Level, HWL) were calculated. The T_Tide package (Pawlowicz et al. 2002) was used for the analysis, using all the constituents available and the nodal corrections. All the stations were used to assess the coefficient MSL to CD to use for the bathymetry-topography merging. However, only four stations (Pushthrough, St. Alban's, Belleoram and Harbour Breton) were used for the estimates of the bays' tidal ranges and volumes (see below).

Seawater temperature

To examine the annual variability of the sea-surface temperature in the area of interest, we used archived data from different sources including hydrographic data downloaded from the Hydrographic Climate Database (Gregory 2004a), the Coastal Time Series database (CTS; Gregory 2004b) and the Ocean Data Inventory (ODI; Gregory 2004c) of the Bedford Institute of Oceanography (BIO), DFO. In addition to those publicly available data, temperature data obtained from the aquaculture industry and data from previous aquaculture related research projects carried out by the department (Tlusty et al. 1999, Pepper et al. 2003ab and 2004, Mansour et al. 2008, Burt et al. 2012) were quality assessed and compiled. For the geographic area of interest, the databases contained measurements from 1931 to 2010 from various types of instrument leading to an estimated accuracy of the order of 0.1°C.

Wind

Weather data collected at Sagona Island (WMO ID: 71408; see Figure 1) were obtained from Environment Canada. The data set covered a period from 1 February 1994 to 31 December 2013 and included time series of hourly atmospheric pressure, temperature, wind speed and wind direction at 59 m above the sea level (+10 m for the wind speed and direction measures). Quality control checks of the data have been carried out by Environment Canada. For the present analysis, no further checking was completed besides removing erroneous and missing records as flagged in the data set.

METRICS ANALYSIS

A set of bathymetry raster surfaces was produced from the merged bathymetry-topography data for CD, MSL and HWL by selecting the cells with values up to and including 0 m, 1 m, and 2 m above CD, respectively. Based on this data set, ArcGIS 10.0 Zonal Statistics tools were used to extract bathymetry statistics within each of the bays of interest (e.g., volumes, depths and section areas). Other metrics (e.g., perimeters, length and width of the bays) were calculated using one or a combination of the dataset described above. Details on the calculations used to compute each parameter of interest are listed below and a summary flow chart is presented in Figure 3.

- **Areas (CD, MSL and HWL)** of the bays were obtained from calculating the sum of 20 m × 20 m cells for each of the different sea level raster surfaces. MSL area was also calculated from the NTS coastline contour for comparison between raster and vector data. The difference between the raster and vector areas ranges from a minimum of about 1.2% in BB (3.7 km^2) to a maximum of about 4.6% in HB-NA (1.1 km^2).
- **Perimeters (MSL)** of the bays were derived from the NTS coastline vector polygon (MSL) using ArcGIS 10.0 Geometry Statistics tools and do not include the bays' mouths.
- **Volumes (CD)** were obtained by calculating the sum of depth values within each bay and multiplying it by the cell area (20 m x 20 m).
- **Axes length and width (MSL)** correspond to the distance from head to open boundary and mean width of the bays, respectively, as based on the NRCan NTS coastline shapefile. Lengths were obtained from head to mouth by digitizing of transects down the center of the bays, following the main axis. The resulting shapefile's geometry attributes provided the length data. Widths were calculated using equidistant (1 km apart) lines running perpendicular to the main axis (Figure 4). Lines were parallel to each other except for BDE and near CB entrance where this was not always possible due to the changing direction of the bay's main axis. The mean width was calculated as the average of the lengths of each line; some bays were subdivided to account for their variability in shape as illustrated in Figure 4. In addition, **axes orientations** are provided as degrees from North (increasing clockwise).
- **Mean depth and maximum depth (CD)** of the bays were obtained from zonal statistics calculated with the ArcGIS 10.0 Spatial Analyst toolset output.
- **Entrance width (MSL), depth (CD) and cross-section area (CD)** were calculated using various ArcGIS 10.0 tools. As with axes lengths, the entrance widths were obtained by calculating the length of transects shapefiles. The 3D Analyst toolset was used to produce a bathymetry profile along these transects based on the bathymetry raster surfaces. This tool

interpolates the depth values along the length of the transect line at intervals equal to that of the raster resolution. Mean and maximum depths were derived from the extracted profile and the cross-section area was calculated by multiplying the depths by the cell resolution (20 m) and summing them up.

- **Tidal ranges** were calculated from 19-year predicted time series following CHS definitions (Fisheries and Oceans Canada 2014). **Mean** tidal range (giving the MHWL) refers to the average from all the high waters minus the average from all the low waters of the 19-year prediction. **Large** tidal range (giving the HWL) refers to the average of the highest high waters (one from each of 19 years of predictions) minus the average of the lowest low waters (one from each of the 19 years of predictions). The ranges from Pushthrough and St. Alban's were averaged to provide a number for BDE. Belleoram data was used for BB and Harbour Breton data was used to derive the range for CB, HB-NA and GBDE.
- **Tidal volumes** were derived by calculating the difference between the CD volumes and the HWL and MHWL volumes. Since the HWL raster accounted for tides of 2 m, the range above 2 m CD of any given bay (e.g., 0.18 m in BB) was multiplied by the surface area of the HWL raster and added to the volume calculated at HWL. Likewise, to produce a volume for MHWL the value above 1 m (e.g., 0.38 m in BB) was multiplied by the surface area of the MSL raster and added to its volume.
- **Tidal currents** were calculated from the mean tidal volumes (i.e., using MHWL) and entrance areas as in Gregory et al. (1993):

$$mean\ tidal\ current = \frac{2}{T} \times \frac{Tidal\ volume}{Section\ Area}$$

where T refers to the M2 tidal constituent period (12.42 hours)

$$peak\ tidal\ current = \frac{\pi}{2} \times (mean\ tidal\ current)$$

- **Flushing time** was also calculated as in Gregory et al. (1993) and represents the time in hours that it takes for a tracer to be reduced to approximately one third of its initial concentration:

$$\frac{-12.42}{\ln\left(\frac{Volume\ (CD)}{Volume\ (CD) + Tidal\ volume}\right)}$$

The method is based on the tidal volume (mean tidal ranges were used here, 12.42 h is the M2 tidal period) and assumes complete mixing of the incoming volume with the surrounding embayment volume, complete removal from the bay of that same incoming volume, and no return of the flushed water to the bay on subsequent tidal cycles.

- **Watershed areas** were estimated using the topographic grid and the ArcGIS 10.0 Spatial Analyst hydrology toolset. The resulting raster data were vectorized to derive watershed polygons and associated areas.
- Monthly and yearly average **freshwater discharges** were estimated using the gauged river data available in the study area and adjusted by watershed areas which were not gauged. For each of the gauged rivers, the ratio of the river discharge (means and quartiles) and the river's watershed area was calculated (Figure 5). The ratio was then applied to the nearby watersheds which were not gauged to calculate their discharge rates. In BDE, 5 gauged river datasets were available (Figure 1) but only two were used as references: Conne River

for all the eastern watersheds and Salmon River at Long Pond for all the western watersheds of the fjord's main SW-NE axis. Salmon River at Powerhouse and at Round Pond data provide 'regulated' discharges subject to the BDE power generation facility demands and are therefore not representative of the natural drainage and discharge rates of the region. Salmon River at Powerhouse data were, however, used 'as is' for the calculation of the total watershed area and discharge rate. Southwest Brook has a small watershed area (10.4 km^2) and has been monitored for a relatively short period of time (2008-13) which made it statistically less robust. In BB, only one gauged river dataset was available and used as a reference (Bay du Nord River). In CB, HB-NA and GBDE, where no gauged river data were available, the Bay du Nord River data were used as a reference set even though it is geographically distant (about 30-80 km from the head of the bays considered).

- **ROFI** were calculated based on the annual average freshwater discharges of each bay and peak summer heat flux as given in Simpson and Sharples (2012; eq. 2.14):

$$Area\ (m^2) = \frac{-R_d \Delta\rho c_p}{\alpha Q_{max}}$$

  where: R_d is the yearly average freshwater discharge (m^3/s), $\Delta\rho$ is the density difference between freshwater and seawater (kg/m^3), c_p is the specific heat of seawater (J/kg/^{o}C), α is the thermal volume expansion coefficient (^{o}C^{-1}) and Q_{max} is the peak atmospheric heat flux in summer (W/m^2). For this study, a value of 26 kg/m^3 was used for $\Delta\rho$, a value of 3,999 J/kg/^{o}C for c_p (corresponding to seawater of 15^{o}C and 35 in salinity at atmospheric pressure), a value of 2.15 x 10^{-4} for α (corresponding to seawater of 15^{o}C and 35 in salinity at atmospheric pressure) and a value of 200 w/m^2 for Q_{max} (June-July value, taken from Umoh et al. 1995).

- **Tidal/Freshwater** ratio was calculated as in Gregory et al. (1993) as the ratio of the mean tidal volume (m^3) to the equivalent amount of freshwater entering the system during one-half tidal cycle (1/2 x 12.42 hours). The amount of freshwater (R_d, m^3/s) was based on the yearly averages (i.e., same R_d used above for the ROFI).

$$\frac{Tidal\ volume\ (mean\ tides)}{R_d\ \times 0.5\ \times 12.42\ \times 3600}$$

All the calculated values were rounded up based on their respective uncertainty. The areas were rounded up to the nearest power of 10 based on a 5% uncertainty (e.g., nearest 10 km^2 for an area from 200 to <2,000 km^2), the perimeters and axes length and width were rounded to the nearest 10 m, the volumes were rounded to the nearest power of 10 based on depth and area uncertainties of 1 m and 5%, respectively (e.g., nearest 100 x 10^6 m^3 for a bay area of 100 x 10^6 m^2). Depths were rounded to the nearest meter and cross-section areas were rounded to the nearest power of 10 based on this same 1 m depth uncertainty (e.g., nearest 1,000 m^2 for a cross-section length of 1,000 m). Tidal ranges, volumes and currents were rounded to the nearest cm, nearest power of 10 based on a 5% area uncertainty (e.g., nearest 10 x 10^6 m^3 for a bay area from 200 to <2,000 km^2) and 0.1 cm/s, respectively. Flushing times were rounded to the nearest hr and days. Tidal/Freshwater ratio and ROFI areas were rounded to the nearest 1 and 1 km^2, respectively. The 0-20 m metrics (volume of the bay and bay entrance area) refers to the upper 20 m of the water column. To obtain these values, the bathymetry raster dataset (CD) was modified to a surface representing only the top 20 m (i.e. raster cells with depth values >20 m were reclassified to 20 m). Using the method described above (for the entire water column), 0-20 m volume and bay entrance cross-section area for each bay were calculated from the reclassified raster surface. This depth range was selected for its relevance to fish farming activities which typically use fish cages which are 15-20 m in height.

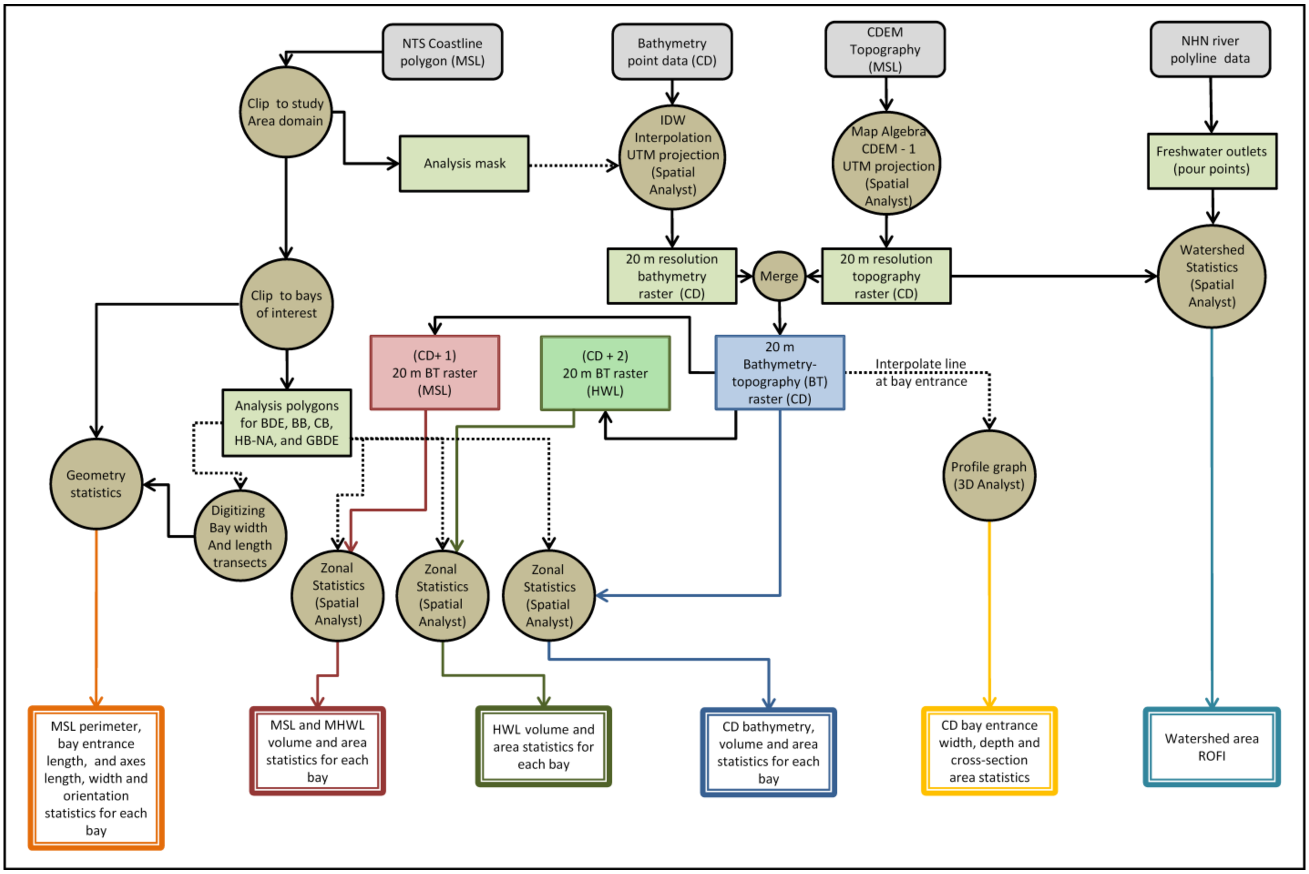


Figure 3: Workflow diagram of spatial analysis conducted, from raw data (grey rounded boxes) to final products, with Esri ArcGIS 10.0 software.

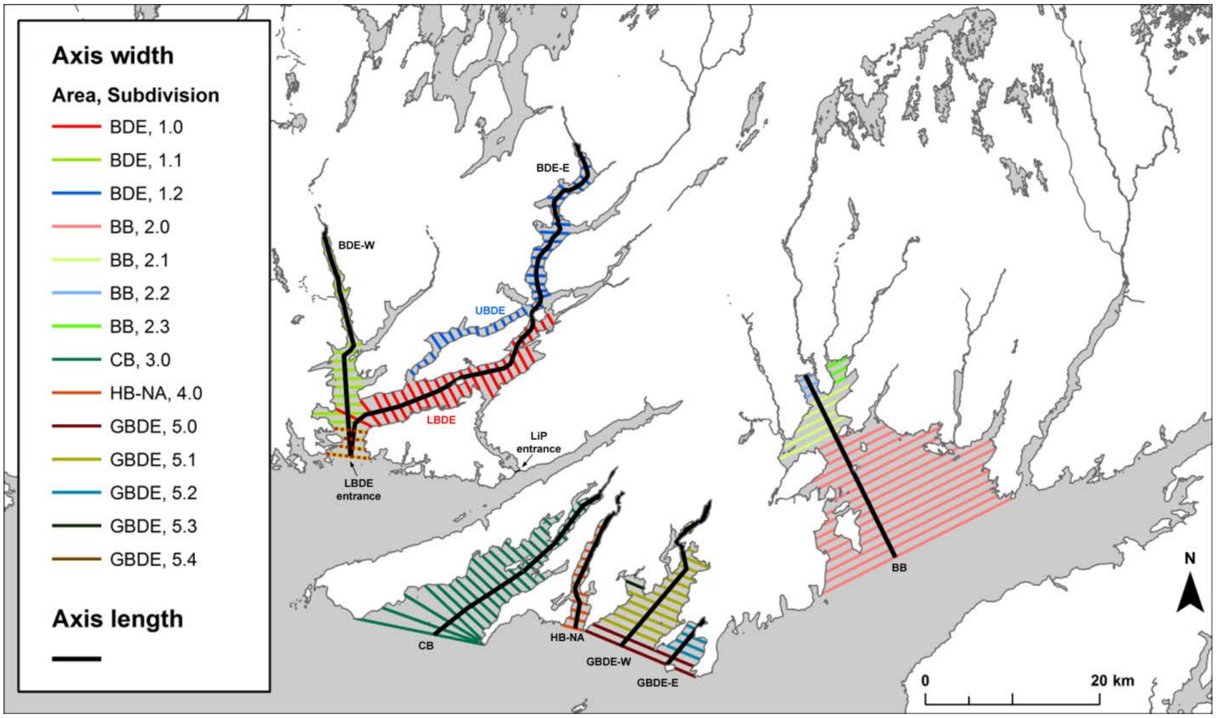


Figure 4: South coast of Newfoundland' bays of interest; within each bay, a change of colour indicates a subdivision of that bay.

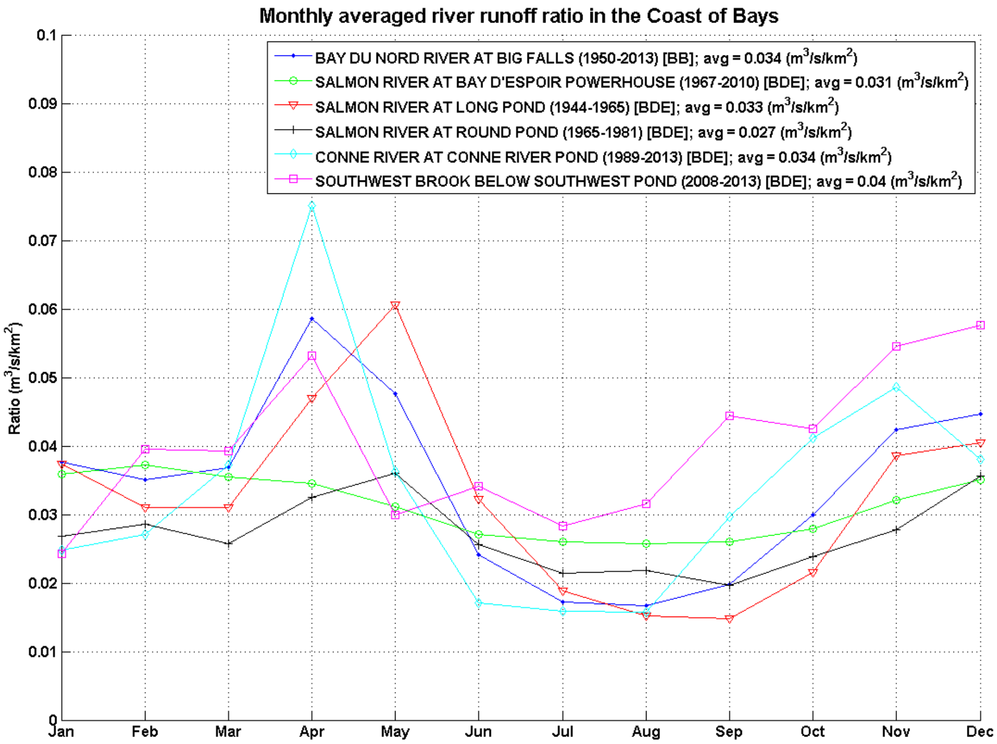


Figure 5: Measured river discharges per unit of drainage area for the region. The ratio is calculated by dividing the monthly mean discharge by the watershed area of the river. In the legend, 'avg' is the yearly average discharge ratio.

BATHYMETRY ANALYSIS

Along-channel transects

Key transects were selected to represent the bathymetric changes along the main channels of each region. The depth profiles for these key transects were generated using the same tools as for the metric analysis of the bays' entrances. The deepest path along a given channel was used as a criterion for transect placement except for HB, the Outer Connaigre Peninsula (OCP), and FB transects.

Transect characteristics such as length and depth (mean and depth) were calculated from the profiles.

Basins and Sills

For each of the bays studied, deep and shallow areas were identified to define basins and sills, respectively.

Polygons were digitized to represent the areas of interest in BDE, BB and in CP, the latter encompassing CB, HB-NA and GBDE. From the bathymetry raster layer, sills were identified and digitized to produce polyline shapefiles by following the shallowest path running along these sills. These polyline features were created running primarily in a south to north direction; if no notable south-north direction was apparent the polyline was created in a west to east direction. These polylines were then used to split the bay polygons into separate basin polygons.

The following metrics were calculated for each basin and sill:

- **Mean depth (CD) and maximum depth (CD) of the basins**
- **Surface Area (CD) and volume (CD) of each basin**
- **Mean depth (CD) and maximum depth (CD) of the sills**
- **Length (CD) and cross-section area (CD) of each sill**

NEAR-SURFACE (0-20 M) SEAWATER TEMPERATURE CLIMATOLOGY

Based on the geographical characteristics of the area, the data were grouped by regions: HB-BDE, FB-BB and CP. The annual cycles and statistics of temperature for each region were calculated for the upper 0-20 m depth layer. This depth range was selected for its relevance with respect to the height of aquaculture cages. In total, the number of stations available for analysis was 895 (836 casts and 59 time series) for HB-BDE, 792 stations (741 casts and 51 time series) for FB-BB and 295 (258 casts and 37 time series) for CP (Figure 6). To account for the trade-off between the relatively high temporal but poor spatial resolution of the time series versus the relatively good spatial but poor temporal distribution of the CTD or bottle casts and to remove the high frequency signals, the data of each station were daily averaged prior to calculating the annual cycles and statistics.

To calculate the annual cycles, a least-square minimization harmonic analysis procedure using a set of cosine functions was fitted to the data following Akenhead (1987) and Craig and Colbourne (2004):

$$T(t) = T_{mean} + \sum_{i}^{N} A_i \cos\left(\frac{2\pi}{\frac{365.25}{i}} t + \varphi_i \right)$$

where $T(t)$ is the temperature [°C], t the time [day], T_{mean} the aperiodic (mean) component [°C] and $\omega = \frac{2\pi}{365.25}$ the annual angular frequency, A_i the amplitude, and $\varphi_i$the phase [rad]. The fit may consider various frequencies, the main ones being N = 1, 2, 3, 4 which correspond to the annual, semi-annual, 4-month, and 3-month harmonic, respectively.

Annual statistics were calculated similarly to the ones reported by the BIO Coastal Shallow Water Temperature Climatology for Atlantic Canada (Fisheries and Oceans Canada 2015). Thus, daily averages were first grouped by month and averaged to create a monthly series for a given region. The annual cycle was then calculated from these later series by averaging the monthly mean values and calculating the standard deviation for a particular month. Minimum and maximum values of a particular month were calculated from the daily average series and thus correspond to the minimum and maximum daily averaged temperatures recorded at any given station of a given region for that particular month. In addition to these statistics, the number of years which had data for a given month and the number of observation days were calculated.

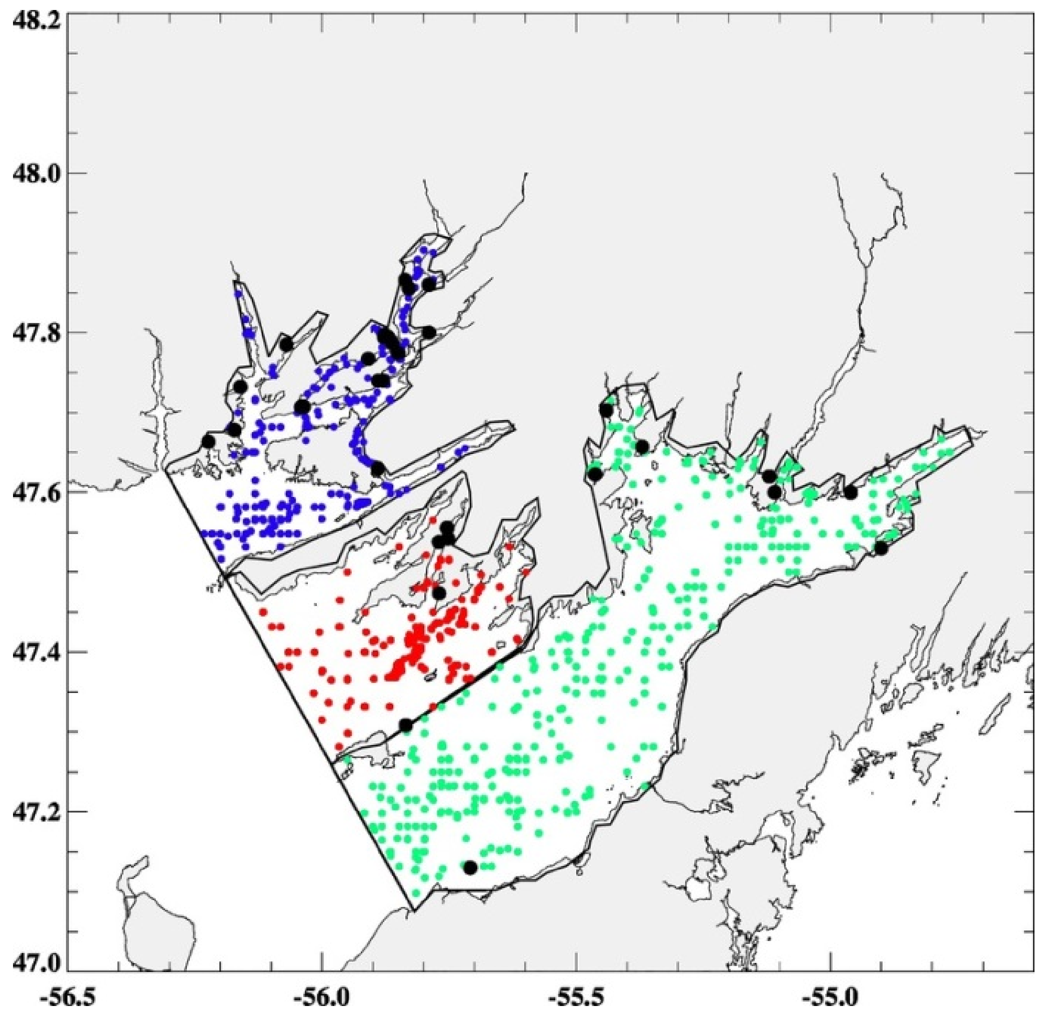


Figure 6: Locations of the stations where archived temperature data were available. Blue, red and green dots are stations used for the HB-BDE, CP and FB-BB domains, respectively. Black dots are the moored recorder stations (i.e., time series).

OFFSHORE WIND CLIMATE

Monthly wind roses and histograms were computed. The time series was first grouped by month. The directions were divided into 12 sectors of 30 degrees each and the number of instances the wind came from each sector was counted. The wind rose figures were constructed with the concentric circles specifying the different percentage of time the wind blew from a particular direction; the colors of the wind roses illustrate the ranges of measured wind speeds.

In addition, persistence analysis of the wind speed was calculated by measuring the duration when the wind speed continuously equals or exceeds a given threshold. Hourly data were considered and only continuous measurements without gaps or with gaps shorter than two hours were considered as sustained wind events.

RESULTS

DATA DESCRIPTION

A map of the bathymetry-topography is presented in Appendix A(i). Tidal constituents for the stations available within the study area are presented in Appendix A(ii) and available river discharge statistics are shown in Appendix A(iii).

METRICS

A summary of the main metrics can be found in Table 1, Table 2 and Table 3. Details of the metrics for each bay can be found in Appendix C which also includes a map and a depth profile of the entrance.

In addition, key parameters were also calculated for the three basins used as overwintering sites for the aquaculture industry in BDE, namely: Northwest Cove (NWC), Roti Bay (RB) and Ship Cove (SC). Maps of those basins are presented in Figure 7 and their metrics are summarized in Table 4.

A summary of the watershed areas and freshwater discharge rates within each bay is presented in Table 5 whereas more detailed information including that from selected BDE and BB main rivers as well as for the inner HB and FB watersheds and discharge rates is included in Appendix B. The main rivers were selected from visual inspection of NRCan 1:50,000 NTS maps and represent about 90% of the total drainage area and amount of freshwater input to BDE and BB overall. For the bays of the Connaigre Peninsula (CB, HB-NA and GBDE) which are surrounded by much smaller watersheds (of the order of 10 km^2 or less), only the total drainage area and discharge rates are given. Estimates of ROFI for the whole Coast of Bays region (detailed below) are illustrated in Figure 8.

The metrics indicate the following scaling information:

Size and topography

- The largest bay by area is BB (310 km^2, MSL) while the smallest bay is HB-NA (22 km^2, MSL).
- BDE coastline is the longest of all with a length of 467.43 km, almost twice that of the second longest, BB, with 255.95 km; the shortest coastline is that of HB-NA with a length of 56.29 km.
- The largest bay by volume is BB (54,100 x 10^6 m^3, CD) and the smallest bay is HB-NA (1,490 x 10^6 m^3, CD).

- The longest axis of a bay is found to be the northeast arm of BDE with 53.28 km whereas the widest bay of all is found to be BB with 11.74 km width on average. HB-NA is both the shortest and narrowest with values of 17.63 km by 1.28 km, respectively.
- The maximum depth of the study area is present in BDE (792 m) while BB is found to be the deepest embayment on average (179m). HB-NA presents both the shallowest maximum depth and shallowest overall mean depth (182 m and 73 m, respectively).
- BB presents the largest entrance with a width of 24.56 km while HB-NA has the smallest at 2.42 km, closely followed by BDE with a total entrance width of 4.74 + 0.61 = 5.35 km.

Tides

- The smallest tidal ranges were found in BDE with 1.27 m and 2.02 m in mean and large tide conditions, respectively. The maximum ranges were found in BB with 1.38 m and 2.18 m in mean and large tide conditions, respectively.
- Tides are largely semi-diurnal with M2 as a dominant constituent. Overall, M2 account for about 60% of the total range (large tides) in our study area. M2 amplitude is about 3 times the amplitude of the semi-diurnal constituent S2, about 5 to 7 times the amplitude of the semi-diurnal constituent N2 and about 9 to 10 times the amplitude of the diurnal constituents O1 and K1 (Table 3); giving some confidence to the use of the M2 period for the calculation of the tidal currents and flushing times.
- Due to its largest surface area, BB also presents the largest tidal volume with a value of about 400 x 10^6 m^3 mean tides, 650 x106 m^3 large tides. Due to its smallest surface area, HB-NA presents the smallest tidal volume with a value of about 28 x 10^6 m^3 mean tides, 47 x 10^6 m^3 large tides.
- Intertidal areas are small with values ranging from 4% (BB) to 16% (HB-NA) of the CD area using the un-rounded estimates of CD and HWL areas (not shown). In BB, the intertidal area is small enough that rounded values of MSL and HWL areas are equal (i.e., there are within the same margin of measurement uncertainty).
- The largest tidal flushing time is found in BB (71 days) closely followed by BDE (69 days); the smallest flushing time is in HB-NA (27 days).
- Tidal currents estimated at the bays' entrances, based on the period of the M2 constituent, are the strongest in BDE (1.0 cm/s; mean tides) and the weakest in BB (0.4 cm/s, mean tides). Overall, however, due to the small tidal volumes (small tidal ranges) and large cross-section area of the bays' entrances (deep basins), the estimated tidal currents at the bays' entrances are very weak with values of the order of 1 cm/s or less.

Freshwater discharge

- Due to its largest watershed area (7,917 km^2), freshwater discharge is also the largest in BDE with an estimated yearly average rate of 251.7 m^3/s. The smallest watershed area and freshwater discharge is found for HB-NA with values of 41.7 km^2 and 1.4 m^3/s (on average), respectively.
- Freshwater inputs are strongly seasonal among the bays, with a larger peak in spring (Apr-May), a low in summer (Jul-Aug) and a smaller peak in late fall to early-winter (Nov-Dec). This seasonal cycle is less pronounced in BDE due to the regulating effect of the power generation facility (ratio spring peak to summer trough of about 1.8 vs. about 3.5 in the other regions).

- Directly proportional to the freshwater discharges, the largest ROFI is that of BDE (about 609 km^2), followed by BB (about 172 km^2) and the CP region (about 6 km^2, 3 km^2 and 15 km^2 for CB, HB-NA and GBDE, respectively). Adding the effect of discharges from the remaining inner HB (~21 m^3/s, see Appendix B, corresponding to a ROFI of about 51 km^2) and FB as whole without BB (~93 m^3/s, see Appendix B, corresponding to a ROFI of about 225 km^2) a total ROFI of about 1,081 km^2 is found for the Coast of Bays as a whole (for a total freshwater discharge of about 447 m^3/s). This latter estimated area is significantly larger than the 792 km^2 combined area (MSL) of the five bays studied. The importance of the Long Harbour river discharge (about 39 m^3/s yearly average) should also be noted; given its proximity to BB, its corresponding ROFI (about 94 km^2) could cover a significant portion of BB (~30% of its total area).

Table 1: Metrics summary of Bay d'Espoir (BDE), Belle Bay (BB), Connaigre Bay (CB), Harbour Breton - Northeast Arm (HB-NA), and Great Bay de L'Eau (GBDE). For BDE, data for the two entrances which are Lower BDE (LBDE) and Little Passage (LiP) and metrics of the two main arms of BDE and GBDE (length and width) are provided (see also Figure 4). Values are rounded based on their uncertainty.

Metrics	BDE	BB	CB	HB-NA	GBDE
Area (CD) [km^2]	210	300	123	20	93
Area (HWL) [km^2]	240	310	137	24	100
Area (MSL) [km^2]	230	310	133	22	97
Perimeter (MSL) [km]	467.43	255.95	128.27	56.29	115.26
Volume (CD) [10^6 m^3]	36,800	54,100	9,900	1,490	7,100
Volume (0-20 m, CD) [10^6 m^3]	3,800	5,700	2,300	360	1,550
Axis Length (MSL) [km]	27.72 (BDE-W) 53.28 (BDE-E)	23.47	29.08	17.63	21.59 (GBDE-W) 7.16 (GBDE-E)
Axis Width (MSL) [km] **(more details given in Table 2)**	2.29 (BDE-W) 2.23 (BDE-E)	11.74	4.71	1.28	3.70
Axis Orientation (^{o}N), see also Figure 4	355° (BDE-W) 70° (BDE-E, LBDE) 15° (BDE-E, UBDE)	335°	50°	20°	30° (GBDE-W) 40° (GBDE-E)
Mean Depth (CD) [m]	172	179	80	73	77
Maximum Depth (CD) [m]	792	606	226	182	313
Entrance Width (MSL) [km]	4.74 (LBDE) 0.61 (LiP)	24.56	15.36	2.42	13.90
Entrance Depth (CD) - **Mean [m]** - **Maximum [m]**	 257 (LBDE); 75 (LiP) 556 (LBDE); 130 (LiP)	 194 349	 59 124	 63 92	 76 196
Entrance Cross-section Area (CD) [m^2]	1,224,000 (LBDE) 44,400 (LiP)	4,750,000	810,000	142,000	900,000
Entrance Cross-section Area (CD), 0-20 m [m^2]	89,000 (LBDE) 11,600 (LiP)	490,000	270,000	43,000	210,000
Tidal Range - **Mean [m]** - **Large [m]**	 1.27 2.02	 1.38 2.18	 1.35 2.12	 1.35 2.12	 1.35 2.12
Tidal Volume - **Mean [10^6 m^3]** - **Large [10^6 m^3]**	 280 460	 400 650	 172 279	 28 47	 128 206
Tidal Current - **Mean [cm/s]** - **Peak [cm/s]**	 1.0 1.5	 0.4 0.6	 1.0 1.5	 0.9 1.4	 0.6 1.0
Flushing Time - **[hr]** - **[days]**	 1647 68	 1708 70	 722 30	 658 27	 695 29
Tidal/Freshwater ratio	49	250	2957	908	954
ROFI [km^2]	609	172	6	3	15

Table 2: Width of the subdivisions for Bay d'Espoir (BDE), Belle Bay (BB), Connaigre Bay (CB), Harbour Breton - Northeast Arm (HB-NA), and Great Bay de L'Eau (GBDE) as illustrated in Figure 4.

Bay	Subdivision number	Mean width (km, MSL)
BDE	1.0	3.10
BDE	1.1	2.29
BDE	1.2	1.37
BB	2.0	17.06
BB	2.1	6.26
BB	2.2	2.16
BB	2.3	2.12
CB	3.0	4.71
HB-NA	4.0	1.28
GBDE	5.0	12.90
GBDE	5.1	4.52
GBDE	5.2	2.63
GBDE	5.3	1.36
GBDE	5.4	0.69

Table 3: Summary of the main tidal constituents (amplitudes -m-; phases -deg. from Greenwich, calculated from local time as provided by CHS in Appendix A(ii)-) for sea level within the Coast of Bays. For BDE, the first row corresponds to the constituents of Pushthrough and the second row to the constituents of St. Alban's.

-	BDE	BB	CP
M2	0.59; 352.4 0.61; 0.9	0.65; 353.7	0.63; 354.9
S2	0.17; 33.0 0.19; 27.5	0.19; 40.9	0.19; 30.2
N2	0.11; 335.5 0.14; 333.3	0.09; 340.2	0.13; 338.0
O1	0.06; 183.8 0.08; 196.4	0.07; 180.3	0.07; 199.9
K1	0.06; 185.6 0.05; 189.9	0.06; 200.9	0.06; 201.9

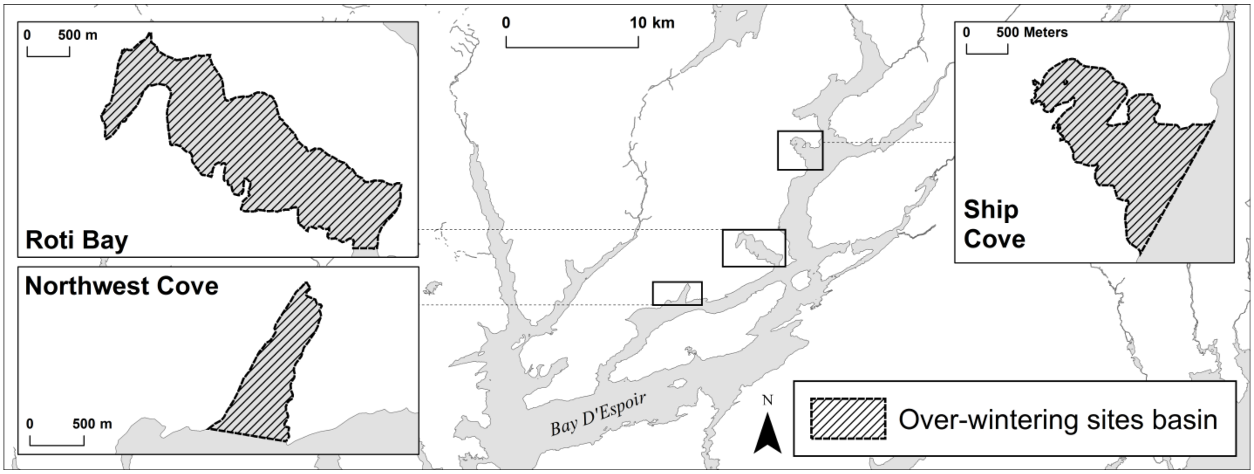


Figure 7: BDE overwintering sites.

Table 4: Northwest Cove (NWC), Roti Bay (RB) and Ship Cove (SC) overwintering site metrics. Values are rounded based on their uncertainty.

Metrics	NWC	RB	SC
Area (CD) [km^2]	0.54	2.8	1.5
Area (HWL) [km^2]	0.68	3.4	2.3
Area (MSL) [km^2]	0.57	3.1	2.1
Perimeter (MSL) [km]	3.42	12.36	8.12
Volume (CD) [10^6 m^3]	20.5	42	44
Mean Depth (CD) [m]	38	15	29
Maximum Depth (CD) [m]	149	44	97
Entrance Width (MSL) [km]	0.73	0.28	1.83
Entrance Cross-section Area (CD) [m^2]	56,900	9,600	134,000
Tidal Volume - **Mean [10^6 m^3]** - **Large [10^6 m^3]**	 0.71 1.24	 3.7 6.4	 2.2 3.9
Tidal Current - **Mean [cm/s]** - **Peak [cm/s]**	 0.1 0.1	 1.7 2.7	 0.1 0.1
Flushing Time - **[hr]** - **[days]**	 368 15	 146 6	 256 11

Table 5: Watershed areas and monthly freshwater discharges summary for Bay d'Espoir (BDE), Belle Bay (BB), Connaigre Bay (CB), Harbour Breton - Northeast Arm (HB-NA), and Great Bay de L'Eau (GBDE). For each watershed, monthly mean, lower quartile and upper quartile discharge is given as series of 3 rows, respectively. All discharge rates are given in m^3/s. 'Avg' is the yearly average; see Appendix B for more details.

River	Watershed	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
TOTAL BDE (main	7,202 km^2	249.2	256.7	255.7	289.5	240.9	188.3	175.7	172.1	186.3	210.1	248.8	257.2	228.1
rivers)		199.9	211.2	201.4	215.2	192.9	149.5	140.4	144.8	151.1	155.3	214.4	218.0	208.4
		298.0	303.3	305.5	352.1	290.8	227.4	208.6	215.8	222.8	254.4	289.7	313.0	254.5
TOTAL BDE (all)	7,917 km^2	272.2	277.7	279.6	331.6	276.8	206.7	188.3	183.1	201.3	231.4	279.4	285.4	251.7
		212.0	221.9	213	242.3	218.0	161.3	146.8	149.7	158.9	166.4	236.9	236.2	228.1
		332.6	331.7	342.1	410.0	340.0	248.5	224.0	232.8	245.8	282.2	327.4	349.5	280.8
TOTAL BB (main rivers)	1,849 km^2	68.6	64.0	67.3	107	87.2	44.1	31.5	30.7	36.2	54.5	77.2	81.5	62.2
		41.9	41.4	45.0	81.7	62.8	33.5	20.0	16.7	22.3	32.2	63.8	60.3	57.2
		84.5	82.6	84.3	133.1	107.7	54.5	38.1	37.6	48.2	67.7	93.2	96.7	69.6
TOTAL BB (all)	2,095 km^2	77.8	72.5	76.2	121.1	98.7	49.9	35.7	34.7	41.0	61.9	87.5	92.3	70.6
		47.4	46.9	50.9	92.7	71.3	37.8	22.8	18.9	25.3	36.6	72.2	68.4	64.9
		95.9	93.6	95.5	150.7	122	61.9	43.2	42.6	54.6	76.8	105.8	109.5	78.9
TOTAL CB	78.0 km^2	2.9	2.7	2.8	4.5	3.7	1.9	1.3	1.3	1.5	2.3	3.3	3.4	2.6
		1.8	1.7	1.9	3.5	2.7	1.4	0.8	0.7	0.9	1.4	2.7	2.5	2.4
		3.6	3.5	3.6	5.6	4.5	2.3	1.6	1.6	2.0	2.9	3.9	4.1	2.9
TOTAL HB-NA	41.7 km^2	1.5	1.4	1.5	2.4	2.0	1.0	0.7	0.7	0.8	1.2	1.7	1.8	1.4
		0.9	0.9	1.0	1.8	1.4	0.8	0.5	0.4	0.5	0.7	1.4	1.4	1.3
		1.9	1.9	1.9	3.0	2.4	1.2	0.9	0.8	1.1	1.5	2.1	2.2	1.6
TOTAL GBDE	177.9 km^2	6.6	6.2	6.5	10.3	8.4	4.2	3.0	2.9	3.5	5.3	7.4	7.8	6.0
		4.0	4.0	4.3	7.9	6.1	3.2	1.9	1.6	2.1	3.1	6.1	5.8	5.5
		8.1	7.9	8.1	12.8	10.4	5.3	3.7	3.6	4.6	6.5	9.0	9.3	6.7

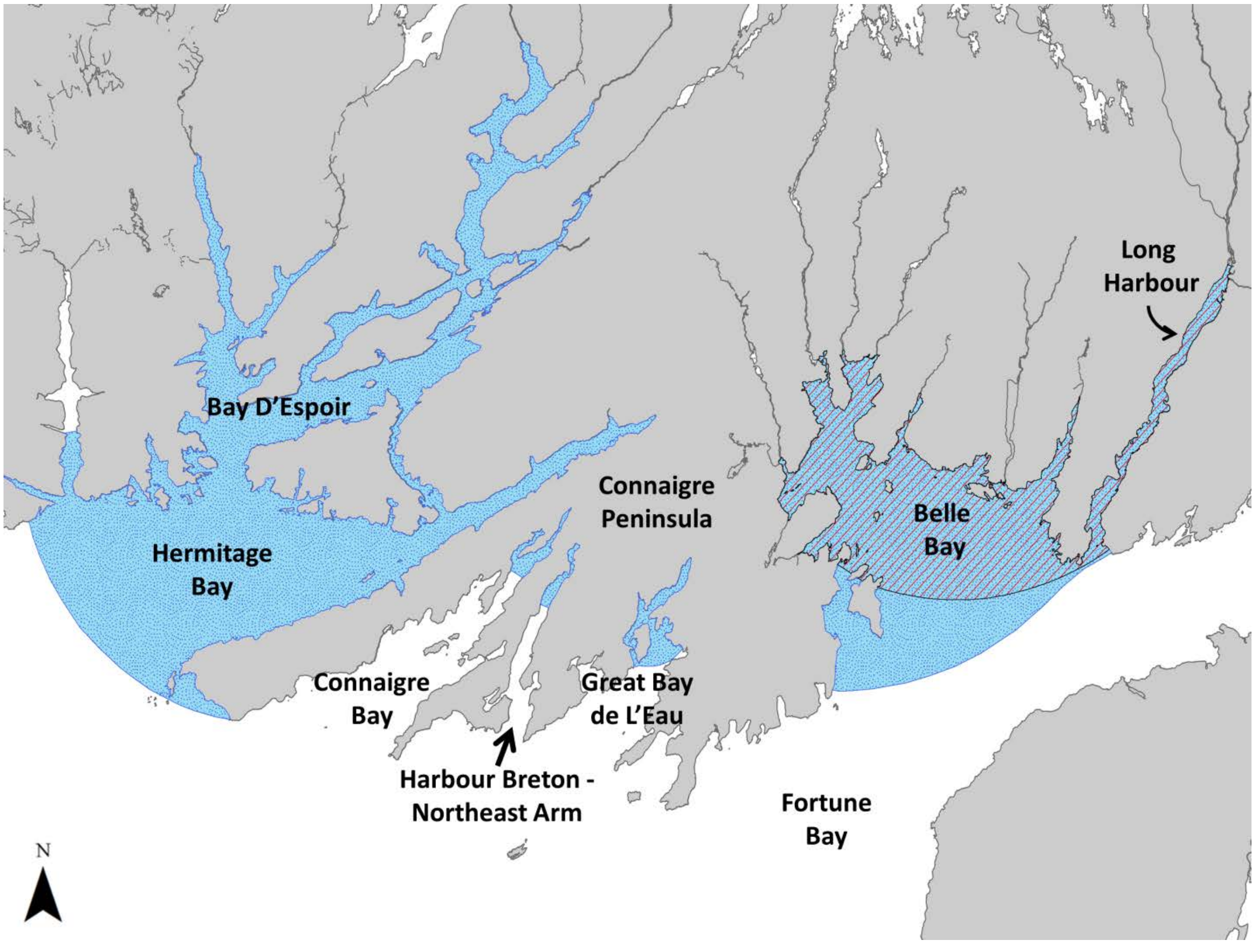


Figure 8: Region of Freshwater Influence (Simpson 1997) estimated areas (in blue) in the Coast of Bays. The red hatched polygon represents the area corresponding to the runoff directly received by Belle Bay and the nearby Long-Harbour estuary. The remaining area corresponds to the runoff received from elsewhere in Fortune Bay.

BATHYMETRY

Along-channel transects

A map with the selected along-channel transects and a summary of their dimensions (length, maximum and mean depth) are presented in Figure 9 and Table 6. The transects are shown in Appendix D.

The transect lengths vary from less than 10 km (FB-LH) to more than 100 km (FB) and are generally deeper in BDE and in BB than in the CP's bays (CB, HB-NA and GBDE).

The transect profiles (Appendix D) illustrate the complexity of the study area's bathymetry and allow identifying basins and sills that are described in more detail in the next section. All depths are with respect to CD.

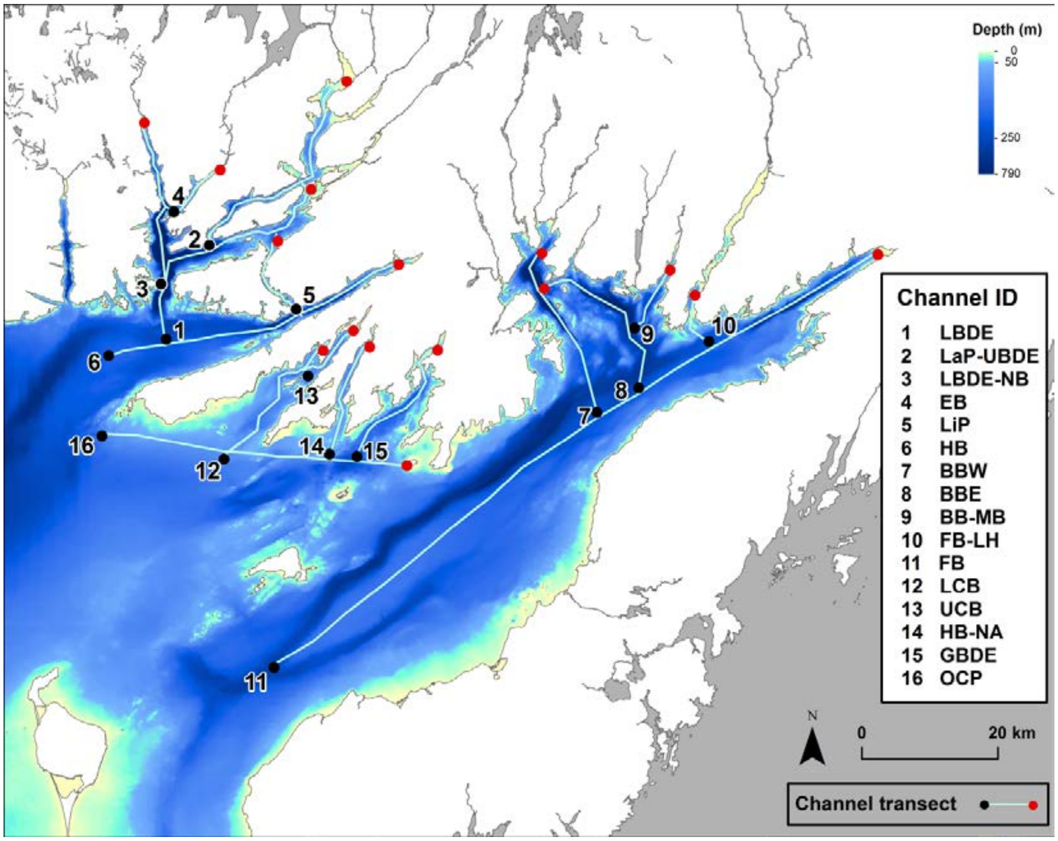


Figure 9: Along-channel transects of the study area.

Table 6: Minimum, maximum, and average depths for along-channel transects, all with respect to CD.

Channel ID	Length (km)	Maximum Channel Depth (m)	Minimum Channel Depth (m)	Mean Channel Depth (m)
1 LBDE	39.36	777	25	326
2 LaP-UBDE	37.36	389	4	154
3 LBDE-NB	25.38	786	1	469
4 EB	10.60	454	2	130
5 LiP	15.65	375	0	124
6 HB	45.82	459	49	285
7 BBW	27.65	604	145	397
8 BBE	27.80	526	105	364
9 BB-MB	11.59	341	126	255
10 FB-LH	9.77	271	3	110
11 FB	107.69	411	104	246
12 LCB	24.46	190	28	140
13 UCB	11.24	220	22	149
14 HB-NA	18.69	189	15	117
15 GBDE	23.07	307	11	184
16 OCP	45.36	315	15	126

Basins and Sills

Results are grouped per region (BDE, BB and CP). Maps of the identified main basins and sills of the region of interest can be found in Figures 10-12. Companion tables to the figures, Table 7 to Table 12, present a summary of their metrics (depths, volumes, lengths and areas). The cross-section profiles of the sills are shown in Appendix E(i) to Appendix E(iii) where the sill label is placed at the starting point of each transect.

Both BDE and BB regions present deep and voluminous basins (order of 10^9 m^3) separated by shallow sills with maximum depth typically around 100 m or less. In the CP region (CB, HB-NA and GBDE), the basins are generally smaller, although CB basin B2 & B3 and GBDE basin B10 are nevertheless substantial in size and volume. The offshore basin B1 of the CP region is also very large, being in fact larger than any basin of the BDE or BB region.

The deepest basin is found in the BDE region (B3) with a maximum depth of 792 m. The deepest basin in the BB region is B2 which has a maximum depth of 606 m. In the CP region, and omitting the large offshore B1, the deepest basin is B10 with a maximum depth of 313 m. The shallowest sill (as of mean depth) of the study area is found in GBDE with a mean depth of 5 m (S16). The shallowest sill in BDE is S4 (Riches Island) with a mean depth of 9 m and the shallowest sill of BB region is S7 (3 m, Long Island).

It should be noted that the list of basins provided in this study is not definitive. Only the main basins meant to be identified, either as being conspicuous side bays (e.g., in BB) and/or well defined depressions by the main along-channel transects (e.g., in BDE).

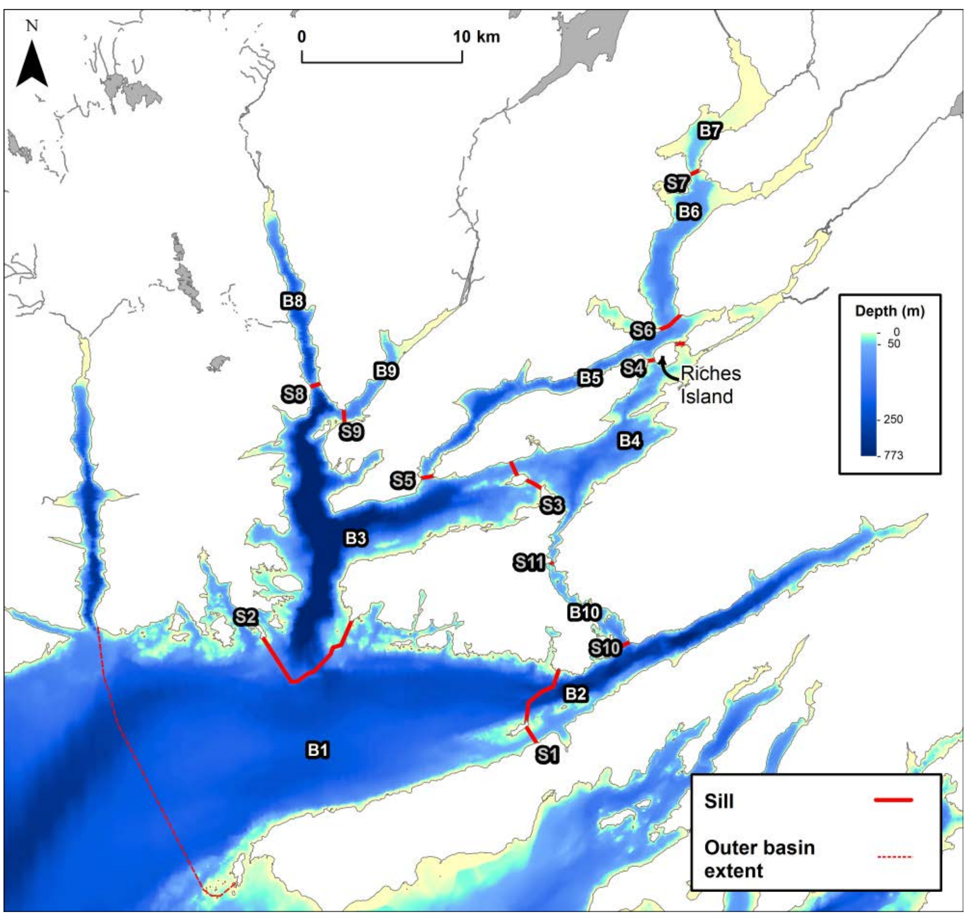


Figure 10: Bay d’Espoir basins (Bn) and sills (Sn).

Table 7: Bay d'Espoir basins' parameters, all with respect CD.

Basin ID	Maximum Depth (m)	Mean Depth (m)	Area (km^2)	Volume (10^6 m^3)
B1	346	200	280.0	55,600
B2	464	168	45.0	7,560
B3	792	270	109.0	29,500
B4	251	85	39.0	3,300
B5	293	115	25.0	2,800
B6	176	75	21.0	1,590
B7	59	16	11.5	180
B8	377	162	11.4	1,850
B9	189	66	7.0	459
B10	175	53	5.6	298

Table 8: Bay d'Espoir sills' parameters, all with respect to CD.

Sill ID	Length (km)	Maximum Depth (m)	Mean Depth (m)	Cross section Area (m^2)
S1	5.77	303	163	861,000
S2	8.99	291	127	1,146,000
S3	2.64	107	53	106,000
S4	2.60	26	9	6,500
S5	0.69	78	53	37,700
S6	1.58	102	49	77,000
S7	0.57	27	17	9,800
S8	0.66	214	115	80,200
S9	0.75	192	120	90,800
S10	0.64	109	70	47,900
S11	0.22	26	14	3,200

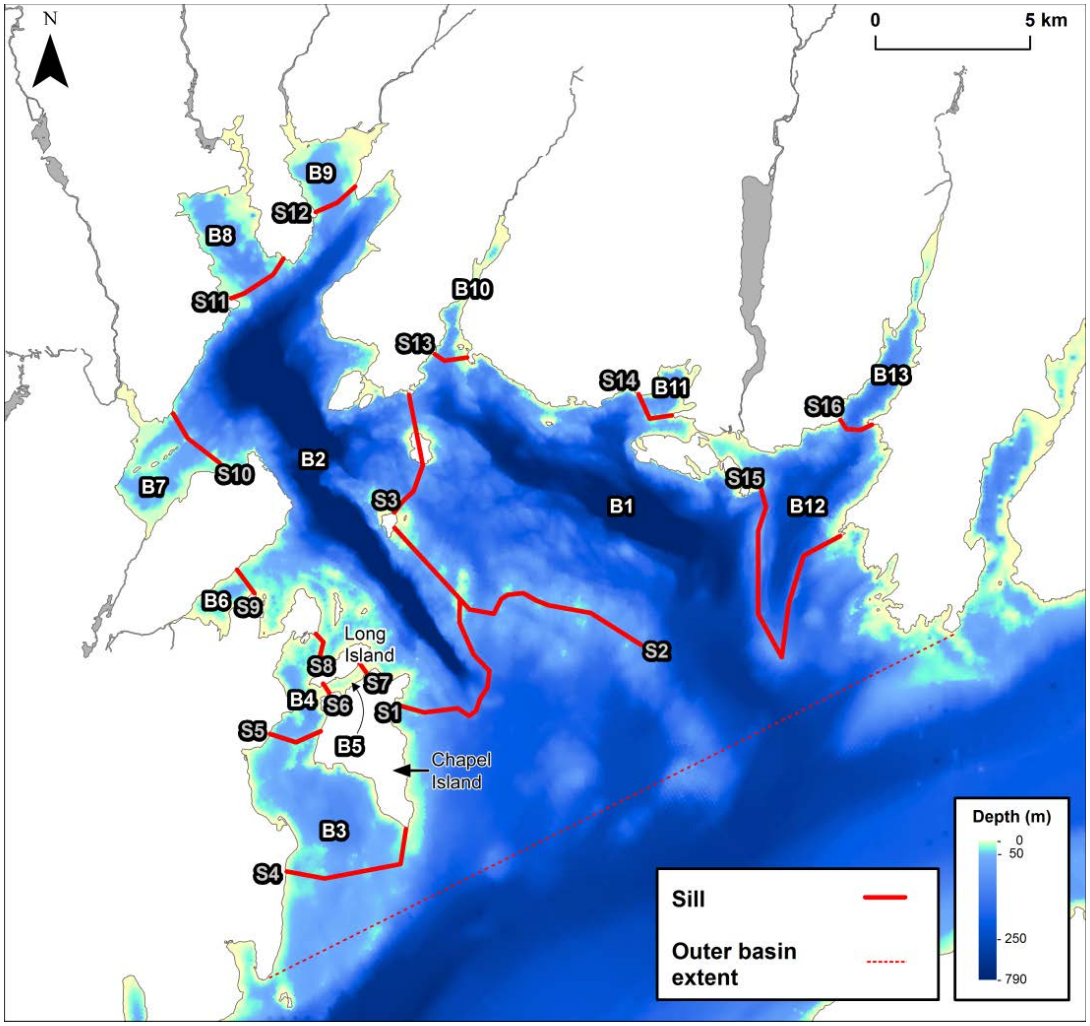


Figure 11: Belle Bay basins (Bn) and sills (Sn).

Table 9: Belle Bay basins' parameters, all with respect to CD.

Basin ID	Maximum Depth (m)	Mean Depth (m)	Area (km^2)	Volume (10^6 m^3)
B1	536	201	168.0	33,400
B2	606	213	73.0	15,370
B3	145	63	15.0	920
B4	108	34	4.2	134
B5	29	8	0.6	3.4
B6	72	26	2.1	49
B7	99	36	6.9	237
B8	131	52	7.3	333
B9	85	36	5.1	154
B10	139	34	2.3	62
B11	149	55	2.1	100
B12	328	178	17.2	2,960
B13	215	81	5.2	385

Table 10: Belle Bay sills' parameters, all with respect to CD.

Sill ID	Length (km)	Maximum Depth (m)	Mean Depth (m)	Cross section Area (m^2)
S1	6.82	213	103	711,000
S2	9.90	101	55	547,000
S3	4.15	138	66	204,000
S4	4.90	94	44	221,000
S5	1.76	51	33	61,000
S6	0.35	9	3	1,000
S7	0.41	6	3	900
S8	1.12	17	7	8,000
S9	0.94	33	22	22,000
S10	2.24	99	56	128,000
S11	2.18	96	53	120,000
S12	1.54	86	46	72,000
S13	1.12	106	52	59,000
S14	1.59	69	34	51,000
S15	11.25	202	124	1,400,000
S16	1.21	166	98	122,000

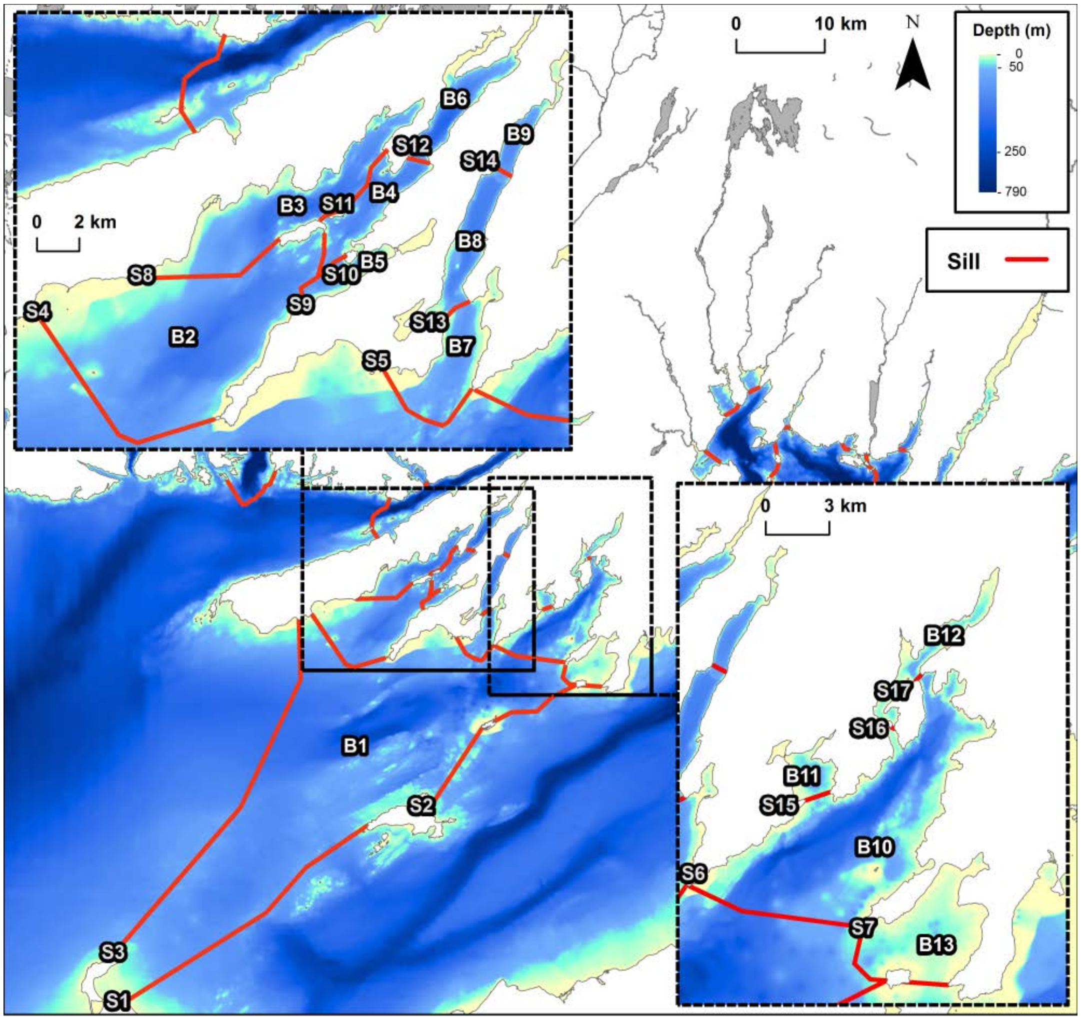


Figure 12: Connaigre Peninsula basins (Bn) and sills (Sn).

Table 11: Connaigre Peninsula basins' parameters, all with respect to CD.

Basin ID	Maximum Depth (m)	Mean Depth (m)	Area (km^2)	Volume (10^6 m^3)
B1	332	120	710.0	84,500
B2	191	88	68.0	5,890
B3	207	82	27.0	2,230
B4	169	89	9.4	827
B5	120	50	4.8	239
B6	226	104	7.5	779
B7	116	58	12.4	710
B8	182	91	9.0	819
B9	137	63	3.8	236
B10	313	106	60.3	6,380
B11	63	25	4.2	102
B12	80	18	6.2	111
B13	74	16	19.0	300

Table 12: Connaigre Peninsula sills' parameters, all with respect to CD.

Sill ID	Length (km)	Maximum Depth (m)	Mean Depth (m)	Cross section Area (m^2)
S1	34.06	125	76	2,580,000
S2	22.58	108	53	1,120,000
S3	44.01	198	111	4,870,000
S4	11.64	106	57	680,000
S5	6.28	117	46	236,000
S6	8.34	199	98	764,000
S7	6.16	42	24	111,000
S8	7.17	124	68	454,000
S9	3.79	93	51	196,000
S10	1.73	84	53	93,000
S11	4.91	131	65	259,000
S12	1.10	92	66	75,000
S13	1.44	86	41	62,000
S14	0.78	104	71	58,300
S15	1.21	34	19	23,000
S16	0.17	9	6	1,000
S17	0.43	18	12	5,400

NEAR-SURFACE (0-20 M) SEAWATER TEMPERATURE CLIMATOLOGY

Figure 13 to Figure 15 show the archived temperature data of the upper 0-20 m and the harmonic fit (N=3) of the upper 0-5 m and upper 5-20 m for the different regions.

A large variation of temperature during the warmer seasons is evident. Temperatures near 0°C have been measured within that 0-20 m layer even in summer when they can also reach more than 20°C. This large variation suggests a relatively shallow thermocline (i.e., within the first 0-20 m depth) and/or a potential for significant short-term variability as a result of processes such as upwelling/downwelling events or internal waves.

Due to this large variation of temperature, surface (0-5 m) and sub-surface (5-20 m) layers were selected for the harmonic analysis. The best fit was found using N=3, corresponding to periods of 12, 6 and 4 months. Mean temperature and the amplitude and phase of the harmonics were computed and are presented in Table 13 and Table 14. Phase is given in day of year from January 1, or year day (yd), and is the day of the cosine maxima (i.e., the highest temperature of the yearly cycle). The whole domain values were calculated using the entire dataset. Using the bootstrap technique of Efron and Tibshirani (1993) 95% confidence intervals of about 0.1°C and <1 d for the annual (i.e., 12 months) harmonic amplitudes and phases were found, respectively.

Monthly statistics of the upper 0-20 m are presented in Table 15 to Table 17 and illustrated below the harmonic fit plots in Figure 13 to Figure 15.

For the near-surface layer (0-5 m), an annual (12 months period harmonic) amplitude of 6.9°C is found for the Coast of Bays area as a whole. The difference of annual amplitude among the bays is of the order of 0.7°C, being larger in CP (7.3°C) and smaller in HB-BDE and FB-BB (6.6°C). Annual phases vary from 232 (yd) in HB-BDE to 239 (yd) in FB-BB, or seven days lag between the two regions; all correspond to an annual maxima occurring in late August. Amplitudes decrease and phases increase in the sub-surface layer (5-20 m) in all the regions with an overall annual amplitude of about 5.3°C and annual phase equal to 248 (yd); 14 days later than in the surface layer. This corresponds to a vertical mixing rate of about $10^2/(14 \times 24 \times 3{,}600) \sim 0.8 \times 10^{-4}\ m^2s^{-1}$. Among the regions, the rate varies from a low of $0.5 \times 10^{-4}\ m^2s^{-1}$ in HB-BDE to a high of $1.3 \times 10^{-4}\ m^2s^{-1}$ in CP. FB-BB condition lays somewhat in the middle with a value of about $1 \times 10^{-}\ m2s^{-1}$.

Over the 0-20 m depth range, monthly averaged temperatures vary from about 0.5-1°C in February-March to about 12.5-13.5°C in August with a standard deviation of the order of 0.5-1°C and 2-3°C, respectively. Comparing among the bays, the coldest temperature was recorded in FB-BB with -1.6°C in February 1975 whereas the warmest daily temperature recorded was in HB-BDE with almost 23°C in July 2009. The daily maximums were systematically recorded in HB-BDE from winter (January) to fall (October) while the daily minimums were also systematically observed in HB-BDE but from mid-summer (August) to fall (November); indicating again that HB-BDE would be subject to stronger stratification and less vertical mixing. In general, winter temperature conditions are found comparable among the bays; on average around 1°C from January to March. Summer conditions (July to September) appear a little warmer in CP than in both HB-BDE and FB-BB; by almost 1°C from the former, on average. It is, however, clearly less extreme than in HB-BDE on a daily basis (colder daily maximums and warmer daily minimums); indicating here also a stronger vertical mixing climate.

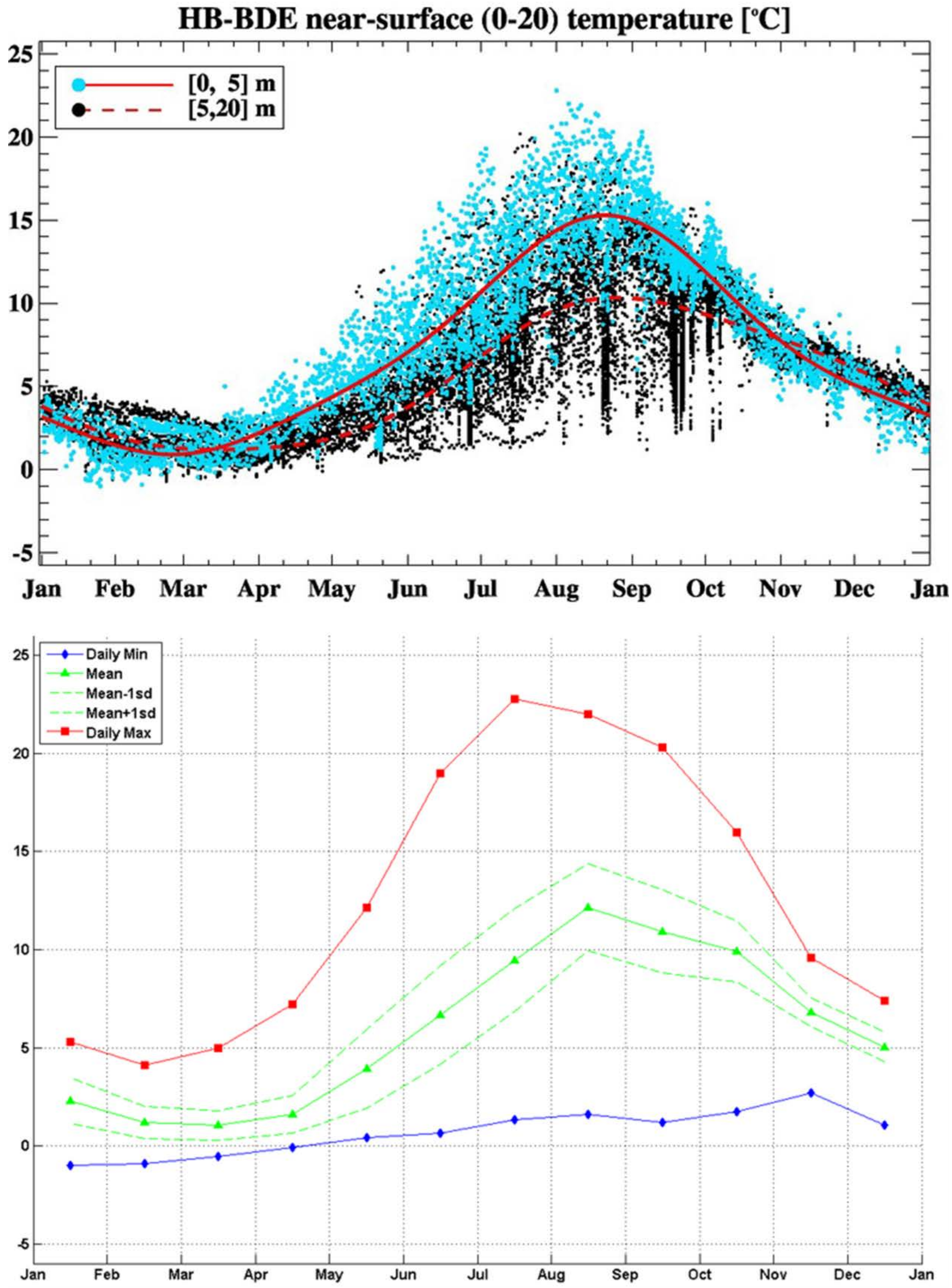
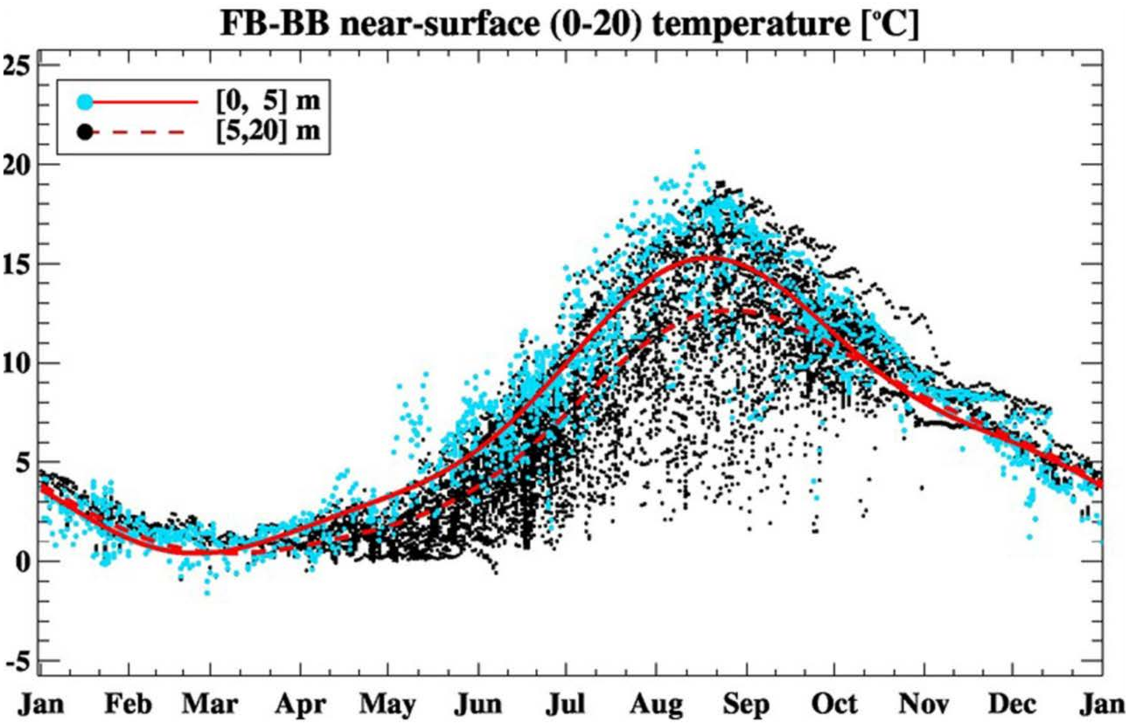


Figure 13: Upper layer (0-20 m) temperatures in HB-BDE from available archived data. Red lines represent the least square fits (N=3) for the 0-5 and 5-20 m layers (top). Monthly statistics are based on the daily averaged series (bottom).



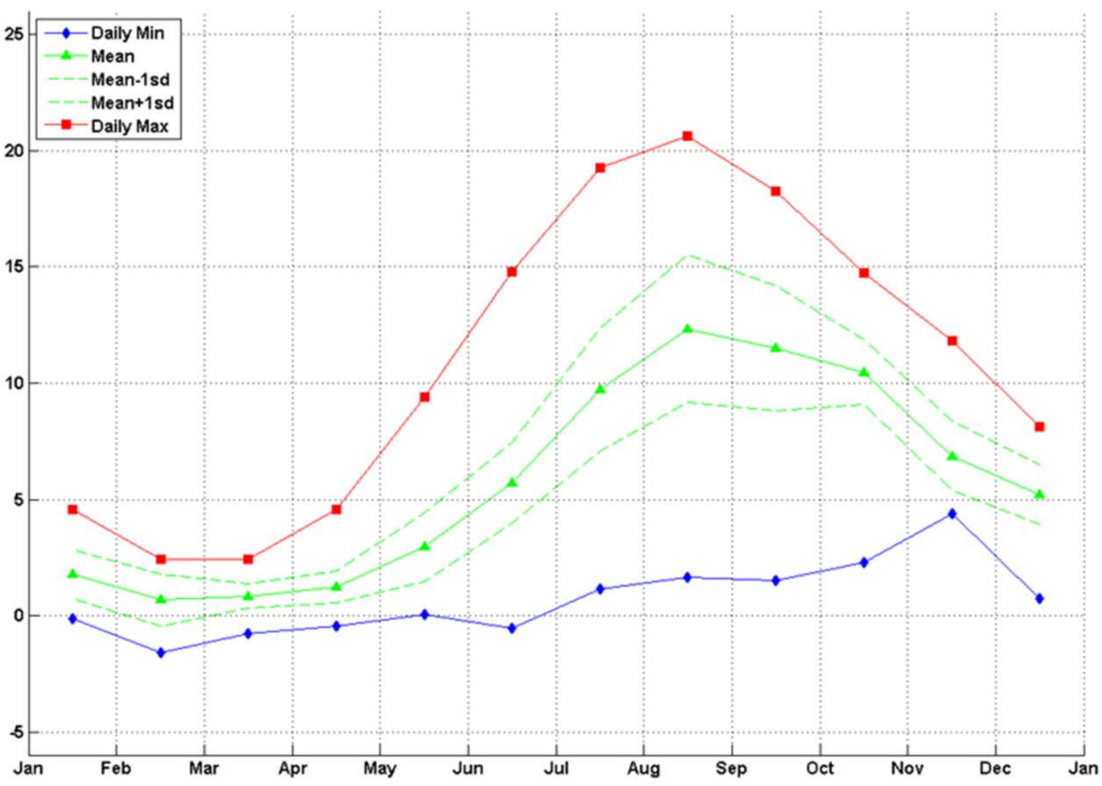


Figure 14: Upper layer (0-20 m) temperature in FB-BB from available archived data. Red lines represent the least square fit (N=3) for the 0-5 and 5-20 m layers (top). Monthly statistics based on the daily averaged series (bottom).

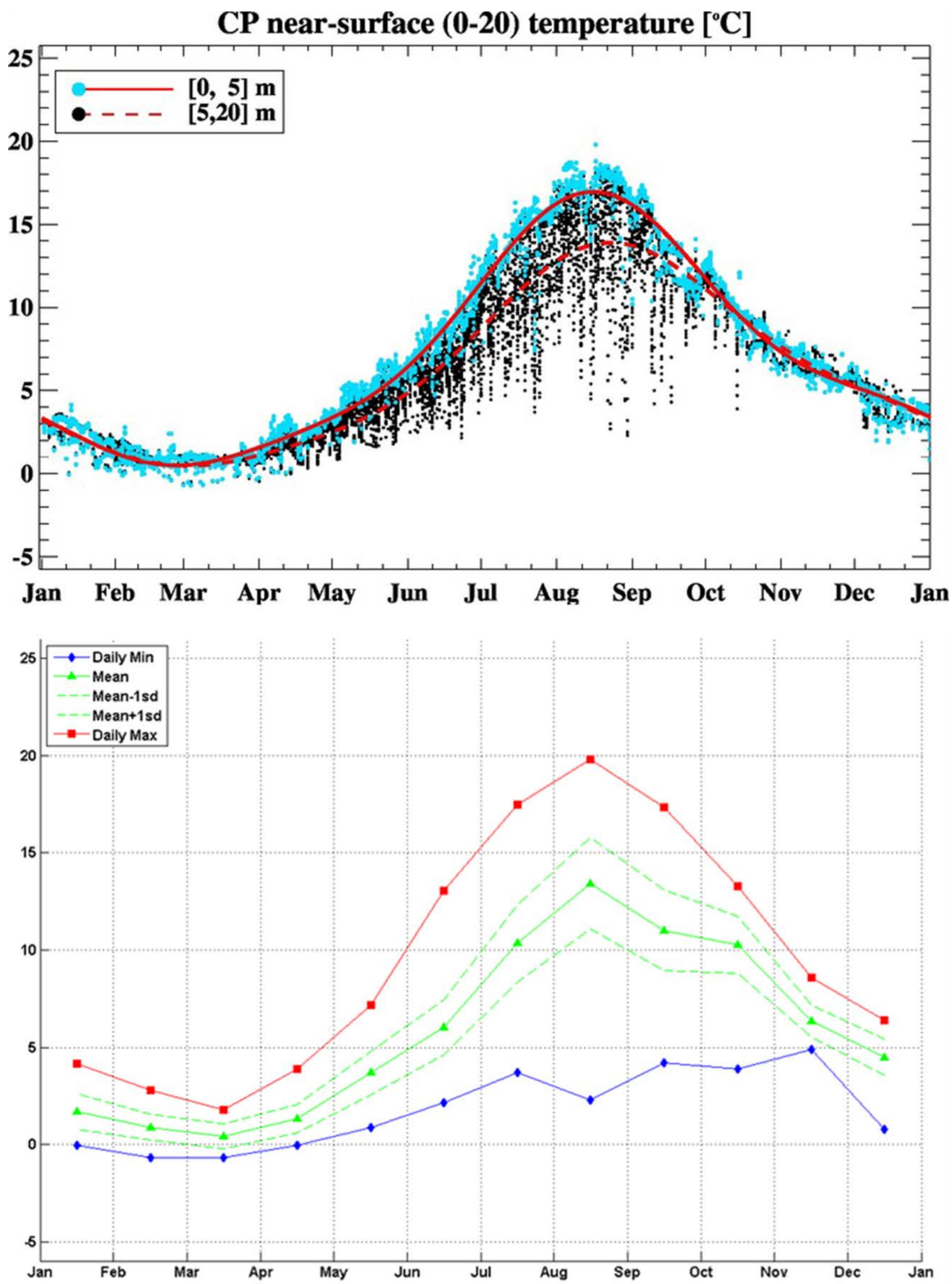


Figure 15: Upper layer (0-20 m) temperature in CP from available archived data. Red lines represent the least square fit (N=3) for the 0-5 and 5-20 m layers (top). Monthly statistics based on the daily averaged series (bottom).

Table 13: Results of the sea-surface temperature (T, 0-5 m) harmonic analysis (N=1 ; N=2 ; N=3).

-	HB-BDE	FB-BB	CP	Whole domain
T mean [°C]	7.0	6.8	7.1	6.9
Amplitude [°C]	6.6; 1.1; 0.6	6.6; 1.2; 0.8	7.3; 1.8; 0.8	6.9; 1.3; 0.7
Phase [yd]	232; 273; 159	239; 263; 132	233; 258; 134	234; 264; 143

Table 14: Results of the sub-surface temperature (T, 5-20 m) harmonic analysis (N=1 ; N=2 ; N=3).

-	HB-BDE	FB-BB	CP	Whole domain
T mean [°C]	5.4	5.8	6.1	5.6
Amplitude [°C]	4.6; 0.5; 0.3	5.8; 0.8; 0.5	6.2; 1.1; 0.5	5.3; 0.8; 0.4
Phase [yd]	254; 265; 93	251; 274; 134	242; 273; 144	248; 272; 120

Table 15: HB-BDE surface (0-20 m depth) temperature statistics.

-	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	-1.0	-0.9	-0.5	-0.1	0.4	0.7	1.3	1.6	1.2	1.8	2.7	1.1
Date	2010	2011	1995	1995	1994	1987	1986	1961	1978	2001	1997	2008
Max	5.3	4.1	5.0	7.2	12.2	19.0	22.8	22.0	20.3	16.0	9.6	7.4
Date	2011	2010	2010	2009	2009	2009	2009	2009	2009	2010	2010	2008
Mean	2.3	1.2	1.0	1.6	3.9	6.7	9.5	12.2	10.9	9.9	6.8	5.0
Std. Dev.	1.2	0.8	0.7	1.0	2.0	2.5	2.6	2.2	2.1	1.5	0.7	0.8
Years	7	12	9	9	12	16	19	14	14	11	9	6
Days	900	929	1,060	1,505	1,739	2,048	2,315	2,189	3,047	2,034	14,20	785

Table 16: FB-BB surface (0-20 m depth) temperature statistics.

-	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	-0.2	-1.6	-0.8	-0.5	0.0	-0.6	1.2	1.6	1.5	2.3	4.4	0.7
Date	2005	1975	1995	1948	1995	1987	1987	2008	2004	1992	1973	2004
Max	4.6	2.4	2.4	4.6	9.4	14.8	19.3	20.6	18.3	14.7	11.8	8.1
Date	2005	1997	2004	2004	2005	2009	2004	2004	2000	2003	2003	2008
Mean	1.8	0.7	0.8	1.2	3.0	5.7	9.7	12.3	11.5	10.5	6.9	5.2
Std. Dev.	1.0	1.1	0.5	0.7	1.5	1.7	2.6	3.2	2.7	1.4	1.5	1.3
Years	12	10	14	16	28	33	25	26	28	24	11	12
Days	957	344	487	725	14,76	2,600	1,268	1,356	1,444	1,244	631	826

Table 17: CP surface (0-20 m depth) temperature statistics.

-	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	0.0	-0.7	-0.7	0.0	0.9	2.2	3.7	2.3	4.2	3.9	4.9	0.8
Date	1999	1995	1995	1995	1995	2003	1957	2009	2009	2009	2009	2009
Max	4.1	2.8	1.8	3.9	7.2	13.1	17.5	19.8	17.4	13.3	8.6	6.4
Date	1997	1997	2010	2009	2009	2009	2009	2009	2009	2009	1996	2009
Mean	1.7	0.9	0.4	1.3	3.7	6.0	10.3	13.4	11.0	10.3	6.3	4.5
Std. Dev.	0.9	0.7	0.6	0.7	1.1	1.4	2.0	2.4	2.1	1.5	0.8	0.9
Years	8	9	6	4	4	8	5	7	6	3	6	9
Days	1,411	1,344	1,382	1,280	1,355	1,386	1,319	1,273	1,116	1,132	1,374	1,636

OFFSHORE WIND CLIMATE

During the 20-year period (1994-2013), the mean wind speed was 33.6 km/h (about 9.3 m/s) with a measured maximum of 133 km/h (about 36.9 m/s) measured on December 9, 1994. The predominant direction is from the W-SW quadrant (Figure 16). Seasonal variability is evident (Figure 17 to Figure 18). In winter (Dec-Feb), the winds are more frequently from the W to the NW. In spring (Mar-May) the winds are predominantly from the W-WSW with a significant component from the N in the early to mid-spring (March and April). In summer (Jun-Aug), the winds are predominantly from the SW with a notable component from the S peaking in July. In fall (Sep-Nov), prevailing winds veer towards the west again with an increasing component from the N-NW from September to November and strong winds (>60 km/h or about 17 m/s) occurring from about all directions from October to November. With regard to the magnitude, a strong seasonal pattern is also evident with increasing speed from summer to spring and a decrease occurring around May. From November to March, median wind speed is of the order of 35-45 km/h (9.7-12.5 m/s) whereas it is about 20-30 km/h (5.6-8.3 m/s) from May to September. April and October appear as transitionary periods from strong to weak wind conditions and vice-versa, respectively.

During that same 20-year period (1994-2013), the maximum duration of wind continuously blowing with speed 10 m/s (36 km/h) or above was 157 hours. The average number of events with consistent wind above 10 m/s and with duration longer than 12 hours was ~73.5/year. For wind above 15 m/s (54 km/h), the maximum duration was 103 hours (occurring in December 2010) and the average number of events with duration longer than 12 hours was ~25/year. Stronger wind of 20 m/s (72 km/h) or above was measured for a period as long as 38 hours and the average number of events with duration longer than 12 hours was ~4/year.

This general seasonal wind pattern for Sagona Island is in agreement with the previous studies (MSRL 1980, de Young 1983, BDE-DA 1984 and Currie et al. 2014) that reported wind climates from other land-based stations such as St. Alban's, albeit with some notable differences in prevailing directions and magnitudes due to important topographic local effects as described in Currie et al. (2014).

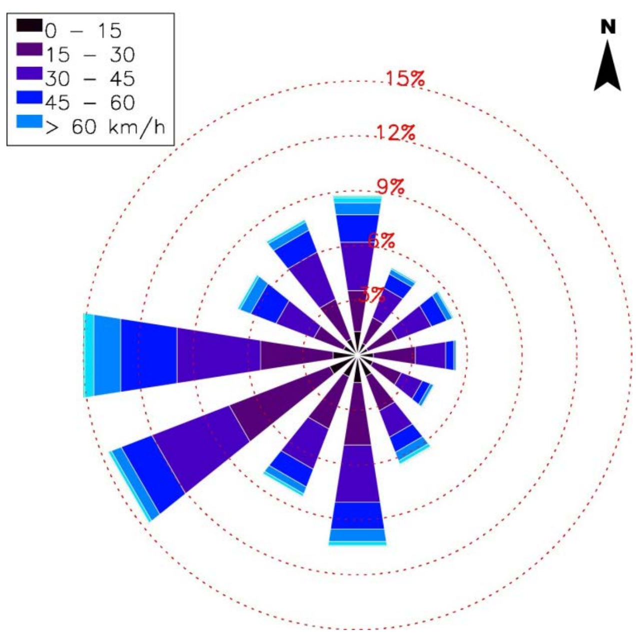


Figure 16: Sagona Island wind rose covering the period from February 1, 1994 to December 31, 2013.

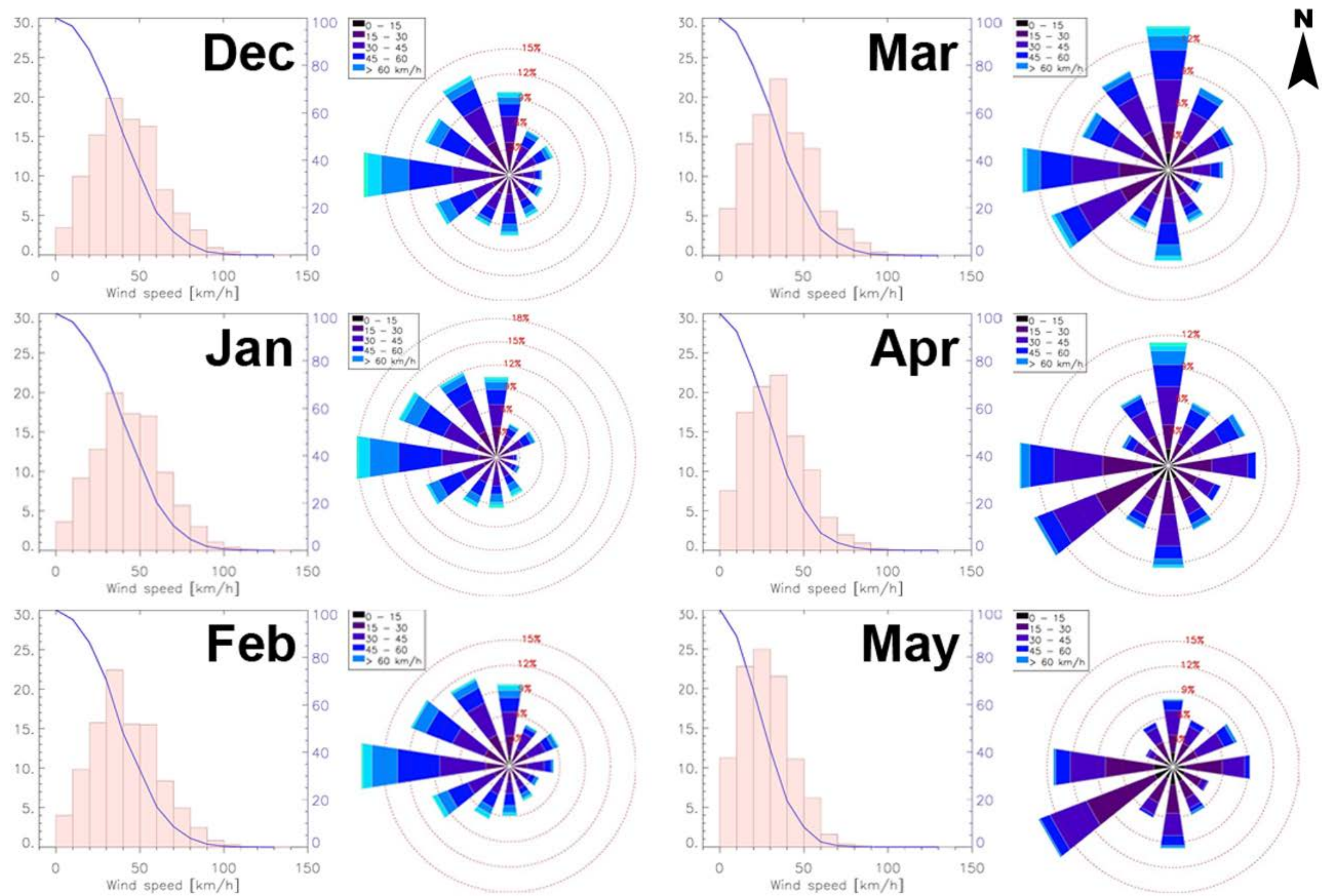


Figure 17: Monthly wind roses and histograms of Sagona Island. Y-axes to the right of the histograms provide the scale for the cumulative wind speed frequency [%] represented by the blue line.

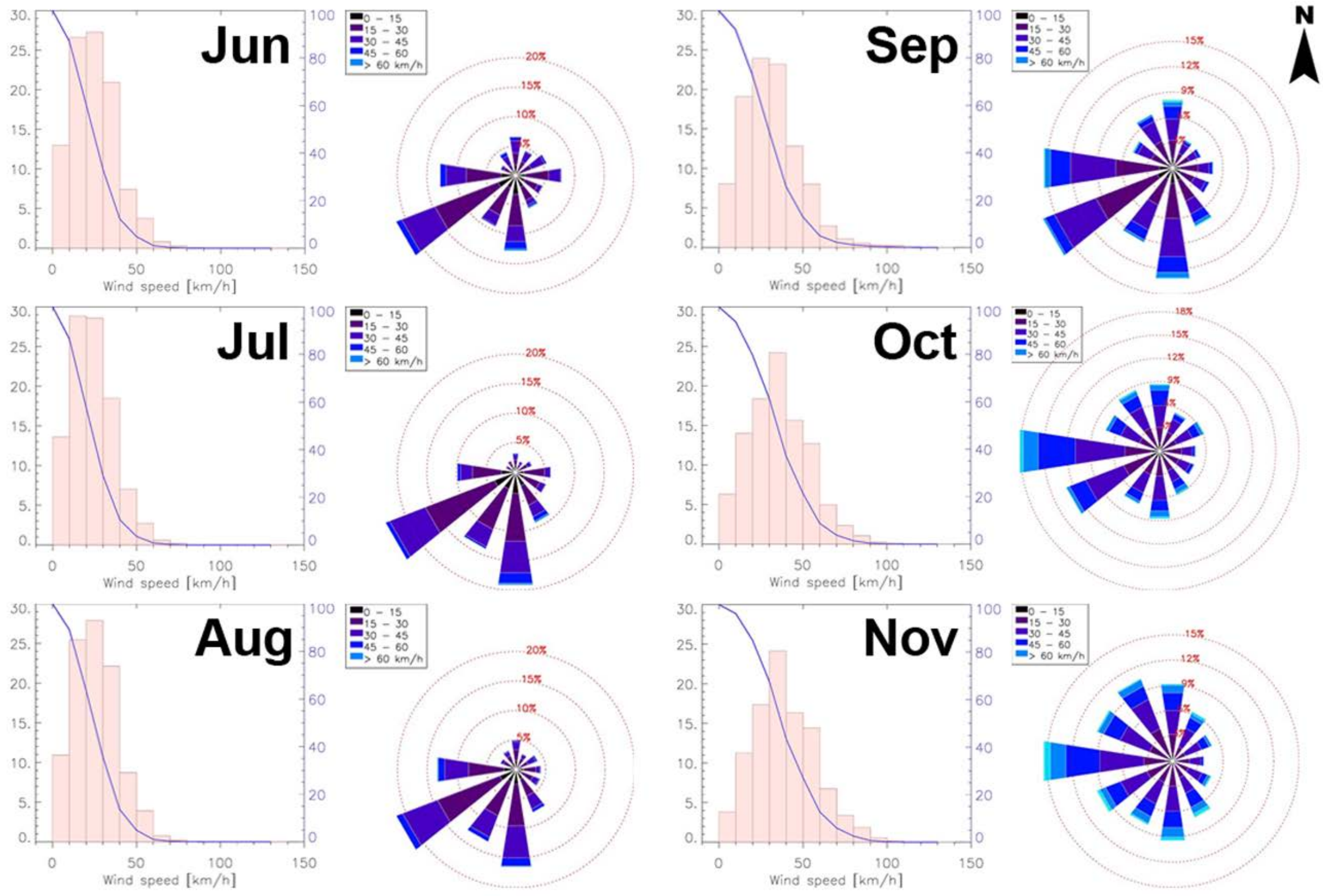


Figure 18: Monthly wind roses and histograms of Sagona Island from June (Jun) to November (Nov). Y-axes to the right of the histograms provide the scale for the cumulative wind speed frequency [%] represented by the blue line.

DISCUSSION

GEOGRAPHY AND HYDROLOGY

The results of our analyses highlight physical differences between three geographically distinct regions.

BDE is a fairly long and narrow fjord (about 30-50 km in maximum length and about 2 km in average width). It has a complex geometry consisting of two main arms and numerous smaller features. The bathymetry of BDE is characterized by deep basins (up to 792 m maximum depth) as well as steep and shallow sills (e.g., less than 26 m at Riches Island S4 in Figure 10). The BDE region is also characterized by a large input of freshwater with an annual average of the order of 252 m^3/s; comparable to that of the largest river of the Island, Exploit River, which has mean annual flow of the order of 270 m^3/s (Department of Environment and Lands 1992). This freshwater discharge is for the most part (about 75%) controlled by a dam located at its northeast end; this region is thereby subject to an unnatural seasonal cycle. As shown in Figure 5, the largest freshwater discharge from the dam occurs during the winter months with a peak in February rather than in April-May (Salmon River at Bay d'Espoir powerhouse data). In addition, the annual cycle is also 'flattened-out' with proportionally smaller discharge rate during the fall and larger discharge rate in the summer than for the uncontrolled rivers of the area. However, the natural river discharges of the area are large in spring, leading to a discharge peak in April despite the power generation discharge peak in February (see Table 5).

BB is a large and deep bay with an average width of about 12 km and a maximum depth of up to 606 m. It is connected to the ocean via the large fjord-like embayment of FB. BB presents the largest volume of all the bays reported in this study with a volume of about 54,100 x 10^6 m^3 at CD. It is also the deepest on average (179 m), though BDE comes close at 172 m average depth. As with BDE, the bathymetry of BB is characterized by deep basins but its geometry is very different, being an open bay as opposed to a narrow fjord. The coastline of BB is made of numerous side bays and inlets which are generally connected to the main body via a sill as shown in Figure 11 and in Appendix E(ii). The bathymetry of the middle of the bay consists of two deep channels (more than 500 m depth), considered here as basins, separated by a shallow bank (less than 100 m depth). The western basin (B2 in Figure 11) is nearly divided in two by an incomplete sill extending from the shallow bank towards the northwest. A large shallow area is also present on the south-western side of the bay, to the north of and around the largest islands of the bay (Chapel Island and Long Island). Although notable freshwater discharge occurs in BB, its magnitude (about 71 m^3/s average discharge rate) is about 3.5 times less than that in BDE. Most of the discharge occurs at the head (about 76% from the combined input of Salmon River, Bay du Nord river, Northwest Brook and Northeast Brook) but a significant source of runoff is also located just outside the mouth of the bay (Long Harbour river, representing about 55% of BB total discharge; that is, equivalent to the discharge of the Bay du Nord river, see Table B1).

CP consists of two open bays (CB and GBDE) and one narrow inlet (HB-NA), all having limited amount of freshwater input compared to BB and BDE with discharge rates of the order of 45 times (in GBDE) to 180 times (in HB-NA) less than in BDE, on average. The yearly average rate of freshwater input is about 10 m^3/s for CP as a whole. While CB and GBDE are similar in shape and are similarly oriented in a southwest to northeast direction, CB is wider (about 4.7 km and 3.7 km, respectively), longer (29.1 km vs. 21.6 km), larger in area (123 km^2 vs. 93 km^2, at CD) and more voluminous (about 9,900 vs. 7,100 x 10^6 m^3) but receives only about half the freshwater inflow of GBDE (2.6 vs 6.0 m^3/s yearly average). Somewhat isolated between those two larger bays, the geometry of HB-NA is more similar to Bay d'Espoir: a fjord connected to the offshore by a relatively shallow outer sill (117 m maximum depth) and characterized by several inner basins and sills (Figure 12). However, its coastline is much less complex (1 main arm only) and its dimensions are much smaller than BDE, being about 1.5 to 3 times shorter, 10 times smaller in area and 1/20th of the volume. In addition, freshwater input in HB-NA is much less (about 180 times less, on average).

OCEANOGRAPHY

ROFI are areas where the input of buoyancy resulting from freshwater runoff is, if spread evenly and as calculated in this study, equivalent to the buoyancy input by heating at the peak summer rate. In other words, ROFI represent areas where the density stratification of the water column is significantly influenced, if not dominated, by freshwater input(s); thus, by salinity changes rather than by temperature changes. This action is of importance since the dynamics of the water column (i.e., ocean currents, water exchanges and mixing) are greatly influenced by the density stratification. Due to the significant freshwater runoff occurring in BDE and BB, their corresponding ROFI are large: covering BDE and the inner part of HB in the HB-BDE region and covering most of BB (all BB if one considers freshwater inputs from elsewhere in FB; though this is unlikely to happen). While it is difficult to predict precisely where these ROFI would occur and their exact extent based on this first and rather simple analysis (e.g., seasonal cycle effects), it illustrates the scale of this physical process in our study area. Clearly, the influence of the freshwater runoff is likely to play an important role with respect to the coastal circulation, mixing and water exchange in the Coast of Bay, particularly in HB-BDE and BB regions.

As noted in MSRL (1980), tides in the study area are semi-diurnal (i.e., two high waters and two low waters a day), but they are also slightly unequal (i.e., one larger and one smaller high and low water a day). With maximum ranges of the order of 2 m the Coast of Bays can be defined as a microtidal environment (Davies 1964); thus, while being some of the largest ranges encountered around Newfoundland (MSRL 1980), they are rather small in comparison to other places in Canada (Yurick and Vanstone 1983) and the rest of the world. For instance, tidal ranges (large tides) in the Bay of Fundy and in the fjords of British Columbia where similar aquaculture activities take place are of the order of 8 m (Passamaquoddy Bay; Gregory et al. 1993) and 5 m (Knight Inlet; Pickard and Rodgers 1959), respectively. In the fjords of Scotland and Norway where finfish aquaculture also takes place, tidal ranges (large tides) are of the order of 4-6 m (from Millport to Kinlockbervie) and 1-4 m (from Stavanger to Tromso), respectively (accessed January 20, 2015). In our study area, tidal ranges slightly decrease from the East to the West with higher ranges found in BB (2.18 m large tides at Belleoram) and smaller ranges found at the mouth of BDE (1.94 m large tides at Pushthrough). Tidal ranges are, however, comparable in all areas where measurements were available, decreasing by about 13% (about 24 cm large tides) from BB (which presents the largest range) to the mouth of BDE (which presents the smallest range) and increasing by about 9% (about 17 cm large tides) from the mouth (Pushthrough) to the head (2.11 m large tides at St. Alban's) of BDE, the later likely the result of geometrical constriction (Dyer 1997). However, due to their differences in geographical characteristics (areas and volumes), tidal flushing rates vary greatly from one bay to another, from as long as about 71 days in BDE to as short as about 27 days in HB-NA. While rather long in general for each of the region as a whole, flushing times may be significantly shorter in some sub-basins or areas. For instance, the aquaculture overwintering sites used (Figure 7) have estimated flushing times of the order of 6 to 15 days (Table 4). Flushing time could be greatly affected by other forcing such as freshwater inflow or wind. Given the orientation of the BDE, for instance, winds from the S and SW (most frequent in summer), as well as from the N and NE (most frequent in winter) could affect the circulation; thus the flushing time. In BB, winds from the SE quadrant (rarely occurring) and winds from the NW (most frequent in winter) would have an effect on the flushing time. Given its wide opening on FB, however, winds from the SW (most frequent in summer) and winds from the NE (most frequent in winter) could also have a significant effect. Previous studies have indicated important oceanographic changes with regard to FB deep water renewal due to this seasonal forcing (de Young 1983; de Young and Hay 1987; Hay and de Young 1989, White and Hay 1994) but the effect of this forcing on the surface layer dynamics is largely unknown and remain to be explored. In CP, CB and GBDE flushing time would be more affected by winds from the SW (most frequent in summer) and from the NE (most frequent in winter) while winds from the S (most frequent in summer) and from the N (most frequent in winter) would affect the flushing time of HB-NA. Similarly, and due to their hydrological characteristics, tidal/freshwater volume ratio also varies greatly from one bay to another, from as large as almost 3,000 in CB to as small as about 50 in BDE; indicating a likely large difference in conditions of stratification among the bays. Near-surface temperatures show a summer heating and winter cooling cycle that is typical of mid-latitude, shelf-seas regions (e.g., Simpson and Sharples 2012) but with large amplitude. In the Coast of Bays in general, an annual amplitude of about 6.9^{o}C and phase of 234 (yd) in the near-surface (0-5 m) is found. In the sub-surface (5-20 m), amplitude diminishes to about 5.3^{o}C and phase increases to 248 (yd). This seasonal amplitude of surface temperatures is large in comparison to the conditions observed in British Columbia (about 3-4^{o}C; Gower and McLaren 2013), but comparable to some regions in Nova Scotia (e.g., zone 4Xq; Fisheries and Oceans Canada 2015) where similar finfish aquaculture operations are currently taking place in Canada. This annual pattern is also comparable with the results of station 27 (located just offshore St. John's, NL) presented in Petrie et al. (1991) who found an annual amplitude of 6.9^{o}C and annual phase of 242 (yd) at the surface (0 m) and an annual amplitude of 5.6^{o}C and annual phase of 255 (yd) at 20 m depth; indicating a coherent regional pattern. Using those later values, however, a vertical mixing rate at station 27 equal to about $20^2/(13*24*3600) \sim 3.6 \times 10^{-4} m^2 s^{-1}$ is found; which is significantly larger than the one estimated in our study area (of the order of $0.8 \times 10^{-4}\ m^2 s^{-1}$) which could, at least partly, be explained by a more exposed (oceanic) location of station 27. Interestingly, differences among the regions increased with depth, both in amplitude and in phase, with differences of the order of 1.6^{o}C and 12 days, respectively, when comparing HB-BDE (lowest amplitude and largest phase) with CP (largest amplitude and smaller phase). This later observation indicates a slower vertical mixing in HB-BDE and, to a lesser extent in FB-BB, than in CP; potentially due to stronger density gradients resulting from a stronger salinity stratification which would impede vertical mixing in the former regions and/or stronger wind forcing resulting in higher surface vertical mixing in the later region. The six months and four months harmonic amplitudes being only about 1/5 and 1/10 that of the annual amplitudes, respectively, they were not used in the inference of vertical mixing rates. However, those harmonics are necessary to represent the full yearly cycle, accounting for the relatively constant, near-freezing, temperatures in the winter and the sharp decline/cooling occurring in fall.

UPDATES TO PREVIOUS STUDIES

The results of our analyses also provide the following updates to the current knowledge of the area:

- Detailed bathymetry characteristics are provided with an extension and update on geomorphological metrics of the sills and basins of BDE previously described in BDE-DA (1984), Richard and Hay (1984) and Tlusty et al. (1999). It also provides similar information for the other bays of aquaculture activities (BB, CB, HB-NA and GBDE) not previously described other than by the published CHS charts. For each of the bays studied, deep and shallow areas were identified to define basins and sills, respectively. These features are particularly important to the study of water exchanges (e.g., Richard and Hay 1984) and can have critical effects on the vertical distribution of DO and nutrient dynamics (e.g., Strain 2002); which, in turn, can affect the operation of finfish and shellfish aquaculture farms (e.g., production density and carrying capacity).

- Tidal information is provided for all bays with slight differences between the previously available data (MSRL 1980) and our estimates. Tidal range (large tides) differences of the order of 5 cm (St. Alban's) and 7 cm (Pushthrough) or about 2.5 to 3.8% (respectively) and up to 15 cm (7.4%) at Hermitage were found.
- For BDE as a whole, a tidal prism (or volume) of 280 x 10^6 m^3, mean tides, is estimated which translates to a flushing time of about 68 days; these values are much larger than the previous estimates reported in the MSRL report (1980) of 13 x 10^6 m^3 and 11.6 days, respectively.
- Based on our estimates of basin and tidal volumes, we calculated flushing rates of about 11 days and 6 days for the overwintering sites of Ship Cove and Roti Bay, respectively. These results differ significantly with the previous estimates given in Tlusty et al. (1999) who indicated flushing rates of 5 days for Voyce Cove and of 20 days for Roti Bay. Voyce Cove is a side bay of Ship Cove and using the same basin volume and area as reported in Tlusty et al. 1999 (2,500,000 m^3 and 250,000 m^2, respectively), a closer estimate equal to about 4 days is found. There is a substantial difference in volume estimates for Roti Bay between the two studies (42,000,000 m^3 in our study vs 51,600,000 m^3 from Tlusty et al. (1999)) which could be due to the quality of bathymetry data or tools used for the calculation. This difference, however, can only partially account for the discrepancies in the calculated flushing rates (20 days vs. 8 days using the area and volume reported in Tlusty et al. 1999). A refinement on the flushing rate of Roti Bay would not only need to consider the morphology of Roti Bay which features basins separated by shallow sills as pointed out by Tlusty et al. (1999) but also of the effect of the stratification leading to a potential isolation of the inner basins' deep water layer.
- To our knowledge, this report presents the most detailed assessment of watershed area and river runoff to date. It greatly extends the previous BDE estimates found in MSRL (1980) and Richard and Hay (1984) as well as the FB estimates found in de Young (1983). It also updates the previous assessment done in the 1990s by the Water Resources Division of the Government of Newfoundland and Labrador (Department of Environment and Lands 1992) for the study area. Large differences of freshwater discharge rates in BDE are, however, noted between our analysis and the MSRL report (1980, vol2-s10; p10.8). The latter indicates a discharge of the order of "40-60 MCF per day", about 13.1-19.7 m^3/s, in summer from the power generation tailrace; these rates are about 10 times less than those reported by Environment Canada' station 02ZE003 (see Appendix A(iii)) and used in the present analysis. We also found a similar discrepancy between the "10 MCF per day", about 3.3 m^3/s, from the combined Conne River and Southeast Brook and our estimates of about 11-12 m^3/s combining the mean monthly discharge of the two rivers from June to August. A close look at the section four of the MSRL report, describing the power plant in more detail, revealed that the discrepancy is likely due to a rounding-off or a unit conversion error in section 10. Thus, the freshwater discharge estimates subsequently used/reported in Richard and Hay (1984), Tlusty et al. (1999 and 2005) and maybe others which used the section 10 of the MSRL report are updated by our findings.
- Using our freshwater discharge rate estimates and the same channel width and upper freshwater layer as those used in MSRL 1980 (1,659 m and 2 m, respectively; sec. 10, p10-8), we estimate an average velocity of 5.6 cm/s (3.3 m/min) using an average discharge rate of 185 m^3/s (corresponding to the average rate of the BDE power generation). Though

this is a rather weak current, it is an order of magnitude larger than that of the previous estimates (0.24 to 0.36 m/min). Using the same layer thickness (2 m) and discharge rate at the most restricted section of the Upper BDE channel (S7, with a width of about 600 m) an average velocity of 15.4 cm/s is found. In comparison, using a tidal range of 1.27 m (mean tides) results in a tidal volume of about 16.2 x 10^6 m^3 passing through S7 (cross-section area of about 9,800 m^2) and a mean and peak tidal current of 7.4 cm/s and 11.6 cm/s, respectively. Thus, assuming mean conditions of river inflow and tides, the surface (0-2 m) flow would always be going southward at the surface (0-2 m depth) and at this location. At peak tidal currents and mean river inflow, the competition between the two forcings would be close but still in favour of a downstream flow. Considering an overall mean freshwater discharges of 251.7 m^3/s for the whole bay, a mean channel width of 2,200 m (corresponding to BDE east arm), and an upper layer thickness of 2 m, the average downstream velocity is found to be 5.7 cm/s. At this speed and without any other external forcing than the rivers' inflow, it would take a little less than 11 days for a particle of water to travel from the northeast head to the main mouth of BDE, a distance of 53,300 m. Considering the same channel geometry and an extreme daily release scenario from the power generation of 1,060 m^3/s (December 1, 1970; see Appendix A(iii), station 02ZE003), a surface current of the order of 24cm/s would occur and the same water particle would travel the whole bay in about 2.6 days. In comparison, assuming a median wind speed of 4m/s in summer and 9 m/s in winter and a surface current speed of the order of 1-2% of the wind speed (e.g., Bigg 2003), surface currents of the order of 4-18 cm/s due to the winds could be expected in BDE. Thus, wind induced currents are likely to be of the same order of magnitude or larger than currents induced by the tides or estuarine flow.

LIMITATIONS

The following limitations should be kept in mind when analysing or using the data from this report:

- While incorporating the latest bathymetry data available to our knowledge, some regions of our study area remain under-sampled and affected our ability to interpolate accurately. This is especially true for GBDE for which the sampling resolution of our bathymetry dataset was better than 150 m for only 26% of the area, and of the remaining 74% nearly half was sampled at a resolution of about 500 m. To a lesser extent, BB and CB were also affected with coarse sampling resolutions on 18% and 9% of the area studied, respectively. The IDW interpolation of these areas produced some undesired artefacts, particularly in shallow and/or coastal areas ('spotting' and 'stretching', see illustration in Appendix A(i)). This lack of data (or up-to-date data), in turn, resulted in cruder approximations of the metrics provided for these regions.
- While the delineation of basins and sills presented in this study is fairly detailed, it cannot be considered as definitive. The main and largest features were certainly identified but more basins and sills may be identified in future, more site (or bay) specific, studies.
- We assumed a 1 m offset (i.e., difference between CD and MSL vertical datum) to merge the bathymetry and topography data based on an overall tidal range of about 2 m for the whole study area. While being an approximation, this approach is thought to be the best compromise and the error introduced is minimal since the topographic data were given with a vertical resolution no better than 1 m.
- Based on the results presented and comparison with previous data (MSRL 1980), we estimate our uncertainties on tidal ranges to be less than 5% overall. However, it should be carefully noted that the ranges presented here are from tidal origin only and do not take into

account any other effects such as but not limited to the atmospheric forcing (i.e., surges) that can be quite large in the area (e.g., of the order of 1 m in BDE as reported by MSRL 1980, and up to 1.6 m in BB as reported in Salcedo-Castro and Ratsimandresy 2013). While much less frequent and less likely in the area than storm surges, tsunamis can result in even much greater rises in sea-level (e.g., 2 to 7 m along the Newfoundland South Coast during the “1929 Grand Banks tsunami”, NRCan 2015).

- Estimates of flushing time were solely based on tidal volume (prism); thus flushing time might be significantly underestimated due to the large freshwater discharge in BDE and to the effect of the wind that has previously been identified as a strong physical forcing agent in the area (Ratsimandresy et al. 2012, de Young 1983, Hay and de Young 1989). On one hand, one could expect the actual flushing time to be longer as complete mixing and complete absence of returning flushed water is never really achieved in nature (e.g., Tomczak 1998). On the other hand, the method is also conservative in the sense that it only considers water exchanges due to the tides; other exchange mechanisms (e.g., due to wind and river influx) can significantly influence the overall flushing rate of a bay, potentially reducing its flushing time.
- Estimates of tidal currents at the entrances and flushing times of bays were based solely on the M2 tidal constituent’ period. M2 was, however, found to be dominant and to result in currents of the order of 3 to 10 times those of the other constituents and to flushing rates 3 to 20 times more efficient; thus justifying this assumption to provide first order estimates.
- While using a relatively simple method, confidence with our watershed analysis was gained by comparing the available watershed areas (see Appendix A(iii)) with our estimates (Appendix B). Overall, discrepancies of about 1.2% (Bay du Nord) to about 12.5% (Southwest Brook) of the total area were found; highlighting larger errors/variability for smaller watersheds. In comparison with the more serious limitation of available river discharge data (historical and current), it is thought that this limitation is of lesser importance.
- The discharge data are based on a limited amount of publically available measurements. Though the data of the main source of freshwater for BDE (Salmon River at Powerhouse) and for BB (Bay du Nord) were available, little or no information was available from the other main rivers flowing into those two bays (e.g., Conne River was measured far upstream and no data were available for Little River or d’Espoir Brook); in addition, no information was available regarding the small rivers flowing into CB, HB-NA or GBDE. For those regions, estimates of discharge were attempted using data from Belle Bay. Considering the mean annual runoff map available in the Water Resources Atlas of Newfoundland (Department of Environment and Lands 1992 - p33), showing a north-south precipitation gradient (increasing southward), slightly larger discharge rates might be occurring in those region. It should also be noted that the information provided here represents averaged values (monthly or gross average), thus not representing extreme events or large daily discharge which frequently occur in the area (e.g., fall/hurricane season).
- It should be noted that the near-surface temperature statistics are based on a limited amount of data (typically less than 20 years for any given month, frequently less than 10 years and as low as three years in CP) and that both spatial and seasonal aspect may be biased by the number of samples used. For instance, while HB-BDE was the most sampled region in summer (about 1,664 data days per month, on average), it was also much more sampled in summer than in winter). It should also be noted that by grouping such a dataset, it is possible that smaller parts of the regions considered in this analysis may have a different climate than a given region as a whole. In particular, the effect of ice-cover isolating

sub-surface water to freezing temperatures in winter may be important such as reported in the MSRL report (1980), the BDE-DA report (1984) and in Tlusty et al. (1999) for the upper BDE region.

- The fact that our water temperature statistics indicate that freezing lethal temperatures occurred within the fish farm depth range in winter even during the recent expansion of the industry (Jan 2010 and Feb 2011 in HB-BDE, Table 15) suggest that there may be spatial and/or depth variations allowing chances of survival (i.e., some sites and depths might get colder than others). Previous overwintering studies done in BDE pointed out that increasing net depth (i.e., to depths >10 m) had a positive effect on fish mortality (Pepper et al. 2003ab). However, theoretical and observational physics tell us that the mixing processes within the ocean surface layer are complex and that the effect of surface cooling typically extend to greater depths than the net depths currently used by the aquaculture industry in the Coast of Bays (i.e., depths greater than 20 m; e.g., Moum and Smyth 2001, Rudnick 2001, Mupparapu and Brown 2002, Colbourne et al. 2015). Thus, despite being a critical aspect to the sustainability of the aquaculture industry, the effect of winter cooling on the water column is very much unknown in the Coast of Bays and would require a dedicated effort to understand its mechanisms as well as its spatial extent (both in an horizontal and vertical/depth sense).
- Likewise, the effect of climate change in the area is totally unknown. For instance, the recent extreme winter of 2013-14 which contributed to the significant production losses experienced in 2014 (-73.1% from 2013, DFA 2015b) followed a regional warming trend that started in the mid-90s (Colbourne et al. 2015) and, as such, was rather unexpected. While the potential links between extreme weather (including seasons) and present climate change is still a subject of debate, some recent and well documented studies argue that these links do exist, particularly in mid-latitudes regions (e.g., Cohen et al. 2014). Clearly, assessing the effect of climate change and finding means of predictions for the Coast of Bays area would be of value and should be pursued.

CONCLUSION AND RECOMMENDATIONS

This report attempts to describe the Coast of Bays area (Newfoundland, Canada) via the quantification of key physical parameters in order to provide a basis to on-going investigations related to the rapid development of the aquaculture industry and its management. In doing so, it also provides significant updates to previous studies carried out in the area (e.g., MSRL 1980) and a basis for future work.

Based on this study, the following key observations can be made:

- The Coast of Bays area where the aquaculture industry is currently operating and expanding consists of three geographically distinct regions: a long and narrow fjord (BDE), a deep and wide bay (BB) and a shallower region more directly exposed to the open ocean (CP) consisting of two open-bays (CB and GBDE) and one narrow inlet (HB-NA).
- In addition to their geometry and geographical locations, one of the main characteristics distinguishing those three regions is their freshwater input: large in BDE, significant in BB and very small in the CP region. Across regions, and particularly in BB and CP, this input of freshwater is strongly seasonal, with a large peak in spring (April-May), a low in summer (July-August) and a second, smaller, peak in late fall (November-December). Important differences among the bays with regard to water stratification and water circulation are expected as a result of this physical forcing.

- Tidal ranges are comparable among the bays with an average of 1.3 m and 2.2 m mean and large tides, respectively. These ranges are small in comparison to other aquaculture areas in Canada and elsewhere. As a result of these small tidal ranges and large basin volumes, flushing times due to the tides are quite large with values in the order of 30 days in the CP region and about 60-70 days in both BDE and BB regions. Also as a result of those small tidal ranges and rugged coastlines, the estimated intertidal areas of the Coast of Bays are small, representing only about 4-16% of the MSL area of the bays examined.
- A clear seasonal cycle in both wind speed and direction is illustrated by the analysis of the data collected just offshore the CP region. In winter, strong winds from the W to NW prevail while in summer, much weaker winds from the SW dominate. Significant oceanographic variations due to this force are expected (e.g., surface dynamics) but remain largely unknown.
- Annual near-surface temperature amplitude of the order of 7^{o}C was found in the Coast of Bays area. This seasonal amplitude is large in comparison to conditions observed in British Columbia but comparable to some regions in Nova Scotia. Notable differences were found among the bays below the sea-surface; indicating geographical variations in water structure. A stronger stratification seem to occur in BDE and, to a lesser degree, in BB due to the larger freshwater runoff acting as a buoyancy force against vertical mixing.
- In BDE, estimates of tidal flows, surface estuarine circulation and wind induced currents are of the same order of magnitude; suggesting that a complex circulation pattern may occur in that area.

Based on those results, the following recommendations can be made:

- The detailed assessment of the bathymetry and the subsequent identification of basins presented in this report can help with the delineation of BMAs but should not be considered as definitive. Other physical characteristics such as spatial distribution of water masses and dispersion potential due to ocean circulation need to be considered.
- The combination of small tidal ranges, geographically diverse freshwater runoff, strong regional heating and cooling seasonal cycle and what appears to be a delicate balance between main physical forces such as the tides, estuarine flow and winds results in a very complex environment. These notable differences require a specific approach with respect to data collection and numerical modelling. Applying a (somewhat) simple approach based on tidal excursions from a barotropic model such as used in New Brunswick is not recommended in the NL context. A more complex approach such as the ‘farm connectivity matrix’ developed in British Columbia and based on a baroclinic model (Foreman et al. 2015) would be more suited.
- As detailed in the limitation section, further work is needed on sea water temperature and physical forces governing flushing rates as well as water exchanges. In particular, a better understanding of the role of the freshwater input on nearshore water structure and the role of wind on surface currents are needed. The role of larger scale coastal currents (e.g., Labrador Current) on the circulation within this coastal area is also very much unknown and should be investigated.
- Finally, other relevant study areas to the sustainable development of the aquaculture industry such as ice cover, inter-annual variation in the hydrology or oceanography, air temperature, wave climate and climate change would be of interest to pursue.

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APPENDIX A(I): COAST OF BAYS BATHYMETRY AND TOPOGRAPHY

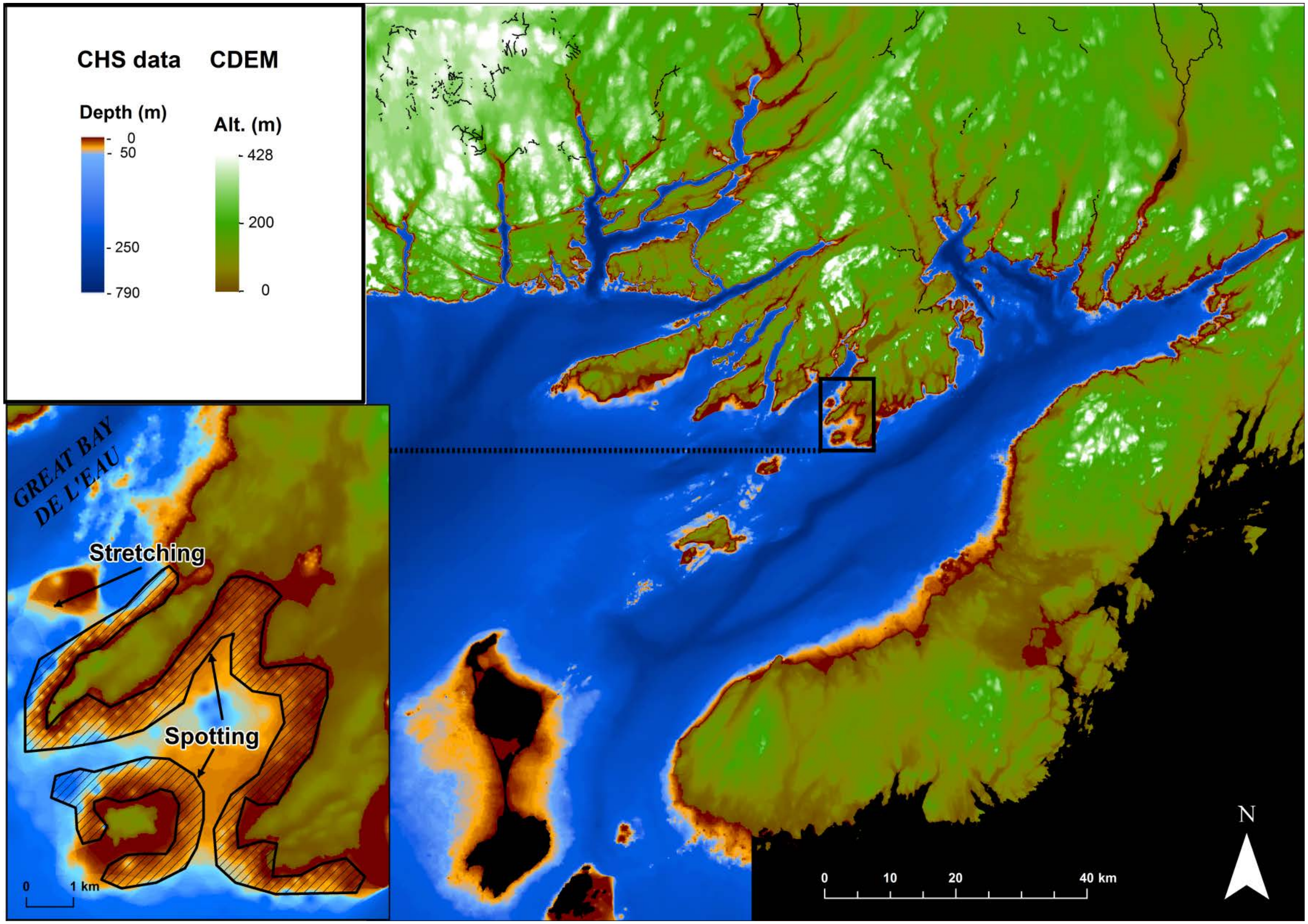

Figure A(i)1: Raster surfaces produced from the Canadian Council On Geomatics (CCOG)' elevation data (Canadian Digital Elevation Model or CDEM) and the Canadian Hydrographic Service (CHS) bathymetry data were merged to produce a bathymetry-topography surface (shown here at Chart Datum). The inset presents examples of 'spotting' and 'stretching' artifacts resulting from the Inverse Weighted Distance interpolation in areas of low resolution bathymetry sampling.

APPENDIX A(II): COAST OF BAYS CHS STATIONS TIDAL CONSTITUENTS

```
WaterLevConstit 00690 PUSHTHROUGH                          00000m 1999/11/02||
MComputed    47 38.0   N  56 10.0   W                        +03.5 0000:00   ||
        13 0029days 100.0% R                                    0000:00 06||
Mitchell, D                                                         00000m||
Reference      0835                                                      0||
                                 0   0       ChartDatum                   ||
01 Const Name [Ref Nam]     0       TW                                    ||
02 Nominal Period hours     1       3W                                    ||
03 Amplitude    metres      2       4W                                    ||
04 Phase Lag[g]     deg     1       2W                                    ||
05 Doodson numbers          0       TW                                    ||
06 Security                 0       TW                                    ||
MEDS-SDMM, Ottawa                                                         ||
B2_TCF.DAT              MEDS Bluefile to TCF     bluefile.con             ||
**         S4                                                             ||
Port type: Sec  Analysis length:  1 X  29  Central Time:       Ref:  0835   ||
Ctime 195509        Conversion program:  BLUE2.C  Version  2.7            ||
Processed on:   Tue Nov  2 13:21:16 1999                                  ||
Const(1), Amplitude(3) and PhaseLag(4) fields copied from source file.    ||
                                                                          ||
                                                                          ||
                                                                          ||
                                                                          ||
Control: <00690      YES 1 SEC MEDS ATL 195505 >                          ||
Z0       0.000  1.1910   0.00  0  0  0  0  0  0 4c
Q1      26.868  0.0060  80.00  1 -2  0  1  0  0 4d
O1      25.819  0.0640 135.00  1 -1  0  0  0  0 4f
P1      24.066  0.0180 133.00  1  1 -2  0  0  0 5e
K1      23.934  0.0570 133.00  1  1  0  0  0  0 48
J1      23.098  0.0060 138.00  1  2  0 -1  0  0 46
MU2     12.872  0.0180 232.00  2 -2  2  0  0  0 3f
N2      12.658  0.1060 236.00  2 -1  0  1  0  0 45
M2      12.421  0.5940 251.00  2  0  0  0  0  0 49
S2      12.000  0.1700 288.00  2  2 -2  0  0  0 57
K2      11.967  0.0450 288.00  2  2  0  0  0  0 4c
M4       6.210  0.0180 206.00  4  0  0  0  0  0 5b
MS4      6.103  0.0120 299.00  4  2 -2  0  0  0 28
```

Figure A(ii)1: Pushthrough tidal constituents.

```
WaterLevConstit 00705 ST ALBAN'S                                  1997/09/29||
!Computed    47 52     N 055 50     W                       +03.5 1000:00   ||
        36 0030days 100.0%                                        0100:00 06||
Charlie                                                                    ||
                                                                          0||
0015:00  60.000min                                                         ||
01 Const Name [Ref Nam]     0       TW                                     ||
02 Nominal Period hours     0       TW                                     ||
03 Amplitude     metres     0       TW                                     ||
04 Phase Lag[g]     deg     0       TW                                     ||
05 Doodson Numbers          0       TW                                     ||
06 Security                 0       TW                                     ||
                                                                           ||
00705c19970029a.wlev     705 in NST               1036008023.tr60          ||
CHANGED. Timezone from 0.000.                                              ||
                                                                           ||
                                                                           ||
                                                                           ||
                                                        .....................||
                                                                           ||
7..........................................................................||
8..........................................................................||
Inf .......................................................................||
A0= 1.3444, Rayleigh=0.80, ResErr=0.0873, MatrixCond=0.7464,  Ctime 199710   ||
Z0       0.000  1.3444 360.00  0  0  0  0  0  0 47
MM     661.309  0.0798 140.74  0  1  0 -1  0  0 28
MSF    354.367  0.0220 157.92  0  2 -2  0  0  0 53
ALP1    29.073  0.0085  74.85  1 -4  2  1  0  0 45
2Q1     28.006  0.0053 325.58  1 -3  0  2  0  0 42
Q1      26.868  0.0088  69.84  1 -2  0  1  0  0 40
O1      25.819  0.0771 147.55  1 -1  0  0  0  0 49
NO1     24.833  0.0050 159.29  1  0  0  1  0  0 23
K1      23.934  0.0453 137.25  1  1  0  0  0  0 4b
J1      23.098  0.0039 236.74  1  2  0 -1  0  0 44
OO1     22.306  0.0080 199.76  1  3  0  0  0  0 20
UPS1    21.578  0.0076 264.22  1  4  0 -1  0  0 58
EPS2    13.127  0.0092 243.99  2 -3  2  1  0  0 4d
MU2     12.872  0.0294 268.90  2 -2  2  0  0  0 3f
N2      12.658  0.1378 233.73  2 -1  0  1  0  0 4e
```

Figure A(ii)2: St. Alban's tidal constituents.

M2	12.421	0.6084	259.48	2	0	0	0	0	0	4f
L2	12.192	0.0198	291.34	2	1	0	−1	0	0	4b
S2	12.000	0.1897	282.48	2	2	−2	0	0	0	50
ETA2	11.755	0.0074	334.86	2	3	0	−1	0	0	5f
MO3	8.386	0.0033	246.86	3	−1	0	0	0	0	3b
M3	8.280	0.0098	138.27	3	0	0	0	0	0	5f
MK3	8.177	0.0009	277.66	3	1	0	0	0	0	3b
SK3	7.993	0.0103	130.44	3	3	−2	0	0	0	2e
MN4	6.269	0.0127	144.05	4	−1	0	1	0	0	3b
M4	6.210	0.0276	211.01	4	0	0	0	0	0	56
SN4	6.160	0.0039	346.25	4	1	−2	1	0	0	21
MS4	6.103	0.0138	322.02	4	2	−2	0	0	0	22
S4	6.000	0.0039	173.63	4	4	−4	0	0	0	4c
2MK5	4.931	0.0001	293.85	5	1	0	0	0	0	20
2SK5	4.797	0.0063	132.12	5	5	−4	0	0	0	33
2MN6	4.166	0.0059	118.02	6	−1	0	1	0	0	21
M6	4.140	0.0068	156.53	6	0	0	0	0	0	58
2MS6	4.092	0.0072	176.17	6	2	−2	0	0	0	33
2SM6	4.046	0.0039	250.80	6	4	−4	0	0	0	3c
3MK7	3.530	0.0006	307.11	7	1	0	0	0	0	2d
M8	3.105	0.0016	138.66	8	0	0	0	0	0	59

Figure A(ii)2: Continued.

```
WaterLevConstit 00710 HERMITAGE                           00000m 1999/11/02||
MComputed    47 34.0   N  55 56.0   W                       +03.5 0000:00   ||
        10 0029days 100.0% R                                      0000:00 06||
Mitchell, D                                                          00000m||
Reference      0835                                                       0||
                                 0   0       ChartDatum                   ||
01 Const Name [Ref Nam]     0       TW                                    ||
02 Nominal Period hours     1       3W                                    ||
03 Amplitude    metres      2       4W                                    ||
04 Phase Lag[g]     deg     1       2W                                    ||
05 Doodson numbers          0       TW                                    ||
06 Security                 0       TW                                    ||
MEDS-SDMM, Ottawa                                                         ||
B2_TCF.DAT              MEDS Bluefile to TCF     bluefile.con             ||
**         S4                                                             ||
Port type: Sec  Analysis length:  2 X  29  Central Time:      Ref:  0835   ||
Ctime 1959-1959     Conversion program:  BLUE2.C  Version  2.7            ||
Processed on:   Tue Nov  2 13:21:16 1999                                  ||
Const(1), Amplitude(3) and PhaseLag(4) fields copied from source file.    ||
                                                                          ||
                                                                          ||
                                                                          ||
                                                                          ||
Control: <00710      YES 1 SEC MEDS ATL 1959-1959 >                       ||
Z0       0.000  1.2780   0.00  0  0  0  0  0  0 48
O1      25.819  0.0820 137.00  1 -1  0  0  0  0 45
P1      24.066  0.0210 161.00  1  1 -2  0  0  0 53
K1      23.934  0.0700 161.00  1  1  0  0  0  0 4a
N2      12.658  0.1310 235.00  2 -1  0  1  0  0 42
M2      12.421  0.6240 255.00  2  0  0  0  0  0 45
S2      12.000  0.1760 284.00  2  2 -2  0  0  0 5d
K2      11.967  0.0480 284.00  2  2  0  0  0  0 4d
M4       6.210  0.0210 201.00  4  0  0  0  0  0 56
MS4      6.103  0.0120 319.00  4  2 -2  0  0  0 21
```

Figure A(ii)3: Hermitage tidal constituents.

```
WaterLevConstit 00720 HARBOUR BRETON                        00000m 1999/11/02||
MComputed    47 28.0   N  55 48.0   W                        +03.5 0000:00   ||
        11 0029days 100.0% R                                      0000:00 06||
Mitchell, D                                                           00000m||
Reference      0835                                                        0||
                                  0   0        ChartDatum                   ||
01 Const Name [Ref Nam]     0       TW                                      ||
02 Nominal Period hours     1       3W                                      ||
03 Amplitude     metres     2       4W                                      ||
04 Phase Lag[g]     deg     1       2W                                      ||
05 Doodson numbers          0       TW                                      ||
06 Security                 0       TW                                      ||
MEDS-SDMM, Ottawa                                                           ||
B2_TCF.DAT                MEDS Bluefile to TCF      bluefile.con            ||
**         S4                                                               ||
Port type: Sec  Analysis length:  3 X  29  Central Time:       Ref:  0835   ||
Ctime 1961-1961     Conversion program:  BLUE2.C  Version  2.7              ||
Processed on:   Tue Nov  2 13:21:16 1999                                    ||
Const(1), Amplitude(3) and PhaseLag(4) fields copied from source file.      ||
                                                                            ||
                                                                            ||
                                                                            ||
                                                                            ||
Control: <00720      YES 1 SEC MEDS ATL 1961-1961 >                         ||
Z0       0.000  1.3060   0.00  0  0  0  0  0  0 40
MF     327.859  0.0350 231.80  0  2  0  0  0  0 2b
O1      25.819  0.0660 151.10  1 -1  0  0  0  0 4e
P1      24.066  0.0190 149.40  1  1 -2  0  0  0 56
K1      23.934  0.0610 149.30  1  1  0  0  0  0 43
N2      12.658  0.1330 238.50  2 -1  0  1  0  0 48
M2      12.421  0.6340 253.50  2  0  0  0  0  0 47
S2      12.000  0.1860 285.20  2  2 -2  0  0  0 51
K2      11.967  0.0500 285.10  2  2  0  0  0  0 44
M4       6.210  0.0280 194.90  4  0  0  0  0  0 59
MS4      6.103  0.0100 320.50  4  2 -2  0  0  0 2c
```

Figure A(ii)4: Harbour Breton tidal constituents.

```
WaterLevConstit 00724 BELLEORAM                            00000m 1999/11/02||
MComputed    47 32.0   N  55 25.0   W                      +03.5 0000:00   ||
        41 0033days 100.0% R                                    0000:00 06||
Mitchell, D                                                          00000m||
Reference       835                                                       0||
                                  0   0       ChartDatum                   ||
01 Const Name [Ref Nam]     0       TW                                     ||
02 Nominal Period hours     1       3W                                     ||
03 Amplitude    metres      2       4W                                     ||
04 Phase Lag[g]     deg     1       2W                                     ||
05 Doodson numbers          0       TW                                     ||
06 Security                 0       TW                                     ||
MEDS-SDMM, Ottawa                                                          ||
B2_TCF.DAT                MEDS Bluefile to TCF     bluefile.con            ||
**         S4                                                              ||
Port type: Sec  Analysis length:  1 X  33  Central Time:      Ref:   835   ||
Ctime 198006       Conversion program:  BLUE2.C  Version  2.7              ||
Processed on:   Tue Nov  2 13:21:16 1999                                   ||
Const(1), Amplitude(3) and PhaseLag(4) fields copied from source file.     ||
                                                                           ||
                                                                           ||
                                                                           ||
                                                                           ||
Control: <00724     YES 1 SEC MEDS ATL 198006 >                            ||
Z0       0.000  1.3220   0.00  0  0  0  0  0  0 46
MM    661.309  0.1070 239.90  0  1  0 -1  0  0 2f
MSF   354.367  0.0180 194.30  0  2 -2  0  0  0 5d
ALP1    29.073  0.0140 139.60  1 -4  2  1  0  0 5e
2Q1     28.006  0.0160  98.40  1 -3  0  2  0  0 5f
Q1      26.868  0.0000 219.40  1 -2  0  1  0  0 5d
O1      25.819  0.0740 131.50  1 -1  0  0  0  0 4f
NO1     24.833  0.0070 343.00  1  0  0  1  0  0 23
P1      24.066  0.0230 150.30  1  1 -2  0  0  0 50
K1      23.934  0.0620 148.30  1  1  0  0  0  0 41
J1      23.098  0.0120 246.90  1  2  0 -1  0  0 40
OO1     22.306  0.0100 322.50  1  3  0  0  0  0 2f
UPS1    21.578  0.0070  90.10  1  4  0 -1  0  0 46
EPS2    13.127  0.0040 213.70  2 -3  2  1  0  0 40
2N2     12.905  0.0170 277.90  2 -2  0  2  0  0 5d
MU2     12.872  0.0250 295.00  2 -2  2  0  0  0 3c
N2      12.658  0.0880 240.70  2 -1  0  1  0  0 44
NU2     12.626  0.0140 276.70  2 -1  2 -1  0  0 37
```

Figure A(ii)5: Belleoram tidal constituents.

```
M2·····12.421··0.6500·252.30··2··0··0··0··0··0·42
L2·····12.192··0.0180·108.80··2··1··0·-1··0··0·4e
S2·····12.000··0.1890·295.90··2··2·-2··0··0··0·54
K2·····11.967··0.0510·298.80··2··2··0··0··0··0·40
ETA2···11.755··0.0030··36.20··2··3··0·-1··0··0·42
MO3·····8.386··0.0060··30.70··3·-1··0··0··0··0·27
M3······8.280··0.0080·119.20··3··0··0··0··0··0·52
MK3·····8.177··0.0100··71.30··3··1··0··0··0··0·24
SK3·····7.993··0.0090·206.80··3··3·-2··0··0··0·2b
MN4·····6.269··0.0070·143.40··4·-1··0··1··0··0·3e
M4······6.210··0.0370·192.10··4··0··0··0··0··0·59
SN4·····6.160··0.0020··63.60··4··1·-2··1··0··0·3c
MS4·····6.103··0.0160·298.50··4··2·-2··0··0··0·28
S4······6.000··0.0000·207.30··4··4·-4··0··0··0·40
2MK5····4.931··0.0050··70.70··5··1··0··0··0··0·31
2SK5····4.797··0.0020·303.80··5··5·-4··0··0··0·3f
2MN6····4.166··0.0060··78.60··6·-1··0··1··0··0·38
M6······4.140··0.0100·129.40··6··0··0··0··0··0·5d
2MS6····4.092··0.0070··88.30··6··2·-2··0··0··0·24
2SM6····4.046··0.0050·197.10··6··4·-4··0··0··0·32
3MK7····3.530··0.0010·178.70··7··1··0··0··0··0·27
M8······3.105··0.0030·104.90··8··0··0··0··0··0·5b
M10·····2.484··0.0010·320.40·10··0··0··0··0··0·5d
```

Figure A(ii)5: Continued.

APPENDIX A(III): COAST OF BAYS RIVERS DISCHARGE STATISTICS

Environment Canada   Environnement Canada   Canada

SALMON RIVER AT ROUND POND

Water Survey of Canada   Station No. 02ZE002

Dartmouth, Newfoundland and Labrador   5080 km^2

Monthly Extremes of Daily Discharges in m^3/s for the Period January 1965 - December 1981

	Maximum Daily	Minimum Daily	
JAN	544 m^3/sec* on Jan 21, 1978	21.0 m^3/sec on Jan 27, 1966	JAN
FEB	428 m^3/sec on Feb 17, 1969	17.3 m^3/sec on Feb 28, 1966	FEB
MAR	315 m^3/sec* on Mar 10, 1979	15.7 m^3/sec on Mar 05, 1966	MAR
APR	648 m^3/sec on Apr 24, 1971	18.6 m^3/sec* on Apr 03, 1967	APR
MAY	552 m^3/sec on May 05, 1981	28.3 m^3/sec on May 01, 1967	MAY
JUN	303 m^3/sec on Jun 01, 1977	30.3 m^3/sec on Jun 30, 1967	JUN
JUL	343 m^3/sec* on Jul 02, 1972	13.6 m^3/sec on Jul 26, 1969	JUL
AUG	221 m^3/sec on Aug 15, 1973	12.0 m^3/sec on Aug 31, 1967	AUG
SEP	388 m^3/sec on Sep 08, 1976	11.1 m^3/sec on Sep 06, 1965	SEP
OCT	340 m^3/sec on Oct 30, 1973	13.3 m^3/sec on Oct 02, 1965	OCT
NOV	405 m^3/sec on Nov 30, 1970	32.3 m^3/sec on Nov 01, 1965	NOV
DEC	702 m^3/sec on Dec 28, 1977	35.7 m^3/sec on Dec 26, 1965	DEC
EXTREME	702 m^3/sec on Dec 28, 1977	11.1 m^3/sec on Sep 06, 1965	EXTREME

Extremes of Monthly Mean Discharges in m^3/s for the Period January 1965 - December 1981

	Maximum Monthly Mean	Minimum Monthly Mean	
JAN	312 m^3/sec in 1978	28.6 m^3/sec in 1966	JAN
FEB	239 m^3/sec in 1978	22.3 m^3/sec in 1966	FEB
MAR	223 m^3/sec in 1978	21.9 m^3/sec in 1966	MAR
APR	361 m^3/sec in 1971	20.1 m^3/sec in 1967	APR
MAY	284 m^3/sec in 1974	83.4 m^3/sec in 1966	MAY
JUN	211 m^3/sec in 1977	44.3 m^3/sec in 1966	JUN
JUL	166 m^3/sec in 1978	19.0 m^3/sec in 1969	JUL
AUG	173 m^3/sec in 1973	15.2 m^3/sec in 1967	AUG
SEP	183 m^3/sec in 1981	14.4 m^3/sec in 1965	SEP
OCT	200 m^3/sec in 1976	26.0 m^3/sec in 1965	OCT
NOV	242 m^3/sec in 1980	39.7 m^3/sec in 1966	NOV
DEC	312 m^3/sec in 1977	55.3 m^3/sec in 1965	DEC
EXTREME	361 m^3/sec in 1971	14.4 m^3/sec in 1965	EXTREME

Figure A(iii)1: Salmon River at Round Pond water level and streamflow statistics.

Monthly Mean Discharges in m^3/s for the Period January 1965 - December 1981

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	PERIOD	
1965	------	------	------	------	------	------	------	------	14.4	26.0	93.0	55.3	15.7	**1965**
1966	28.6	22.3	21.9	90.6	83.4	44.3	33.1	31.6	32.3	38.5	39.7	82.5	45.9	**1966**
1967	53.7	26.9	25.8	20.1	209	73.9	23.2	15.2	18.0	37.9	117	92.0	59.7	**1967**
1968	61.6	71.9	91.1	77.8	89.6	72.9	47.4	25.1	61.8	33.7	60.4	97.9	65.9	**1968**
1969	42.6	168	68.5	144	167	80.3	19.0	60.0	47.8	82.7	88.0	204	97.2	**1969**
1970	126	88.5	153	160	130	80.9	128	164	80.8	94.3	151	275	136	**1970**
1971	49.8	177	48.0	361	151	113	121	81.7	105	137	188	111	136	**1971**
1972	125	96.7	109	138	182	147	148	128	43.8	152	199	229	142	**1972**
1973	120	168	116	153	219	166	118	173	135	177	149	190	157	**1973**
1974	184	188	173	165	284	140	138	127	111	191	135	211	171	**1974**
1975	164	226	164	232	179	135	128	145	115	131	138	177	161	**1975**
1976	174	165	195	207	198	168	81.0	107	170	200	117	227	168	**1976**
1977	182	209	169	160	248	211	163	167	166	176	210	312	198	**1977**
1978	312	239	223	204	183	206	166	140	145	137	131	187	189	**1978**
1979	160	157	203	180	218	143	155	128	106	129	130	186	158	**1979**
1980	207	------	------	------	129	126	108	127	166	121	242	248	144	**1980**
1981	185	182	203	185	251	176	165	152	183	190	202	199	190	**1981**

	Mean Monthly Discharge in m^3/s	Median Discharge in m^3/s	Lower Quartile in m^3/s	Upper Quartile in m^3/s	Median Cumulative Runoff Depth in mm	
JAN	136	143	55.7	184	75.22	**JAN**
FEB	145	168	88.5	188	143.34	**FEB**
MAR	131	153	68.5	195	204.58	**MAR**
APR	165	160	138	204	320.41	**APR**
MAY	183	183	135	219	399.19	**MAY**
JUN	130	138	80.5	168	470.38	**JUN**
JUL	109	124	55.8	153	533.60	**JUL**
AUG	111	128	65.5	150	600.84	**AUG**
SEP	100	106	45.8	155	618.38	**SEP**
OCT	121	131	60.6	176	690.72	**OCT**
NOV	141	135	105	194	786.88	**NOV**
DEC	181	190	104	228	882.46	**DEC**
PERIOD	138	157	97.2	171		**PERIOD**

This report was produced on August 19, 2014 using the Water Level and Streamflow Statistics application located at http://www.wsc.ec.gc.ca/staflo/index_e.cfm?cname=main_e.cfm

Figure A(iii)1: Continued.

Environment Canada | Environnement Canada

Canada

SALMON RIVER AT LONG POND

Water Survey of Canada
Dartmouth, Newfoundland and Labrador

Station No. 02ZE001
2640 km^2

Monthly Extremes of Daily Discharges in m^3/s for the Period January 1944 - December 1965

	Maximum Daily	Minimum Daily	
JAN	362 m^3/sec on Jan 18, 1963	26.7 m^3/sec on Jan 17, 1959	JAN
FEB	221 m^3/sec on Feb 10, 1952	15.8 m^3/sec on Feb 25, 1961	FEB
MAR	278 m^3/sec* on Mar 06, 1954	15.7 m^3/sec on Mar 22, 1950	MAR
APR	388 m^3/sec* on Apr 07, 1962	25.0 m^3/sec on Apr 02, 1959	APR
MAY	368 m^3/sec* on May 04, 1950	49.6 m^3/sec on May 23, 1951	MAY
JUN	348 m^3/sec* on Jun 03, 1948	13.3 m^3/sec on Jun 24, 1946	JUN
JUL	193 m^3/sec* on Jul 01, 1944	11.3 m^3/sec on Jul 29, 1949	JUL
AUG	154 m^3/sec on Aug 11, 1951	5.47 m^3/sec on Aug 31, 1961	AUG
SEP	128 m^3/sec* on Sep 15, 1957	3.68 m^3/sec on Sep 23, 1961	SEP
OCT	283 m^3/sec* on Oct 30, 1944	3.11 m^3/sec on Oct 02, 1961	OCT
NOV	283 m^3/sec on Nov 01, 1944	9.94 m^3/sec on Nov 05, 1950	NOV
DEC	391 m^3/sec on Dec 26, 1954	22.6 m^3/sec on Dec 01, 1950	DEC
EXTREME	391 m^3/sec* on Dec 26, 1954	3.11 m^3/sec on Oct 02, 1961	EXTREME

Extremes of Monthly Mean Discharges in m^3/s for the Period January 1944 - December 1965

	Maximum Monthly Mean	Minimum Monthly Mean	
JAN	219 m^3/sec in 1963	36.1 m^3/sec in 1959	JAN
FEB	140 m^3/sec in 1952	20.1 m^3/sec in 1961	FEB
MAR	180 m^3/sec in 1949	20.3 m^3/sec in 1950	MAR
APR	263 m^3/sec in 1962	64.8 m^3/sec in 1958	APR
MAY	286 m^3/sec in 1950	65.7 m^3/sec in 1949	MAY
JUN	238 m^3/sec in 1948	33.6 m^3/sec in 1951	JUN
JUL	144 m^3/sec in 1944	18.0 m^3/sec in 1949	JUL
AUG	90.1 m^3/sec in 1951	7.98 m^3/sec in 1961	AUG
SEP	90.9 m^3/sec in 1958	4.18 m^3/sec in 1961	SEP
OCT	205 m^3/sec in 1944	7.50 m^3/sec in 1961	OCT
NOV	199 m^3/sec in 1944	12.5 m^3/sec in 1950	NOV
DEC	201 m^3/sec in 1945	44.7 m^3/sec in 1947	DEC
EXTREME	286 m^3/sec in 1950	4.18 m^3/sec in 1961	EXTREME

Figure A(iii)2: Salmon River at Long Pond water level and streamflow statistics.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	PERIOD	
1944	70.0	85.8	129	164	233	180	144	72.4	86.6	205	199	122	141	**1944**
1945	152	138	73.8	183	254	103	58.8	64.8	67.5	82.6	155	201	128	**1945**
1946	184	132	133	175	131	63.4	60.8	57.4	27.9	34.1	55.6	66.5	93.2	**1946**
1947	61.1	74.7	132	114	125	71.2	55.3	29.0	13.5	23.3	19.9	44.7	63.7	**1947**
1948	154	107	113	113	212	238	92.6	57.1	82.2	78.7	74.0	49.6	114	**1948**
1949	156	53.2	180	78.1	65.7	35.4	18.0	8.62	26.9	54.0	90.0	164	77.9	**1949**
1950	50.4	34.5	20.3	92.4	286	61.6	22.6	19.0	9.20	7.83	12.5	53.4	56.1	**1950**
1951	93.9	138	81.7	152	85.8	33.6	26.5	90.1	36.4	29.5	124	104	82.4	**1951**
1952	115	140	73.8	99.0	222	69.1	38.5	31.4	24.3	16.9	141	108	89.7	**1952**
1953	57.9	106	51.5	176	93.9	100	33.4	22.2	22.5	77.4	90.9	121	79.1	**1953**
1954	66.3	111	155	90.6	116	86.9	54.0	72.1	32.1	35.1	124	188	94.2	**1954**
1955	133	65.1	83.0	76.6	85.2	94.3	43.3	37.0	22.0	50.4	117	75.4	73.5	**1955**
1956	150	76.1	44.3	125	215	98.5	65.1	40.5	17.5	22.9	72.2	135	88.8	**1956**
1957	94.1	48.1	39.6	70.8	117	39.7	19.3	39.1	74.9	75.0	94.2	136	70.8	**1957**
1958	106	76.1	76.4	64.8	72.6	59.1	65.7	52.4	90.9	80.3	123	117	82.0	**1958**
1959	36.1	45.0	33.7	122	115	43.3	24.2	23.7	26.9	23.9	137	132	63.5	**1959**
1960	54.8	70.1	57.6	77.9	149	50.8	36.3	15.0	8.02	24.3	84.8	60.6	57.4	**1960**
1961	49.0	20.1	28.2	96.6	230	71.2	20.1	7.98	4.18	7.50	45.3	68.3	54.4	**1961**
1962	51.5	95.2	85.9	263	140	92.1	50.5	38.2	30.7	69.4	195	100	101	**1962**
1963	219	77.0	31.6	128	230	86.5	46.2	37.8	86.2	82.8	75.2	124	102	**1963**
1964	41.1	62.2	51.3	178	163	81.8	79.8	47.3	49.9	112	122	76.3	88.7	**1964**
1965	78.9	48.6	128	81.6	188	113	40.0	22.2	20.3	------	------	------	60.2	**1965**

	Mean Monthly Discharge in m^3/s	Median Discharge in m^3/s	Lower Quartile in m^3/s	Upper Quartile in m^3/s	Median Cumulative Runoff Depth in mm	
JAN	98.8	86.4	54.0	151	87.69	**JAN**
FEB	82.0	76.1	52.0	108	162.48	**FEB**
MAR	81.9	75.1	43.1	128	266.80	**MAR**
APR	124	114	80.7	167	387.18	**APR**
MAY	160	144	110	224	528.58	**MAY**
JUN	85.1	76.5	57.0	98.9	574.37	**JUN**
JUL	49.8	44.7	25.9	61.9	641.84	**JUL**
AUG	40.2	38.0	22.2	57.2	695.35	**AUG**
SEP	39.1	27.4	19.6	69.3	723.17	**SEP**
OCT	56.8	50.4	23.6	79.5	757.46	**OCT**
NOV	102	94.2	73.1	131	879.60	**NOV**
DEC	107	108	67.4	134	984.77	**DEC**
PERIOD	85.8	82.4	67.2	97.4		**PERIOD**

Figure A(iii)2: Continued.

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SALMON RIVER AT BAY D'ESPOIR POWERHOUSE

Water Survey of Canada
Dartmouth, Newfoundland and Labrador

Station No. 02ZE003
5910 km^2

Monthly Extremes of Daily Discharges in m^3/s for the Period January 1967 - December 2010

	Maximum Daily	Minimum Daily	
JAN	670 m^3/sec on Jan 15, 1983	42.8 m^3/sec on Jan 27, 1968	JAN
FEB	804 m^3/sec on Feb 18, 1969	36.0 m^3/sec on Feb 29, 1968	FEB
MAR	428 m^3/sec on Mar 16, 1968	37.7 m^3/sec on Mar 03, 1968	MAR
APR	640 m^3/sec on Apr 19, 1971	32.6 m^3/sec on Apr 13, 1968	APR
MAY	603 m^3/sec on May 23, 1969	2.71 m^3/sec on May 03, 1994	MAY
JUN	564 m^3/sec on Jun 28, 1972	4.40 m^3/sec on Jun 06, 2002	JUN
JUL	362 m^3/sec on Jul 03, 1972	1.74 m^3/sec on Jul 01, 2002	JUL
AUG	306 m^3/sec on Aug 18, 1970	16.8 m^3/sec on Aug 26, 2002	AUG
SEP	456 m^3/sec on Sep 03, 1971	3.70 m^3/sec on Sep 11, 2002	SEP
OCT	340 m^3/sec on Oct 24, 2008	3.91 m^3/sec on Oct 07, 2002	OCT
NOV	915 m^3/sec on Nov 30, 1970	6.18 m^3/sec on Nov 14, 2002	NOV
DEC	1060 m^3/sec on Dec 01, 1970	0.278 m^3/sec on Dec 24, 2002	DEC
EXTREME	1060 m^3/sec on Dec 01, 1970	0.278 m^3/sec on Dec 24, 2002	EXTREME

Extremes of Monthly Mean Discharges in m^3/s for the Period January 1967 - December 2010

	Maximum Monthly Mean	Minimum Monthly Mean	
JAN	351 m^3/sec in 1978	79.1 m^3/sec in 1969	JAN
FEB	338 m^3/sec in 1994	97.9 m^3/sec in 1968	FEB
MAR	318 m^3/sec in 1999	101 m^3/sec in 1971	MAR
APR	473 m^3/sec in 1971	58.1 m^3/sec in 1968	APR
MAY	288 m^3/sec in 1974	74.9 m^3/sec in 1994	MAY
JUN	222 m^3/sec in 1981	57.0 m^3/sec in 2002	JUN
JUL	225 m^3/sec in 2000	50.9 m^3/sec in 2002	JUL
AUG	209 m^3/sec in 2000	52.0 m^3/sec in 2002	AUG
SEP	248 m^3/sec in 1984	38.3 m^3/sec in 2002	SEP
OCT	250 m^3/sec in 2008	37.2 m^3/sec in 2002	OCT
NOV	284 m^3/sec in 2000	50.5 m^3/sec in 1967	NOV
DEC	283 m^3/sec in 1993	42.5 m^3/sec in 2002	DEC
EXTREME	473 m^3/sec in 1971	37.2 m^3/sec in 2002	EXTREME

Figure A(iii)3: Salmon River at Bay d'Espoir Powerhouse water level and streamflow statistics.

Monthly Mean Discharges in m^3/s for the Period January 1967 - December 2010

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	PERIOD	
1967	------	------	------	------	------	------	------	66.1	73.4	61.9	50.5	67.6	26.8	**1967**
1968	96.9	97.9	149	58.1	117	76.4	69.0	64.9	61.3	76.2	69.5	103	86.9	**1968**
1969	79.1	196	104	176	193	82.2	82.9	78.3	85.9	106	91.3	184	121	**1969**
1970	141	108	209	160	170	102	122	141	138	104	175	260	153	**1970**
1971	124	107	101	473	107	105	87.0	85.1	175	118	124	138	145	**1971**
1972	127	106	122	170	178	173	153	108	122	130	283	208	157	**1972**
1973	171	191	163	140	203	165	145	191	153	155	252	190	177	**1973**
1974	225	208	199	153	288	157	152	134	150	181	180	188	185	**1974**
1975	212	229	208	195	165	153	134	141	155	135	140	188	171	**1975**
1976	200	231	227	197	222	202	178	175	176	196	186	204	199	**1976**
1977	222	253	234	225	215	212	199	195	206	222	214	264	222	**1977**
1978	351	297	281	253	233	196	184	149	149	148	164	176	215	**1978**
1979	181	218	191	238	209	165	168	109	125	115	151	205	172	**1979**
1980	208	192	159	132	183	132	108	150	141	171	265	247	174	**1980**
1981	221	214	223	233	204	222	205	170	173	241	237	253	216	**1981**
1982	299	310	244	208	249	182	181	150	133	194	162	163	206	**1982**
1983	239	226	235	224	240	200	193	192	193	211	223	218	216	**1983**
1984	240	271	268	244	202	212	182	195	248	245	204	200	226	**1984**
1985	185	218	180	163	184	131	128	152	160	155	179	159	166	**1985**
1986	172	212	205	232	154	160	135	178	160	147	171	175	175	**1986**
1987	143	152	180	213	121	121	105	87.7	81.6	88.6	186	173	137	**1987**
1988	147	189	287	193	132	174	168	159	173	158	187	219	182	**1988**
1989	167	201	212	201	190	139	117	118	125	146	198	234	170	**1989**
1990	208	237	170	136	213	137	138	138	107	131	170	194	165	**1990**
1991	219	186	205	237	221	155	142	157	147	206	212	211	192	**1991**
1992	202	226	184	193	200	193	177	157	153	180	217	202	190	**1992**
1993	217	227	228	217	254	176	149	166	161	190	211	283	207	**1993**
1994	341	338	259	286	74.9	215	173	183	203	233	244	214	230	**1994**
1995	198	220	180	194	170	149	188	175	153	196	204	268	191	**1995**
1996	200	228	249	200	165	172	199	205	169	204	233	217	203	**1996**
1997	222	261	228	255	185	154	176	185	206	197	217	221	209	**1997**
1998	231	163	166	254	179	196	178	153	161	158	194	272	192	**1998**
1999	254	265	318	310	256	215	190	160	195	244	210	263	240	**1999**
2000	224	282	237	250	217	201	225	209	178	196	284	230	227	**2000**
2001	243	282	231	199	151	142	160	162	121	119	145	150	175	**2001**
2002	181	195	194	201	149	57.0	50.9	52.0	38.3	37.2	65.7	42.5	105	**2002**
2003	182	220	218	148	184	163	186	187	160	113	220	212	183	**2003**
2004	247	230	240	155	194	196	213	181	165	204	210	246	207	**2004**
2005	259	219	203	210	246	198	164	177	170	184	196	256	207	**2005**
2006	296	292	251	156	132	161	167	166	177	186	230	259	206	**2006**
2007	270	279	232	212	154	121	116	184	181	152	193	265	196	**2007**
2008	250	244	277	212	136	151	164	159	223	250	234	239	211	**2008**
2009	260	226	215	141	129	128	136	136	159	188	188	235	178	**2009**
2010	243	216	183	144	153	127	130	190	171	178	205	208	179	**2010**

Figure A(iii)3: Continued.

	Mean Monthly Discharge in m^3/s	Median Discharge in m^3/s	Lower Quartile in m^3/s	Upper Quartile in m^3/s	Median Cumulative Runoff Depth in mm	
JAN	212	217	181	243	98.50	**JAN**
FEB	220	220	195	253	188.11	**FEB**
MAR	210	212	180	237	281.60	**MAR**
APR	204	201	160	233	369.33	**APR**
MAY	184	184	153	215	456.78	**MAY**
JUN	160	161	132	196	530.62	**JUN**
JUL	154	164	130	182	605.91	**JUL**
AUG	152	159	137	183	674.14	**AUG**
SEP	154	160	134	176	739.89	**SEP**
OCT	165	174	130	197	813.04	**OCT**
NOV	190	197	171	219	898.90	**NOV**
DEC	207	212	185	247	1,001.01	**DEC**
PERIOD	185	190	171	207		**PERIOD**

This report was produced on August 19, 2014 using the Water Level and Streamflow Statistics application located at http://www.wsc.ec.gc.ca/staflo/index_e.cfm?cname=main_e.cfm

Figure A(iii)3: Continued.

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Canada

CONNE RIVER AT OUTLET OF CONNE RIVER POND

Water Survey of Canada
Dartmouth, Newfoundland and Labrador

Station No. 02ZE004
99.5 km^2

Monthly Extremes of Daily Discharges in m^3/s for the Period January 1989 - December 2013

	Maximum Daily	Minimum Daily	
JAN	52.5 m^3/sec on Jan 28, 2000	0.231 m^3/sec on Jan 13, 1996	JAN
FEB	41.6 m^3/sec on Feb 20, 2008	0.254 m^3/sec on Feb 28, 1997	FEB
MAR	54.9 m^3/sec on Mar 25, 1992	0.163 m^3/sec on Mar 25, 1997	MAR
APR	50.8 m^3/sec on Apr 01, 2003	0.413 m^3/sec on Apr 03, 1990	APR
MAY	27.5 m^3/sec on May 02, 1993	0.361 m^3/sec on May 17, 2006	MAY
JUN	25.0 m^3/sec on Jun 08, 2010	0.126 m^3/sec on Jun 30, 1998	JUN
JUL	27.1 m^3/sec on Jul 29, 2011	0.124 m^3/sec on Jul 31, 2004	JUL
AUG	40.3 m^3/sec on Aug 31, 2013	0.031 m^3/sec on Aug 06, 2004	AUG
SEP	45.7 m^3/sec on Sep 21, 2010	0.065 m^3/sec on Sep 08, 2002	SEP
OCT	51.9 m^3/sec on Oct 06, 2003	0.423 m^3/sec on Oct 01, 2003	OCT
NOV	44.5 m^3/sec on Nov 23, 2003	0.655 m^3/sec on Nov 29, 1997	NOV
DEC	44.1 m^3/sec on Dec 21, 2004	0.343 m^3/sec on Dec 25, 1997	DEC
EXTREME	54.9 m^3/sec on Mar 25, 1992	0.031 m^3/sec on Aug 06, 2004	EXTREME

Extremes of Monthly Mean Discharges in m^3/s for the Period January 1989 - December 2013

	Maximum Monthly Mean	Minimum Monthly Mean	
JAN	5.80 m^3/sec in 2000	0.640 m^3/sec in 1991	JAN
FEB	7.37 m^3/sec in 2008	0.594 m^3/sec in 1992	FEB
MAR	7.68 m^3/sec in 1992	0.636 m^3/sec in 2006	MAR
APR	14.1 m^3/sec in 2004	2.45 m^3/sec in 1996	APR
MAY	8.35 m^3/sec in 1997	1.32 m^3/sec in 2006	MAY
JUN	4.74 m^3/sec in 2011	0.506 m^3/sec in 2005	JUN
JUL	5.78 m^3/sec in 1996	0.276 m^3/sec in 2005	JUL
AUG	4.61 m^3/sec in 2008	0.141 m^3/sec in 2001	AUG
SEP	6.28 m^3/sec in 2010	0.315 m^3/sec in 2003	SEP
OCT	12.4 m^3/sec in 2003	1.66 m^3/sec in 2001	OCT
NOV	8.78 m^3/sec in 1991	1.89 m^3/sec in 2010	NOV
DEC	7.10 m^3/sec in 2004	1.02 m^3/sec in 1994	DEC
EXTREME	14.1 m^3/sec in 2004	0.141 m^3/sec in 2001	EXTREME

Figure A(iii)4: Conne River at Outlet of Conne River Pond water level and streamflow statistics.

Monthly Mean Discharges in m^3/s for the Period January 1989 - December 2013

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	PERIOD	
1989	------	------	------	------	2.83	0.900	0.950	1.34	2.71	2.92	3.64	1.25	1.81	**1989**
1990	2.60	1.54	1.12	10.6	3.84	1.69	0.970	0.740	1.47	5.25	5.63	5.68	3.43	**1990**
1991	0.640	3.54	5.32	8.55	4.79	0.900	0.430	0.610	3.88	5.47	8.78	1.21	3.66	**1991**
1992	2.11	0.590	7.68	4.81	5.64	3.31	1.42	1.26	2.36	4.72	2.22	3.60	3.33	**1992**
1993	1.17	4.33	3.86	10.2	5.80	1.46	2.05	3.08	1.70	7.01	5.42	6.52	4.38	**1993**
1994	3.60	1.16	6.12	11.4	5.54	1.93	0.900	0.520	2.56	2.63	4.81	1.02	3.52	**1994**
1995	4.11	0.820	6.12	10.6	3.43	1.46	1.14	1.08	4.45	3.19	5.74	2.79	3.75	**1995**
1996	3.50	7.01	2.84	2.45	2.92	1.57	5.78	0.540	2.66	3.03	3.31	4.67	3.35	**1996**
1997	3.82	0.820	0.660	6.38	8.35	1.71	0.430	0.390	4.39	2.40	3.99	2.40	2.98	**1997**
1998	1.30	2.91	4.02	10.6	2.56	1.30	0.840	0.230	3.42	1.97	3.90	2.52	2.94	**1998**
1999	4.92	6.92	5.16	5.69	2.61	0.800	0.560	2.71	3.28	4.86	3.61	3.36	3.68	**1999**
2000	5.80	1.81	5.52	4.23	3.44	0.660	2.73	2.40	1.14	7.46	3.42	3.65	3.55	**2000**
2001	0.890	0.610	1.97	8.55	5.11	1.67	1.76	0.140	1.40	1.66	4.28	2.94	2.58	**2001**
2002	1.25	3.42	6.69	4.15	2.03	1.13	0.540	0.460	1.02	1.74	5.33	2.56	2.52	**2002**
2003	1.59	4.65	1.60	7.48	3.55	1.50	0.900	0.350	0.320	12.4	5.04	4.31	3.64	**2003**
2004	0.930	0.750	0.870	14.1	3.14	1.54	0.610	0.870	5.20	3.85	6.95	7.10	3.80	**2004**
2005	2.63	2.74	1.33	10.7	4.49	0.510	0.280	0.280	2.98	4.95	5.21	5.07	3.42	**2005**
2006	5.45	1.02	0.640	7.98	1.32	1.64	1.72	2.67	4.22	3.82	4.60	4.38	3.29	**2006**
2007	3.09	1.02	3.62	2.61	2.46	0.590	1.77	3.45	1.84	1.68	5.31	2.48	2.51	**2007**
2008	1.85	7.37	2.45	8.37	3.67	1.39	0.880	4.61	3.55	1.70	5.90	5.79	3.93	**2008**
2009	1.05	1.90	5.37	7.14	2.66	2.07	1.13	2.82	2.71	5.22	4.91	5.71	3.56	**2009**
2010	1.78	0.870	1.79	4.80	2.90	4.40	3.19	1.66	6.28	4.60	1.89	5.13	3.28	**2010**
2011	2.19	1.55	4.86	7.71	2.84	4.74	5.30	1.50	1.31	4.68	3.23	3.56	3.63	**2011**
2012	1.86	3.51	2.17	7.06	1.95	1.03	0.980	1.81	3.06	2.48	7.70	3.89	3.11	**2012**
2013	1.10	3.86	7.34	3.18	2.31	2.69	2.15	3.48	5.84	2.49	6.07	2.80	3.60	**2013**

	Mean Monthly Discharge in m^3/s	Median Discharge in m^3/s	Lower Quartile in m^3/s	Upper Quartile in m^3/s	Median Cumulative Runoff Depth in mm	
JAN	2.47	1.98	1.19	3.57	53.43	**JAN**
FEB	2.70	1.85	0.903	3.78	123.05	**FEB**
MAR	3.71	3.74	1.65	5.48	223.16	**MAR**
APR	7.47	7.60	4.80	10.5	412.73	**APR**
MAY	3.61	3.14	2.58	4.64	517.67	**MAY**
JUN	1.70	1.50	0.968	1.82	561.72	**JUN**
JUL	1.58	0.979	0.728	1.91	593.77	**JUL**
AUG	1.56	1.26	0.489	2.69	621.46	**AUG**
SEP	2.95	2.71	1.58	4.05	729.07	**SEP**
OCT	4.09	3.82	2.44	5.08	851.34	**OCT**
NOV	4.84	4.91	3.62	5.68	960.60	**NOV**
DEC	3.78	3.60	2.54	5.10	1,086.50	**DEC**
PERIOD	3.36	3.43	3.04	3.65		**PERIOD**

This report was produced on August 19, 2014 using the Water Level and Streamflow Statistics application located at http://www.wsc.ec.gc.ca/staflo/index_e.cfm?cname=main_e.cfm

Figure A(iii)4: Continued.

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SOUTHWEST BROOK BELOW SOUTHWEST POND

Water Survey of Canada — Station No. 02ZE005

Dartmouth, Newfoundland and Labrador — 10.4 km^2

Monthly Extremes of Daily Discharges in m^3/s for the Period January 2008 - December 2013

	Maximum Daily	Minimum Daily	
JAN	1.11 m^3/sec on Jan 31, 2008	0.021 m^3/sec on Jan 25, 2010	JAN
FEB	4.45 m^3/sec* on Feb 19, 2008	0.026 m^3/sec on Feb 07, 2010	FEB
MAR	3.63 m^3/sec on Mar 04, 2009	0.051 m^3/sec on Mar 25, 2009	MAR
APR	2.54 m^3/sec on Apr 09, 2009	0.055 m^3/sec on Apr 02, 2008	APR
MAY	2.33 m^3/sec on May 18, 2012	0.048 m^3/sec on May 29, 2009	MAY
JUN	3.78 m^3/sec on Jun 03, 2011	0.009 m^3/sec on Jun 26, 2012	JUN
JUL	2.48 m^3/sec on Jul 31, 2010	0.029 m^3/sec on Jul 27, 2009	JUL
AUG	2.86 m^3/sec* on Aug 31, 2013	0.016 m^3/sec on Aug 30, 2010	AUG
SEP	4.33 m^3/sec* on Sep 21, 2010	0.009 m^3/sec on Sep 07, 2010	SEP
OCT	2.66 m^3/sec on Oct 04, 2011	0.024 m^3/sec on Oct 09, 2008	OCT
NOV	2.81 m^3/sec on Nov 28, 2009	0.076 m^3/sec on Nov 17, 2010	NOV
DEC	3.39 m^3/sec on Dec 11, 2008	0.067 m^3/sec on Dec 31, 2013	DEC
EXTREME	4.45 m^3/sec on Feb 19, 2008	0.009 m^3/sec* on Jun 26, 2012	EXTREME

Extremes of Monthly Mean Discharges in m^3/s for the Period January 2008 - December 2013

	Maximum Monthly Mean	Minimum Monthly Mean	
JAN	0.443 m^3/sec in 2012	0.141 m^3/sec in 2013	JAN
FEB	0.970 m^3/sec in 2008	0.104 m^3/sec in 2010	FEB
MAR	0.603 m^3/sec in 2013	0.173 m^3/sec in 2010	MAR
APR	0.901 m^3/sec in 2011	0.282 m^3/sec in 2013	APR
MAY	0.367 m^3/sec in 2012	0.258 m^3/sec in 2011	MAY
JUN	0.565 m^3/sec in 2010	0.092 m^3/sec in 2012	JUN
JUL	0.577 m^3/sec in 2010	0.055 m^3/sec in 2009	JUL
AUG	0.427 m^3/sec in 2008	0.132 m^3/sec in 2011	AUG
SEP	0.731 m^3/sec in 2010	0.180 m^3/sec in 2011	SEP
OCT	0.756 m^3/sec in 2011	0.217 m^3/sec in 2008	OCT
NOV	0.814 m^3/sec in 2013	0.189 m^3/sec in 2010	NOV
DEC	1.05 m^3/sec in 2008	0.295 m^3/sec in 2013	DEC
EXTREME	1.05 m^3/sec in 2008	0.055 m^3/sec in 2009	EXTREME

Figure A(iii)5: Southwest Brook below Southwest Pond water level and streamflow statistics.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	PERIOD	
Monthly Mean Discharges in m^3/s for the Period January 2008 - December 2013														
2008	0.240	0.970	0.340	0.630	0.310	0.190	0.130	0.430	0.540	0.220	0.660	1.05	0.470	**2008**
2009	0.180	0.210	0.530	0.620	0.290	0.360	0.060	0.340	0.250	0.400	0.700	0.720	0.390	**2009**
2010	0.160	0.100	0.170	0.280	0.300	0.570	0.580	0.360	0.730	0.610	0.190	0.420	0.370	**2010**
2011	0.340	0.270	0.560	0.900	0.260	0.560	0.350	0.130	0.180	0.760	0.380	0.570	0.440	**2011**
2012	0.440	0.360	0.230	0.580	0.370	0.090	0.120	0.320	0.400	0.340	0.640	0.520	0.370	**2012**
2013	0.140	0.510	0.600	0.280	0.340	0.340	0.540	0.380	0.660	0.320	0.810	0.300	0.430	**2013**

	Mean Monthly Discharge in m^3/s	Median Discharge in m^3/s	Lower Quartile in m^3/s	Upper Quartile in m^3/s	Median Cumulative Runoff Depth in mm	
JAN	0.251	------	------	------	54.04	**JAN**
FEB	0.409	------	------	------	154.03	**FEB**
MAR	0.407	------	------	------	280.24	**MAR**
APR	0.550	------	------	------	398.07	**APR**
MAY	0.310	------	------	------	487.95	**MAY**
JUN	0.353	------	------	------	555.28	**JUN**
JUL	0.293	------	------	------	631.94	**JUL**
AUG	0.327	------	------	------	724.96	**AUG**
SEP	0.460	------	------	------	862.64	**SEP**
OCT	0.440	------	------	------	995.63	**OCT**
NOV	0.565	------	------	------	1,101.66	**NOV**
DEC	0.596	------	------	------	1,251.98	**DEC**
PERIOD	0.413	------	------	------		**PERIOD**

This report was produced on August 19, 2014 using the Water Level and Streamflow Statistics application located at http://www.wsc.ec.gc.ca/staflo/index_e.cfm?cname=main_e.cfm

Figure A(iii)5: Continued.

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BAY DU NORD RIVER AT BIG FALLS

Water Survey of Canada
Dartmouth, Newfoundland and Labrador

Station No. 02ZF001
1170 km^2

Monthly Extremes of Daily Discharges in m^3/s for the Period January 1950 - December 2013

	Maximum Daily	Minimum Daily	
JAN	537 m^3/sec on Jan 14, 1983	10.5 m^3/sec on Jan 30, 1991	JAN
FEB	369 m^3/sec on Feb 06, 1984	7.87 m^3/sec on Feb 26, 1975	FEB
MAR	251 m^3/sec on Mar 03, 1988	7.99 m^3/sec on Mar 08, 1975	MAR
APR	303 m^3/sec on Apr 17, 1986	8.27 m^3/sec on Apr 18, 1967	APR
MAY	194 m^3/sec on May 02, 1993	18.5 m^3/sec on May 05, 1979	MAY
JUN	108 m^3/sec on Jun 20, 2011	7.36 m^3/sec on Jun 30, 1979	JUN
JUL	87.0 m^3/sec on Jul 01, 1980	5.05 m^3/sec on Jul 31, 1991	JUL
AUG	170 m^3/sec on Aug 06, 1951	1.79 m^3/sec on Aug 31, 1987	AUG
SEP	178 m^3/sec on Sep 21, 2010	1.20 m^3/sec on Sep 14, 1987	SEP
OCT	212 m^3/sec* on Oct 24, 2003	2.27 m^3/sec on Oct 02, 1961	OCT
NOV	193 m^3/sec on Nov 23, 2003	6.91 m^3/sec on Nov 04, 1961	NOV
DEC	194 m^3/sec on Dec 27, 1977	13.2 m^3/sec on Dec 18, 1961	DEC
EXTREME	537 m^3/sec on Jan 14, 1983	1.20 m^3/sec on Sep 14, 1987	EXTREME

Extremes of Monthly Mean Discharges in m^3/s for the Period January 1950 - December 2013

	Maximum Monthly Mean	Minimum Monthly Mean	
JAN	166 m^3/sec in 1983	13.4 m^3/sec in 1975	JAN
FEB	132 m^3/sec in 1984	9.13 m^3/sec in 1975	FEB
MAR	138 m^3/sec in 1988	16.2 m^3/sec in 2006	MAR
APR	137 m^3/sec in 1990	11.4 m^3/sec in 1967	APR
MAY	106 m^3/sec in 1982	23.9 m^3/sec in 1979	MAY
JUN	59.5 m^3/sec in 2011	13.1 m^3/sec in 1979	JUN
JUL	46.7 m^3/sec in 1996	7.73 m^3/sec in 1979	JUL
AUG	60.7 m^3/sec in 1951	3.07 m^3/sec in 1987	AUG
SEP	64.1 m^3/sec in 2013	2.07 m^3/sec in 1987	SEP
OCT	114 m^3/sec in 2003	6.75 m^3/sec in 1961	OCT
NOV	85.8 m^3/sec in 2003	14.4 m^3/sec in 1950	NOV
DEC	100 m^3/sec in 1969	20.8 m^3/sec in 1961	DEC
EXTREME	166 m^3/sec in 1983	2.07 m^3/sec in 1987	EXTREME

Figure A(iii)6: Bay du Nord River at Big Falls water level and streamflow statistics.

Monthly Mean Discharges in m^3/s for the Period January 1950 - December 2013

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	PERIOD	
1950	------	------	------	------	------	------	------	------	------	10.4	14.4	------	2.13	**1950**
1951	------	------	32.5	54.8	41.7	16.5	11.9	60.7	19.3	17.2	56.2	57.6	31.0	**1951**
1952	63.1	81.8	45.7	56.1	63.9	27.8	20.3	19.3	21.6	18.9	64.0	55.4	44.7	**1952**
1953	41.3	58.0	35.1	79.0	39.9	35.0	15.7	10.1	9.24	30.2	50.3	72.1	39.5	**1953**
1954	60.3	66.6	71.2	55.2	39.2	30.4	20.3	21.7	13.6	24.8	53.3	81.0	44.7	**1954**
1955	54.5	34.7	43.3	38.2	29.2	38.8	25.9	25.2	17.3	36.0	58.9	42.9	37.1	**1955**
1956	73.3	38.5	32.7	86.3	74.6	39.1	30.9	22.2	16.0	18.3	50.1	73.7	46.3	**1956**
1957	51.3	30.4	28.8	42.0	40.4	15.2	8.80	15.3	45.3	35.6	46.2	66.2	35.5	**1957**
1958	53.0	34.0	30.4	24.2	31.5	30.4	23.4	24.4	40.1	31.3	52.7	54.9	35.9	**1958**
1959	29.3	45.3	46.3	66.9	53.6	21.5	11.6	10.2	13.5	18.7	69.2	60.4	37.1	**1959**
1960	27.1	34.0	26.9	42.8	47.1	22.3	14.9	8.50	5.83	16.2	30.0	31.7	25.6	**1960**
1961	25.5	11.6	35.1	52.6	79.3	24.9	8.67	4.23	2.47	6.75	15.5	20.8	24.1	**1961**
1962	25.4	66.4	51.8	109	36.2	22.3	17.0	16.1	16.5	31.5	84.8	54.6	43.9	**1962**
1963	93.3	31.9	21.6	60.8	78.7	37.4	27.8	18.9	41.5	38.7	33.3	61.9	45.6	**1963**
1964	28.9	39.8	25.7	89.3	45.2	20.6	23.9	25.7	22.9	61.0	53.2	45.0	40.0	**1964**
1965	44.3	30.0	57.7	54.7	61.8	34.6	24.4	19.4	20.7	20.8	61.5	41.1	39.3	**1965**
1966	23.3	20.1	23.6	59.6	44.9	24.0	21.3	21.0	23.2	26.8	32.6	56.3	31.4	**1966**
1967	45.7	30.3	32.2	11.4	96.0	35.9	12.9	23.9	19.5	27.4	66.2	68.2	39.3	**1967**
1968	67.2	57.5	66.5	44.3	62.3	41.1	28.2	20.0	37.7	27.4	45.9	61.3	46.6	**1968**
1969	27.1	96.7	53.6	55.2	45.8	22.4	9.94	10.2	26.2	41.0	54.9	100	44.9	**1969**
1970	47.6	26.7	73.6	57.4	53.9	32.5	19.4	34.1	31.4	20.7	48.8	59.2	42.2	**1970**
1971	33.2	64.4	36.3	133	51.8	25.8	30.0	17.9	18.6	21.1	60.0	57.2	45.5	**1971**
1972	33.9	30.5	63.4	50.2	98.1	38.6	21.9	9.27	10.9	54.6	67.5	56.6	44.7	**1972**
1973	33.0	60.8	30.9	46.1	89.3	34.0	36.5	53.8	29.7	33.9	79.3	48.7	47.9	**1973**
1974	30.8	19.2	29.4	63.0	65.9	29.9	18.2	10.7	11.4	46.6	44.4	53.7	35.4	**1974**
1975	13.4	9.13	17.1	71.3	77.0	16.6	8.68	12.9	18.3	42.5	51.2	78.0	34.8	**1975**
1976	85.7	67.8	36.5	110	55.0	20.9	11.0	9.54	17.1	41.0	49.7	64.1	47.2	**1976**
1977	72.0	36.7	29.1	71.9	55.1	37.2	18.3	20.8	27.9	55.5	30.8	50.4	42.2	**1977**
1978	105	39.5	24.9	60.7	68.6	29.9	21.3	9.58	8.82	22.9	24.2	30.9	37.3	**1978**
1979	51.9	46.7	59.6	33.3	23.9	13.1	7.73	16.1	27.7	43.7	52.2	36.8	34.3	**1979**
1980	24.2	17.2	38.1	------	------	39.9	46.1	55.1	40.4	41.5	67.9	37.4	35.3	**1980**
1981	58.6	52.1	40.0	51.7	87.9	22.2	33.5	22.5	28.1	99.2	55.1	50.6	50.2	**1981**
1982	29.3	22.7	41.6	75.9	106	26.8	23.9	16.9	20.3	21.2	16.2	44.7	37.2	**1982**
1983	166	47.5	77.5	65.3	36.2	28.1	17.1	41.0	41.7	23.3	37.4	39.2	51.8	**1983**
1984	58.6	132	41.7	60.7	67.6	50.0	17.2	21.0	58.2	29.7	17.4	29.1	48.2	**1984**
1985	20.6	19.2	28.9	31.6	84.4	39.2	28.7	20.2	16.3	11.3	15.6	24.5	28.5	**1985**
1986	54.1	34.3	23.9	137	37.9	27.1	20.5	12.9	12.5	24.0	32.0	32.3	37.2	**1986**
1987	21.8	36.1	39.6	114	45.3	19.2	8.64	3.07	2.07	16.7	56.6	46.1	33.9	**1987**
1988	17.7	61.0	138	96.1	45.4	36.6	34.0	11.0	8.48	15.5	40.1	29.0	44.3	**1988**
1989	28.8	21.6	26.9	70.0	59.6	21.3	14.2	13.1	16.7	31.6	37.6	31.2	31.1	**1989**

Figure A(iii)6: Continued.

1990	26.1	34.0	27.1	137	61.6	37.5	22.9	8.30	8.41	38.0	53.9	78.7	44.4	**1990**
1991	20.5	35.0	66.7	64.9	52.4	21.4	7.93	5.78	14.7	59.8	62.5	30.4	36.8	**1991**
1992	23.9	19.4	56.3	86.8	70.0	35.2	20.9	15.3	18.5	31.4	38.5	33.1	37.4	**1992**
1993	25.1	42.6	55.2	84.8	94.2	28.7	35.7	39.8	14.7	53.7	74.3	78.8	52.4	**1993**
1994	54.0	37.5	66.4	115	77.9	33.3	16.9	15.5	16.3	18.4	42.9	23.7	43.1	**1994**
1995	49.6	23.3	54.0	86.6	51.8	21.9	14.5	18.7	43.6	49.4	56.6	55.1	43.8	**1995**
1996	34.7	61.1	51.1	33.9	32.9	22.7	46.7	21.0	14.3	36.1	31.0	54.4	36.7	**1996**
1997	46.1	35.3	17.6	59.6	83.5	32.5	16.4	9.70	40.1	24.2	46.5	30.9	36.8	**1997**
1998	25.3	29.6	48.7	111	55.0	20.9	10.5	5.23	15.8	34.3	43.4	44.9	37.0	**1998**
1999	56.0	77.3	73.6	60.0	42.7	22.3	12.3	14.8	31.6	55.1	43.2	44.3	44.2	**1999**
2000	57.6	55.5	49.8	59.7	44.6	17.8	21.3	24.1	21.5	59.9	52.9	39.5	42.0	**2000**
2001	22.3	16.1	30.9	55.7	79.8	34.4	23.9	11.2	14.4	18.0	51.9	36.2	33.0	**2001**
2002	33.6	39.5	77.3	58.1	27.9	15.0	9.44	6.80	8.04	15.9	44.7	49.8	32.1	**2002**
2003	22.8	41.7	19.2	67.4	56.8	25.5	12.0	8.88	8.76	114	85.8	68.7	44.3	**2003**
2004	30.9	15.1	19.7	115	56.4	20.8	16.2	12.9	30.9	48.0	61.6	82.4	42.5	**2004**
2005	46.9	28.7	27.7	104	51.7	17.6	11.1	10.8	14.7	44.6	66.6	70.5	41.2	**2005**
2006	66.7	25.6	16.2	69.9	28.4	21.3	17.7	31.5	31.6	41.4	59.5	59.0	39.1	**2006**
2007	39.5	26.0	33.8	38.0	30.6	16.3	16.3	35.8	24.6	17.8	54.3	38.7	31.0	**2007**
2008	33.2	73.2	45.0	65.8	54.6	27.8	14.8	29.3	49.3	19.7	49.4	89.4	45.8	**2008**
2009	36.2	29.1	43.2	73.5	37.0	22.6	17.5	15.8	25.3	41.2	43.4	70.0	37.9	**2009**
2010	37.3	18.2	21.9	34.4	36.3	47.2	28.4	29.2	56.0	68.7	43.5	45.5	39.0	**2010**
2011	51.6	29.0	53.1	76.7	47.5	59.5	35.4	27.9	12.9	47.3	45.6	52.8	45.0	**2011**
2012	38.3	42.9	34.4	67.0	41.9	22.0	16.1	13.2	25.0	35.5	74.6	55.1	38.7	**2012**
2013	29.1	50.2	68.8	43.1	26.5	26.4	32.5	31.6	64.1	31.9	65.2	54.1	43.5	**2013**

	Mean Monthly Discharge in m^3/s	Median Discharge in m^3/s	Lower Quartile in m^3/s	Upper Quartile in m^3/s	Median Cumulative Runoff Depth in mm	
JAN	44.0	36.7	26.8	54.2	84.06	**JAN**
FEB	41.0	35.1	26.5	52.9	170.86	**FEB**
MAR	43.1	38.1	28.8	54.0	271.99	**MAR**
APR	68.5	61.9	52.4	85.2	424.61	**APR**
MAY	55.8	53.0	40.3	69.0	574.45	**MAY**
JUN	28.2	26.8	21.4	35.0	634.74	**JUN**
JUL	20.2	18.2	12.9	24.4	672.94	**JUL**
AUG	19.6	16.9	10.7	24.1	689.45	**AUG**
SEP	23.2	19.3	14.3	30.9	762.52	**SEP**
OCT	35.0	31.6	20.7	43.4	848.40	**OCT**
NOV	49.5	50.8	40.8	59.8	941.11	**NOV**
DEC	52.2	53.7	38.7	61.9	1,059.02	**DEC**
PERIOD	39.9	39.4	36.7	44.6		**PERIOD**

This report was produced on August 19, 2014 using the Water Level and Streamflow Statistics application located at http://www.wsc.ec.gc.ca/staflo/index_e.cfm?cname=main_e.cfm

Figure A(iii)6: Continued.

APPENDIX B: MAIN BAYS WATERSHED AREAS AND MAIN RIVERS DISCHARGE ESTIMATES

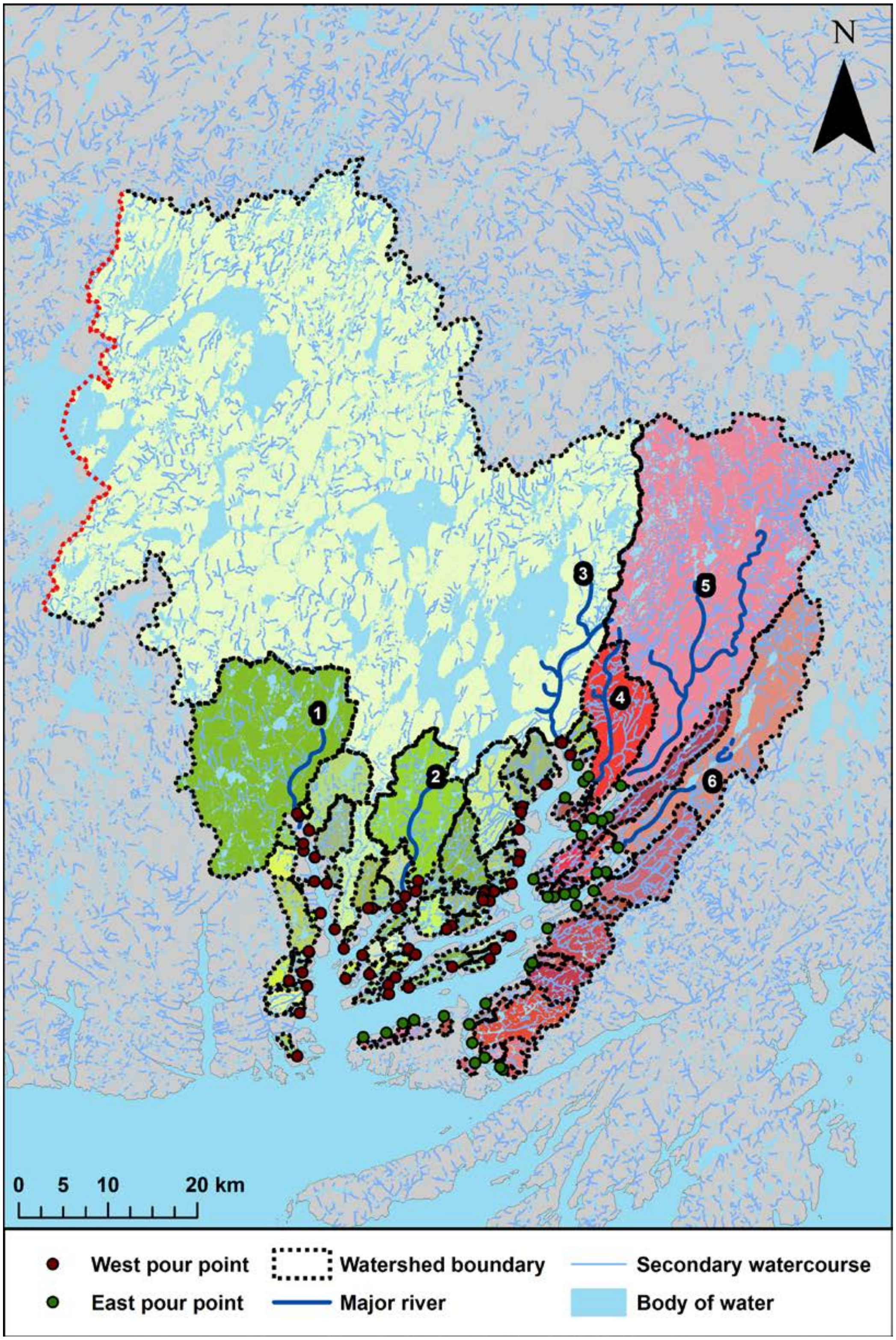


Figure B1: Bay d'Espoir watersheds. Shades of green (red) represent western (eastern) watersheds from the main SW-NE axis of the fjord. Major rivers are highlighted and numbered as: D'Espoir Brook (1), Salmon River (East Bay) (2), Salmon River (powerhouse) (3), Southeast Brook (4), Conne River (5) and Little River (6). Red dashed line shows the estimated western limit of Salmon River (powerhouse) natural watershed which, in fact, now extends much further west due to man-made water diversion.

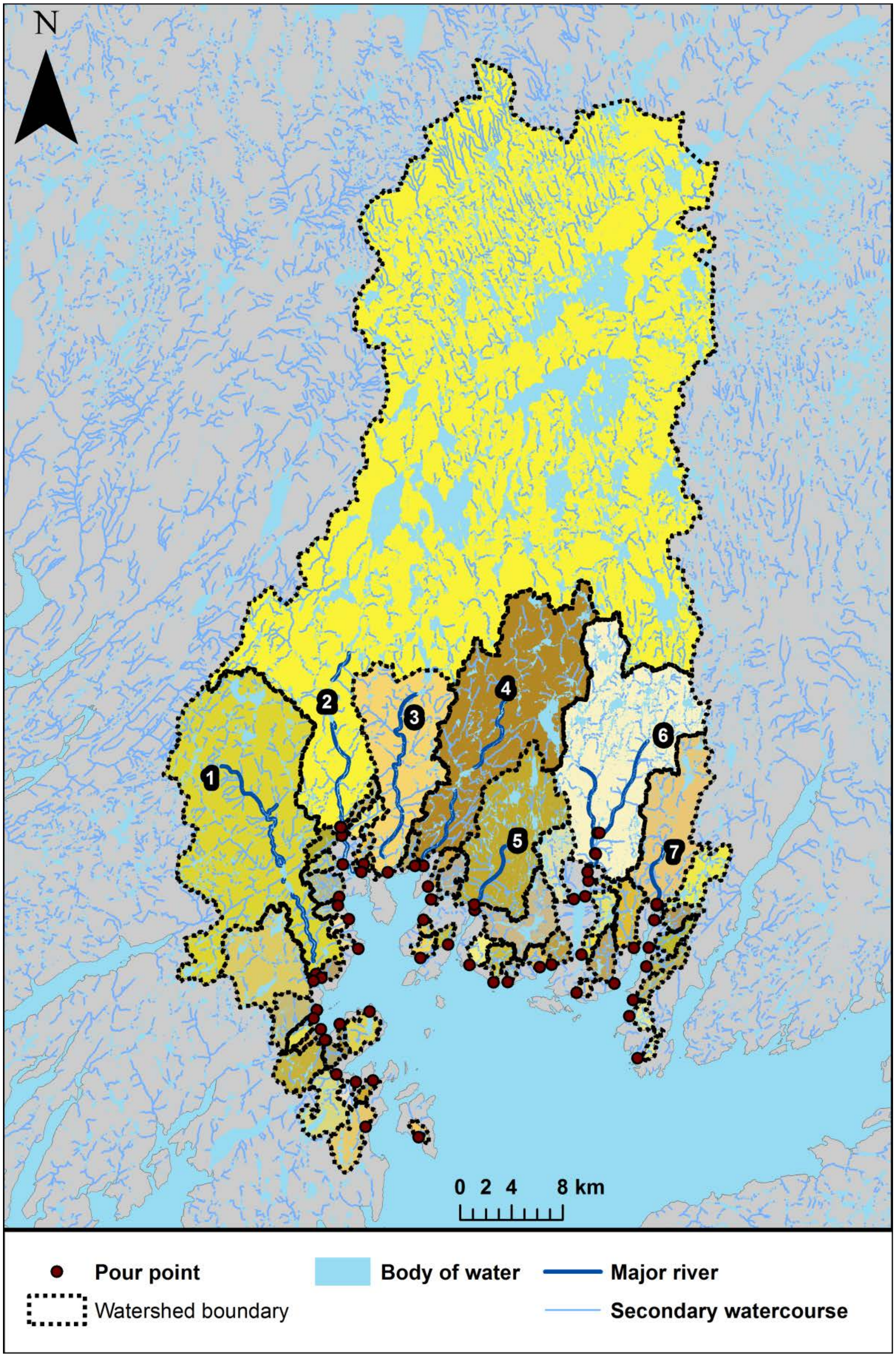


Figure B2: Belle Bay watersheds. Major rivers for Belle Bay are numbered as: Salmon River (1), Bay du Nord River (2), North West Brook (3), North East Brook (4), Bell Harbour (5), Rencontre Brook (6) and Mal Bay Brook (7).

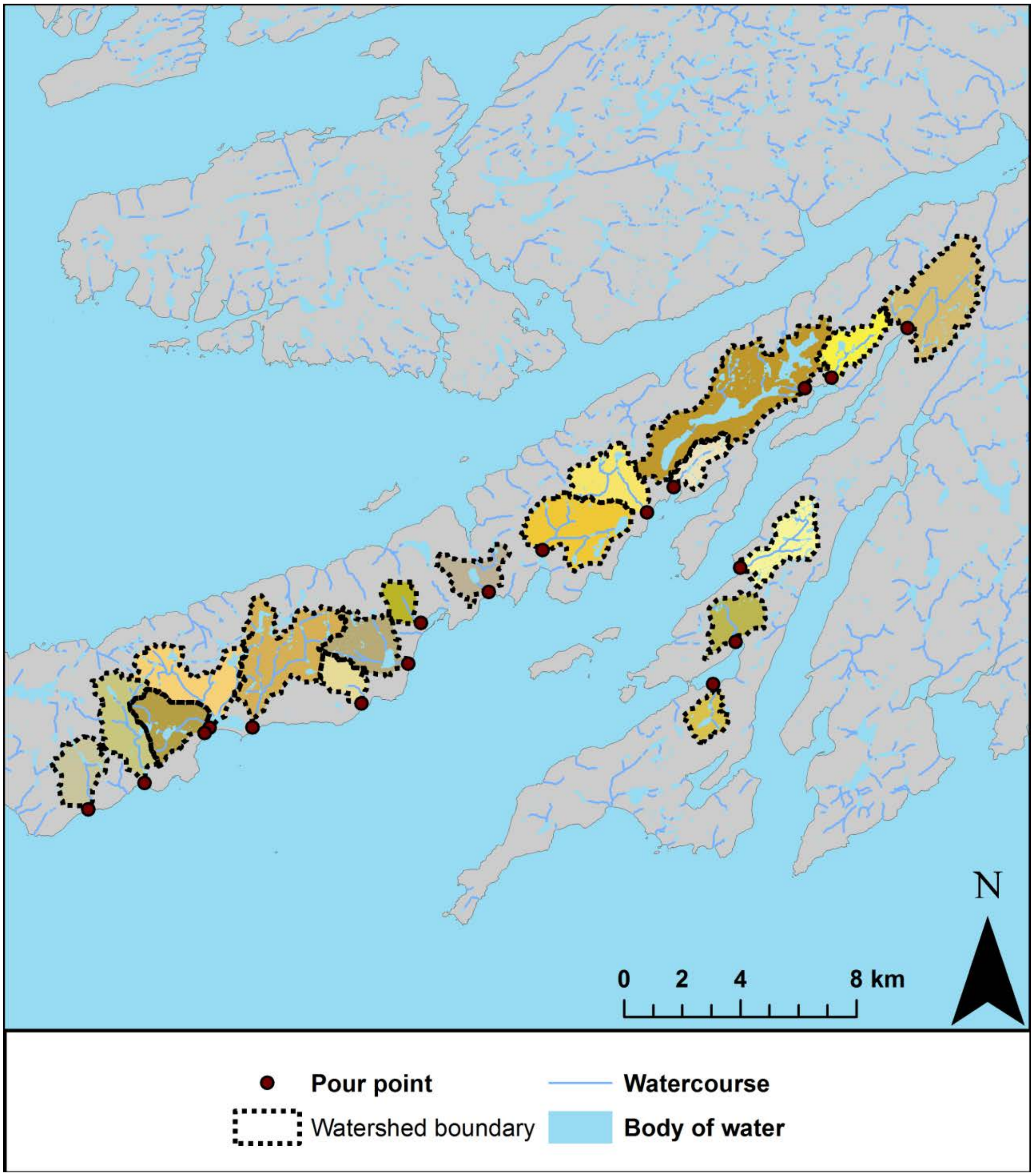


Figure B3: Connaigre Bay watersheds.

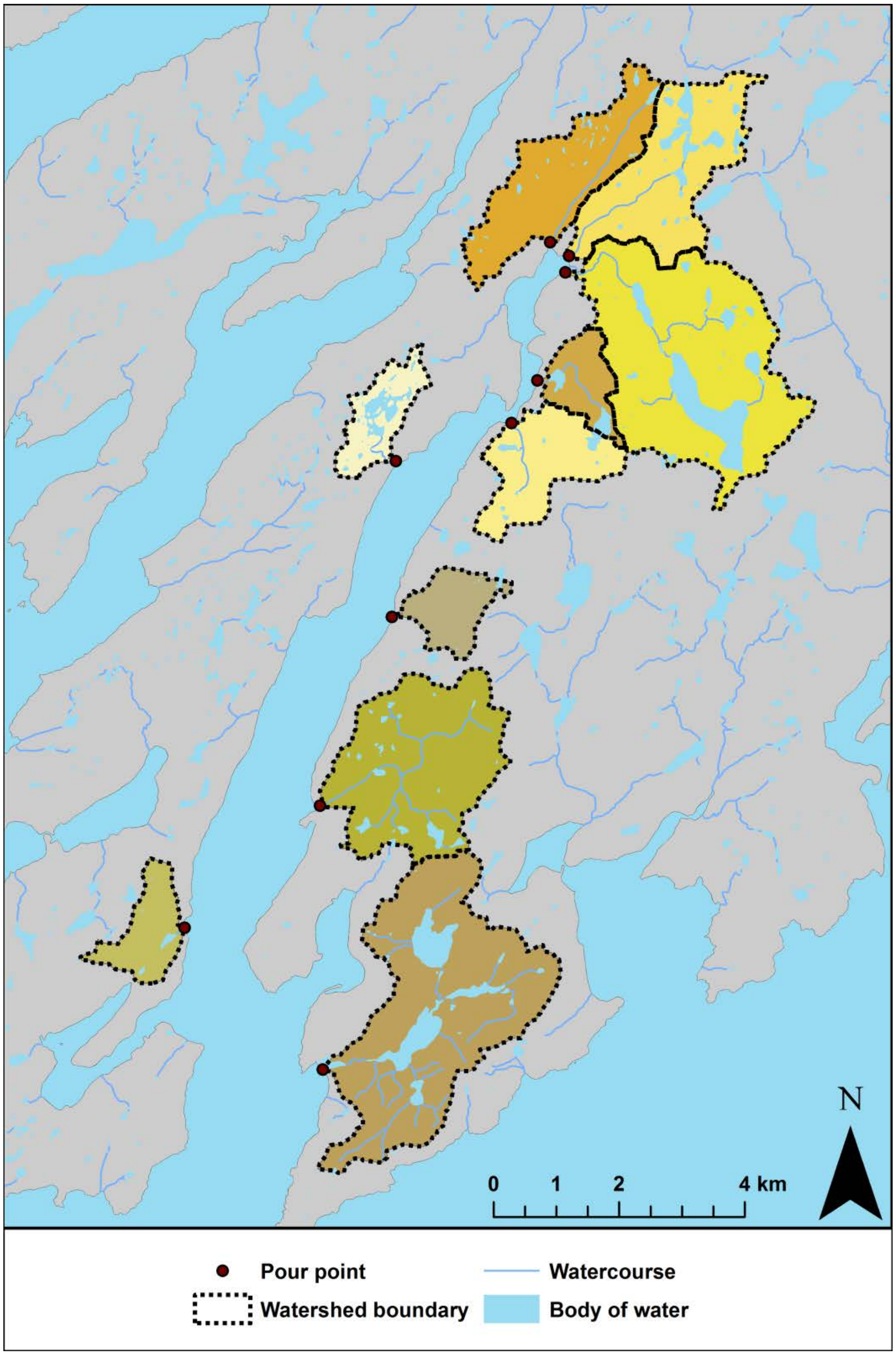


Figure B4: Harbour Breton – Northeast Arm watersheds.

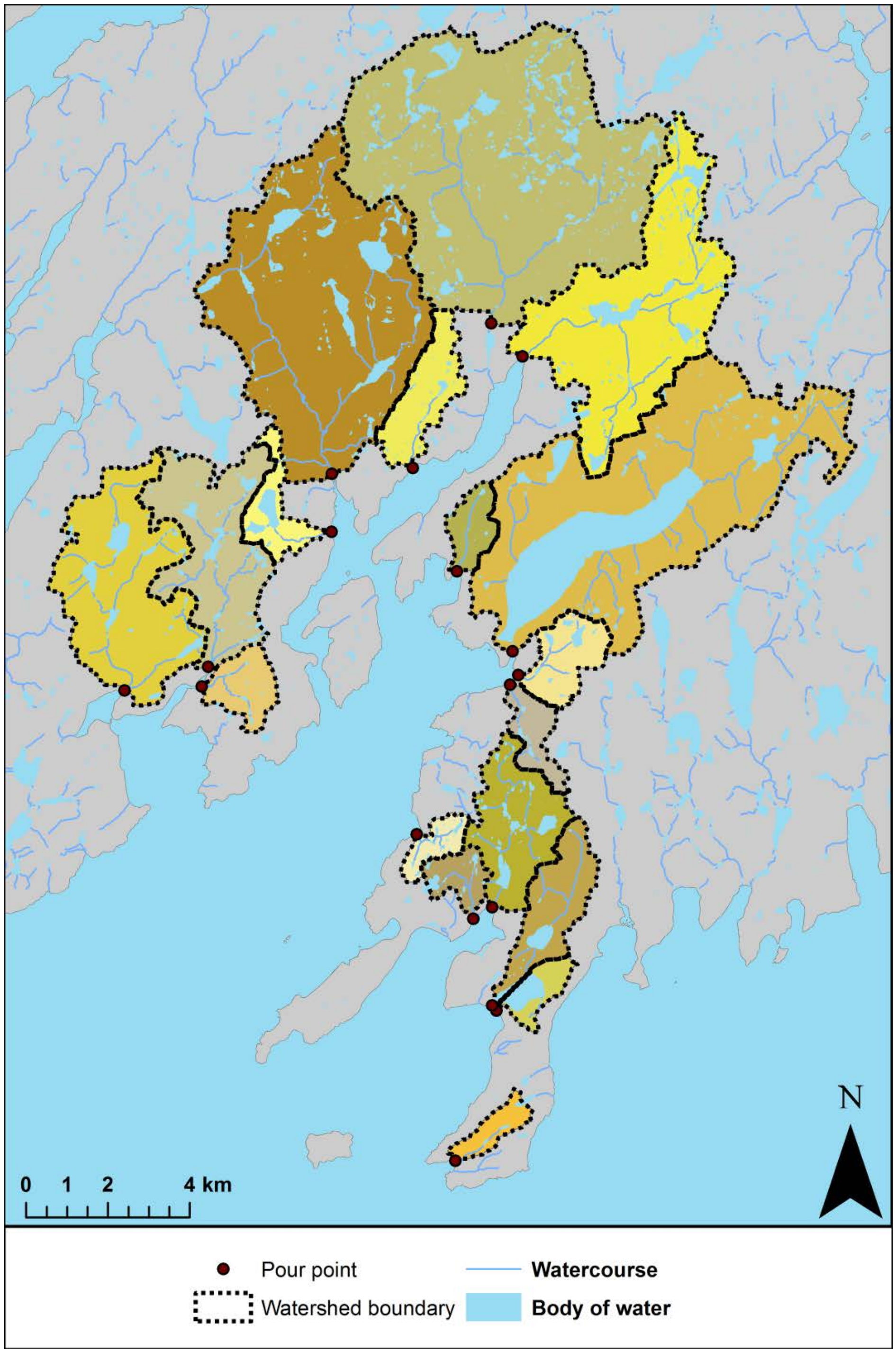


Figure B5: Great Bay de L'Eau watersheds.

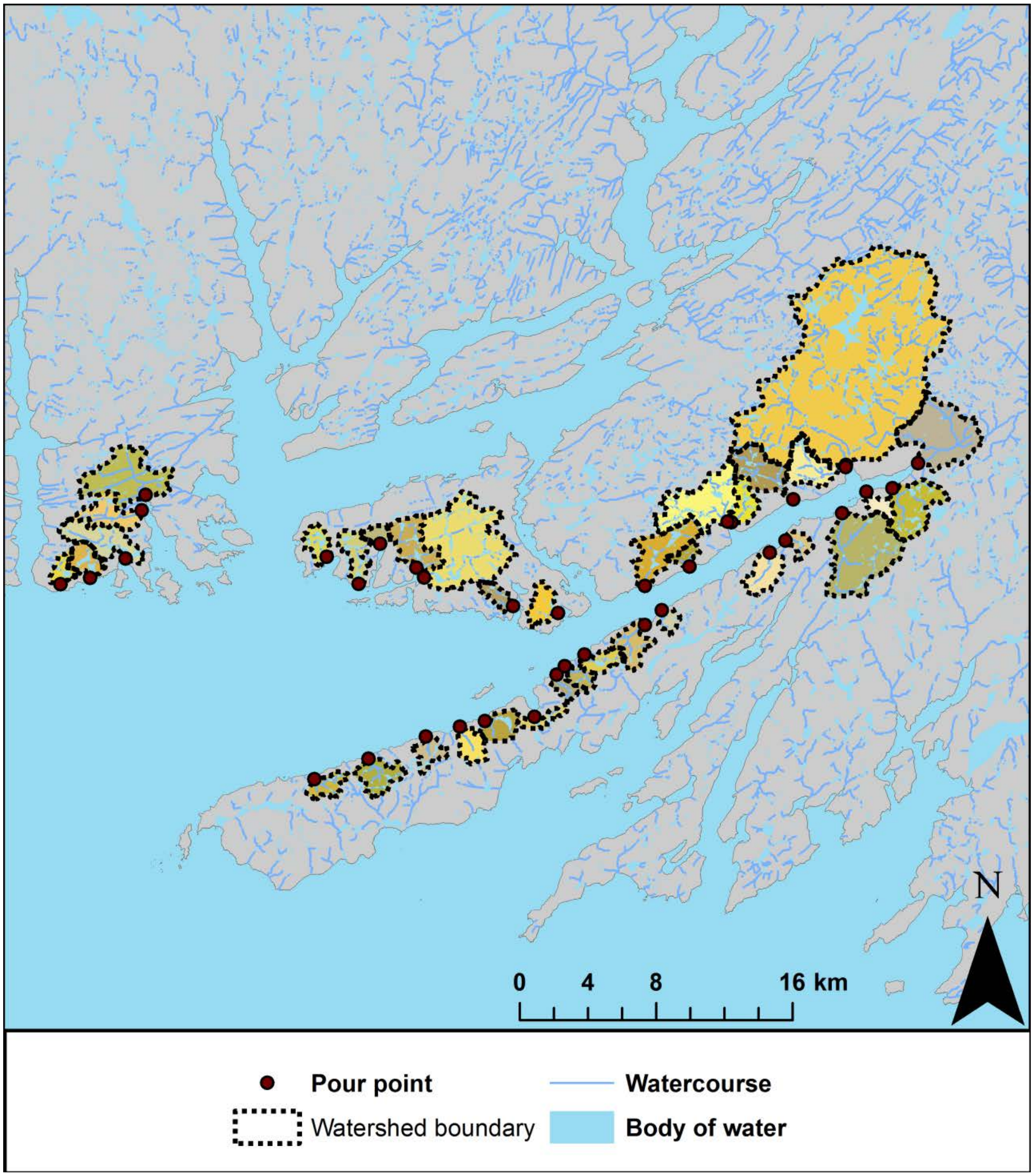


Figure B6: Hermitage Bay watersheds.

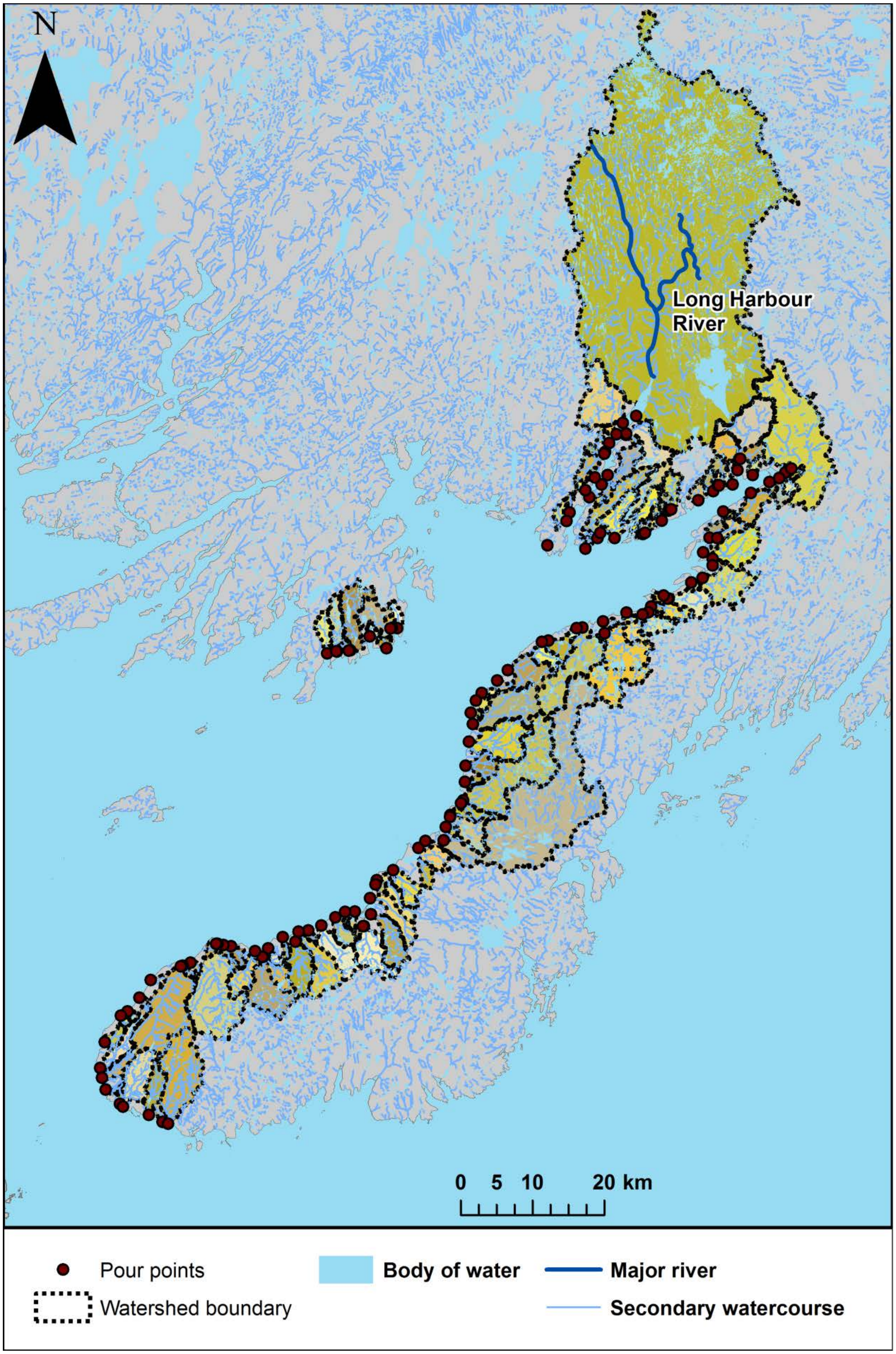


Figure B7: Fortune Bay watersheds.

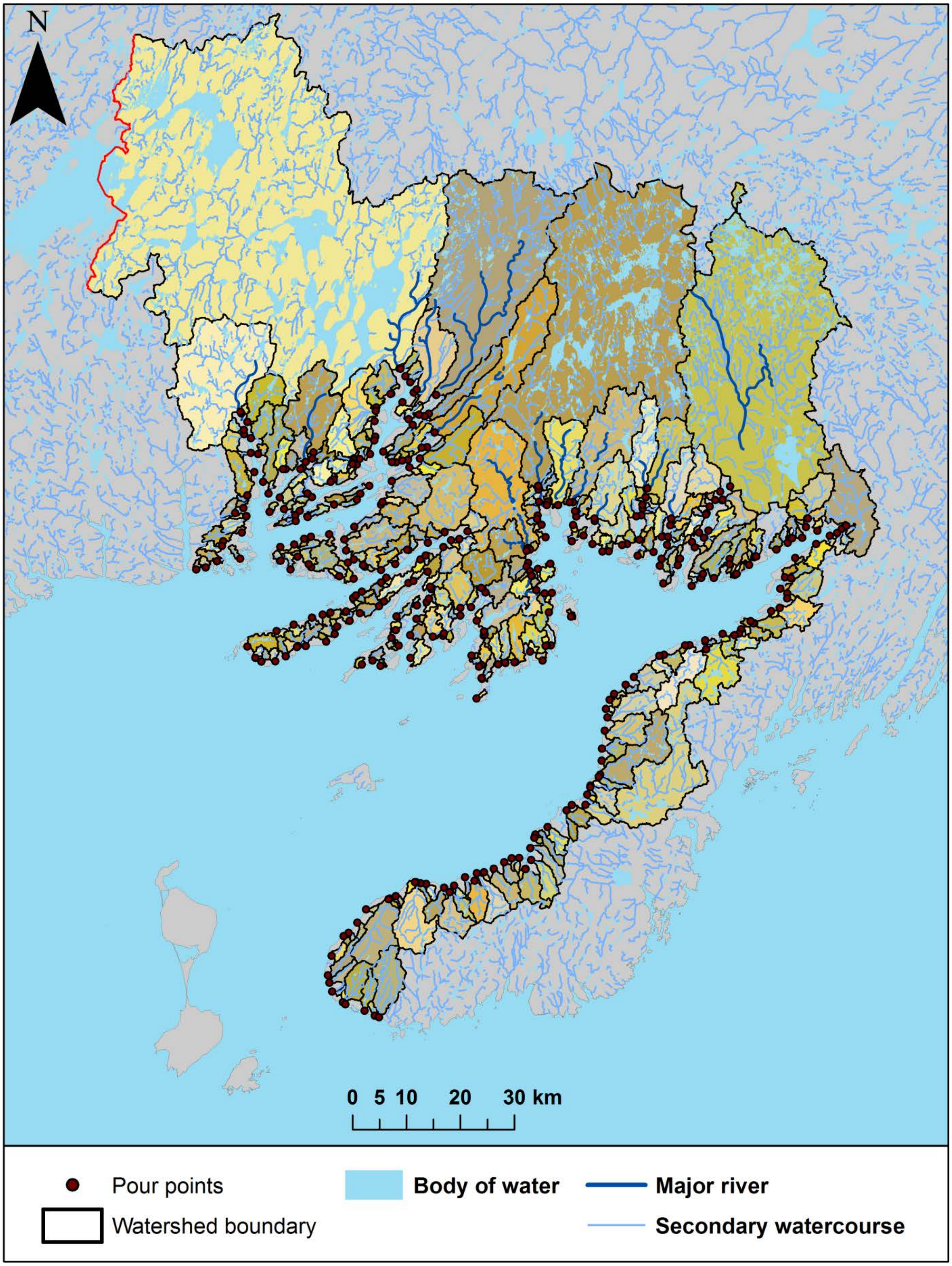


Figure B8: Coast of Bays watersheds.

Table B1: Watershed statistics of the Coast of Bays area.

River	Watershed km^2	Jan m^3/s	Feb m^3/s	Mar m^3/s	Apr m^3/s	May m^3/s	Jun m^3/s	Jul m^3/s	Aug m^3/s	Sep m^3/s	Oct m^3/s	Nov m^3/s	Dec m^3/s	Avg m^3/s
Salmon River – Powerhouse - (Mean)	5910	212.0	220.0	210.0	204.0	184.0	160.0	154.0	152.0	154.0	165.0	190.0	207.0	185.0
Salmon River – Powerhouse - (Lower Q.)	5910	181.0	195.0	180.0	160.0	153.0	132.0	130.0	137.0	134.0	130.0	171.0	185.0	171.0
Salmon River – Powerhouse - (Upper Q.)	5910	243.0	253.0	237.0	233.0	215.0	196.0	182.0	183.0	176.0	197.0	219.0	247.0	207.0
Southeast Brook (Mean)	88.2	2.2	2.4	3.3	6.6	3.2	1.5	1.4	1.4	2.6	3.6	4.3	3.4	3.0
Southeast Brook (Lower Q.)	88.2	1.1	0.8	1.5	4.3	2.3	0.9	0.6	0.4	1.4	2.2	3.2	2.3	2.7
Southeast Brook (Upper Q.)	88.2	3.2	3.4	4.9	9.3	4.1	1.6	1.7	2.4	3.6	4.5	5.0	4.5	3.2
Conne River (Mean)	613.6	15.2	16.7	22.9	46.1	22.3	10.5	9.7	9.6	18.2	25.2	29.8	23.3	20.7
Conne River (Lower Q.)	613.6	7.3	5.6	10.2	29.6	15.9	6.0	4.5	3.0	9.7	15.0	22.3	15.7	18.7
Conne River (Upper Q.)	613.6	22.0	23.3	33.8	64.8	28.6	11.2	11.8	16.6	25.0	31.3	35.0	31.5	22.5
Little River (Mean)	182	4.5	4.9	6.8	13.7	6.6	3.1	2.9	2.9	5.4	7.5	8.9	6.9	6.1
Little River (Lower Q.)	182	2.2	1.7	3.0	8.8	4.7	1.8	1.3	0.9	2.9	4.5	6.6	4.6	5.6
Little River (Upper Q.)	182	6.5	6.9	10.0	19.2	8.5	3.3	3.5	4.9	7.4	9.3	10.4	9.3	6.7
D'Espoir Brook (Mean)	303.3	11.4	9.4	9.4	14.2	18.4	9.8	5.7	4.6	4.5	6.5	11.7	12.3	9.9
D'Espoir Brook (Lower Q.)	303.3	6.2	6.0	5.0	9.3	12.6	6.5	3.0	2.6	2.3	2.7	8.4	7.7	7.7
D'Espoir Brook (Upper Q.)	303.3	17.3	12.4	14.7	19.2	25.7	11.4	7.1	6.6	8.0	9.1	15.1	15.4	11.2
Salmon River - East Bay - (Mean)	105	3.9	3.3	3.3	4.9	6.4	3.4	2.0	1.6	1.6	2.3	4.1	4.3	3.4
Salmon River - East Bay - (Lower Q.)	105	2.1	2.1	1.7	3.2	4.4	2.3	1.0	0.9	0.8	0.9	2.9	2.7	2.7
Salmon River - East Bay - (Upper Q)	105	6.0	4.3	5.1	6.6	8.9	3.9	2.5	2.3	2.8	3.2	5.2	5.3	3.9
BDE TOTAL - main rivers - (Mean)	7202.1	249.2	256.7	255.7	289.5	240.9	188.3	175.7	172.1	186.3	210.1	248.8	257.2	228.1
BDE TOTAL - main rivers - (Lower Q.)	7202.1	199.9	211.2	201.4	215.2	192.9	149.5	140.4	144.8	151.1	155.3	214.4	218.0	208.4
BDE TOTAL - main rivers - (Upper Q.)	7202.1	298.0	303.3	305.5	352.1	290.8	227.4	208.6	215.8	222.8	254.4	289.7	313.0	254.5

Table B1: Continued.

River	Watershed km²	Jan m³/s	Feb m³/s	Mar m³/s	Apr m³/s	May m³/s	Jun m³/s	Jul m³/s	Aug m³/s	Sep m³/s	Oct m³/s	Nov m³/s	Dec m³/s	Avg m³/s
BDE TOTAL - all rivers- (Mean)	7916.7	272.2	277.7	279.6	331.6	276.8	206.7	188.3	183.1	201.3	231.4	279.4	285.4	251.7
BDE TOTAL - all rivers - (Lower Q.)	7916.7	212.0	221.9	213.0	242.3	218.0	161.3	146.8	149.7	158.9	166.4	236.9	236.2	228.1
BDE TOTAL - all rivers - (Upper Q.)	7916.7	332.6	331.7	342.1	410.0	340.0	248.5	224.0	232.8	245.8	282.2	327.4	349.5	280.8
Salmon River (Mean)	197	7.3	6.8	7.2	11.4	9.3	4.7	3.4	3.3	3.9	5.8	8.2	8.7	6.6
Salmon River (Lower Q.)	197	4.5	4.4	4.8	8.7	6.7	3.6	2.1	1.8	2.4	3.4	6.8	6.4	6.1
Salmon River (Upper Q.)	197	9.0	8.8	9.0	14.2	11.5	5.8	4.1	4.0	5.1	7.2	9.9	10.3	7.4
Bay du Nord (Mean)	1184.3	44.0	41.0	43.1	68.5	55.8	28.2	20.2	19.6	23.2	35.0	49.5	52.2	39.9
Bay du Nord (Lower Q.)	1184.3	26.8	26.5	28.8	52.4	40.3	21.4	12.9	10.7	14.3	20.7	40.8	38.7	36.7
Bay du Nord (Upper Q.)	1184.3	54.2	52.9	54.0	85.2	69.0	35.0	24.4	24.1	30.9	43.4	59.8	61.9	44.6
Northwest Brook (Mean)	77.5	2.9	2.7	2.8	4.5	3.7	1.8	1.3	1.3	1.5	2.3	3.2	3.4	2.6
Northwest Brook (Lower Q.)	77.5	1.8	1.7	1.9	3.4	2.6	1.4	0.8	0.7	0.9	1.4	2.7	2.5	2.4
Northwest Brook (Upper Q.)	77.5	3.5	3.5	3.5	5.6	4.5	2.3	1.6	1.6	2.0	2.8	3.9	4.1	2.9
Northeast Brook (Mean)	142.9	5.3	4.9	5.2	8.3	6.7	3.4	2.4	2.4	2.8	4.2	6.0	6.3	4.8
Northeast Brook (Lower Q.)	142.9	3.2	3.2	3.5	6.3	4.9	2.6	1.6	1.3	1.7	2.5	4.9	4.7	4.4
Northeast Brook (Upper Q.)	142.9	6.5	6.4	6.5	10.3	8.3	4.2	2.9	2.9	3.7	5.2	7.2	7.5	5.4
Belle Harbour (Mean)	65.7	2.4	2.3	2.4	3.8	3.1	1.6	1.1	1.1	1.3	1.9	2.7	2.9	2.2
Belle Harbour (Lower Q.)	65.7	1.5	1.5	1.6	2.9	2.2	1.2	0.7	0.6	0.8	1.1	2.3	2.1	2.0
Belle Harbour (Upper Q.)	65.7	3.0	2.9	3.0	4.7	3.8	1.9	1.4	1.3	1.7	2.4	3.3	3.4	2.5
Rencontre Brook (Mean)	133.1	4.9	4.6	4.8	7.7	6.3	3.2	2.3	2.2	2.6	3.9	5.6	5.9	4.5
Rencontre Brook (Lower Q.)	133.1	3.0	3.0	3.2	5.9	4.5	2.4	1.4	1.2	1.6	2.3	4.6	4.3	4.1
Rencontre Brook (Upper Q.)	133.1	6.1	5.9	6.1	9.6	7.8	3.9	2.7	2.7	3.5	4.9	6.7	7.0	5.0
Mal Bay Brook (Mean)	48.3	1.8	1.7	1.8	2.8	2.3	1.2	0.8	0.8	0.9	1.4	2.0	2.1	1.6
Mal Bay Brook (Lower Q.)	48.3	1.1	1.1	1.2	2.1	1.6	0.9	0.5	0.4	0.6	0.8	1.7	1.6	1.5

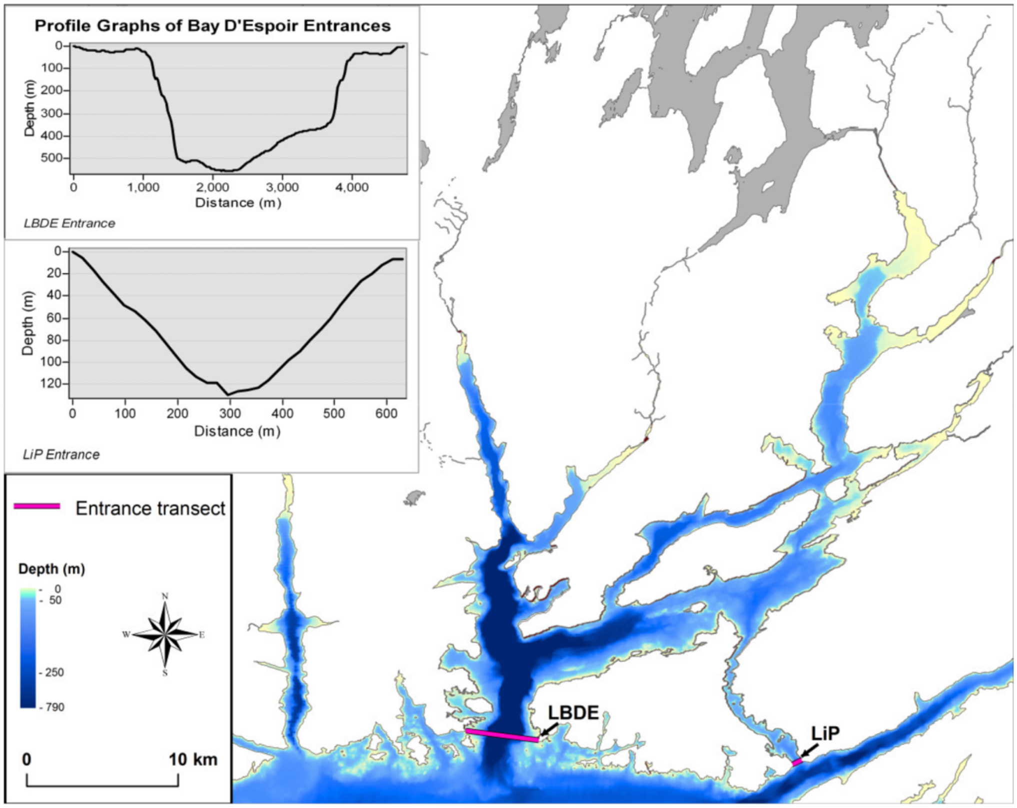
Table B1: Continued.

River	Watershed km^2	Jan m^3/s	Feb m^3/s	Mar m^3/s	Apr m^3/s	May m^3/s	Jun m^3/s	Jul m^3/s	Aug m^3/s	Sep m^3/s	Oct m^3/s	Nov m^3/s	Dec m^3/s	Avg m^3/s
BB TOTAL - main rivers - (Mean)	1848.8	68.6	64.0	67.3	107.0	87.2	44.1	31.5	30.7	36.2	54.5	77.2	81.5	62.2
BB TOTAL - main rivers - (Lower Q.)	1848.8	41.9	41.4	45.0	81.7	62.8	33.5	20.0	16.7	22.3	32.2	63.8	60.3	57.2
BB TOTAL - main rivers - (Upper Q.)	1848.8	84.5	82.6	84.3	133.1	107.7	54.5	38.1	37.6	48.2	67.7	93.2	96.7	69.6
BB TOTAL - all rivers - (Mean)	2094.5	77.8	72.5	76.2	121.1	98.7	49.9	35.7	34.7	41.0	61.9	87.5	92.3	70.6
BB TOTAL - all rivers - (Lower Q.)	2094.5	47.4	46.9	50.9	92.7	71.3	37.8	22.8	18.9	25.3	36.6	72.2	68.4	64.9
BB TOTAL - all rivers - (Upper Q.)	2094.5	95.9	93.6	95.5	150.7	122.0	61.9	43.2	42.6	54.6	76.8	105.8	109.5	78.9
CB TOTAL - all rivers - (Mean)	78	2.9	2.7	2.8	4.5	3.7	1.9	1.3	1.3	1.5	2.3	3.3	3.4	2.6
CB TOTAL - all rivers - (Lower Q.)	78	1.8	1.7	1.9	3.5	2.7	1.4	0.8	0.7	0.9	1.4	2.7	2.5	2.4
CB TOTAL - all rivers - (Upper Q.)	78	3.6	3.5	3.6	5.6	4.5	2.3	1.6	1.6	2.0	2.9	3.9	4.1	2.9
HBNA TOTAL - all rivers - (Mean)	41.7	1.5	1.4	1.5	2.4	2.0	1.0	0.7	0.7	0.8	1.2	1.7	1.8	1.4
HBNA TOTAL - all rivers - (Lower Q.)	41.7	0.9	0.9	1.0	1.8	1.4	0.8	0.5	0.4	0.5	0.7	1.4	1.4	1.3
HBNA TOTAL - all rivers - (Upper Q.)	41.7	1.9	1.9	1.9	3.0	2.4	1.2	0.9	0.8	1.1	1.5	2.1	2.2	1.6
GBDE TOTAL - all rivers - (Mean)	177.9	6.6	6.2	6.5	10.3	8.4	4.2	3.0	2.9	3.5	5.3	7.4	7.8	6.0
GBDE TOTAL - all rivers - (Lower Q.)	177.9	4.0	4.0	4.3	7.9	6.1	3.2	1.9	1.6	2.1	3.1	6.1	5.8	5.5
GBDE TOTAL - all rivers - (Upper Q.)	177.9	8.1	7.9	8.1	12.8	10.4	5.3	3.7	3.6	4.6	6.5	9.0	9.3	6.7
HB TOTAL - all rivers - (Mean)	263.6	15.2	16.7	22.9	46.1	22.3	10.5	9.7	9.6	18.2	25.2	29.8	23.3	20.7
HB TOTAL - all rivers - (Lower Q.)	263.6	7.3	5.6	10.2	29.6	15.9	6.0	4.5	3.0	9.7	15.0	22.3	15.7	18.7

Table B1: Continued.

River	Watershed km^2	Jan m^3/s	Feb m^3/s	Mar m^3/s	Apr m^3/s	May m^3/s	Jun m^3/s	Jul m^3/s	Aug m^3/s	Sep m^3/s	Oct m^3/s	Nov m^3/s	Dec m^3/s	Avg m^3/s
HB TOTAL - all rivers- (Upper Q.)	263.6	22.0	23.3	33.8	64.8	28.6	11.2	11.8	16.6	25.0	31.3	35.0	31.5	22.5
Long Harbour River (Mean)	1156.3	43.0	40.0	42.1	66.9	54.5	27.5	19.7	19.1	22.7	34.2	48.3	51.0	39.0
Long Harbour River (Lower Q.)	1156.3	26.2	25.9	28.1	51.2	39.3	20.9	12.6	10.4	14.0	20.2	39.8	37.8	35.8
Long Harbour River (Upper Q.)	1156.3	52.9	51.6	52.7	83.2	67.4	34.2	23.8	23.5	30.2	42.4	58.4	60.4	43.5
FB TOTAL - all rivers - (Mean)	2752.3	102.3	95.3	100.2	159.2	129.7	65.5	46.9	45.6	53.9	81.3	115.0	121.3	92.7
FB TOTAL - all rivers - (Lower Q.)	2752.3	62.3	61.6	66.9	121.8	93.7	49.7	30.0	24.9	33.2	48.1	94.8	89.9	85.3
FB TOTAL - all rivers- (Upper Q.)	2752.3	126.0	122.9	125.5	198.0	160.4	81.3	56.7	56.0	71.8	100.9	139.0	143.9	103.6

APPENDIX C: MAIN BAYS METRICS



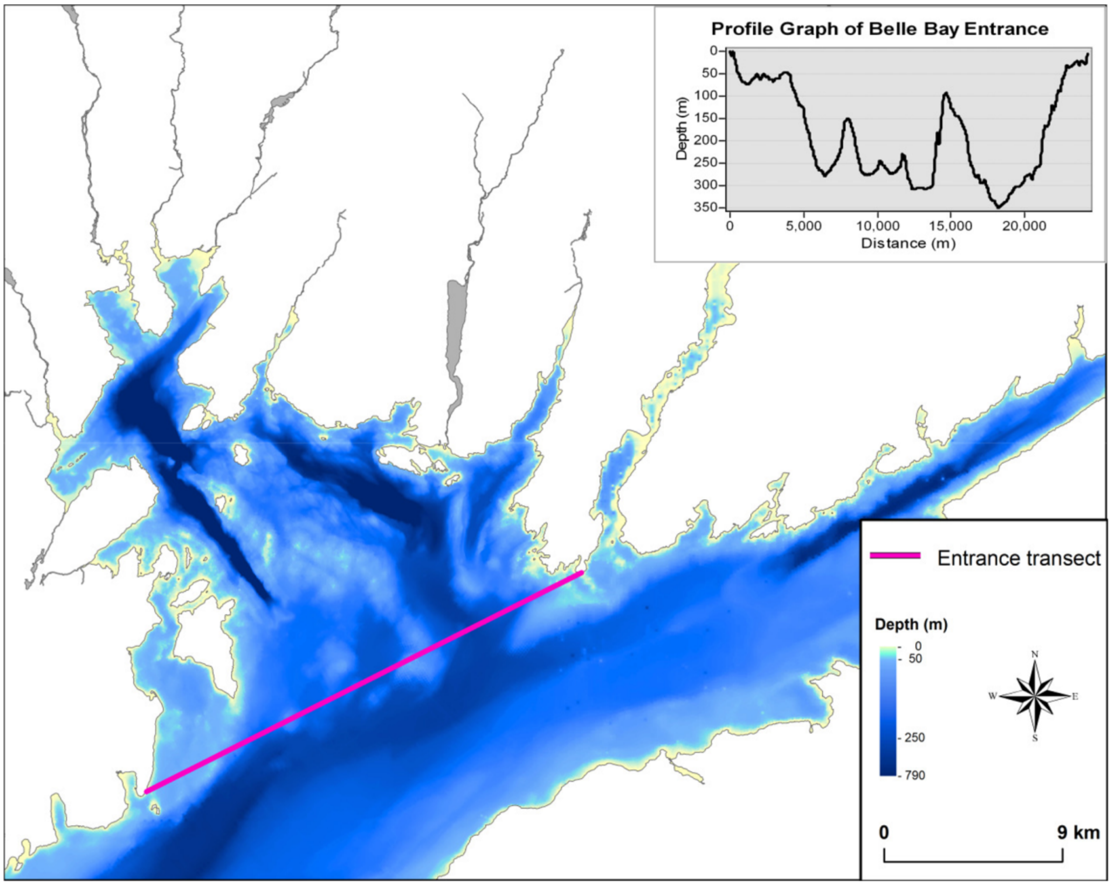
Area (CD)	210 km²	**Area (HW)**	240 km²	**Area (MSL)**	230 km²
Perimeter (MSL)	467.43 km				
Volume (CD)	36,800 10^6 m³	**Volume (HW)**	37,200 10^6 m³	**Volume (MSL)**	37,000 10^6 m³

Axis Length (MSL)	53.28 km (East) 27.72 km (West)	**Axis Width (MSL)**	2.23 km 2.29 km
Axis Orientation	70° (East – LBDE)	15° (East – UBDE)	355° (West)
Maximum Depth (CD)	792 m	**Mean Depth (CD)**	172 m
Entrance Width (MSL)	4.74 km (LBDE) 0.61 km (LiP)	**Cross-section Area (CD)**	1,224,000 m² (LBDE) 44,400 m² (LiP)
Entrance Maximum Depth (CD)	556 m (LBDE) 130 m (LiP)	**Entrance Mean Depth (CD)**	257 m (LBDE) 75 m (LiP)
Mean Tidal Range	1.27 m	**Large Tidal Range**	2.02 m
Mean Tidal Volume	280 10^6 m³	**Large Tidal Volume**	460 10^6 m³
Mean Tidal Current	1.0 cm/s	**Peak Tidal Current**	1.5 cm/s
Flushing time	1,647 hr	**Tidal/Freshwater ratio**	49
Watershed Area	7,916.7 km²		

Bay D'Espoir Freshwater Discharge (m³/s) [Monthly mean, Lower and Upper Quartile]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
272.2	277.7	279.6	331.6	276.8	206.7	188.3	183.1	201.3	231.4	279.4	285.4	251.7
212	221.9	213	242.3	218	161.3	146.8	149.7	158.9	166.4	236.9	236.2	228.1
332.6	331.7	342.1	410	340	248.5	224	232.8	245.8	282.2	327.4	349.5	280.8

Figure C1: Bay d'Espoir (BDE) metrics.



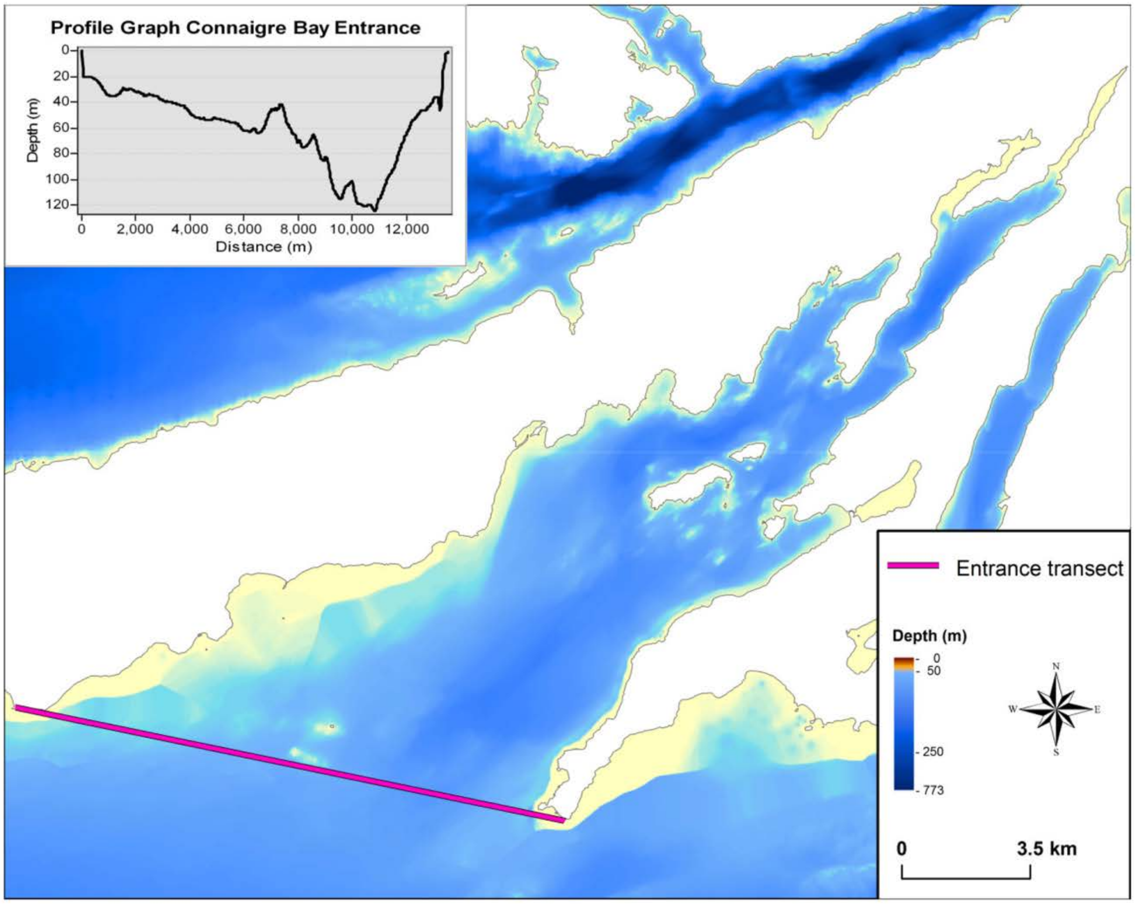
Area (CD)	300 km²	**Area (HW)**	310 km²	**Area (MSL)**	310 km²
Perimeter (MSL)	255.95 km				
Volume (CD)	54,100 10^6 m³	**Volume (HW)**	54,800 10^6 m³	**Volume (MSL)**	54,400 10^6 m³

Axis Length (MSL)	23.47km	**Axis Width (MSL)**	11.74 km
Axis Orientation	335°		
Maximum Depth (CD)	606 m	**Mean Depth (CD)**	179 m
Entrance Width (MSL)	24.56 km	**Cross-section Area (CD)**	4,750,000 m²
Entrance Maximum Depth (CD)	349 m	**Entrance Mean Depth (CD)**	194 m
Mean Tidal Range	1.38 m	**Large Tidal Range**	2.18 m
Mean Tidal Volume	400 10^6 m³	**Large Tidal Volume**	650 10^6 m³
Mean Tidal Current	0.4 cm/s	**Peak Tidal Current**	0.6 cm/s
Flushing time	1,708 hr	**Tidal/Freshwater ratio**	250
Watershed Area	2,094.5 km²		

Bay D'Espoir Freshwater Discharge (m³/s) [Monthly mean, Lower and Upper Quartile]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
77.8	72.5	76.2	121.1	98.7	49.9	35.7	34.7	41	61.9	87.5	92.3	70.6
47.4	46.9	50.9	92.7	71.3	37.8	22.8	18.9	25.3	36.6	72.2	68.4	64.9
95.9	93.6	95.5	150.7	122	61.9	43.2	42.6	54.6	76.8	105.8	109.5	78.9

Figure C2: Belle Bay (BB) metrics.



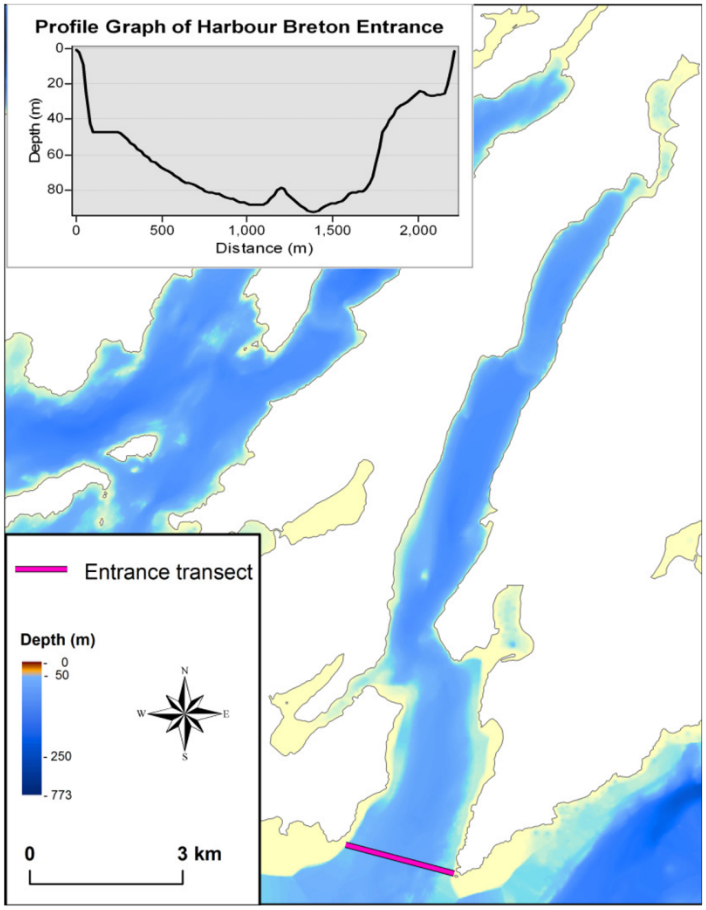
Area (CD)	123 km²	**Area (HW)**	137 km²	**Area (MSL)**	133 km²
Perimeter (MSL)	128.27 km				
Volume (CD)	9,900 10^6 m³	**Volume (HW)**	10,200 10^6 m³	**Volume (MSL)**	10,000 10^6 m³

Axis Length (MSL)	29.08 km	**Axis Width (MSL)**	4.71 km
Axis Orientation	50°		
Maximum Depth (CD)	226 m	**Mean Depth (CD)**	80 m
Entrance Width (MSL)	15.36 km	**Cross-section Area (CD)**	810,000 m²
Entrance Maximum Depth (CD)	124 m	**Entrance Mean Depth (CD)**	59 m
Mean Tidal Range	1.35 m	**Large Tidal Range**	2.12 m
Mean Tidal Volume	172 10^6 m³	**Large Tidal Volume**	279 10^6 m³
Mean Tidal Current	1.0 cm/s	**Peak Tidal Current**	1.5 cm/s
Flushing time	722.0 hr	**Tidal/Freshwater ratio**	2,957
Watershed Area	78 km²		

Bay D'Espoir Freshwater Discharge (m³/s) [Monthly mean, Lower and Upper Quartile]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2.9	2.7	2.8	4.5	3.7	1.9	1.3	1.3	1.5	2.3	3.3	3.4	2.6
1.8	1.7	1.9	3.5	2.7	1.4	0.8	0.7	0.9	1.4	2.7	2.5	2.4
3.6	3.5	3.6	5.6	4.5	2.3	1.6	1.6	2	2.9	3.9	4.1	2.9

Figure C3: Connaigre Bay (CB) metrics.



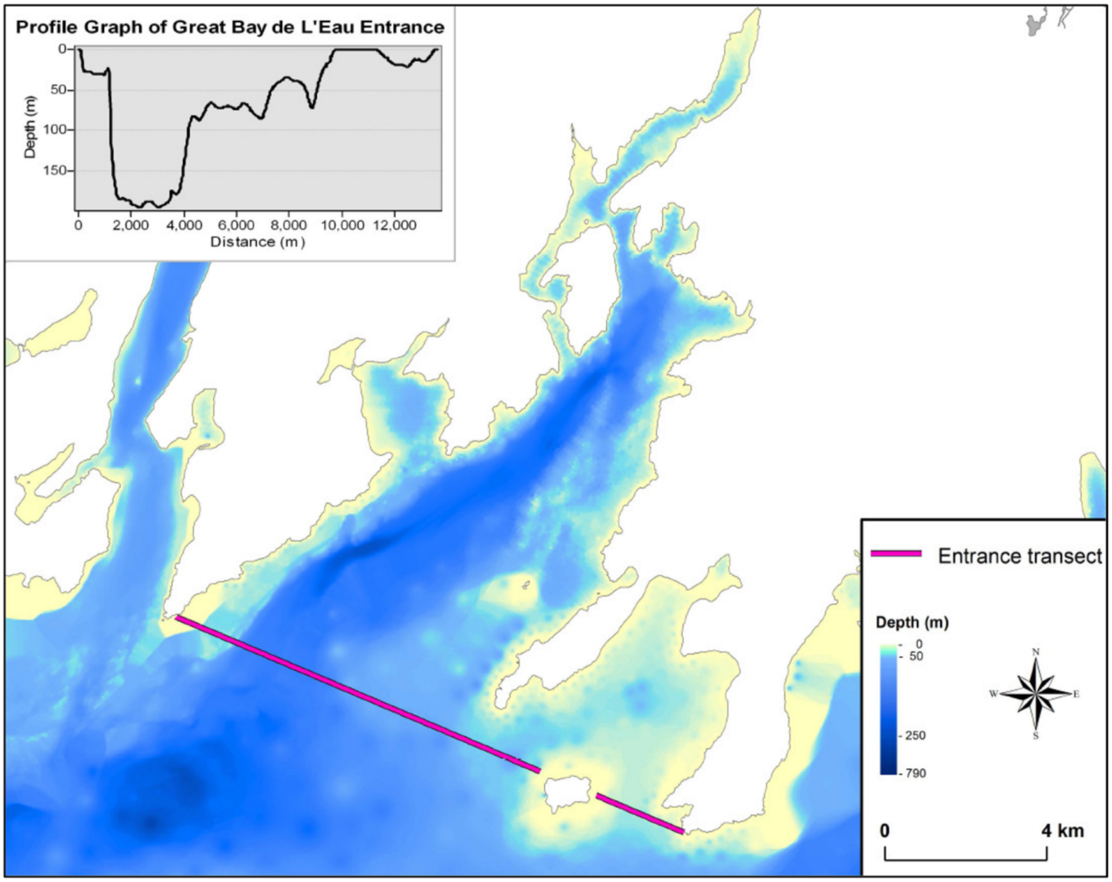
Area (CD)	20 km²	**Area (HW)**	24 km²	**Area (MSL)**	22 km²
Perimeter (MSL)	56.29 km				
Volume (CD)	1,490 10^6 m³	**Volume (HW)**	1,540 10^6 m³	**Volume (MSL)**	1,510 10^6 m³

Axis Length (MSL)	17.63 km	**Axis Width (MSL)**	1.28 km
Axis Orientation	20°		
Maximum Depth (CD)	182 m	**Mean Depth (CD)**	73 m
Entrance Width (MSL)	2.42 km	**Cross-section Area (CD)**	142,000 m²
Entrance Maximum Depth (CD)	92 m	**Entrance Mean Depth (CD)**	63 m
Mean Tidal Range	1.35 m	**Large Tidal Range**	2.12 m
Mean Tidal Volume	28 10^6 m³	**Large Tidal Volume**	47 10^6 m³
Mean Tidal Current	0.9 cm/s	**Peak Tidal Current**	1.4 cm/s
Flushing time	658 hr	**Tidal/Freshwater ratio**	908
Watershed Area	41.7 km²		

Bay D'Espoir Freshwater Discharge (m³/s) [Monthly mean, Lower and Upper Quartile]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1.5	1.4	1.5	2.4	2	1	0.7	0.7	0.8	1.2	1.7	1.8	1.4
0.9	0.9	1	1.8	1.4	0.8	0.5	0.4	0.5	0.7	1.4	1.4	1.3
1.9	1.9	1.9	3	2.4	1.2	0.9	0.8	1.1	1.5	2.1	2.2	1.6

Figure C4: Harbour Breton – Northeast Arm (HB-NA) metrics.



Area (CD)	93 km²	**Area (HW)**	100 km²	**Area (MSL)**	97 km²
Perimeter (MSL)	115.26 km				
Volume (CD)	7,100 10^6 m³	**Volume (HW)**	7,300 10^6 m³	**Volume (MSL)**	7,190 10^6 m³

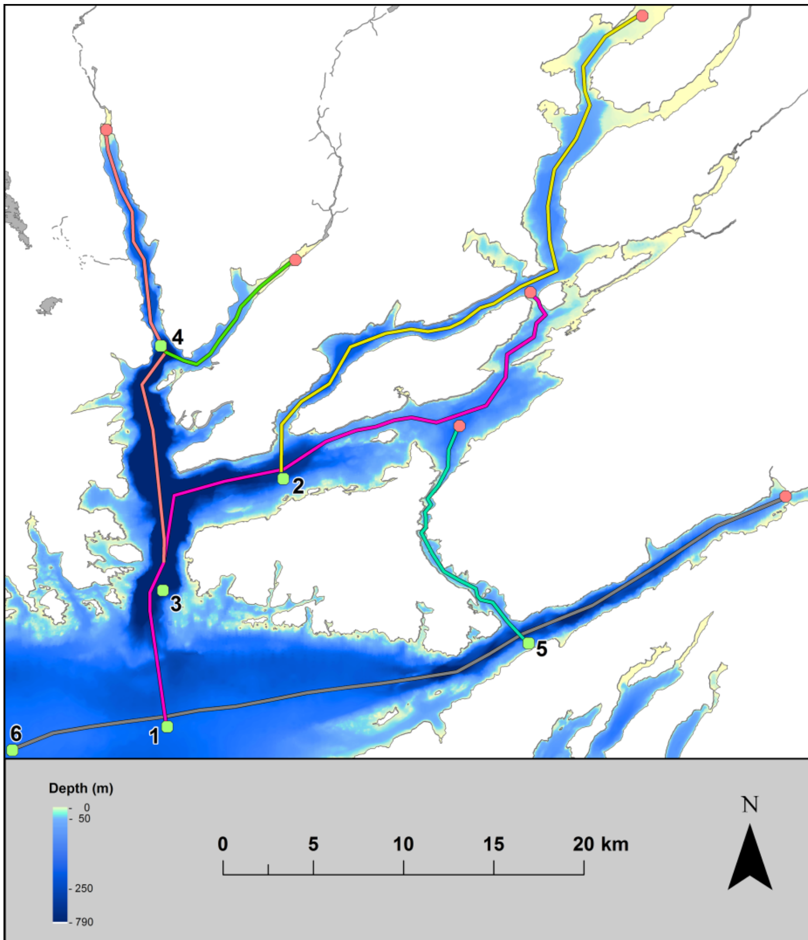
Axis Length (MSL)	7.16 km (East) 21.59 km (West)	**Axis Width (MSL)**	3.70 km
Axis Orientation	40° (East)	30° (West)	
Maximum Depth (CD)	313 m	**Mean Depth (CD)**	77 m
Entrance Width (MSL)	13.90 km	**Cross-section Area (CD)**	900,000 m²
Entrance Maximum Depth (CD)	196 m	**Entrance Mean Depth (CD)**	76 m
Mean Tidal Range	1.35 m	**Large Tidal Range**	2.12 m
Mean Tidal Volume	128 10^6 m³	**Large Tidal Volume**	206 10^6 m³
Mean Tidal Current	0.6 cm/s	**Peak Tidal Current**	1.0 cm/s
Flushing time	695 hr	**Tidal/Freshwater ratio**	954
Watershed Area	177.9 km²		

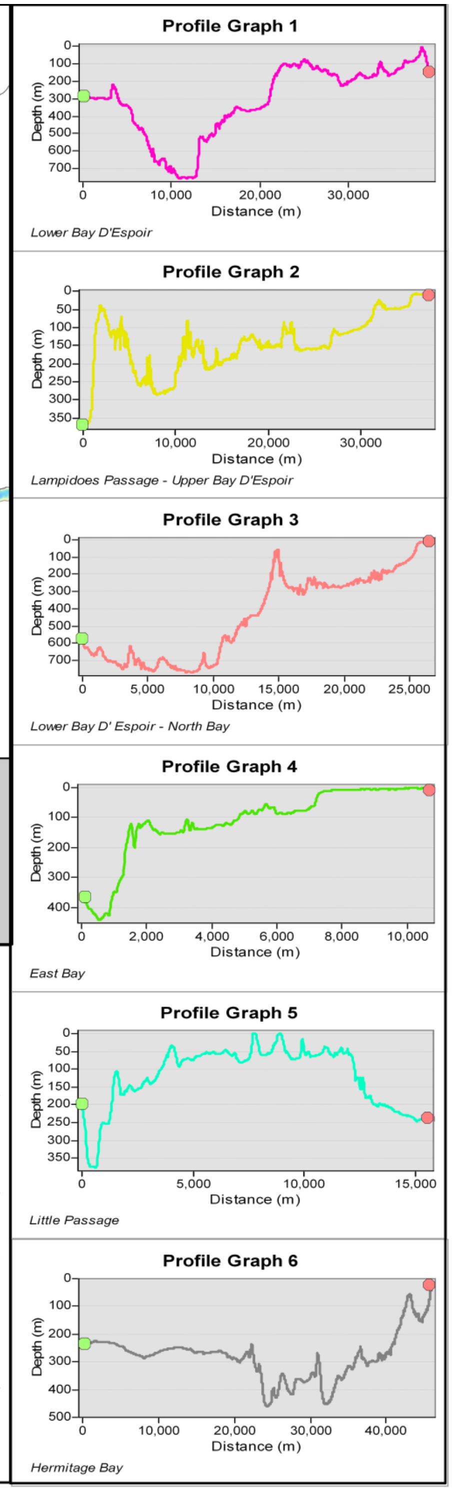
Bay D'Espoir Freshwater Discharge (m³/s) [Monthly mean, Lower and Upper Quartile]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
6.6	6.2	6.5	10.3	8.4	4.2	3.0	2.9	3.5	5.3	7.4	7.8	6.0
4.0	4.0	4.3	7.9	6.1	3.2	1.9	1.6	2.1	3.1	6.1	5.8	5.5
7.4	7.9	8.1	12.8	10.4	5.3	3.7	3.6	4.6	6.5	9.0	9.3	6.7

Figure C5: Great Bay de L'Eau (GBDE) metrics.

APPENDIX D: MAIN BAYS ALONG-CHANNEL BATHYMETRY

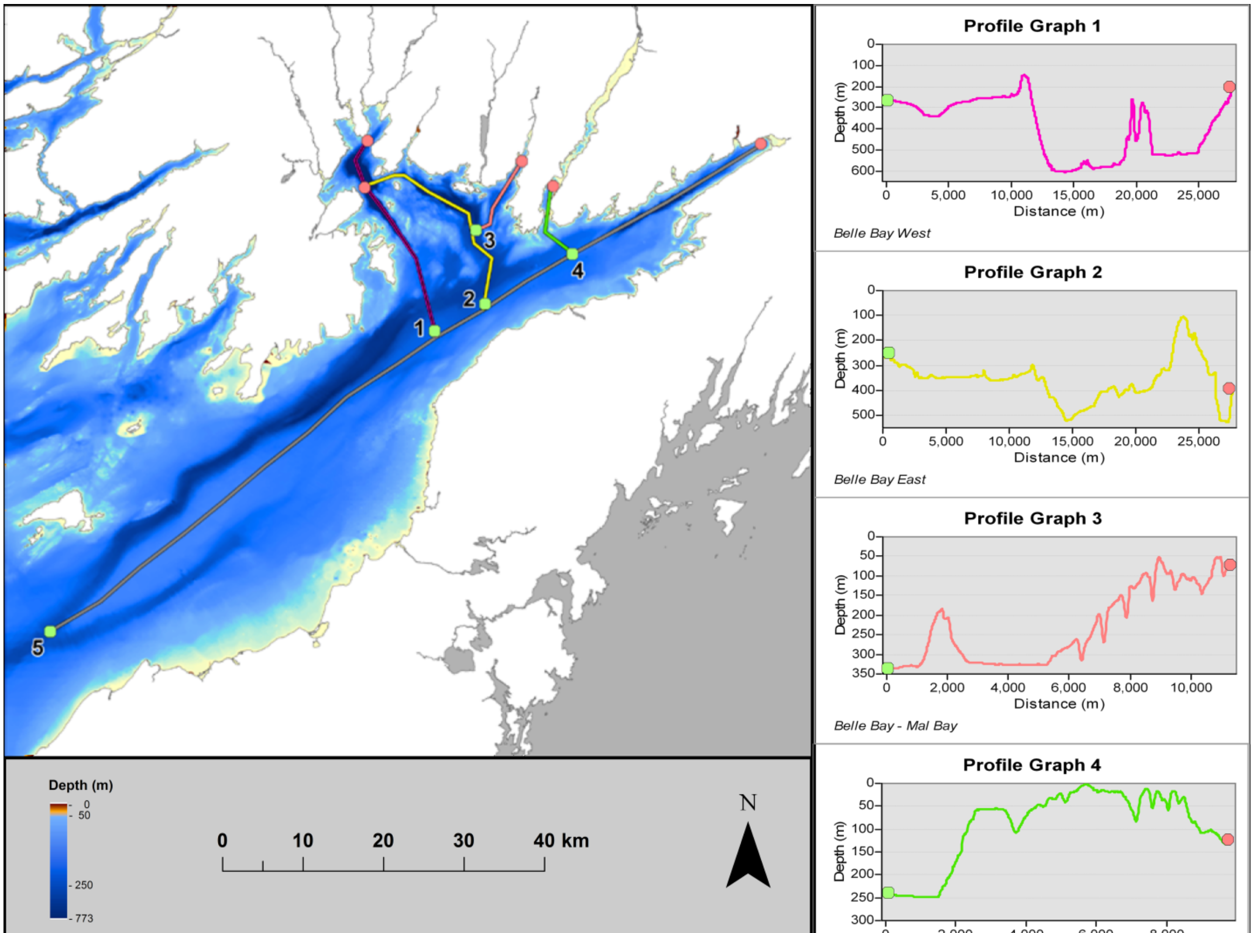




Along-channel transects statistics (CD)

Transect No.	Channel ID	Length (km)	Maximum Channel Depth (m)	Minimum Channel Depth (m)	Mean Channel Depth (m)
1	LBDE	39.4	777	25	326
2	LaP-UBDE	37.4	389	4	154
3	LBDE-NB	25.4	786	1	469
4	EB	10.6	454	2	130
5	LiP	15.7	375	0	124
6	HB	45.8	459	49	285

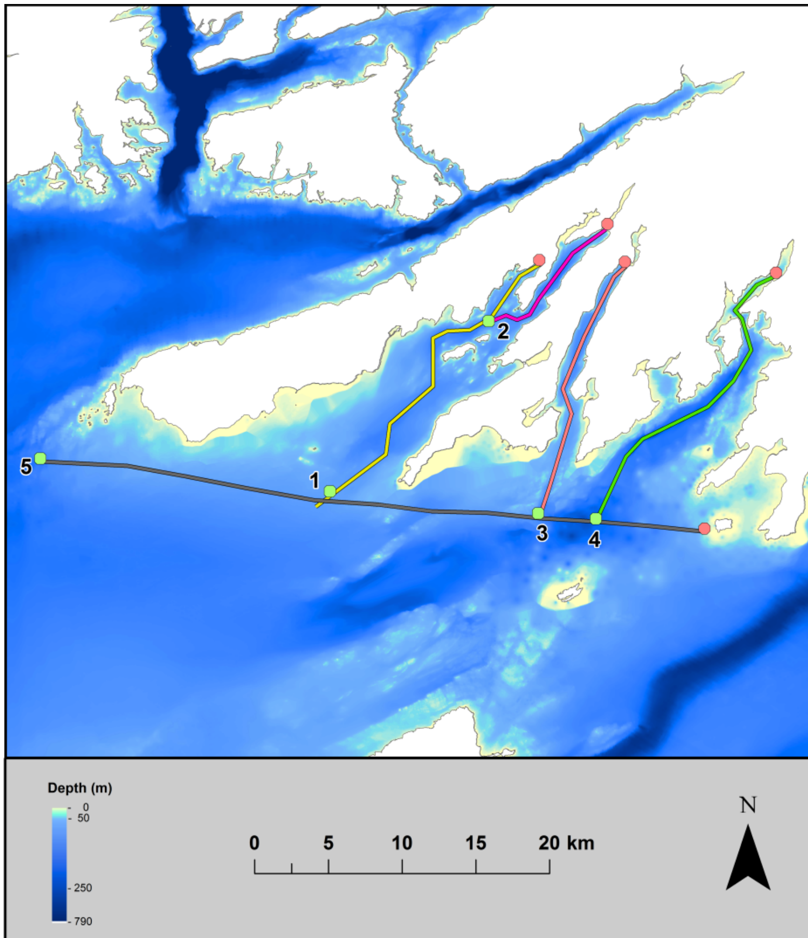
Figure D1: Bay d'Espoir (BDE) along-channel bathymetry.



Along-channel transects statistics (CD)

Transect No.	Transect ID	Length (km)	Maximum Transect Depth (m)	Minimum Transect Depth (m)	Average Transect Depth (m)
1	BBW	27.7	604	145	397
2	BBE	27.8	526	105	364
3	BB-MB	11.6	341	126	255
4	FB-LH	9.8	271	3	110
5	FB	107.7	411	104	246

Figure D2: Belle Bay (BB) along-channel bathymetry.



Along-channel transects statistics (CD)

Transect No.	Channel ID	Length (km)	Maximum Channel Depth (m)	Minimum Channel Depth (m)	Mean Channel Depth (m)
1	LCB	24.5	190	28	140
2	UCB	11.2	220	22	149
3	HB-NA	18.7	189	15	117
4	GBDE	23.1	307	11	184
5	OCP	45.4	315	15	126

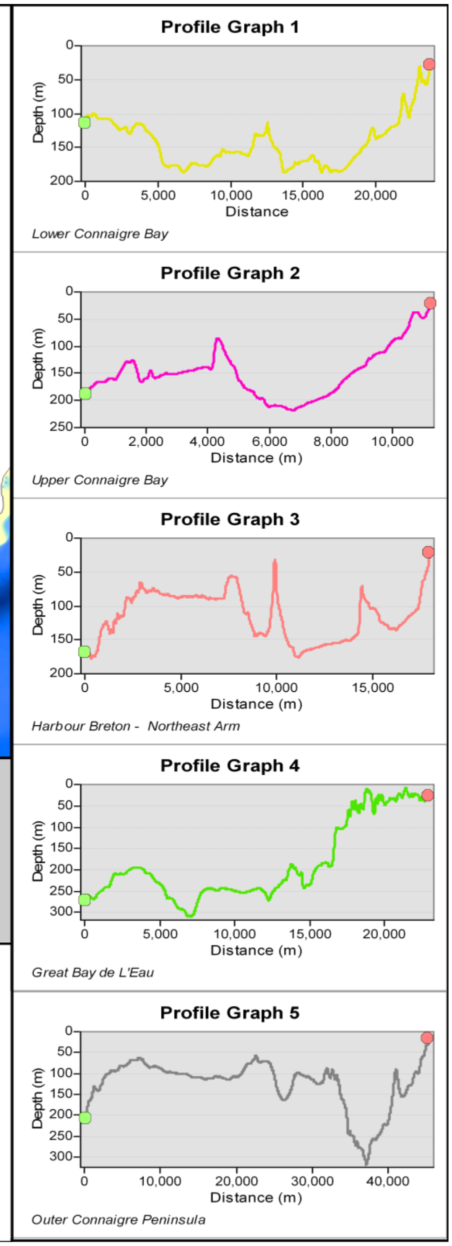


Figure D3: Connaigre Bay (CB), Harbour Breton – Northeast Arm (HB-NA) and Great Bay De L'Eau (GBDE) along-channel bathymetry.

APPENDIX E(I): BAY D'ESPOIR SILL PROFILES

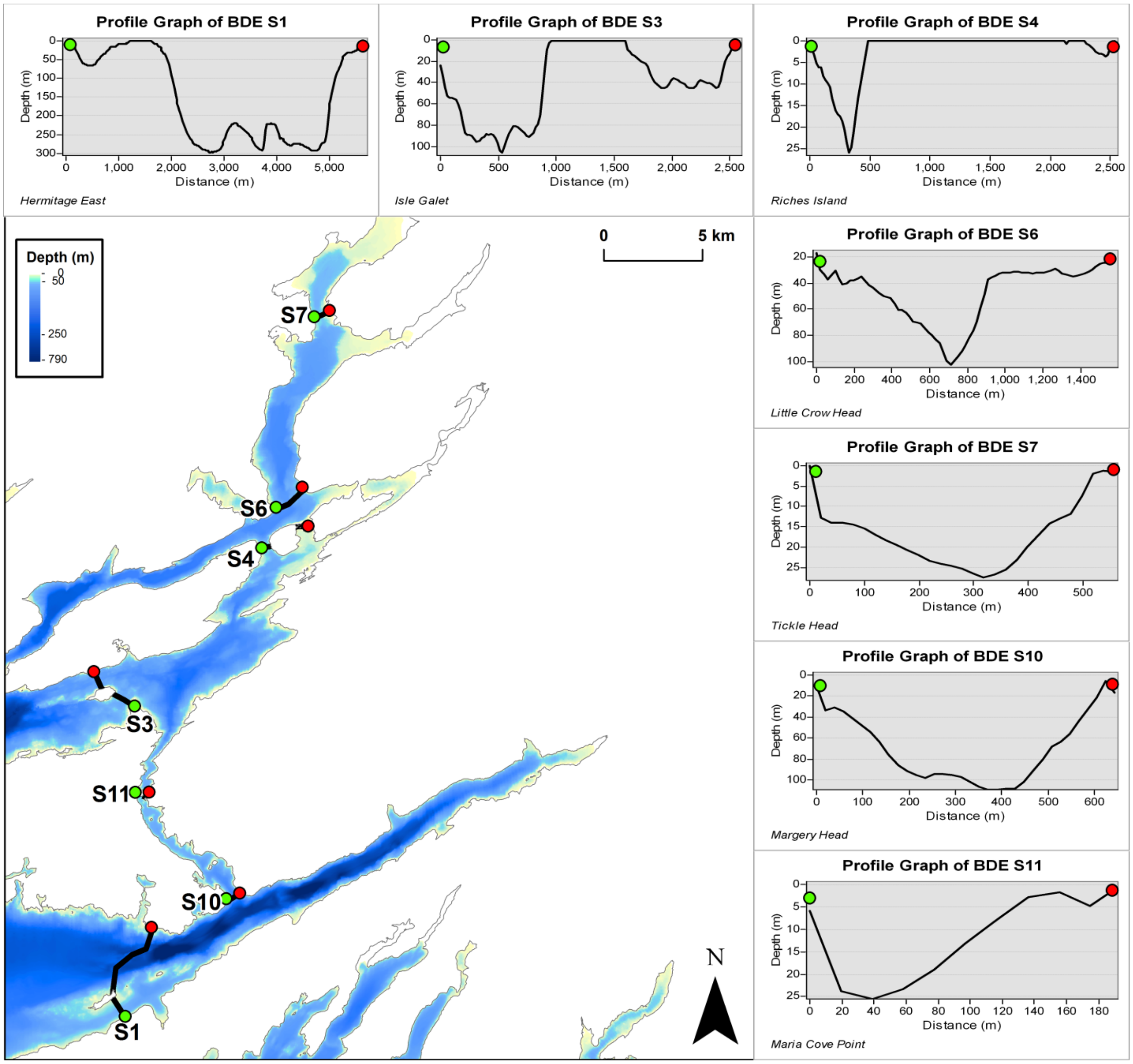


Figure E(i)1: Sill profiles at Hermitage East (S1), Isle Galet (S3), Riches Island (S4), Little Crow Head (S6), Tickle Head (S7), Margery Head (S10), and Maria Cove Point (S11), in the Bay d'Espoir region.

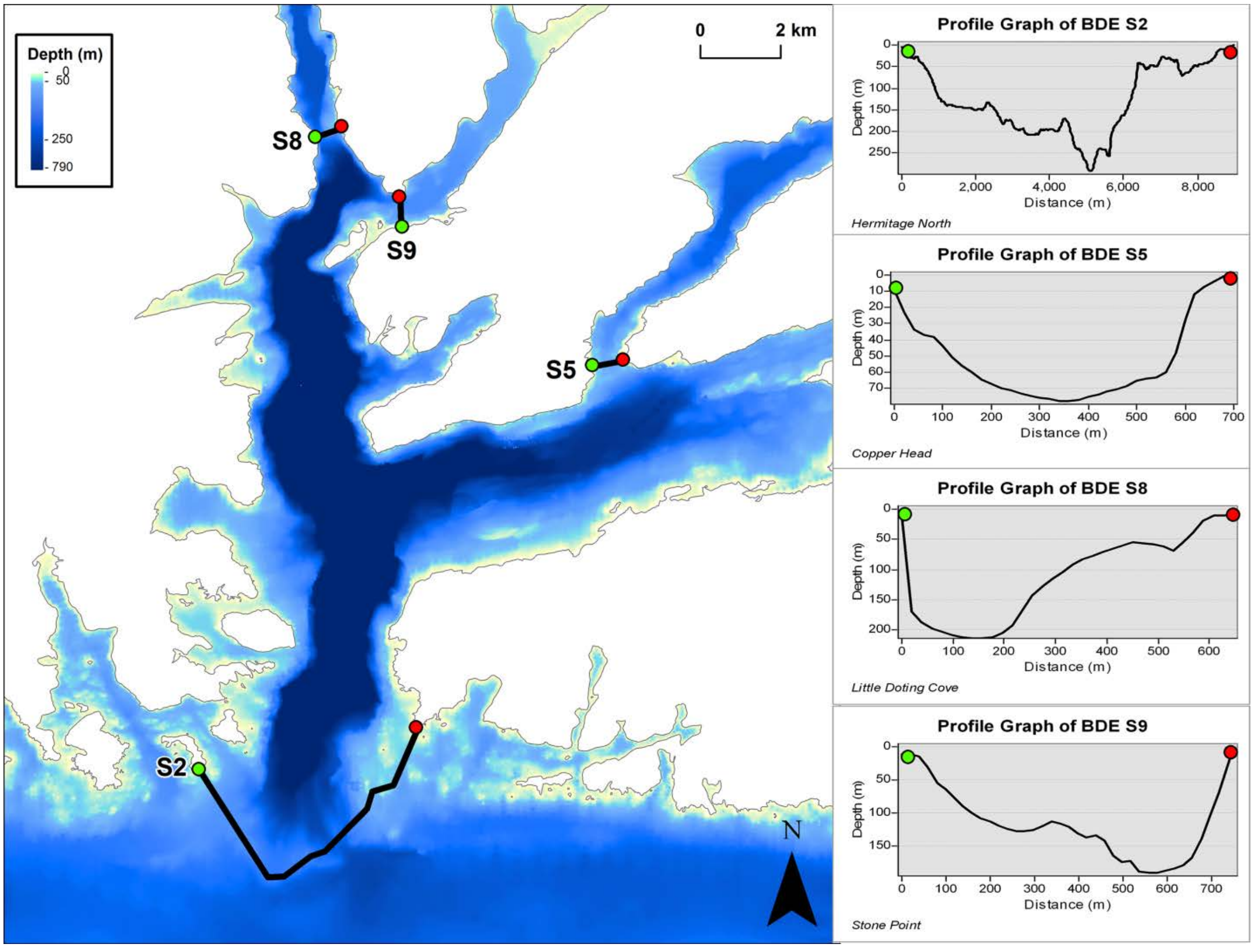


Figure E(i)2: Sill profiles at Hermitage North (S2), Copper Head (S5), Little Doting Cove (S8), and Stone Point (S9), in the Bay d'Espoir region.

APPENDIX E(II): BELLE BAY SILL PROFILES

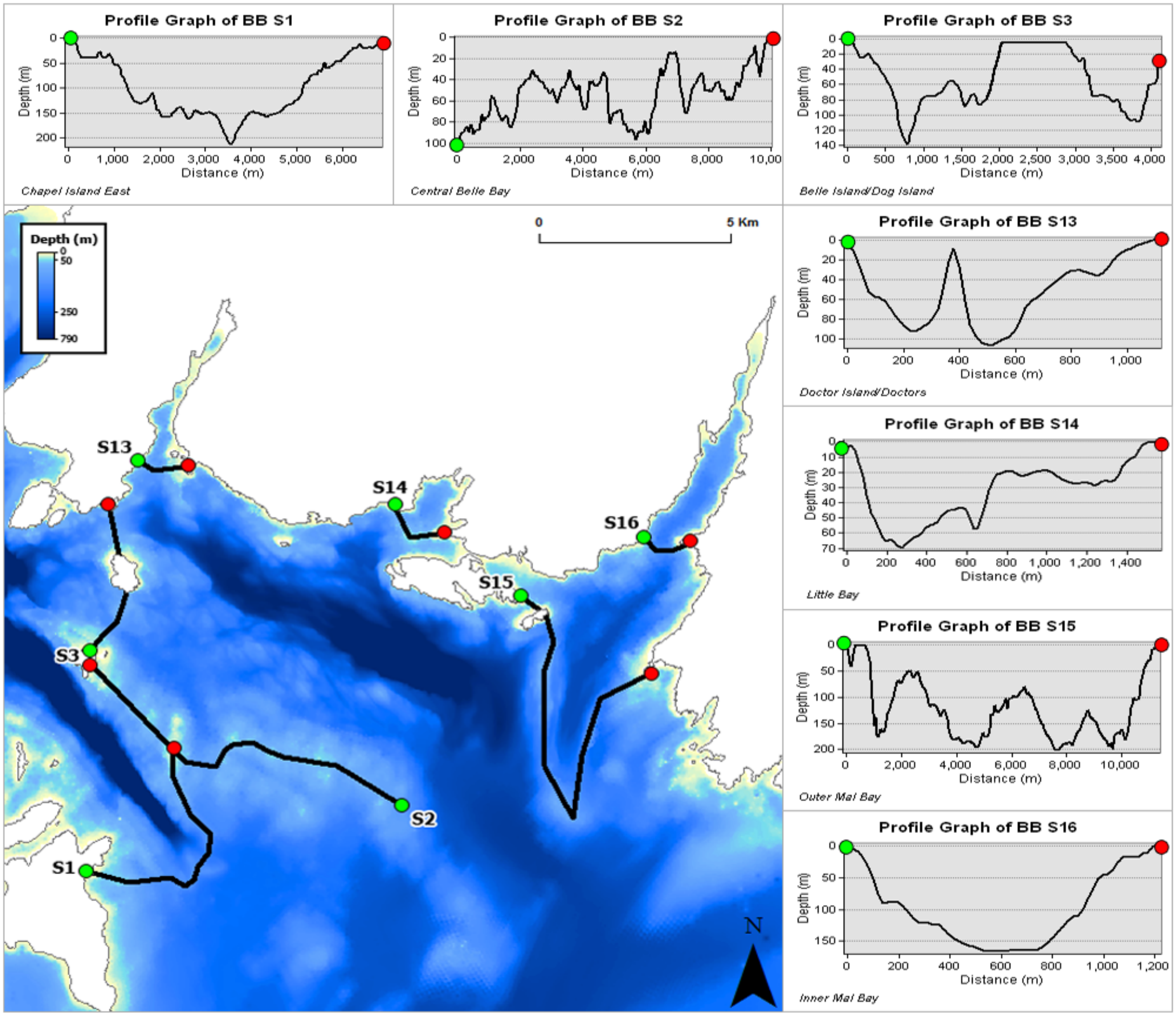


Figure E(ii)1: Sill profiles at Chapel Island East (S1), Central Belle Bay (S2), Belle Island/Dog Island (S3), Doctor Island (S13), Little Bay (S14), Outer Mal Bay (S15), and Inner Mal Bay (S16), in the Belle Bay region.

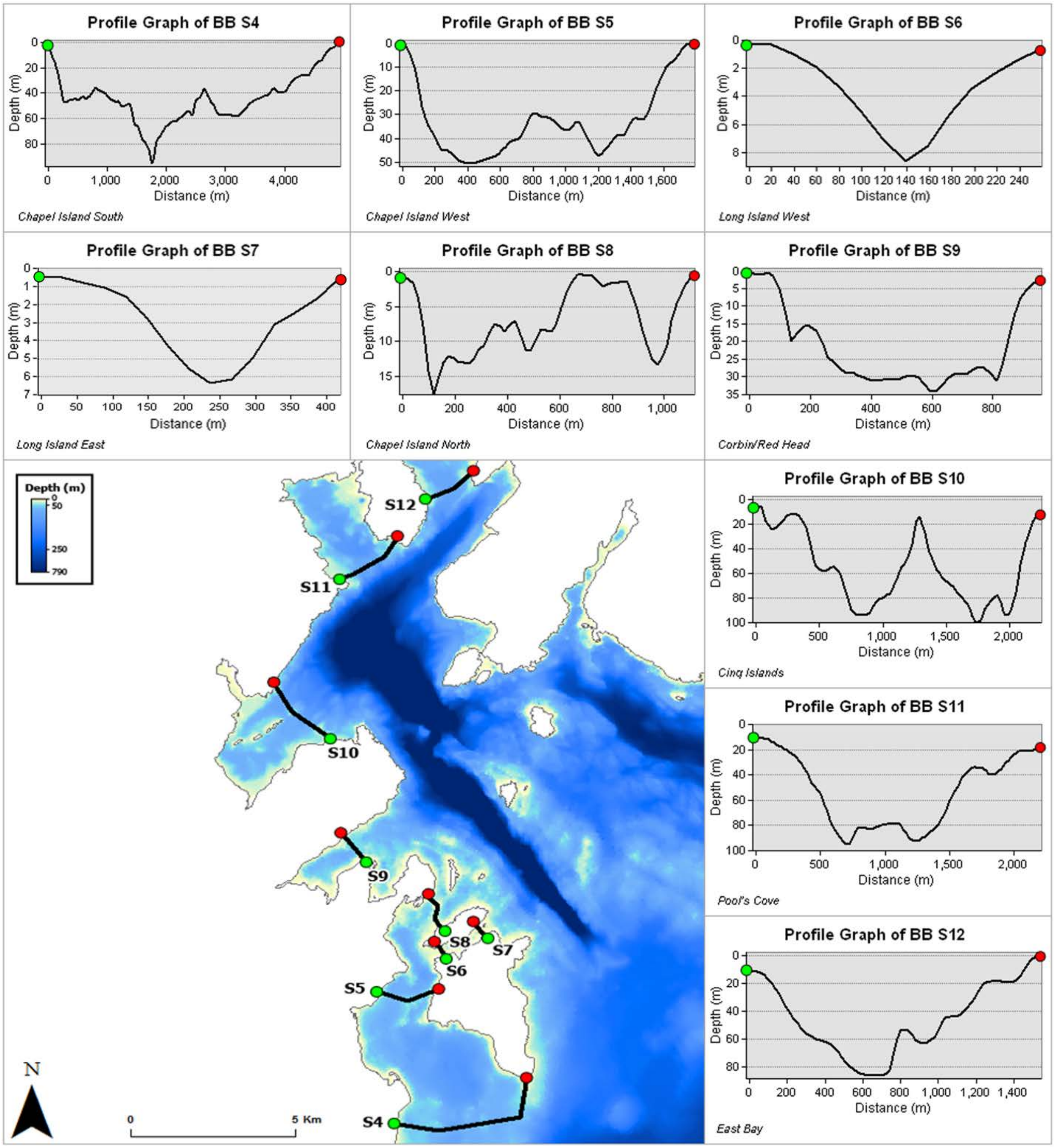


Figure E(ii)2: Sill profiles at Chapel Island South (S4), Chapel Island West (S5), Chapel Island North (S6/S7), Long Island North (S8), Corbin/Red Head (S9), Cinq Islands (S10), Pool's Cove (S11), and East Bay (S12), in the Belle Bay region.

APPENDIX E(III): CONNAIGRE PENINSULA SILL PROFILES

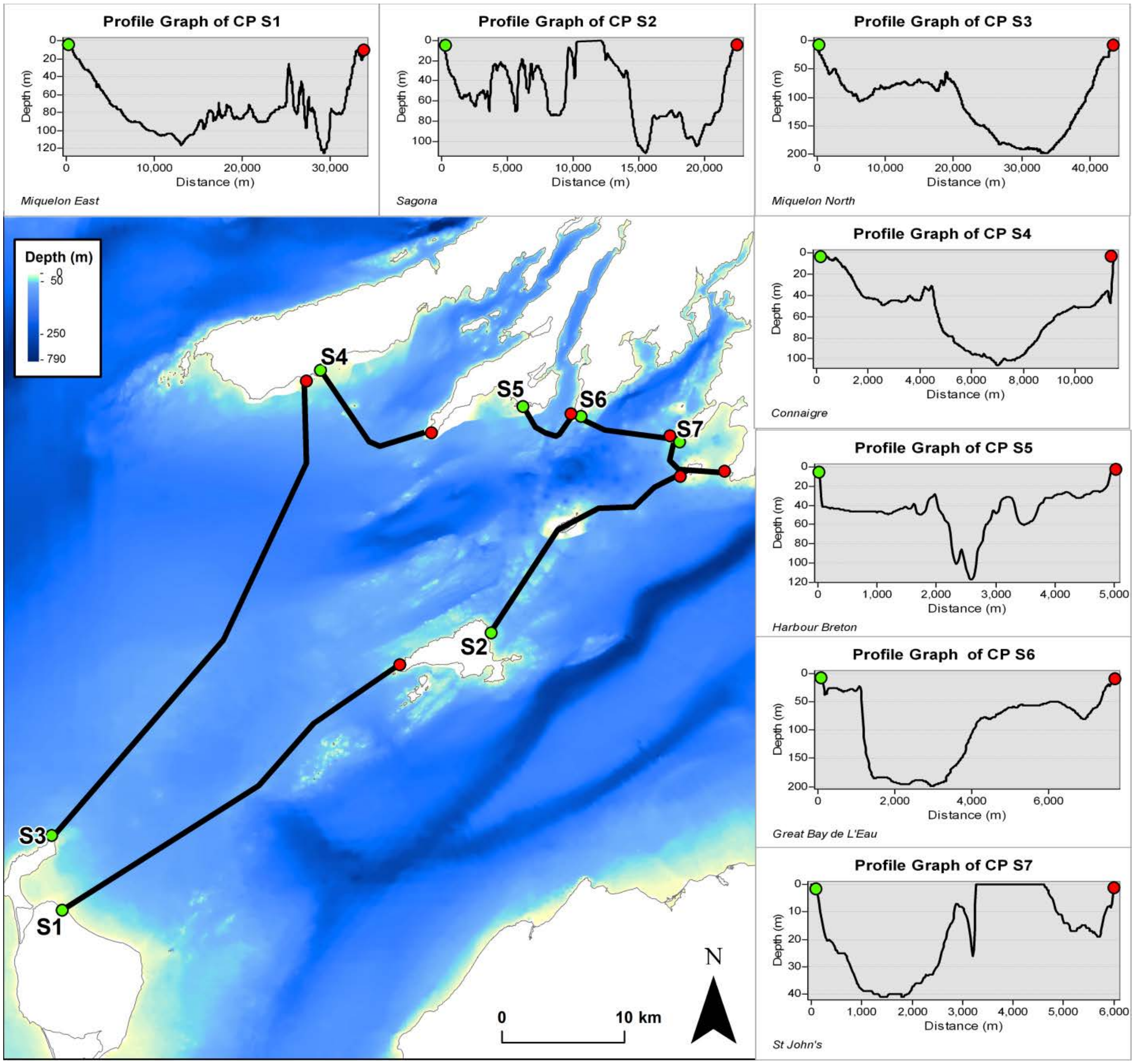


Figure E(iii)1: Sill profiles at Miquelon East (S1), Sagona (S2), Miquelon North (S3), Connaigre (S4), Harbour Breton (S5), Great Bay de L'Eau (S6), and St. John's (S7), in the Connaigre Peninsula region.

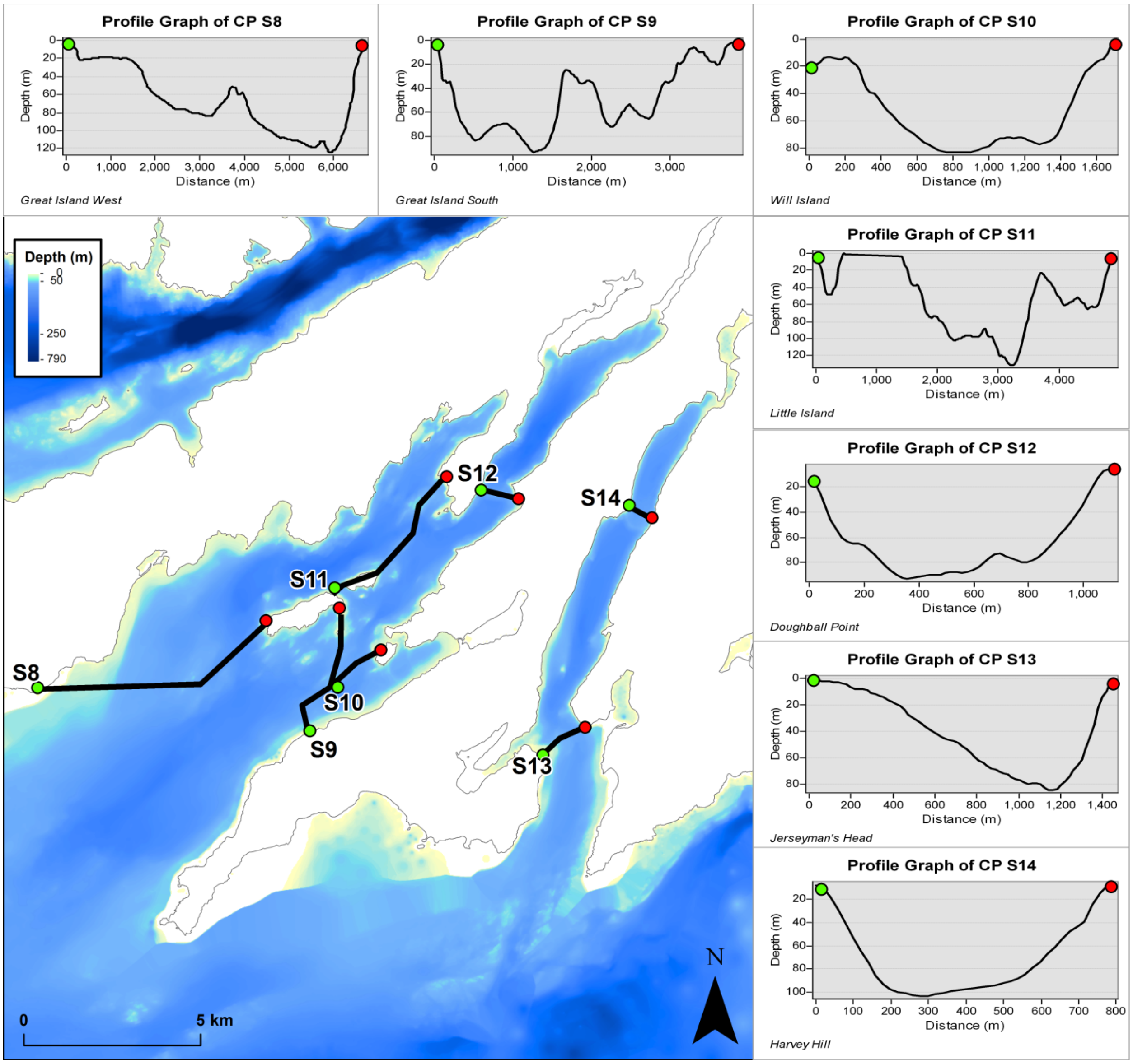


Figure E(iii)2: Sill profiles at Great Island West (S8), Great Island South (S9), Will Island (S10), Little Island (S11), Doughball Point (S12), Jerseyman's Head (S13), and Harvey Hill (S14), in the Connaigre Peninsula region.

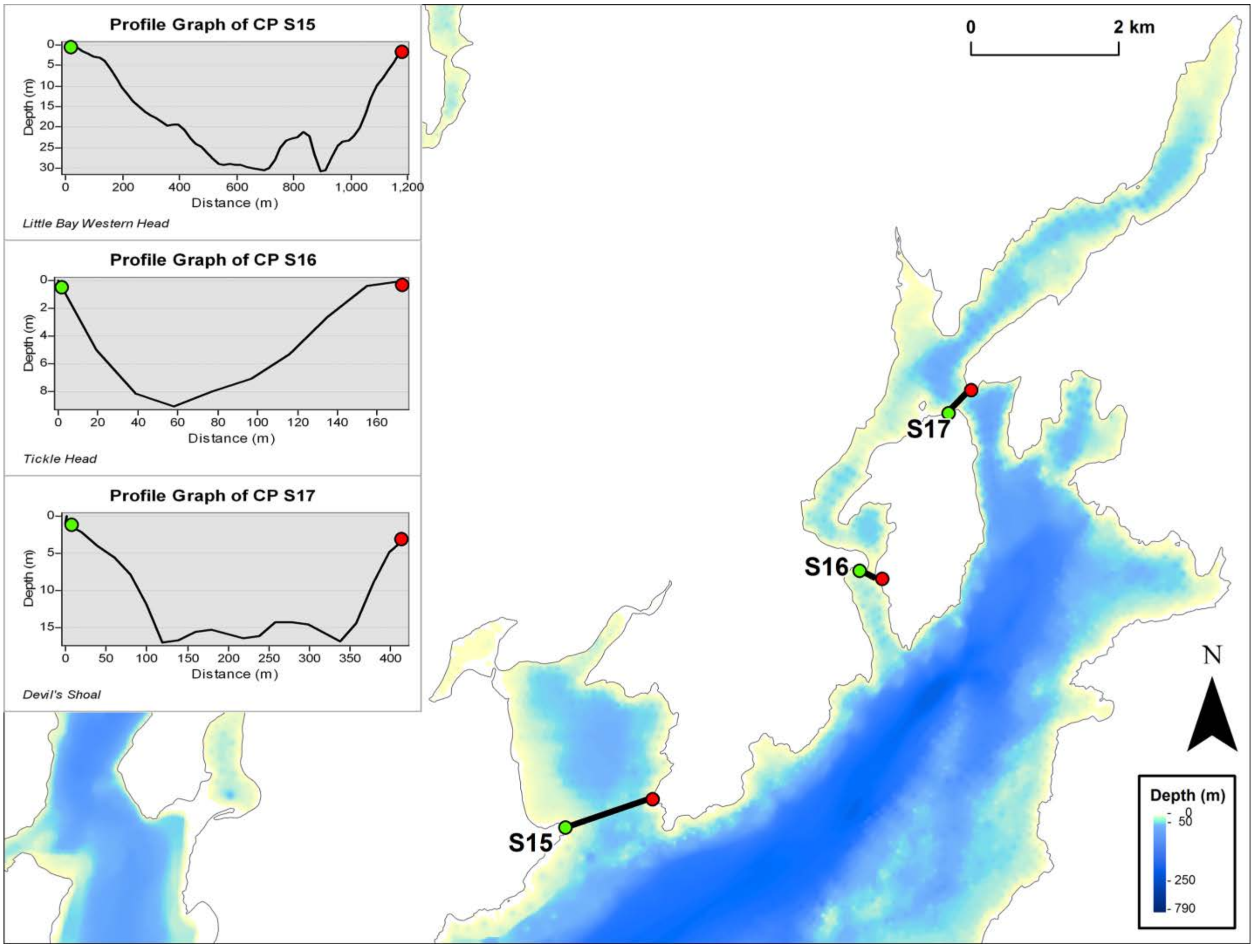


Figure E(iii)3: Sill profiles at Little Bay Western Head (S15), Tickle Head (S16), and Devil's Shoal (S17), in the Connaigre Peninsula region.