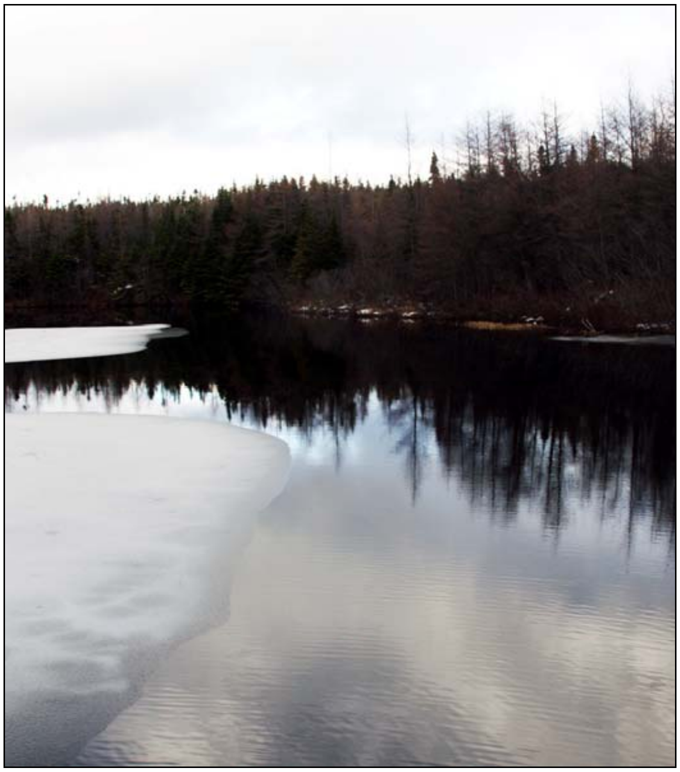
Atlantic Climate Adaptation Solutions Association
Solutions d'adaptation aux changements climatiques pour l'Atlantique

Climate Change Adaptation
Groundwater Management in Atlantic Canada



St. George's, NL

By

Trina Adams

Government of Newfoundland and Labrador
Department of Environment and Conservation

December, 2011

Nova Scotia · New Brunswick / Nouveau-Brunswick · Prince Edward Island Canada · Newfoundland Labrador · Natural Resources Canada / Ressources naturelles Canada · Canada

Report prepared by: Trina Adams and commissioned by the Atlantic Climate Solutions Association (ACASA), a non-profit organization formed to coordinate project management and planning for climate change adaptation initiatives in Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland and Labrador and supported through the Regional Adaptation Collaborative, a joint undertaking between the Atlantic provinces, Natural Resources Canada and regional municipalities and other partners.

Project management: Policy and Planning Division, Department of Environment and Conservation, Government of Newfoundland and Labrador. P.O. Box 8700, St. John's, NL, A1B 4J6.

Reconnaissance of Southwest Newfoundland: Examining Potential Sea-Water Intrusion in Past and Current Public Water Supply Wells, Southwest Newfoundland-NL Case Study

Trina F. Adams

Abstract Due to the growing concern of climate change and its current and future impact on coastal communities, adaptation is essential to carry on in a changing climate. The Atlantic Canada Adaptation Solutions (ACAS) Project is a partnership by four Atlantic Provinces in Canada and Natural Resources Canada (NRCan) to work alongside local communities, organizations and professionals to investigate the susceptibility and influence of climate change and to offer a basis for community acclimatization decisions

This reconnaissance study provides baseline data as a foundation for further investigation, and potential long-term monitoring by the Groundwater Section, Department of Environment and Conservation, Newfoundland and Labrador. A total of eleven wells were studied and sampled in the southwestern portion of Newfoundland. Wells that yielded measurable bromide ions and were less then 500 metres from the coast are discussed in this case study. An indepth paper with results and study particulars can be found in the appendices.

Purpose / Location

The small study completed by the Department of Environment and Conservation. Newfoundland and Labrador was intended to provide baseline data in regards to salt water intrusion along the southwest portion of the island and to also provide reconnaissance on government owned abandoned wells. Salt water intrusion is not known to have been studied in specific regard to climate change, and with the persistence of sea level rise induced by climate change, the need for one was apparent. Groundwater data contained within the provincial Drilled Well Database is inconsistent and does not provide an adequate means of assessing meaningful baseflow parameters. This study provided the opportunity to collect baseline data and supply a foundation to make community decisions on groundwater and engage further study and data collection.

Based on the International Panel for Climate Change predictions, Batterson and Liverman (2010) predicted local sea level rise for four zones in Newfoundland and Labrador. The southwest portion of the island falls within zone 2 where sea water for the region is expected to rise less than 2 mm per year. This equates to a projected sea level rise of 40 cm by the year 2049 and greater than 100 cm by the year 2099.

Furthermore, a sensitivity index assembled by NRCan to provide a national atlas illustrating coastal sensitivities to sea level rise in Canada indicates a large region in the Bay of St. George area with high coastal vulnerability to sea level rise (Fig. 2). The index was based on scores from

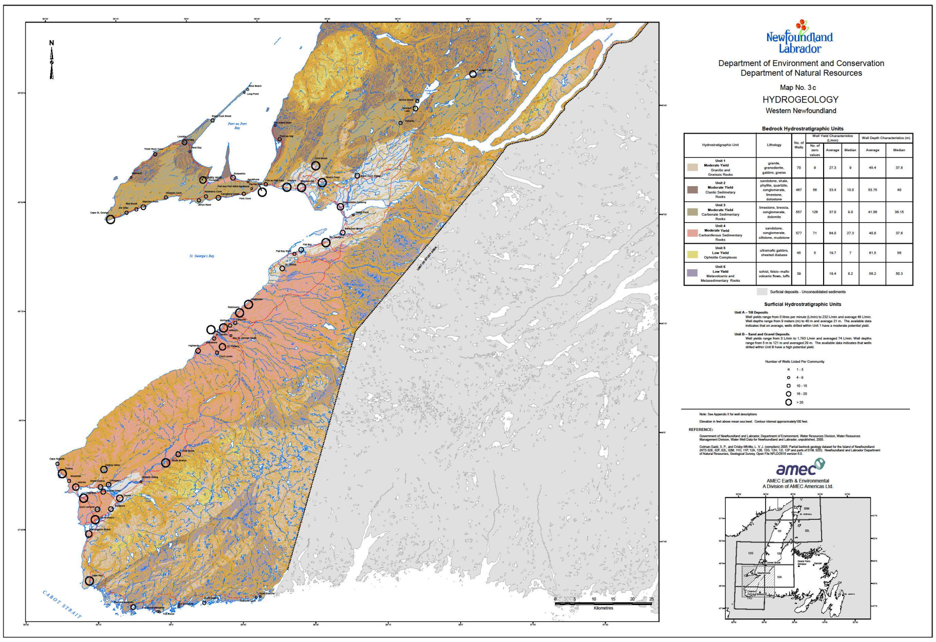


Figure 1: Hydrogeology of southwest Newfoundland
http://atlas.nrcan.gc.ca/auth/english/maps/climatechange/potentialimpacts/coastalsensitivitysealevelrise

1 to 5 and relies on seven variables: relief, geology, coastal landform, sea-level tendency, shoreline displacement, tidal range and tidal height. The index showed that the majority of Newfoundland and Labrador is of moderate to low sensitivity to sea level change. The exception however, is the northwest coast of the Burin Peninsula, and the projects study area of St. George's Bay (Batterson and Liverman, 2010).To provide an overall reconnaissance of the southwest portion of the Island, the Port aux Port Peninsula and the Codroy Valley area were also included in the study. Although the index does not rate potential for sea water intrusion directly, it does correlate to the variables used in the index.

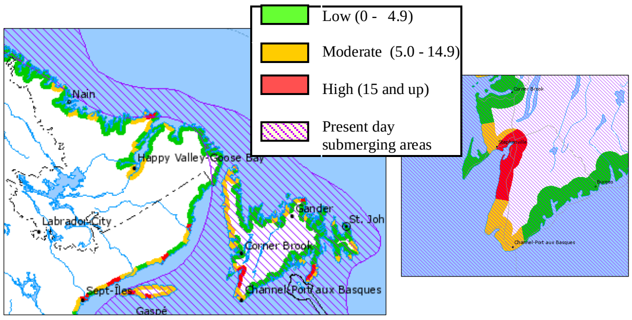


Figure 2: Coastal Sensitivity to Sea-Level Rise
http://atlas.nrcan.gc.ca/auth/english/maps/climatechange/potentialimpacts/coastalsensitivitysealevelrise

The southwest portion of the island is largely underlain by different types of carboniferous bedrock, and provides an average yield of 64 Lpm (Amec Environmental, 2008). This is a relatively high yield in comparison with other areas of the province. The region has been heavily inundated by past glacial events and glaciofluvial surficial deposits of up to 50 metres in some areas. Coupled with elevations as low as 1 metre above sea level in some areas, bedrock is often found at some depth below sea level. The southwest portion of the island also has many communities that rely on groundwater as a public water source. Depending on usage, the fresh water-sea water interface could potentially be drawn in to current supplying aquifers. The seven variables listed previously may also accommodate storm surges which would also put groundwater at risk of sea water intrusion. One or a combination of these factors could play a part in sea water intrusion.

Methodologies / Challenges

For the purpose of reconnaissance in the study area, the locations of abandoned government water wells were investigated and located, often with the assistance of communities during fieldwork. After locating each well, an assessment was made as a case by case scenario in regards to appropriateness of the wells use. When deemed adequate as a study well, an initial well log was completed that included length of casing above ground, GPS coordinates, static water level, temperature profile, conductivity profile, and well depth. Static water level, well depth, temperature and conductivity were gathered using the Solinst Temperature, Level, and Conductivity Meter (TLC). The TLC meter was calibrated each morning in accordance with manufacturer's specification and periodically throughout each day. Spikes in conductivity were used as a basis for grab sample location, which were taken at various depths in the well using the Solinst Discrete Interval Sampler. For some wells that were assessed as having vulnerability of salt water intrusion, a borehole video was completed using the GeoVision Dual-Scan Micro Borehole Video System. This allowed an evaluation into the integrity of well construction and overall well condition. Using conductivity spikes and borehole video, the AquaVision Colloidial Borescope was used in select wells to evaluate aquifer velocity and direction. In wells that contained conductivity of roughly 1000 µS or greater or contained appropriate bromide chloride ratios from water chemistry collected during the earlier field work, samples for enriched tritium were collected and sent to the University of Illinois for analysis. Results are pending. The Grundfos Redi Flo-2 pump was used to obtain the 500 ml quantity needed for the analysis. Due to various reasons such as well accessibility, weather conditions, time constraints, permission of private property access, and relevance to the study, work completed on each well varied.

There were some challenges encountered in regard to the methodology. Identifying government owned abandoned drilled wells that were sited to condone salt water intrusion was very challenging. When wells were located in promising sites, either well depth did not allow opportunity to puncture the interface at depth or the well was obstructed by rocks, or well plug. Considering these wells were originally drilled as to avoid interaction with the interface, this scenario was anticipated.

Lack of prior knowledge regarding which communities had abandoned government water wells was a reoccurring issue. Much of the time spent in the study area was used traveling between communities and locating town officials or residents that could give insight on the topic. Much time was also spent in locating wells that were identified. Information regarding basic well construction, initial well yield and aquifer tests were not available for most of the study wells. The abandoned wells were largely unrecorded in the Drilled Well Database, which made community visits a necessary component of the reconnaissance. Permission of access was also an issue as the wells were often located on personal property.

Challenges regarding equipment were also experienced. The groundwater pump purchased for the study contained a defect that prevented proper function.

The pump was sent back to the manufacturer for repair and could not be used during the first field trip. The pump was repaired prior to the second field excursion.

Main Findings

Upon completion of the study, many things were revealed not only about the prospect of salt water intrusion for the study area, but also about fundamental data gaps in the Department of Environments Drilled Well Database. There were a total of eleven wells sampled throughout the study area and eleven abandoned government drilled wells that could not be used due to well obstruction or unsuitability for the study. This number is considered to underestimate the number of government abandoned wells in the study area. It was found that basic knowledge of the wells such as drilling year, depth of well, problems encountered were in most cases not known by Town officials or residents. Neither are they recorded in the Department of Environments Drilled Well Database.

Although it is still unclear whether or not some of the study wells are experiencing recent sea water intrusion, the presence of bromide in select wells suggest that at one time, sea water may have entered into the aquifer. Wells that contained various concentrations of bromide were the Flat Bay West (ABD 15), the two Port aux Port East wells (Abd 16 & 19), the Highland well (Abd 22) and Mainland well (Abd 25). Although these wells contain bromide, the question of recent sea water intrusion remains unanswered. Source water from the remaining wells that did not yield any detectable bromide are not considered to be influenced by sea water intrusion and are not included in these findings(see attached report for further details). Chloride was found in all sampled wells with concentrations varying from 10.7 ppm to 171 ppm, averaging at 42 ppm. These chloride levels do not support any strong influence of sea water intrusion, and may be reflective of formational or anthropogenic sources.

The highest concentration of chloride was found in the Mainland well, which also showed the highest level of bromide with a bromide chloride ratio of 0.00830. Since the wells were not pumped prior to sampling; prolonged ambient conditions of the wells may have left chemical constituents higher in concentration compared to true aquifer chemistry. This also leaves ratios such as the chloride to bromide for seawater unreliable. The presence of bromide most likely indicates the presence of seawater, either as present or relic sea water intrusion, or may be caused by contamination of road salt. At current ambient conditions and shallow depth, it is unlikely that this well is under considerable influence of current sea water intrusion. Although a local resident of Mainland recalls the well never being activated due to salt in the well, this has not been confirmed by the study. Although ions are high in relevance to samples from other wells, concentrations still fall within drinking water parameters set forth by Health Canada. Taking all complexities such as site selection and water well chemistry into account, the Mainland well is at some risk of developing or currently experiencing some form of sea water intrusion. This does not indicate that the mainland well aquifer contains the highest risk of sea water intrusion, but rather the well is coincidently sited with the highest risk.

Community	Well ID	Sample depth	Cl^- ppm	Br^- ppm
Flat Bay West	Abd 15	16	66.8	0.188
Port aux Port East	Abd 16	37	23	0.221
Port aux Port East	Abd 16	39.5	26.2	0.132
Port aux Port East	Abd 16	49.5	26.9	0.14
Highlands	Abd 22	Whole	54.8	0.616
Mainland	Abd 25	8.6	171	1.42

Table 1: Chloride and bromide source water results from selected study wells

Source water samples were collected for tritium analysis in wells that are thought as having or developing some degree of current sea water intrusion. These samples were collected from the Mainland well, Tompkins well, Flat Bay East well and the Highlands well. Results are expected to be made available in the early New Year, 2012. Tritium samples were taken during the second field trip and water chemistry of the wells, with the exception of the Highlands well, was unknown. If tritium is present in any of these wells, recent sea water intrusion would be a likely source. Long term monitoring of water chemistry and conductivity may be a possible avenue for future study.

Conductivity profiles for each well containing bromide and that are within 500 meters from the coast are shown in figures 3, 4 and 5. Although the Highlands well met these parameters, a profile could not be completed for the well. Each profile reveals useful information about the well and aquifer that were unknown prior to the study.

1. As shown in the Figure 3, conductivity for the Mainland well peaked at roughly 1050 µS at 9.3 metres, while temperature increased incrementally after 5.3 meters depth. The Mainland well is constructed within clastic sedimentary bedrock

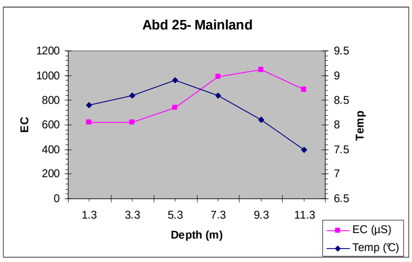


Figure 3: Temperature, Conductivity profile for the Mainland study well (Abd 25).

and extends to a depth of 12 meters below surface. The well is roughly 68 metres from the coast with a 7 metre elevation above sea level. Due to time constraints and private land issues, equipment requiring a generator was not used at this site. The colloidial borescope could therefore not be used.

2. The Flat Bay West well showed moderate conductivity that was measured at a high of 507 µS at 21 metres and remained fairly consistent throughout the entire depth of the well. Temperature also remained consistent after a depth of 17 metres where it remained at 6.5°C to the bottom. Total well depth was measured at 31 metres. The well is constructed in an area where surficial deposits have been measured up to 50 meters in depth (AMEC Environmental, 2008). Borehole video of the well show that well casing is extended to the bottom of the well with what appears to be strategically placed joints in the casing. This may or may not be an attempt at a well screen for a surficial well.

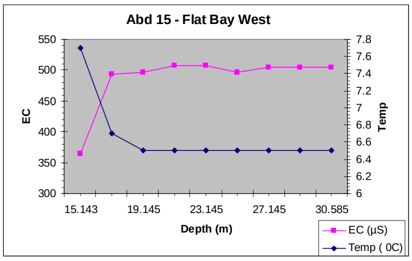


Figure 4: Temperature, conductivity profile for the Flat Bay West study well (Abd 15)

The colloidial borescope was used at this well as a tool to assess aquifer flow direction and velocity. As shown in figure 6, colloids suspended in the well water form a loose, but apparent pattern. The use of jointed casing to the entire depth of the well may be a cause of scatter amongst the data, and could prohibit accurate measurement. From the graph it is shown that the colloids are moving in and easterly direction (90.78 azimuths), with an average velocity of 99.84 um/sec. From these results it would suggest that the aquifer is moving inland as opposed to towards the shore.

3. The Port aux Port well is located within 500 meters from the shore but is not suspected to contain any recent sea water intrusion activity. Although the well extends roughly 25 metres below sea level, given it's elevation of 72 metre above sea level elevation, and its 420 metre distance for the coast, the well is thought to have a low risk of imminent sea water intrusion.

The temperature, conductivity profile completed on the well reveals defined intervals. The profile depicts an inverted well, with highest conductivity and lowest temperatures in the shallower portion of the well. This well in located at the base of a high grade, and is known to flow during high precipitation events. The inverted nature of the well may be explained by artesian properties. Pressures may cause heavier ions to accumulate at the top of the well as opposed to settling at the bottom.

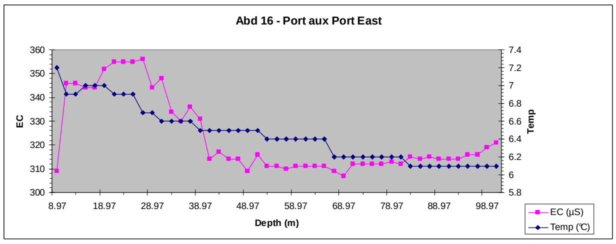


Figure 5: Temperature, conductivity profile for Port aux Port East study well (Abd 16)

The well water chemistry obtained from the study revealed some expected and unexpected results in regard to aquifer chemistry. Some wells located adjacent to the coastline with a relatively high conductivity in relevance to other wells in the study area, did not have any measurable amount of bromide (a signature element of sea water). Aquifers that have experienced sea water intrusion either at present or as relic would expect to yield this common signature ion. The Flat Bay East well (Abd 21), Tompkins (Abd 20) and St. Georges wells did not have any measurable bromide, in spite of favorable conditions and past sea level rise. Abandoned well 16 in Port aux Port East, did contain measurable bromide. The well however is over 400 metres from the coast and is located at the base of a high grade, 75 metres above sea level.

Conclusions

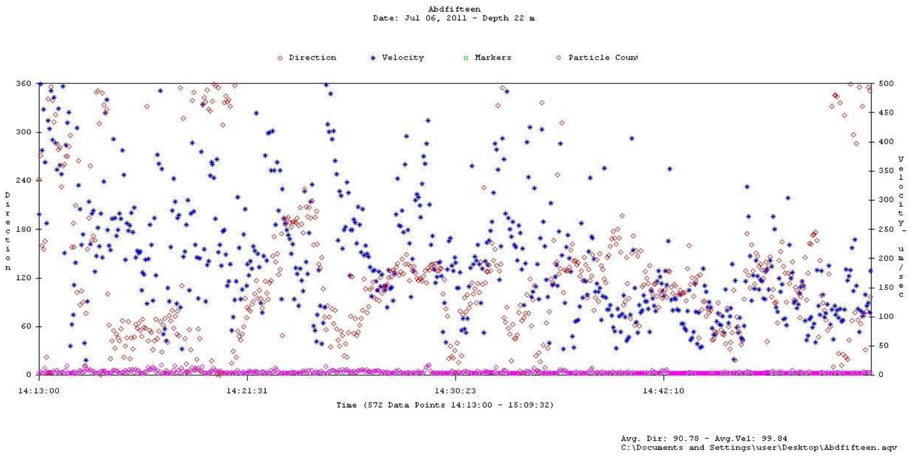


Figure 6: Graph produced by the Collodial Borescope for the Port aux Port East well (Abd 16). Measurements were taken at a depth of 22 metres in the well and show a loose pattern for both velocity and direction of suspended colloids.

The study was a ground up attempt to shed light on the effects of climate change and sea level rise on coastal aquifers. Until tritium analysis' are completed on the selected wells mentioned, it is yet unknown if salt water intrusion is present. However, salt water-fresh water interface is not thought to have been intersected in any of the study wells.

Only through studies and monitoring can proper adaptation take place and contribute to the long term preservation of coastal groundwater. Baseline studies such as these are crucial to not only recognize sea water intrusion but also to supply a foundation on how to protect coastal aquifers while still maintaining a standard of living in which society has become accustomed.

Acknowledgments
Communities of St. Georges, Flat Bay East, Flat Bay West, Tompkins, Mainland, Cape St. George, Stephenville, Port aux Port East, Bay St. George South. The Department of Environment and Conservation, Policy and Planning Division for funding and in kind contribution. A special thanks to Eric Watton and Kimberly Bitterman for technical and field support. Dorothea Hanchar for supervision and guidance. The Department of Environment Water Resources Management Division and Groundwater Section for in kind contribution. Newfoundland Department of Natural Resources Geochemistry Lab for in kind water sampling.

References

AMEC Environmental, (2008). Hydrogeology of Western Newfoundland. The Water Resources Management Division, Department of Environment and Conservation, 70 pages.

Barlow, Paul.M., (2003). Ground water in fresh water-salt water environments of Atlantic Coast. U.S. Geological Survey, Reston, Virginia, 113 pages.

Barlow, Paul, M., (2010). Saltwater intrusion in coastal regions of North America.Hydrogeology Journal, v. 18, pgs 247-260.

Batterson, M.J.(2003).Quaternary Geography and Sedimentology of the Humber River Basin and Adjacent Areas. Newfoundland and Labrador Department of Mines and Energy. Geological Survey. Report 03-02. 194 pages.

Batterson M., and Liverman D (2010).Past and Future Sea-Level Change in Newfoundland and Labrador: Guidelines for Policy and Planning. Current Research. Newfoundland and Labrador Department of Natural Resources Geological Survey, Report 10-1, pages 129-141.

Batterson M., and Sheppard K. (2000). Past and future sea-level change in Newfoundland and Labrador: guidelines for Policy and Planning. *In* Current Research. Newfoundland and Labrador Department of Natural Resources Geological Survey, Report 10-1, pages 129-141.

Bell, Trevor, Martin J. Batterson, David G.E. Liverman, and John Shaw (2003).A New Late-glacial Sea-level Record for St. George's Bay, Newfoundland. Canadian Journal of Earth Sciences 40, pages 1053-070.

Brune, Gunnar and Besse, Helen C. (2002). Springs of Texas. Texas University Press, Vol. 1. 590 pages.

Catto, Norm (2002). Anthropogenic Pressures on Coastal Dunes, Southwestern Newfoundland. The Canadian Geographer 46, No 1, pages 17-32.

Colman-Sadd, S. P., Crisby-Whittle, L. V. J. (compilers), (2005). Partial bedrock geology dataset for the Island of Newfoundland (NTS 02E, 02F, 02L, 02M, 11O, 11P, 12A, 12B, 12G, 12H, 12I, 12P and parts of 01M, 02D). Newfoundland and Labrador Department of Natural Resources Geological Survey, Open File NFLD/2616 version 6.0.

Dyke, A.S., Morris, T.F., and Green, D.E.C.(1991). Postglacial tectonic and sea level history of the central Canadian artic. Geological Survey of Canada, Bulletin 397.

Emery, K.O. and Foster J.F., (1948). Water Table in Beaches, J.Mar. Res., 7 (3), pages 644 – 654.

Fracflow Consultants (1999). Well Field Completion Report, Stephenville, NL. Prepared for BAE-Newplan Group Limited.

Fracflow Consultants (2003). Drilling Project of the Town of St. Georges. 284 pages.

Gale, J. E., Bursey, G.G., Parsons, M.C., Seok, E., and Keeping, G. (2XXX).Use of Dual Pump Systems and Inclined Wells to Optimize Potable Water Recovery and Hydrocarbon Remediation in Coastal Aquifers. Fracflow Consultants Inc, 15 pages.

Golder and Associates (1985). Hydrology of St. Georges Bay. *Edited by* the Water Resources Management Division, Department of Environment and Conservation. 66 pages.

Grant, U.S., (1948). Influence of the Water Table on Beach Aggradation and Degradation, J. Mar.Res., 7 (3), pages 655-660.

Hem, John D. (1985). Study Interpretation of Chemical Characteristics of Natural Water. U.S. Geological Survey. Third Edition. 271 pages.

Intergovernmental Panel on Climate Change (IPCC), (2007). Climate Change 2007. Fourth assessment report of the IPCC. 3 volume series. Cambridge University Press.

Jones B. F., Rosenthal E., Vengosh A., and Yechieli Y., (1999). Geochemical Investigations. *In* Seawater Intrusion in Coastal Aquifers: Concepts, Methods and Practices. Theory and Applications of Transport in Porous Media. *Compiled by* John Bear. Page 68.

Knight, Ian (199X). Carboniferous Stratigraphy Bay St. George Area (Diagram). Bedrock mapping and stratigraphic studies in Cambro-Ordivician shelf rocks, western Newfoundland and last call for the Bay of St. George Subbasin. Geological Survey of Newfoundland and Labrador.

Liverman, D.G.E., Taylor, D.M. (1990). Surficial geology of insular Newfoundland; preliminary version: Newfoundland Department of Mine and Energy, Geological Survey Branch Map 90-08.

Pearsall III, Sam H (2005). Managing for Future Change on the Albemarle Sound." *Comp*. Thomas E. Lovejoy and Lee Jay Hannah (2006). Climate Change and Biodiversity. New Haven: Yale UP, 359 pages.

Peltier, W.R. (1990). Glacial isostatic adjustment and relative sea level change. *In* Sea Level Change. *Edited by* R. Revelle. National Academy Press, Studies in Geophysics Series, Washington, DC., pages 73-87

Revelle, R.R. (1990). Sea Level Change. National Academy Press, Studies in Geophysics Series, Washington, DC.

Rivera, Alfonso, Allen Diana M., and Maathius Harm (2004). Threats to Water Availability in Canada. Climate Variability and Change – Groundwater Resources, Chapter 10, pages 77-83.

Sato, Michio (1991). Underground Water Table and Beach Face Erosion. Proceedings of the Coastal Engineering Conference 22ND. Vol 3, pages 2644 – 2657.

Shaw J., Taylor R.B., Forbes, D.L., Ruz, M-H. and Solomon S. (1998). Sensitivity of the coasts of Canada to sea-level rise. Geological Survey of Canada Bulletin, 505 pages.

Sherif, Mohsen M., and. Singh, Vijay P. (1999). Effect of Climate Change on Sea Water Intrusion in Coastal Aquifers. Hydrological Processes 13, pages 1277-287.

Tyagi, A. K. (2005). Impact of Sea Level Rise on Saltwater Intrusion on Coastal Aquifers. School of Civil Engineering, Oklahoma State University, 12 pages.

Tiruneh, Nebiyu D., and Motz, Louis H. (2004). Climate Change, Sea Level Rise, and Saltwater Intrusion. Bridging the Gap: Meeting the World's Water and Environmental Resources Challenges - Proceedings of the World Water and Environmental Resources Congress 11, pages 1-10.

Walton, Todd L. Jr. (2007). Projected Sea Level Rise in Florida. Journal of Ocean Engineering, 34. Pages 1832-1840.