# Mapping Cape Breton's waterscape – approach and challenges

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ABSTRACT
This field oriented approach accommodates the Hydrological, Geochemical and Debris Cycles, as well as their interaction. The key was to condense 174 geological units into 18 hydrostratigraphic units, based upon five physical characteristics, including architecture, flow, storage, yield and erodability, as well as four chemical concepts including character, signature, fingerprint and evolution. These Abuilding blocks@ were then combined in distinctive groupings to define eight Hydrological Regions, further subdivided into 15 Hydrological Districts. Conceptual three-dimensional block models were developed to aid in understanding the occurrence, quantity, quality and pathways for the movement and chemical evolution of water and sediment as they are transported through the waterscapes.

RÉSUMÉ
L'approche de travail sur le chantier s'adapte aux cycles hydrologique, géochimique et des débris, ainsi qu'à leur interaction. La clef a été de condenser 174 unités géologiques en 18 unités hydro-stratigraphiques, en se basant sur 5 caractéristiques physiques, incluant l'architecture, l'écoulement, la rétention, le rendement et l'érodabilité, ainsi que quatre concepts chimiques incluant le caractère, la signature, l'empreinte et l'évolution. Ces éléments d'assemblage ont ensuite été combinés en groupes distinctifs afin de délimiter huit régions hydrologiques qui ont à leur tour été divisées en 15 districts hydrologiques. Des modèles conceptuels de blocs 3-D ont été développés afin d'aider à la compréhension de la venue, de la quantité, de la qualité et du cheminement du mouvement et l'évolution chimique de l'eau et des sédiments, à mesure qu'ils sont transportés à travers les surfaces d'eau.

## 1 INTRODUCTION

Cape Breton Island forms the northern tip of Nova Scotia, along the eastern seaboard of Canada. It encompasses some 11,700 $km^2$, inclusive of the central large estuary of the Bras d'Or Lakes (Figure 1).

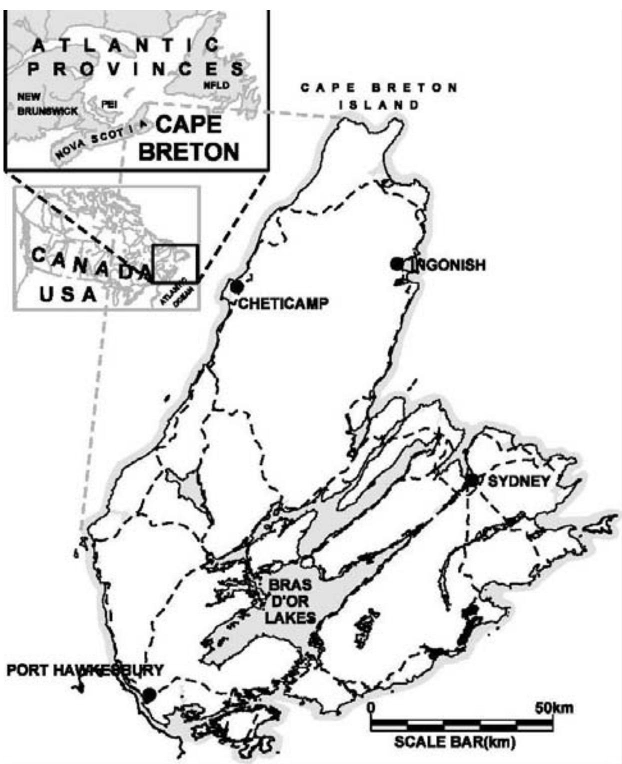


**Figure 1: Location Map**

The Island's one billion year geological history has engraved a complex terrain, with a wide variety of waterscapes; where the weatherscape meets the landscape. This complexity resulted initially from its position at the edge of an active continental margin during the creation of the Appalachian Mountain Belt. This left remnants of magma chambers with associated metamorphosed country rocks, as well as thrust belts and large scale San Andreas style faults. The subsequent erosion of the mountain belt created Carboniferous sedimentary basins infilled initially with coarse alluvial fans, followed by evaporites and finally braided and anastomosed fluvial deposits, the latter resulting in the largest coal field in eastern Canada. During the Holocene, the Island came under the influence of both continental and independent ice caps, as well as the associated rise and fall of sea level. At present, the Island is positioned in a transition zone where continent meets ocean, the cold Labrador Current meets the warm Gulf Stream just offshore, the northern hardwood forest transitions into the Boreal forest and where continental air masses are modified by the North Atlantic, placing it in the track of Atlantic hurricanes.

Historical mapping of various components pertinent to water resource studies have spanned some 40 years, all at different scales. Physiographic features were identified by Roland (1982) and Grant (1994). Forestry was described by Loucks (1962) and Rowe (1972). Regional surficial and bedrock geology, as well as pedology and wetlands have been mapped by Grant (1994), Lynch et al (1995), Cann et al (1963) and Anderson et al (1988), respectively. Watersheds were delineated and provided with an alpha-numeric ID system by Maritime Resource Management Service (1980). Springs were mapped and quantified by Cross et al (2000). Gates (1975) defined the climatology, the chemistry of which was assessed by Underwood (1984). Regional water resource evaluations focusing primarily on groundwater resources occurred in the late 1970's and early 1980's, as exemplified by Baechler (1986). This was followed by the Biophysical Land Classification system (Nova Scotia Museum, 1997) and subsequently refined with the Ecological Land Classification (Neily et al, 2003). Recent mapping of Groundwater Regions with relevant attribute data has been made available on a GIS web based system by the Nova Scotia Department of Environment (www.gov.ns.ca/nse/water/groundwater).

This paper outlines an approach and the challenges associated with attempting to integrate and expand on these various mapping schemes. It focuses on the concept that the key to understanding and managing the Island's fresh water resources is to be able to map the occurrence, quantity, quality, pathways and chemical evolution for water and sediment as they are transported through the waterscapes.

The need for more integrated mapping and analysis became apparent in the 1990's, when reduction in water resource programs reached such an extent that the Canadian Geoscience Council (1993) concluded that the current Canadian effort in water monitoring, protection and research were inadequate to achieve responsible and effective management of this important freshwater resource. The same theme was reiterated by Sharpe et al (2002), who noted that the current understanding of regional hydrology in Canada has not kept pace with the need for this knowledge and cannot address many emerging issues.

## 2 APPROACH

The approach utilizes the definition of hydrology outlined by Van Buren and Watt (1998), where hydrology is the science that treats the waters of the earth, the occurrence, circulation and distribution, their chemical and physical properties and their reaction with the environment, including their relation to living things. This necessitated expanding the existing mapping approaches to integrate all aspects of the Hydrological, Geochemical and Debris (sediment) Cycles, as well as understanding the role played by palaeohydrology. The latter is defined as the science of waters of the earth within ancient landscapes (Schumm, 1965). It is through palaeohydrology that the "past can be used as an analogy for the future" (Baker et al, 1996), which will aid in understanding impacts on water resources from climate change. This approach is embedded within the ongoing International Geosphere-Biosphere Program (IGBP) – Past Global Changes (PAGES) project (Pilcher, 1996).

To date, knowledge of the Island's waterscapes has grown by studying "bits and pieces", through site-specific projects, while disregarding the ecosystem as a whole. Although there is a need for the numerous local studies, they are driven by practicality, rather than by trying to achieve major advances in understanding (Phillips, 2002). The fact that the real world is immensely complex becomes apparent when trying to put the "bits and pieces" together; when turning from "analysis" to "synthesis" (White et al, 1984).

To synthesize an integrated picture of Cape Breton's waterscape a framework, or operating manual, was required. Such a framework was provided by the concept of "systems" (Chorley et al, 1971 and Christopherson, 1997), three of which were critical to this mapping approach.

1) Morphological System: comprising the arrangement of climate, hydrostratigraphic units (HUs), topography and vegetation.
2) Cascade System: utilizing the watershed approach, since it provides a unit of the earth's surface within which a balance can be struck in terms of inflow and outflow (Leopold et al, 1964).
3) Process-Response-Control System: representing the interaction of the Morphological and Cascade system as they mutually adjust themselves to changing conditions within a particular watershed.

Mapping and analysis was constrained by the limited availability of data, necessitating extrapolating from local sites with intensive data collection. Digital base mapping is, therefore, at a regional scale of 1:125,000.

It focuses on the physical and chemical aspects of water and sediment. It does not accommodate the biological aspects of aquatic life living within the fresh water resources. However, the overall approach has been influenced by data requirements posed of the authors by aquatic biologists with whom we have worked closely over the years.

While most mapping techniques focus on fresh water resources, the nature of an Island study area necessitated including brackish, estuarine and near shore coastal marine waters. This arose from the author's involvement in ongoing inter-disciplinary studies focusing on Coastal Zone Management, specifically the nurseries within barachois', the oceanography of the Bras d'Or Lakes estuary and adaptation to sea level rise associated with climate change (Baechler, 2007).

One of the difficulties in any mapping approach is the depth boundary for delineating groundwater resources. Rather than defining it by water quality for human use, this ecosystem approach keys to that portion normally drawn on by man and other life forms, with an arbitrary depth limitation set at 200 metres. It does, however, include fossil hypersaline groundwater at depths of up to 600 metres, within sub sea coal mines.

The approach makes use of case studies by consultants, government and university researchers. It was found that useful academic and applied research resided within numerous reports and journal articles left all too long on shelves. Pertinent reports available over the last 100 years were reviewed and some 50 case studies selected for inclusion in the mapping and analysis.

The overall approach is best described by LeGrand et al (2000), where the focus is on using generalizations and inferences with existing information to draw conclusions from imprecise and incomplete information. It is not equation based, but, instead a rule-based system of inferences. The approach also recognizes that it is not necessarily important to know all the answers, but just as critical to understand what the right questions are to ask (Wood, 2001).

## 3 HYDROSTRATIGRAPHIC UNITS

The key to mapping the waterscapes was to initially define the major HUs, which form the "building blocks". Existing regional bedrock and surficial geological mapping was combined with pedological (soils) mapping, equating to some 174 lithological units. Based upon existing information, case studies and literature values, these were condensed into 18 HUs, as defined by five physical and four chemical indicators.

One of the challenges in this approach was the selection of attributes that would define how these HUs controlled groundwater, surface waters, groundwater-stream interaction and sedimentation. This necessitated incorporation of near surface processes within soils residuum and wetlands. Given the absence of data on the microbial communities and groundwater fauna, aquifer ecosystems (Steube et al, 2009) have not been incorporated as an attribute at this time.

The need for including wetlands results from the large provincial percentage on-Island including some 25,000 hectares, comprising 15% of the provincial resource. This is a function of a large annual precipitation (1500 mm) and water balance surplus (290 mm).

Minimal studies have been undertaken on the hydrogeological and chemical properties of soils residuum and wetlands on-Island. However, both have been mapped at regional scales. Literature studies were drawn on to provide a range of conditions thought to be characteristic of what might be found on-Island.

One of the ongoing challenges is incorporation of forests. In historical water resource evaluations, forest cover has not been included as a mapping parameter, but instead factored in through an evapotranspiration rate. However, the Island's high precipitation, topographic relief (sea level to 520 metres) and highland orographic snowbelt have allowed development of three major forest cover types (Acadian, Boreal and Taiga). Not only do they exert differing control over evapotranspiration rates, but also other critical factors such as snowpack accumulation and release, frost penetration, infiltration rates and chemistry. The optimum approach, including possibly inclusion of forest cover as an HU, is still not resolved.

Five major physical parameters were utilized to define the HUs including: 1) architecture (geological mapping and environmental setting in which they were created); 2) ability to transmit water (hydraulic conductivity, transmissivity); 3) ability to store water (porosity and storage coefficient); 4) 20 year well safe yield ($Q_{20}$); and 5) inherent erodability for unconsolidated HUs. The latter was based upon the inherent erodability factor of the Universal Soil Loss Equation (Weishmeir et al, 1978).

The ranges in transmissivity and hydraulic conductivity were developed from 109 on-Island pump tests and numerous slug tests from case studies. The hydraulic conductivity values derived from this database and literature reviews for 13 HUs are presented in Figure 2, ranging over eight orders of magnitude from 1 to $10^{-8}$ cm/sec.

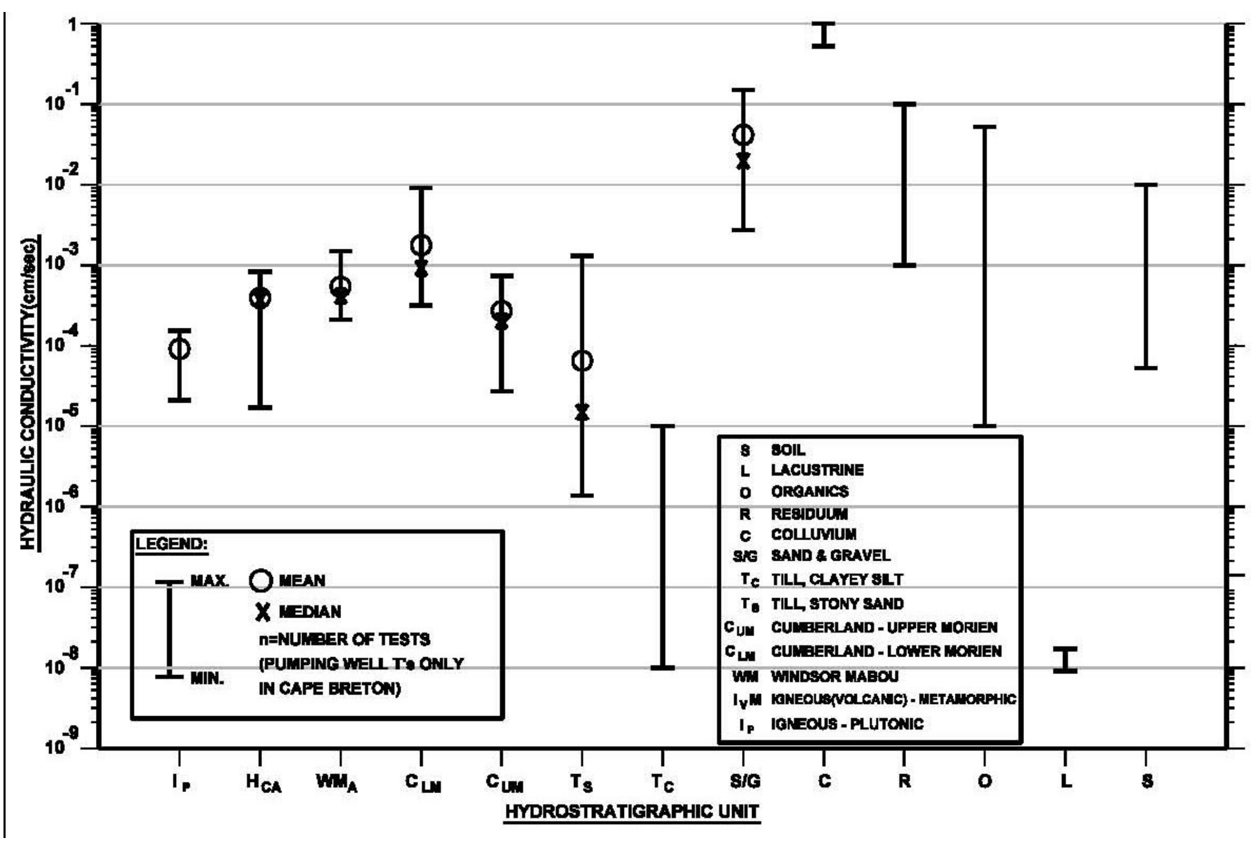


**Figure 2: Summary of Hydraulic Conductivity for Pertinent HUs**

Water chemical characteristics of individual HUs focused on four concepts utilizing a database of 250 chemical analyses. These include: Chemical Character (nine indicators including total dissolved solids, pH, chloride, sulphate, alkalinity, nitrate, organic carbon, iron and manganese), Chemical Signature (trilinear diagrams), Chemical Fingerprint (Scholler diagrams with 11 ratios) and Chemical Evolution. The last concept formed the larger challenge, that of defining the evolution of water chemistry as it moved through the various HUs within each waterscape. To that end a three-dimensional trilinear plot was utilized, incorporating the central diamond of the tri-linear diagram with a vertical axis calibrated for total dissolved solids.

Identifying indicators for sediment geochemistry continues to form a challenge, not fully resolved at this time. A total of 12 metals were available for stream and lake sediment from provincial data bases. Only select sites have data available for glacial tills. Lab analyses have used different lab protocols on varying grain sizes making comparisons difficult. The provincial mineral occurrence database was drawn upon to assess the potential zones of mineralization with the bedrock HUs.

## 4 HYDROLOGICAL REGIONS

The Island encompasses a wide diversity of waterscapes condensed into a relatively small 11,700 $km^2$ area. Mapping the extent and complexity of these waterscapes necessitated incorporating three-dimensional mapping and four-dimensional analysis.

The waterscapes were mapped by defining areas with characteristic types, numbers and orientation of HUs, coupled with climate and topographic relief. These were then used to delineate the unique character of Hydrological Regions and Districts. This approach was refined from the concepts of Heath (1988) and Randall et al (1988). The mapping emphasized those aspects of a waterscape that are representative, rather than rare; it was concerned with the common and conspicuous.

The approach to modelling the movement of water, chemicals and sediment through the various Regions and Districts drew on a variety of conceptual models. The input was derived from the water balance model by Thornthwaite (1948). Once the surplus reached ground surface, the paths taken as it flowed out of the watershed were characterized by using the hydrogeological environment and groundwater regime attributes for groundwater flow (Toth, 1970), infiltration using HELP (US Army Corps of Engineers), overland flow (Horton, 1933), hill slope processes of interflow and saturated overland flow (Dunne and Leopold, 1978), susceptibility to contamination by DRASTIC (Aller et al, 1987), groundwater-stream interaction (Sophocleous, 2002), sea water intrusion (Werner et al., 2009), channel/valley morphology (Rosgen, 1996), sediment erosion (Weischmier et al, 1978) and river stability/ sediment supply (Rosgen, 2006).

This approach led to the delineation of six Hydrological Regions on-land (Figure 3) and two coastal marine areas. The former have been further subdivided into 15 Hydrological Districts.

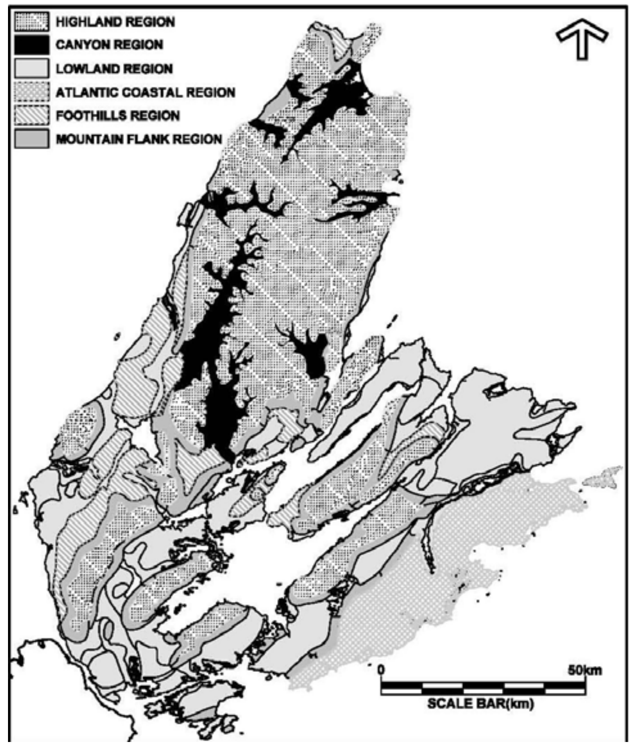


**Figure 3: Hydrological Regions On-Land**

A challenge in this approach is that while GIS systems are excellent for mapping layers of pertinent information and attribute files, they are less suited for looking at water resources in the three-dimensional view required. As a result the Regions and Districts were conceptually modelled based upon three-dimensional block diagrams, which characterize the presence and orientations of the HUs. An example of one such conceptual model for the Lowland Region Homoclinal Flank District region is provided in Figure 4.

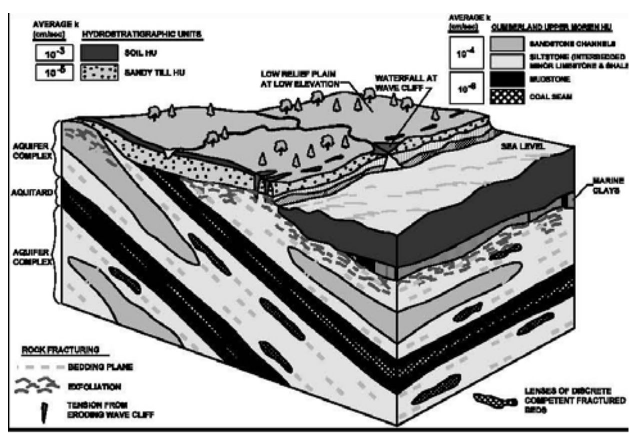


**Figure 4: Conceptual Block Model Lowland Region – Homoclinal Flank District**

The development of the block diagrams underscored the need for modelling at a variety of vertical scales. These ranged from approximately 0 to 1 metre depth for sediment erosion and transport; 0 to 3 metres for near surface runoff processes, 0 to 5 metres for channel development, 0 to 10 metres for groundwater-stream interaction; 10 to 200 metres for shallow and intermediate groundwater flow and 200 to 2000 metres plus for flow into mine workings, carbon dioxide sequestration and hydrocarbon exploration.

Once the three-dimensional mapping approach was developed, the four-dimensional analysis necessitated an understanding of Palaeohydrology. This procedure provided a critical role not only in assessing the architecture of the various HUs, but the important role of Holocene, glacially induced sea level fluctuations.

At 9000 years before present (BP), sea level was lower by >120 metres, resulting in the Island being joined with the mainland and Prince Edward Island (Shaw, 2002). The present saline 1100 km$^2$ estuary of the Bras d'Or Lake was represented by a series of small fresh water lakes. At 6,000 years BP, sea level had risen sufficiently high enough to commence flooding of the lakes to create the present two thirds salinity of this estuary comprising 9.5% of the Island. Therefore, an additional two Hydrological Regions are positioned off-shore over what are now saline waters, including Bras d'Or Marine and Coastal Marine Regions. The fresh water inputs to these areas form components for coastal zone management.

Sea level rise also resulted in erosion of aquifers from coastlines (presently 0.3 to 2 metres per year in the sedimentary strata exposed in the Sydney coalfield). It flooded river valleys creating localized brackish water estuaries, as well as saline water intrusion into fresh water aquifers. During times of lower sea levels, river valleys became deeply incised into the bedrock. During de-glaciation these were infilled with the Sand/Gravel HU forming present day aquifers; to date identified at seven different sites. Two of these have been utilized for central groundwater supplies, as exemplified for the Village of Inverness (ADI, 2002).

## 5 MODELLING

It was important to refine the accuracy of the conceptual block models. However, while numerous numerical models exist for various individual components of the Hydrological, Geochemical and Debris Cycles, the ability to integrate all the components is still in its infancy. Therefore, it was decided to focus on two field based approaches. The first was quantifying how the movement of water and sediment through the various Regions and Districts manifested themselves at surface through drainage basin and channel morphology. The second aspect involved monitoring to investigate the watershed outputs, as the Regions and Districts respond to input from climate. This modelling is presently underway, the approach is summarized below.

Using the Cascade System approach, 100 watersheds of varying size were selected to characterize natural conditions within the various Regions and Districts. The Island is characterized by relatively small drainage basins. The three largest watersheds range from 625 to 3597 km$^2$, encompassing approximately 45% of the Island. Of the remainder, 27 watersheds are 50 to 500 km$^2$ and 46 watersheds are 10 to 50 km$^2$ range. The remainder are considered shore drainage (<10 km$^2$). Therefore, present streams represent only small order tributaries of once larger river systems, the lower reaches of which have now been drowned out by sea level rise.

The manifestation of water and sediment transport out of these watersheds was defined through use of 26 drainage basin morphological parameters within seven categories including: position, area, length, shape, relief, drainage network and hypsiometric analysis, as outlined by Gregory et al (1973) and Leopold et al (1964). Channel and valley morphology utilized 10 variables as outlined in Rosgen's (1996) Levels 1 and 2 methodologies.

The monitoring component was challenged by the relatively low level of government based, automated monitoring programs presently underway for such a complex waterscape. At present there are eight active climate stations monitoring two of the Regions, five groundwater observation wells monitoring four HUs, six surface water stations monitoring only 9% of the Island and one tidal station. Wetlands, lakes and springs are not included in the monitoring effort. Water chemistry sampling recently commenced at select groundwater and stream stations; no dry fallout, precipitation and/or snow pack chemistry is being monitored. Integrated monitoring is not actively employed, where stations are grouped to allow for assessment of systems using a cluster approach (Spence et al, 2009).

This existing system has been augmented for this mapping by the establishment of monitoring stations at the mouths of the 100 indicator watersheds. Manual monitoring and research is presently ongoing for a select suite of indicators for flow, chemistry and sediment. Also included are two lakes, one wetland and 10 springs.

## 6 CONCLUSIONS

The Island's one billion year geological history has engraved a complex terrain, with a wide variety of waterscapes. Various components pertinent to water resource studies have been mapped independently over some 40 years, all at different scales. This paper outlines an approach and challenges associated with attempting to integrate and expand on these various mapping schemes. This was accomplished by integrating the Hydrological, Geochemical and Debris Cycles. Mapping and analysis was constrained by the limited availability of data, necessitating extrapolating from local sites with intensive data collection. It focused on the physical and chemical aspects of water and sediment in fresh, estuarine and near shore coastal marine waters.

The key to mapping the Hydrological Regions was to define the major HUs, which form the "building blocks" of the waterscapes. This resulted in the definition of 18 HUs as defined by five physical and four chemical indicators.

The waterscapes were mapped by defining areas with characteristic types, numbers and orientation of HUs, coupled with climate and topographic relief. This approach led to the delineation of six Hydrological Regions on-land and two coastal marine areas. The former were subdivided into 15 Hydrological Districts. These were conceptually modelled based upon three-dimensional block diagrams, and four-dimensional analysis through palaeohydrology. The models are presently being refined by monitoring 100 watersheds chosen to be representative analogues of various Regions and Districts

REFERENCES

ADI Limited, 2002, *The Community of Inverness Water System: Development of Production Well No. 2*, prepared for the Municipality of the County of Inverness 16 pgs.

Aller, L., T. Bennett, J. Lehr, R. Petty and G. Hackett, 1987 DRASTIC: *A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings*, EPA-600/2-87-035, 455 pgs.

Anderson, A.R., W.A. Broughn, 1988, *Evolution of Nova Scotia's Peatland Resources*, Nova Scotia Department of Mines and Energy, Bulletin 6, 109 pgs.

Baechler, F.,1986, *Regional Water Resources Sydney Coalfield, Nova Scotia*, Nova Scotia Department of Environment, 111 pgs.

Baechler, F., 2007, *Climate Variability and Change: Implications for Water Management in Cape Breton*, oral presentation to Water Resource Management A Science Forum, February 21, 2007, sponsored by Nova Scotia Environmental and Cape Breton University.

Baker, V.T., 1996, *Discovering Earth's Future in Its Past: Palaeohydrology and Global Environmental Change*, from Bronson, J., A.G., Brown and K.I. Gregory (Eds), Global Continental Changes: The Context of Palaeohydrology, Geological Society Special Publication, No. 115, pp 73-84.

Canadian Geoscience Council, 1993, *Groundwater Issues and Research in Canada*, a report prepared for the Canadian Geoscience Council by the Task Force on Groundwater Resource Research, Morgan, A.V., Ed: Canadian Geoscience Council, Waterloo, Ontario, 16 pgs.

Cann, D., J.I. MacDougall and J.D. Hilchey, 1963, *Soil Survey of Cape Breton Island, NS,* Report 12, Nova Scotia Soil Survey, Truro, Nova Scotia, 85 pgs.

Chorley, R.J. and B.A. Kennedy, 1971, Physical Geography, A Systems Approach, *Prentice Hall International Inc.*, London, 370 pgs.

Christopherson, R.W., 1997, *Geosystems, An Introduction to Physical Geography,* 3rd Edition, Prentice Hall, New Jersey, 656 pgs.

Cross, H.J. and R.J Goyette, 2000, *Hydrogeological Evaluation of Springs of Nova Scotia*, by Heather J. Cross, 2000, Dartmouth Nova Scotia, 166 pgs.

Dunne. T. and L. Leopold, 1978, *Water in Environmental Planning*, W.H. Freeman and Co., San Francisco, 818 pgs.

Gates, A.D., 1975, *The Tourism and Outdoor Recreation Climate of the Maritime Provinces*; Environment Canada Publications in Applied Meteorology, Rec, 3-73, 133 pgs.

Grant, D.R. 1994, *Quaternary Geology, Cape Breton Island, Nova Scotia*, Geological Survey of Canada, Bulletin 482, 159 pgs.

Gregory, K.J. and D.E. Walling, 1973, *Drainage Basin Form and Process, a Geomorphological Approach*, Edward Arnold Publishers Ltd, London England 457 pgs.

Heath, R.D., 1988, *Hydrogeological Setting of Regions,* in Hydrogeology, the Geology of North America, Baeck, W., J.S. Rosenshein and P.R. Seaber (eds), Geological Society of America, 524 pgs.

Horton, R. E., 1933, *The Role of Infiltration in the Hydrologic Cycle*; EOS American Geophysical Union Transactions, Vol. 14, pp 446-460.

LeGrand, H.E. and L. Rosen, 2000, Systematic Makings of early Stage Hydrogeologic Conceptual Models, *Groundwater*, Vol 38, No 6, pp 887-893.

Leopold, L.B., M.F. Wolman and J.P. Miller 1964, *Fluvial Processes in Geomorphology*, W.H. Freeman and Co., San Francisco, 522 pgs.

Loucks, O.L, 1962, *A Forest Classification for the Maritime Provinces,* Proceeding of the Nova Scotia Institute of Science, Vol. 25, pp 85-167, Halifax, Nova Scotia.

Lynch, G., S.M. Barr, T. Houlahan and P. Giles, 1995, *Geological Compilation, Cape Breton Island, Nova Scotia*, Geol. Survey of Canada, Open file 3159, Scale 1:250,000.

Maritime Resource Management Service, 1980, *Nova Scotia Watershed Areas* for Government of Canada and Province of Nova Scotia, 1:50,000 scale mapping.

Neily, P.E., E. Quigley, L. Benjamin, B. Stewart, T. Duke, 2003, *Ecological Land Classification for Nova Scotia, Volume 1, Mapping Nova Scotia's Terrestrial Ecosystem*, Nova Scotia Department of Natural Resources, Renewable Resources Branch, 82 pgs.

Nova Scotia Museum, 1997, *The Natural History of Nova Scotia Volume 2 Theme Regions*, edited by Davis, D.S. and S. Browne, Nimbus Publishing, 304 pgs.

Phillips, F.M., 2002 Hydrogeology: T*ime for a New Beginning?,* Groundwater, Vol 40 #3, pg 217.

Pilcher, J.R., 1996, *The Past Global Changes (PAGES) Project,* from Branson, J., A.G. Brown and K.I Gregory (eds), Global Continental Changes: The Context of Palaeohydrology, Geol. Society Special Publication No 115, pp 251-256.

Randall, A.D., R.M. Francis, M.H. Frimpter, and J.M. Emery, 1988 *Region 19, Northeastern Appalachians*, in Back, W., J.S. Rosenshein and P.R. Seaber, eds Hydrogeology: Boulder, Colorado, Geological Society of America, the Geology of North America, V.-2.

Roland, A. E., 1982, *Geological Background and Physiography of Nova Scotia*, The Nova Scotia Institute of Science of Nova Scotia Museum, Ford Publishing Co., 311 pgs.

Rosgen, D., 2006, *Watershed Assessment of River Stability and Sediment Supply (WARSSS)* Wildland Hydrology, Fort Collins, Colorado.

Rosgen, D., 1996, *Applied River Morphology*, Wildland Hydrology, Pagosa Springs, Colorado.

Rowe, J. S., 1972, *Forest Regions of Canada*, Canadian Forestry Service Bull., 1300, Ottawa.

Schumm, A., 1965, *Quaternary Palaeohydrology*, in Wright, H.E. and D.G. Frey, Eds, The Quaternary of the United States, Princeton University Press, Princeton, pg 783-794.

Sharpe, D. R., M.J. Hinton, J.A.J. Russel and A. J. Desbarats, 2002, The Need for Basin Analysis in Regional Hydrogeological Studies: Oak Ridges Morraine, Southern Ontario, *Geoscience Canada*, Vol. 29, #1, pp 3-20.

Shaw, J., P. Gareau, R.C. Courtney, 2002, Palaeogeography of Atlantic Canada 13 – 0 kyr, *Quaternary Science Reviews* 21 1861-1878.

Sophocleous, M., 2002, Interactions Between Groundwater and Surface Water; The State of the Science, *Hydrogeology Journal*, Vol. 10, pp 52-67.

Spence, C., S. Hamilton, P.J Whitfield, M.N Demuth, D. Harvey, D. Hutchinson, B. Davison, T. B. M. Jouarda, J.G Deveau, H. Goertz, J.W. Pomeroy and P. Marsh 2009 Invited Commentary: A Framework for Integrated Research and Monitoring (FIRM), *Canadian Water Resources Journal* 34(1):1-6.

Steube, C, S. Richter, C. Griebler, 2009, First Attempts Towards an Integrative Concept for the Ecological Assessment of Groundwater Ecosystems, *Hydrogeology Journal*, 17:23-35

Thornthwaite, C., 1948, An Approach Towards a Rational Classification of Climate. *Geog Rev.,* vol. 38, pp 55-94.

Toth, J., 1970 A Conceptual Model of the Groundwater Regime and Hydrogeologic Environment, *Journal of Hydrology*, Vol 10, pp 164-176.

Underwood, J. K., 1984, *An Analysis of the Chemistry of Precipitation in Nova Scotia 1977* – 1980, PhD Thesis, TUNS, 264 pgs.

Van Bruen, M., and E. Watt, 1998, *Hydrological Science Research in Canada: An Inventory for Canadian Water Resources Association*, 13 pgs. www.cwra.089/hydrology/arts/research

Werner, A.D. and C.T. Simmons 2009 Impact of Sea-Level Rise on Sea Water Intrusion in Coastal Aquifers, *Groundwater* 47,No 2: 197-204

White, I.D., D.N. Mottersheard and S.J. Harrison, 1984 Environmental Systems An Introductory Test, *Unwin Hyman, London*, 495 pgs.

*Wischmeier, W.H. and D.D. Smith, 1978, Predicting Rainfall Erosion Losses – A Guide to Conservation Planning*, U.S. Department of Agriculture, Handbook No. 537.

Wood, W.W., 2001, Misperception: A Challenge for Geoscience, *Groundwater,* Vol. 39 91):1.